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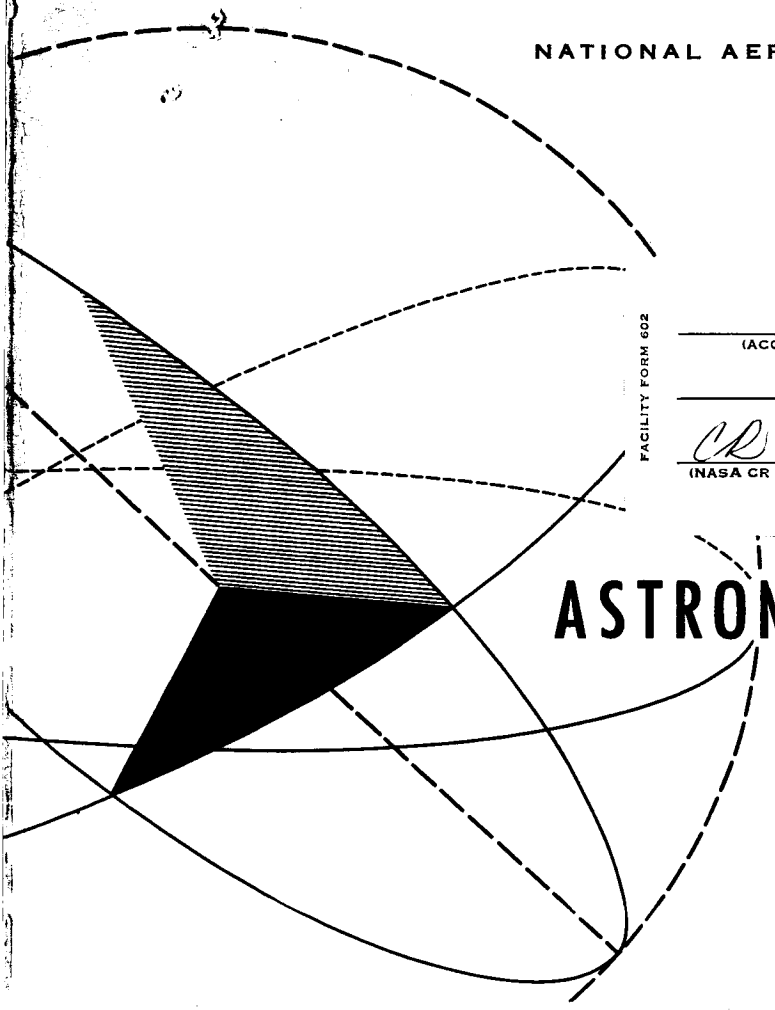

ASTRONAUTICS INFORMATION

LITERATURE SEARCH NO. 541

INTERACTIONS OF SPACECRAFT AND OTHER MOVING BODIES WITH NATURAL PLASMAS

DECEMBER 1965

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CALIFORNIA

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COMPILED BY

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CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CALIFORNIA

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FOREWORD

Recent space exploration has provided data on the interactions of a moving spacecraft (satellite, rocket or missile) with the surrounding ionized medium—ionosphere, magnetosphere, or interplanetary plasma. The practical aspects of the complex and interrelated electrical and magnetic phenomena are of primary interest. These include electrical hazards to spacecraft; effects on spacecraft communications, tracking, and detection; effects on measurement of environmental plasma parameters.

This search has been prepared at the request of personnel at the Jet Propulsion Laboratory. Although most of the references presented (approximately two-thirds) concern spacecraft phenomena and related ionospheric instrumentation and data, the search also includes literature on interactions of other types of moving man-made bodies and on similar natural phenomena.

The references are arranged in seven sections followed by an author index. Conferences, bibliographies, books, extensive reviews, and similar material are presented in the **General References** subsections. Within each subsection, abstracts are arranged alphabetically by first author.

Some overlapping between main sections and between subsections has been unavoidable. The techniques and instrumentation used in rocket and satellite ionospheric research are also relevant to the study of spacecraft interactions with the ionosphere, and many such ionospheric and instrumentation studies include information on the spacecraft interactions. References of this type appear in the **Spacecraft** section only if the abstract indicates that specific information on a spacecraft parameter (such as the potential) was obtained. Other instrumentation and ionospheric studies appear under **Ionospheric Research**. Some interrelationships exist within the **Spacecraft** section: **General Effects** comprises references to processes of ionization and charge accumulation during spaceflight; **Reentry and Plasma Sheath Effects** covers all references concerning electrical reentry effects (including those of a general nature) and plasma sheaths (when so-designated), as well as related antenna and communications effects.

Most of the entries appeared in the sources during the period 1960 through June 1965. However, a few earlier references are included — especially within the **Aircraft** section. The following sources were consulted in the preparation of this document: NASA *Scientific and Technical Aerospace Reports* (N-prefixed numbers), DDC and ASTIA *Technical Abstract Bulletin* (AD-prefixed numbers), *Physics Abstracts* (*PA*), *International Aerospace Abstracts* (*IAA*), *Dissertation Abstracts* (*DA*), *Meteorological and Geoastrophysical Abstracts (MGA),* National Research Council, Prevention of Deterioration Center — *Environmental Effects on Materials and Equipment Abstracts* (*NRC*), *Astronautics Information Abstracts* (*AI/A*), *Astronautics Information Survey* (*AI/S*), *Engineering Index* (*EI*), *Applied Science and Technology Index, Monthly Index of Russian Accessions, Cumulative Book Index,* JPL Library acquisitions, and miscellaneous sources.

The compiler wishes to acknowledge the valuable editorial and bibliographic assistance of Ruth Sippel in the preparation of this document.

CONTENTS

SPACECRAFT

GENERAL REFERENCES

1. **ARTIFICIAL SATELLITES IN RAREFIED PLASMA**
Al'pert, Ya. L., Gurevich, A. V., Pitaevskii, L. P.
Izdatel'stvo Nauka (Nauka Publishing House), Moscow, USSR, 1964

The various effects associated with the motion of artificial satellites and rockets in the ionosphere and through interplanetary space are discussed in terms of kinetic theory. Particular attention is given to the motion of a body exceeding the Debye radius in size, with a velocity much greater than the thermal velocity of neutral particles and ions; however, a study is also made of the effects which take place when the size of the body is of the order of the Debye radius and the velocity is comparable to the particle velocity. The properties of the upper ionosphere, the interaction between a moving body and the ionosphere, and the equations in kinetic theory are reviewed. Disturbed concentrations of ions, electrons, and neutrals are calculated, as are the induced electric and magnetic fields about the body. The scattering of radio waves from the wake formed by the electric and magnetic fields behind the body is examined, and the disturbances and electric field of a plasma near a charged body at rest are treated. Using these calculations, an exact theory is developed for the motion of a spherical probe in a rarefied plasma; the results differ appreciably from the approximate theories usually employed. This book, which is based primarily on the authors' previous results in this field and is limited to problems that lend themselves to analytical solution or require a minimum of computational labor, should be of interest to both scientists and students in the fields of radio and geophysics. 382 pages. (*IAA*, A64-28, 044)

2. **PLASMA PHYSICS AND MAGNETOHYDRODYNAMICS. AN ASTIA REPORT BIBLIOGRAPHY**
Aukland, M. F., Compiler
March 5, 1962
Armed Services Technical Information Agency, Arlington, Va.
AD-271,170
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This bibliography was prepared by ASTIA in response to requests for information concerning both general and specific aspects of plasma physics and magnetohydrodynamics. The citations presented cover the period from 1953 to early 1962, which coincides with the period of greater development in these fields. Although many references may be related to more than one category, they appear only once in the bibliography under the subject area best indicated in the report. In addition to the general references on theory, analysis, and instrumentation, entries have been included which cover the specific subject areas of electron-ion collisions, electromagnetic waves, gas ionization, magnetic pinch effects, and microwaves, as well as plasma jets, plasma sheaths, propellants and propulsion, oscillations, nuclear applications, reentry aerodynamics, shock waves and shock tubes, and solar and extraterrestrial effects. Entries are arranged alphabetically by subject and by AD number within each subject. 135 pages; 1350 references.

3. **INTERACTIONS OF RAPIDLY MOVING BODIES IN TERRESTRIAL ATMOSPHERE**
Chopra, K. P.
***Reviews of Modern Physics*, v. 33, no. 2, pp. 153–189, April 1961**
(Also available as PIBAL Report 624, Polytechnic Institute of Brooklyn, N.Y., 1960, AFOSR-TN-60-398A, AD-260,301)

This comprehensive review surveys the literature through 1960. The discussion covers the basic phenomena and related theory of the interactions of a body moving in a conducting fluid with a pervading magnetic field, as is the case for an artificial Earth satellite. The following main subject categories are included: general electrohydrodynamic effects of satellites; various theories regarding the Coulomb drag effect on satellites; induction drag; wave drag. A particularly detailed treatment is given to the electrical interactions of a satellite in the upper atmosphere; this includes consideration of the satellite potential both (1) as a diagnostic tool, and (2) with respect to the effects on rocket and satellite data on electron and ion densities and electron temperatures. Satellite wakes are also discussed. The last section contains suggestions for future laboratory and wind tunnel experiments. 151 references.

4. **RF BLACKOUT PHENOMENA: AN ANNOTATED BIBLIOGRAPHY**
Evans, G. R., Compiler
April 1962
Lockheed Missiles and Space Company, Sunnyvale, Calif.
SB-62-68, Report 3-77-62-14, AF 04(647)-787

When a space vehicle or missile reenters the Earth's atmosphere, the ionization of the air around the reentry body in the presence of applied magnetic fields creates an RF blackout. This prevents communication between the space vehicle and ground stations, and increases the difficulty of radar identification of a reentry body.

The 150 references cited contain information on the theoretical and experimental studies of the causes of the RF blackout phenomenon and possible solutions to the problem. This report covers the period from 1959–February 1962. 80 pages.

5. MISSILE PHENOMENOLOGY: AN ANNOTATED BIBLIOGRAPHY
Evans, G. R., Compiler
August 15, 1962
Lockheed Missiles and Space Company, Sunnyvale, Calif.
SB-61-68, Report 3-80-61-43, NORd-17017
AD-296,379, N63-17,639

The references comprise information on the natural and induced environment of a missile in midcourse flight and in reentry. Information on the missile in the exosphere and ionosphere is included, and the launch phase has been excluded. The period covered is 1953–January 1962. 96 pages; 213 references.

6. AVIONICS RESEARCH: SATELLITES AND PROBLEMS OF LONG RANGE DETECTION AND TRACKING
Glazier, E. V. D., Rechtin, E., Voge, J., Editors
Pergamon Press, Inc., New York, N.Y., 1960 (available as AGARDograph 40)
(Papers presented at the AGARD Avionics Panel Meeting, Copenhagen, Denmark, October 20–25, 1958)

The proceedings of the (NATO) AGARD Symposium on the Detection and Tracking of Targets at High Altitudes and Extreme Ranges are published here under the title "Avionics Research: Satellites and Problems of Long Range Detection and Tracking." The symposium was held during AGARD's Eighth General Assembly in Copenhagen, October 1958, which had the general theme "The Impact of Space Technology on Research and Development." The proceedings are published by Pergamon Press for the North Atlantic Treaty Organization Advisory Group for Aeronautical Research and Development, Paris, France.

This volume is comprised of the following papers:

"A Generalized Theory of Radar Observations," by R. J. Lees, pp. 1–5

"The Calculus of Radar Observations," by P. M. Woodward, pp. 6–11

"Echoing Area Characteristics," by J. S. Hey, H. Gent, and P. G. Smith, pp. 12–28

"Ground Scatter by Ionospheric Radar," by W. Dieminger, pp. 29–43

"The Sun as a Noise Source in Radar Aerial Investigations," by E. Eastwood, pp. 44–56

"UHF Radar Propagation Research," by B. C. Blevis and J. H. Chapman, pp. 57–67

"The Electrostatic Field About an Ion Moving Slowly Through a Highly Ionized Gas," by S. Rand, pp. 68–74 (Entry 805)

"Plasma Motions Induced by Satellites in the Ionosphere," by L. Kraus and K. M. Watson, pp. 75–91 (Entry 93)

"Electrohydrodynamic Properties of Satellites," by L. Kraus, pp. 92–100 (Entry 94)

"Ondes Électromagnétiques et Satellites Echos des Trainées Ionisées de Satellites en H. F." ["Electromagnetic Waves and Satellite Echoes From the Ionized Layers of Satellites at High Frequencies"], by A. Flambard and M. Reyssat, pp. 101–112

"Observation of Reentry of an IRBM," by D. D. Woodbridge, pp. 113–124

"Earth Satellite Observations Made With the Millstone Hill Radar," G. H. Pettengill and L. G. Kraft, Jr., pp. 125–134

"Radio Observations of the Russian Earth Satellites," by J. G. Davies, pp. 135–139

"Radar Echoes Obtained From Earth Satellites 1957 Alpha and 1957 Beta," by A. M. Peterson, R. L. Leadebrand, W. E. Jaye, R. B. Dyce, L. T. Dolphin, R. I. Presnell, L. H. Rorden, and J. C. Schlobohm, pp. 140–155

"Sputnik Modulation Patterns," by W. E. Brown, Jr., pp. 156–173

"Satellite Tracking From Several Coordinated Doppler Receiving Stations," by W. S. McDonald, pp. 174–187

"Vehicle Motions as Inferred From Radio-Signal-Strength Records," by W. C. Pilkington, pp. 188–235

"Forty-Megacycle Satellite Images and Beyond-the-Horizon Propagation," by H. W. Wells, pp. 236–239

"An Interesting Propagation Effect of *Sputnik I*," by E. Dewan, pp. 240–257.

7. RF BLACKOUT IN PLASMA SHEATH SURROUNDING A REENTRY VEHICLE: AN ANNOTATED BIBLIOGRAPHY
Goldmann, J. B., Compiler
April 1964
Lockheed Missiles and Space Company, Sunnyvale, Calif.
SB-64-10, Report 2-60-64-23, NOw-63-0050-c
AD-441,586, N64-23,884

Both theoretical and industry-proven techniques of RF transmission during reentry are emphasized in this annotated bibliography. References that have appeared in print between the years 1960–1963 are included, and are arranged in alphabetical order according to personal or corporate author. Author and corporate source indexes are included. 47 pages.

8. REENTRY PHYSICS. VOLUME III. INTERACTION OF VEHICLES IN EARLY REENTRY ENVIRONMENT. CHAPTERS 1–5
Hughes, R., Vachon, D., Kornhauser, M., Altshuler, T., Good, L.
December 1960
General Electric Company, Space Sciences Laboratory, Philadelphia, Pa.
Special Report for the Reentry Physics Data Correlation, Evaluation and Documentation Program,
DA-36-034-ORD-3187
AD-600,669
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This volume, the third in a series on reentry physics, covers various aspects of the interaction of vehicles in an early reentry

environment. In Chapter 1, the following topics are discussed: the surface charge accumulation on the moving vehicle and the resulting electrostatic drag; the charge interaction with a magnetic field; the induction drag; and the reentry perturbation of the Earth's magnetic field.

9. AERODYNAMICS OF THE UPPER ATMOSPHERE
Masson, D. J., Compiler
The Rand Corporation, Santa Monica, Calif., 1959, 1962 (available as R-339)

This volume is comprised of a compilation of papers submitted to the Rand-sponsored Symposium on Aerodynamics of the Upper Atmosphere. The symposium was held June 8–10, 1959, to discuss problems of rarefied gasdynamics as they pertain to the forces on satellite-type bodies. The interaction of a high-velocity body with the upper atmosphere is discussed, as well as the implications in interpreting satellite orbit data. In addition, useful reference material covering the gasdynamic characteristics of upper-atmosphere flight is presented. 478 pages. (See Entry 330)

10. SPACE RESEARCH IV
Muller, P., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1964
(Proceedings of the Fourth International Space Science Symposium, Warsaw, Poland, June 4–10, 1963)

The Fourth International Space Science Symposium, held from June 4 through June 10, 1963, in Warsaw, Poland, was organized jointly by the Committee on Space Research (COSPAR) and the Polish Academy of Sciences.

The emphasis was on geophysical research. About 90 of the more than 120 papers presented at the symposium comprised the geophysical program, and these constitute the material for the present volume.

Papers concerning the ionosphere, which comprise Part III of this volume, are listed as follows:

"The Ionospheric Conditions," by M. Nicolet and W. Swider, Jr., p. 357

"An Interpretation of a Rocket Measurement of Electron Density in the Lower Ionosphere," by A. C. Aikin, J. A. Kane, and J. Troim, pp. 358–362

"Electron Densities in the D Region Deduced From Rocket Measurements," by J. E. Hall, pp. 363–364

"Electron Densities and Electric Fields in the Aurora," by A. Kavadas and D. W. Johnson, pp. 365–370 (Entry 707)

"Rocket Investigations of the Electrical Structure of the Lower Ionosphere," by R. C. Sagalyn and M. Smiddy, pp. 371–387

"Some Theoretical Considerations Concerning Radio-Frequency Impedance Probes," by T. R. Kaiser, p. 388

"Formation of an Electron Depleted Region in the Ionosphere by Chemical Releases," by D. Golomb, N. W. Rosenberg, J. W. Wright, and R. A. Barnes, pp. 389–398 (Entry 790)

"A Study of Ionospheric Irregularities in the Auroral Zone Using Satellite Transmissions at 54 Mc," by L. Liszka, pp. 399–406

"Some Results of Radio Observation of Courier 1B," by Y. Nakata and R. Nemugaki, pp. 407–412

"Instrumentation of the Ionospheric Sounder Contained in the Satellite 1962 Beta Alpha (Alouette)," by A. R. Molozzi, pp. 413–436

"Ionospheric Results From the Topside Sounder Satellite Alouette," by G. L. Nelms, pp. 437–448

"The Structure of the Upper Ionosphere as Observed by the Topside Sounder Satellite," by J. W. King, P. A. Smith, H. Helm, D. Eccles, and G. F. Fooks, pp. 449–451

"Rocket Experiments Aimed at Detection of an Electric Field in the Ionosphere," by G. L. Gdalevich, pp. 452–453

"Some Ionospheric Measurements with Satellite-Borne Ion Traps," by G. W. Sharp, W. B. Hanson, and D. D. McKibbin, pp. 454–470 (Entry 121)

"Ionospheric Results Using Langmuir Probes in the 'Ariel I' Satellite," by P. J. Bowen, R. L. F. Boyd, C. L. Henderson, W. J. Raitt, and A. P. Willmore, pp. 471–472

"Changes of the Distribution of Charged Particle Density With Height and of the Ionic Composition of the Outer Ionosphere Since the Solar Activity Maximum According to Data Collected by Ion Traps on the Cosmos 2 Satellite," by K. I. Gringauz, B. N. Gorozhankin, N. M. Shutte, and G. L. Gdalevich, pp. 473–479

"Electron Density Distribution in the Topside Ionosphere at Medium and High Magnetic Latitudes and During Magnetic Disturbances," by P. Rothwell, pp. 480–487

"Scientific Uses of 'Trailer Satellites'," by K. Rawer, pp. 488-490

"Sur la Détermination du Contenu Total d'Electrons de l'Ionosphere à l'Aide des Satellites Artificiels," by E. Vassy, pp. 491–497

"Ionospheric Electron Content and Its Variations From Faraday Fading of Satellite Radio Transmissions," by Y. V. Somayajulu, T. Ram Tyagi, and V. P. Bhatnagar, pp. 498–507

"Plasma Temperatures and Recombination Parameters in the Outer Ionosphere," by K. H. Schmelovsky, pp. 508–515

"Ionizing Radiation and Heating of the Upper Atmosphere," by V. I. Lasarev, pp. 516–524

"On the Interpretation of the Seasonal Variations of Electron Density in the F_2 Region of the Ionosphere," by G. S. Ivanov-Kholodny, pp. 525–533

"Alfvén Waves in a Dipole Magnetic Field," by R. Gajewski, pp. 534–541

"Results of a Radioastronomical Investigation of Heterogeneous Structure of the Ionosphere," by Ju. L. Kokurin, pp. 542–552

"On the Mechanism of Formation of a Region of Higher Atomic Density With Atoms of Meteoric Origin at 100–110 km," by V. N. Lebedinets, pp. 553–562.

11. IONIZATION AND RADIATION IN REENTRY FLOW FIELDS: A SELECTIVE BIBLIOGRAPHY
Owens, G. E., Compiler
June 1961
Lockheed Aircraft Corporation, Missiles and Space Division, Sunnyvale, Calif.
SB-61-34

This bibliography is concerned with the interaction between the ionized flow field surrounding hypersonic objects and the electromagnetic radiations which are used to detect, observe, or communicate with the objects. (*AI/A*, 1961, #4393)

12. ELECTROMAGNETIC ASPECTS OF HYPERSONIC FLIGHT
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Proceedings of the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass., April 10–12, 1962)

This volume contains the proceedings of the unclassified sessions of the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection. The three-day meeting was held in Boston, Mass., on April 10, 11, and 12, 1962, under the sponsorship of the Electromagnetic Radiation Laboratory of the Air Force Cambridge Research Laboratories. The interaction of electromagnetic radiation with the ionized flow about aerospace vehicles was examined, and several other related topics were discussed.

The ionized flow fields about aerospace vehicles can arise from any of several causes: shock heating of atmospheric gases during reentry, the plume exhausts of both chemical rockets and electrical propulsion engines, and nuclear and solar radiations. The interaction of electromagnetic radiation with ionized gases is made manifest in aerospace research primarily through two effects: first, the radio signals emitted from a spacecraft can be severely attenuated, modified, or degraded; second, the radar cross section of a reentry body can be changed significantly from its free-space value. The importance of these phenomena as a limiting factor for both military and civilian space exploration is evidenced by the extensive government-sponsored research programs in reentry physics.

The sessions at this symposium concerned the subjects of reentry communications, diagnostic techniques, instrumentation for research in reentry physics, and radar cross-section studies. The communications studies emphasize techniques for reducing radio signal attenuation during reentry. Among the suggested solutions to this problem were the following: proper selection of operating frequencies, aerodynamic modifications to the airframe and its radiating systems, chemical additives for the reduction of electron densities in the flow fields, and static magnetic fields which can open radio frequency "windows" in the plasma. (See Entries 173, 185, 195, 209, 233, 240, 715, 774, 799)

13. AN ANNOTATED BIBLIOGRAPHY OF SPACE VEHICLE REENTRY AND ASSOCIATED PHENOMENA (JANUARY 1956–MARCH 1963)
Schorsch, R. H., Compiler
October 1963
Air Force Systems Command, Space Systems Division, Andrews AFB, Washington, D.C.
SSD-TDR-63-389

This publication is an annotated bibliography based on an extensive literature survey of the theory and physical phenomena associated with the reentry of space vehicles. The related subjects covered include the following: the interaction of electromagnetic waves with the hypersonically generated ionization sheath, techniques of reentry trajectory analysis and optimization, and structural and material considerations. Only a limited number of references pertaining to specific reentry projects are included. 458 pages; 1150 references.

14. IONIZATION IN HIGH-TEMPERATURE GASES
Shuler, K. E., Fenn, J. B., Editors
Academic Press, Inc., New York, N.Y., and London, England, 1963

This book is published as Volume 12 of the Progress in Astronautics and Aeronautics Series. The volume is based to a large extent on the Conference on Ions in Flames and Rocket Exhausts sponsored by the American Rocket Society in Palm Springs, California, October 10–12, 1962. A number of the papers presented at the meeting are included in this book. In addition, in order to present a fairly comprehensive and self-contained survey of the field, the editors solicited several review papers from a number of experts for inclusion in this volume. (See Entries 287, 291, 308, 820)

15. SATELLITE PLASMA SHEATH ANOMALIES
Singer, S. F., Bettinger, R. T., Walker, E. H.
1961
Electro-Jet Corporation, Washington, D.C.
Final Report, NObsr-84714
AD-403,287
(Also available through U.S. Dept of Commerce, Office of Technical Services, Washington, D.C.)

This document is a collection of papers on the plasma sheath surrounding artificial satellites, and includes the following:

"Experimental Studies of the Kraus Effect," by R. T. Bettinger

"Plasma Sheath and Screening Around a Rapidly Moving Body," by E. H. Walker (Entry 137)

"Plasma Compression Effects Produced by Space Vehicles in a Magneto-Ionic Medium," by S. F. Singer and E. H. Walker (Entry 368)

"Reflection of Radio Waves Incident to Boundary Surfaces With Application to the Theory of the Kraus Effect," by E. H. Walker (Entry 268)

"Interaction of West Ford Needles With the Earth's Magnetosphere," by S. F. Singer

"Further on the Interaction of West Ford Needles With the Earth's Magnetosphere," by S. F. Singer

"The Generation of Electromagnetic Waves in the Wake of a Satellite," by E. H. Walker.

16. TORQUES AND ATTITUDE SENSING IN EARTH SATELLITES
Singer, S. F., Editor
Academic Press, Inc., New York, N.Y., and London, England, 1964

This book is Volume 7 of the Applied Mathematics and Mechanics Series. A number of the papers in this volume were presented at the Second Robert H. Goddard Memorial Symposium of the American Astronautical Society, held in Washington, D.C., March 16–17, 1962. The discussions do not deal directly with the design of attitude control systems, but only with the external torques and with the means of attitude sensing. The major effects that have been recognized to date are elucidated, and their relative importance is discussed. (See Entries 127, 363, 481)

17. INTERACTIONS OF SPACE VEHICLES WITH AN IONIZED ATMOSPHERE
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965

A Memorial Symposium for Dr. Robert H. Goddard, which was held on March 17, 1961, in Washington, D.C., and was sponsored by the American Astronautical Society, provided the impetus for this volume. Following the symposium, additional papers were solicited to further amplify the subject matter. This volume contains most of the symposium papers, as well as the additional invitational papers. The few papers presented orally but not included in this book are referenced elsewhere in this literature search (Entries 34, 137, 347, 710).

In this collection, interest is focused on the various possible interactions between a space vehicle moving beyond the Earth's lower atmosphere (in the ionosphere, magnetosphere, and interplanetary space) and its environment of ionized gas. Such factors as magnetic fields, the electric charge of the body, and similar electromagnetic parameters are taken into account in discussing the effect of the body upon a plasma (i.e., the resulting perturbations, compressions, waves) and in determining the effects of the plasma upon the body itself (i.e., the various electromagnetic drag effects). Also considered are the complicated effects of various plasma properties on the electric charge of the body, as well as plasma effects on rocket antennas and radio propagation. Some of the applications of the techniques discussed are quite far-reaching, e.g., (1) the electromagnetic drag of dust particles in interplanetary space, (2) the drag of the West Ford needles in the magnetosphere, and (3) the problems created by the electric sheaths of space vehicles, their electric potential in various regions of space, and the relationship to communications and radar detection.

This volume is arranged as follows:

Part I: Plasma Sheaths—Physical Measurements and Theory

"Particle Distribution and Motion in a Field of Force," by E. J. Öpik, pp. 3–60 (Entry 803)

"Screening of a Moving Body in a Plasma," by E. H. Walker, pp. 61–162 (Entry 139)

"Probe Experiments on Plasma Sheaths," by R. T. Bettinger, pp. 163-270 (Entry 31)

"Plasma Sheath Effects on Rocket Antennas," by W. Pfister and J. C. Ulwick, pp. 271–281 (Entry 242)

"Free Molecular Heat Transfer in Interactions," by L. M. Gilbert and S. M. Scala, pp. 283–303 (Entry 59)

"Sheaths From Secondary Electron Emission and Photoemission," by D. B. Medved, pp. 305–321 (Entry 103)

Part II: Radiowave Reflections—Observations and Hypotheses

"The Satellite Ionization Phenomenon," by J. D. Kraus, pp. 325–372 (Entry 92)

"Detection of Artificial Satellites by Their Influence on the Ionosphere," by T. G. Hame and W. D. Stuart, pp. 373–388 (Entry 71)

"A Search for HF Radar Effects of Satellites," by T. A. Croft and O. G. Villard, Jr., pp. 389–427 (Entry 50)

"Single Frequency Radio Transmission From Satellites," by T. G. Hame and B. C. Potts, pp. 429–435 (Entry 680)

"Reflection of Radio Waves From Boundaries," by E. W. Walker, pp. 437–446 (Entry 268)

"Coherent Scattering of a Metallic Body in the Presence of an Ionized Shell," by L. Peters, Jr., and W. G. Swarner, pp. 447–463 (Entry 241)

"Disturbance Due to a Satellite," by K.-M. Chen, pp. 465–481 (Entry 47)

"Plasma Compression Effects," by S. F. Singer and E. H. Walker, pp. 483–501 (Entry 368)

18. PROCEEDINGS OF SYMPOSIUM ON THE PLASMA SHEATH, DECEMBER 7-9, 1959
1960
Air Force Cambridge Research Center, Electronics Research Directorate, Bedford, Mass.
AFCRC-TR-60-108 (Volume I)
AD-236,932

Most of the papers presented at this symposium appear in full in *Planetary and Space Science*, v. 6, 1961 (Entry 22). However, since it was impossible to include all of the unclassi-

fied papers in a single volume, the papers which are given only in abstract form have been collected separately and published in full by the Air Force Cambridge Research Laboratories as AFCRC-TR-60-108(I). For the complete unclassified proceedings of the symposium, the reader is referred to these two publications.

The papers included in the AFCRC report are:

"Methods of Approximating the Ion Field Surrounding Advanced Missiles," by R. L. Daniels (Entry 170)

"Relaxation Phenomena in Shock Fronts (A Review)," by I. P. Shkarofsky, T. W. Johnston, and M. P. Bachynski

"Radio Frequency Radiation From Hypersonic Plasmas With Impressed Oscillating Electric Fields," by C. A. Roberts

"Propagation of Electromagnetic Waves in a Plasma With an Inhomogeneous Electron Density," by A. J. Penico

"Peculiar Wave Propagation Characteristics of a Plasma With Constant Magnetic Field," by H. Poeverlein

"Nonlinear Modeling of Maxwell's Equations," by J. E. Belyea and K. M. Siegel

"The Region Behind a Body Moving Through a Rarified Ionized Atmosphere," by E. T. Kornowski (Entry 87)

"Experimental Investigation of the Effects of a Hypersonic Environment Upon Electromagnetic Radiation," by W. Rotman and G. Meltz (Entry 251).

19. SHOCK WAVES AS RELATED TO DETECTION AND TRACKING
May 19, 1961
Library of Congress, Air Information Division, Washington, D.C.
AID 61-77, Background Report for January 1958–January 1960
AD-257,932
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This background report consists of annotations of Soviet journal articles both directly and indirectly related to the subject.

20. REENTRY COMMUNICATIONS. A PARTIALLY ANNOTATED BIBLIOGRAPHY
November 10, 1962
North American Aviation, Inc., Downey, Calif.
SID 62-1354
AD-421,544

Reentry communications is complicated by the blackout of speech carrier frequencies or the ion sheath buildup about a reentry spacecraft. Current proposals indicate that communications in the kilocycle-megacycle ranges may be a means of overcoming this blackout. The remaining problem is that these high frequencies are not practical for transmission of human speech. A partially annotated bibliography on reentry communications is presented. 31 pages.

21. PHYSICAL CHEMISTRY IN AERODYNAMICS AND SPACE FLIGHT
***Planetary and Space Science*, v. 3, pp. 1–282, February 1961**

A conference organized by the Air Force Office of Scientific Research and the Space Sciences Laboratory of the General Electric Company's Missile and Space Vehicle Department was held on September 1–3, 1959 at the University of Pennsylvania. Papers presented at the conference are included in this volume. (See Entry 156)

22. SYMPOSIUM ON THE PLASMA SHEATH: ITS EFFECTS ON COMMUNICATION AND DETECTION
***Planetary and Space Science*, v. 6, pp. 1–218, June 1961**

This conference was held at Boston, Massachusetts, December 7–9, 1959, under the auspices of the Electromagnetic Radiation Laboratory of the United States Air Force Cambridge Research Laboratory. Most of the papers presented at the symposium are included in this volume of *Planetary and Space Science*, which carries the subtitle "Electromagnetic Effects of Reentry—Selected Papers From the Symposium on The Plasma Sheath: Its Effects on Communication and Detection." The volume is divided into four major sections: Section A—Thermodynamic and Electrical Properties of Shock-Ionized Flow Fields (seven papers); Section B—Interaction of Microwaves and Ionized Air (five papers); Section C—Voltage Breakdown of Antennas (three papers); and Section D—Experimental Techniques for Exploring the Interaction of Microwave Energy With Ionized Flow Field (five papers).

The material included in this volume stresses a comprehensive grasp of the many engineering ramifications of the plasma sheath–electromagnetic interaction; it is expected to contribute to a synoptic understanding of the overall problem, in addition to correlating past and present investigations and highlighting areas which require future study. Abstracts of all the papers on the agenda are included.

This volume is comprised of the following papers:

"Analysis of Radio Signal Interference Effects due to Ionized Layer Around a Reentry Vehicle," by W. C. Taylor, pp. 1–9 (Entry 261)

"Comparison of the Ionized Shock Layer About Two- and Three-Dimensional Blunt Shapes at Hypersonic Speeds," by H. W. Ridyard, pp. 10–23 (Entry 250)

"Collision Frequency Associated With High Temperature Air and Scattering Cross Sections of the Constituents," by I. P. Shkarofsky, M. P. Bachynski, and T. W. Johnston, pp. 24–46

"Basic Hypersonic Plasma Data of Equilibrium Air for Electromagnetic and Other Requirements," by W. B. Sisco and J. M. Fiskin, pp. 47–73

"The Effect of Errors in Rate Constants on Nonequilibrium Shock Layer Electron Density Calculations," by M. H. Bortner, pp. 74–78

"Electron Concentration in Closed Form for High Temperature Air and Air With Additives," by A. R. Hochstim, pp. 79–93

"Rate of Ionization Behind Shock Waves in Air," by S. C. Lin, pp. 94–99

"Waves in a Plasma in a Magnetic Field," by R. J. Papa and W. P. Allis, pp. 100–104

"Interaction of a Nonuniform Plasma With Microwave Radiation," by M. M. Klein, H. D. Greyber, J. I. F. King, and K. A. Brueckner, pp. 105–115

"Radiation and Admittance of a Slotted-Sphere Antenna Surrounded by a Plasma Sheath," by J. W. Marini, pp. 116–122

"On the Change in Radar Cross Section of a Spherical Satellite Caused by a Plasma Sheath," by C. L. Dolph and H. Weil, pp. 123–132 (Entry 175)

"Echo Area of a Plasma-Coated Sphere," L. Peters, Jr., and R. B. Green, pp. 133–141 (Entry 238)

"Power-Handling Capability of Antennas at High Altitude," by W. E. Scharfman and T. Morita, pp. 142-148

"RF Antenna Breakdown Conditions in the Presence of the Plasma Sheath," by R. F. Whitmer and A. D. MacDonald, pp. 149–154 (Entry 271)

"Microwave Breakdown of Antenna Radomes at High Altitudes," by P. P. Keenan, pp. 155–171

"Experiments With Plasmas Produced by Alkali-Metal-Seeded Cyanogen-Oxygen Flames for Study of Electromagnetic Wave Propagation at the Langley Research Center," by P. W. Huber, pp. 172–179

"Experimental Investigation of Electromagnetic Propagation Through the Plasma Sheath in a Hypersonic Low Density Wind Tunnel," by R. L. Chuan, pp. 180–185

"Microwave Techniques for Hypersonic Ballistic Ranges," by R. I. Primich, pp. 186–195

"Some Measurements of the Physical Properties of the Plasma Sheath Around Hypersonic Projectiles," by C. J. Maiden and C. St. Pierre, pp. 196–206 (Entry 483)

"Telecommunications During Reentry," by K. M. Baldwin, O. E. Basset, E. I. Hawthorne, and E. Langberg, pp. 207–218

Papers presented at the symposium but not included in this volume are abstracted on page 219.

The papers which do not appear in full have been collected separately and published as an AFCRL technical documentary report, AFCRC-TR-60-108(I) (Entry 18).

GENERAL EFFECTS: STATIC CHARGE AND IONIZATION

23. INVESTIGATION OF THE IONOSPHERE AND OF INTERPLANETARY GAS WITH THE AID OF ARTIFICIAL SATELLITES AND SPACE ROCKETS
Al'pert, Ya. L.
***Uspekhi Fizicheskikh Nauk*, v. 71, no. 3–4, pp. 369–409, July–August 1960**
(Translated from the Russian in *Soviet Physics—Uspekhi*, v. 3, no. 4, pp. 479–503, January–February 1961, and in *ARS Journal, Russian Supplement*, v. 32, no. 1, pp. 151–170, January 1962)

Various methods are discussed for investigating the electromagnetic properties of the upper ionosphere and interplanetary gas by means of satellites and cosmic rockets. Special attention is directed to the problem of the interaction of moving bodies with the plasma. The analysis makes extensive use of related experimental data available in the literature. 52 references. (*IAA*, 61-6574)

24. THE STUDY OF THE IONOSPHERE AND INTERPLANETARY GAS EMPLOYING ARTIFICIAL EARTH SATELLITES AND SPACE ROCKETS (METHODS AND SOME RESULTS OF RADIO INVESTIGATION)
Al'pert, Ya. L.
***Iskusstvennye Sputniki Zemli*, no. 7, pp. 125–169, 1961**
(Translated from the Russian in *Planetary and Space Science*, v. 9, pp. 391–433, 1962)

Experimental possibilities are examined for the outer section of the ionosphere, extending 300 to 400 km beyond the principal maximum and several thousand kilometers from the Earth, and passing over into the interplanetary gas. Charged particle densities, elastic collisions, nonuniform electron or ion formations, plasma waves, and the electromagnetic emission of particles are considered. Since the instruments are housed in a body traveling at a speed exceeding or comparable with the thermal velocity of the particles of the gaseous medium, it is necessary to take into account the interaction of the body with the plasma and with the radiation field in which it is traveling. These difficulties are enhanced by the intervening ionosphere zones which introduce masking and perturbing effects. A brief account of results to date points to the necessity for a diversity of methods in line with the diversity of the problems. One group of experiments is based on the analysis of radio waves emitted from the satellite and received at different points on the ground. A second group employs probes, transmitting the readings to the Earth. Interest derives also from the study of plasma as such, independently of the various geophysical or cosmic physics problems. 49 references. (*PA*, 1962, #8992)

25. SCATTERING OF ELECTROMAGNETIC WAVES BY INHOMOGENEITIES EXCITED IN A PLASMA BY A RAPIDLY MOVING BODY
Al'pert, Ya. L., Pitaevskii, L. P.
Geomagnetizm i Aeronomiia, v. 1, no. 5, pp. 709–724, 1961
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 1, no. 5, pp. 627–640, 1961; see also *AIAA Journal, Russian Supplement*, v. 1, no. 4, pp. 1001–1008, April 1963)

Computer calculations were made of the scattering cross section of a wake produced by a spherical satellite vehicle traversing typical regions of the ionosphere. The analysis assumes that the mean free path of the particles is much larger than the radius of the body, and that the vehicle velocity is much greater than the thermal velocity of the ions but much less than the thermal velocity of the electrons. The influence of a magnetic field is specifically included. Numerical results of the calculations are presented which indicate the effects of height, frequency, ion temperature, vehicle velocity, and geometry.

26. EFFECTS PRODUCED BY AN ARTIFICIAL SATELLITE RAPIDLY MOVING IN THE IONOSPHERE OR IN AN INTERPLANETARY MEDIUM
Al'pert, Ya. L., Gurevich, A. V., Pitaevskii, L. P.
Uspekhi Fizicheskikh Nauk, v. 79, no. 1, pp. 23–80, January 1963
(Translated from the Russian in *Soviet Physics—Uspekhi*, v. 6, no. 1, pp. 13–46, July–August 1963)

The results of theoretical investigations into the interaction of moving bodies with a rarefied plasma are reviewed and discussed. Particular attention is given to the case when the velocity of motion of the body is much larger than the thermal velocity of the neutral particles and ions and the dimensions of the body are large compared with the Debye radius. Topics considered in detail are: the structure of the disturbed plasma in the vicinity of the rapidly moving body; the scattering of radio waves by the "trail" of the satellite; the effects of altitude, temperature, wavelength, and direction of motion of the body on the effective scattering cross section; and, finally, the problem of determining the unperturbed particle density of the plasma from probe measurements in the vicinity of the satellite. It is shown that the effects of body–plasma interaction are very strong so that the physical environment of the body differs appreciably from the unperturbed state. The necessity of taking these effects into account in the analysis of results, particularly those obtained with rocket probes, is emphasized. 39 references.

27. ON THE EFFECTS PRODUCED BY A FAST-MOVING BODY IN A PLASMA
Al'pert, Ya. L., Gurevich, A. V., Pitaevskii, L. P.
In "Space Research III," pp. 1224–1271
Priester, W., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N. Y., 1963
(Paper presented at the Third International Space Science Symposium, Washington, D. C., May 2–8, 1962—Entry 496)

A theoretical investigation of the disturbance of neutral particles, ions, and electrons caused by a body moving in a plasma is reported, which is based on the solution of the kinetic equations. Calculations are made which include the effects of an outer magnetic field. In addition, the electric field around the body produced by the difference in ion and electron concentrations is determined. A region of "condensation" is formed ahead of the body and a region of "rarefaction" behind it. On the basis of the solution of the kinetic equations and the Poisson equation for the Fourier components of the electron disturbance, the effective scattering cross section is calculated, taking into account the influence of the electric field and the number of collisions of particles in a zone away from the body, where scattering is predominant. It is shown, in particular, that some of the results obtained earlier by Kraus and Watson (Entry 93) are incorrect. The effective scattering cross section, σ, is shown to be a sharply directed multilobe function dependent to a considerable degree on the direction of the motion of the body with respect to the magnetic field; σ increases greatly with longitudinal motion of the body. Theoretical formulas for the altitude range 300–700 km are tabulated by means of an electronic computer. Results of the numerical calculations are presented. 11 references. (*IAA*, A63-20,033)

28. ELECTROMAGNETIC EFFECTS NEAR AN ARTIFICIAL EARTH SATELLITE OR SPACESHIP MOVING IN THE IONOSPHERE OR INTERPLANETARY MEDIUM
Al'pert, Ya. L.
International Astronautical Federation, Paris, France
Paper presented at the 15th International Astronautical Congress, Warsaw, Poland, September 7–12, 1964
(in Russian)
(See also *Geomagnetizm i Aeronomiia*, v. 5, no. 1, pp. 3–31, 1965)

This article reviews the theoretical and experimental data published since the beginning of large-scale experimentation with artificial satellites and space probes. A detailed description is given of the effects arising in the neighborhood of an artificial Earth satellite or rocket in the ionosphere or interplanetary medium and of the changes with increasing distance from the Earth. The results of theoretical computations are discussed, and various influences are analyzed, such as changes in particle flux and concentration, the potential of the body, scattering, the electric field, excitation of longitudinal plasma waves, and evaporation. There are a few electromagnetic effects which are not discussed in the paper due to lack of space. 84 pages; 26 references.

29. SOME ESTIMATES OF ELECTRON DENSITIES IN THE VICINITY OF A HYPERSONIC BLUNT BODY
Baum, H. R.
August 1959

Arnold Engineering Development Center, Tullahoma, Tenn.
AEDC-TN-59-101, AF 40(600)-732
AD-220,499

The electron population in the flow field over a blunt-nosed body in hypersonic flight was calculated. The body shape considered is a hemispherical nose with a circular cylindrical afterbody at zero incidence. The conditions investigated are $M=15$ at 150,000-ft altitude, and $M=20$ at 200,000-ft altitude. The pressure, compressibility factor, temperature, and electron density distributions on the body surface and behind the shock wave are presented. 21 pages.

30. IONOSPHERIC LIMITATIONS ON ATTAINABLE SATELLITE POTENTIAL

Beard, D. B., Johnson, F. S.
***Journal of Geophysical Research*, v. 66, no. 12,**
pp. 4113–4122, December 1961

Artificial satellites orbiting in the ionosphere normally tend to acquire a slight negative charge due to the high velocity of the electrons relative to the ion and satellite velocities. (At very high altitudes, where the ionospheric electron concentrations are small, and in the presence of solar radiation, satellites tend to have a small positive charge due to the photoelectric effect, which in this case predominates over the ionospheric effect.) If the attempt is made to change the potential of a satellite by ejecting energetic beams of electrons or positive ions, the ionosphere provides some rather stringent limitations on the potential that can be achieved, since a substantial potential on a satellite causes appreciable currents to flow between the satellite and the ionosphere (which is a highly conducting medium containing a large reservoir of charge). The physics of the ionospheric limitation on satellite charge was investigated, and it is shown how the satellite charge and potential depend on injection currents and ambient charge density if (1) a pulsed current of high-energy electrons is injected into the environment, (2) a pulsed current of energetic positive ions is ejected, (3) a continuous current of electrons is ejected, or (4) a continuous beam of positive ions is ejected. Several examples of interest to Van Allen layer studies are discussed. (*PA*, 1962, #4871)

31. PROBE EXPERIMENTS ON PLASMA SHEATHS

Bettinger, R. T.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 163–270
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N. Y., 1965
(See Entry 17)

The ionosphere has been the subject of experimental investigation for many years. The advent of the rocket sounding vehicle—and, more recently, the satellite—has considerably intensified this activity. The earlier work utilized various propagation techniques involving the interaction of the ionospheric electrons and electromagnetic radiation. Much of the current experimental emphasis has shifted to *in situ* probes which are potentially capable of more refined measurements of various ionospheric parameters, such as (1) nonthermal components of the electron energy distribution, (2) small-scale ionization inhomogeneities, (3) negative ion concentrations in the lower ionospheric regions, and (4) time and spatial variations in the foregoing parameters.

This increased versatility is achieved at the expense of experimental complexity in both equipment and data interpretation. The most difficult problem encountered is the electric potential acquired by the carrier vehicle and its variations and perturbations.

A complete *in situ* probe system has been designed and tested. The system consists of (1) thermal equalization probes capable of independently measuring vehicle potential, (2) a pulse probe to measure electron concentration and energy distribution, and (3) a Langmuir probe which will supply information on positive ion and electron temperatures. This system, along with the requisite telemetry elements, was then packaged into an ejectable rocket payload. Preliminary flight test results are presented indicating generally satisfactory operation of the various probes and pointing to a number of design modifications.

Vehicle potentials have been measured on several flights, and the effects of DC sweeps, vehicle velocity, and solar radiation are demonstrated and discussed. It is concluded that a high-energy tail exists in the normal daytime electron energy distribution.

32. THE FREE-MOLECULE FLOW FIELD OF A MOVING BODY IN THE UPPER ATMOSPHERE

Bird, G. A.
In "Rarefied Gas Dynamics," pp. 245–260
Talbot, L., Editor
Academic Press, Inc., New York, N. Y., and London, England, 1961
(Paper presented at the Second International Symposium on Rarefied Gas Dynamics, Berkeley, Calif., August 3–6, 1960—Entry 606)

The energies imparted to atmospheric particles (molecules and atoms) upon collision with a body traveling at satellite or reentry speeds are sufficiently large to cause the ionization of a significant number of the particles. Therefore, the density and shape of the cloud of reflected particles may be of importance in the tracking or detection of a vehicle from the ground, or in communications with the vehicle.

The number density of the particles in this cloud will decrease as the square of the distance from the body, due to the essentially spherical nature of the problem, and the significant portion of the cloud will not extend very far from the body. In many cases of interest, the vehicle will be traveling at altitudes where the mean free path is large compared not only with a typical dimension of the body, but also with a typical dimension of the significant portion of the

reflected particle cloud. The concept of free molecule flow may then be applied to the analysis of this cloud.

The quantitative description of the cloud of reflected molecules depends critically on the nature of the reflection process at the surface of the body. This process is discussed and it is concluded that, although the reflection process for very high speed molecules may not be adequately described by the classical cases of specular and diffuse reflection, plausible models can be proposed which are merely modifications of these limiting cases. However, at low speeds there is ample evidence that the reflection process is predominately diffuse so that the analysis for specular reflection may be simplified by the assumption of a large molecular speed ratio. When a molecule undergoes a reaction (such as ionization) at the surface, the ionized molecules may be reflected quite differently from the remainder of the incident molecules; electrostatic effects will, however, ensure that the electron cloud remains coincident with the ion cloud.

33. THE FLOW ABOUT A MOVING BODY IN THE UPPER IONOSPHERE

Bird, G. A.

***Journal of the Aerospace Sciences*, v. 29, no. 7, pp. 808–814, July 1962**

A study was made of the flow pattern around a body moving in the upper layers of the ionosphere. The effects of distant encounters between charged particles (dynamic friction) and of the Earth's magnetic field were taken into account. It is shown that, when the magnetic lines of force are parallel to the direction of motion of the body, there may be a marked concentration of charged particles in the vicinity of the body and a considerable fraction of the reflected or deflected charged particles may reimpinge on the body surface. Numerical examples are given for the size and shape of the charged particle density contours in the flow field surrounding a circular disc, and these are compared with the corresponding neutral particle contours. 12 references. (*MGA*, 1963, 14.2-192)

34. MEASUREMENTS OF SHEATH CURRENTS AND EQUILIBRIUM POTENTIAL ON THE EXPLORER VIII SATELLITE

Bourdeau, R. E., Donley, J. L., Serbu, G. P., Whipple, E. C., Jr.

American Astronautical Society, Inc., New York, N. Y. Preprint 61-63, presented at the AAS Symposium on Interaction of Space Vehicles With an Ionized Atmosphere, Washington, D. C., March 17, 1961

(Also available as TN D-1064, National Aeronautics and Space Administration, Washington, D. C., July 1961, AD-259,683; see also *Journal of the Astronautical Sciences*, v. 8, no. 3, pp. 65–73, Fall 1961)

Experimental data obtained from *Explorer VIII* are presented for parameters pertinent to the problem of the interaction of space vehicles with an ionized atmosphere.

Measured values are given for electron-diffusion, ion-diffusion, and photoemission currents, as functions of the orientation of those points relative to the velocity, solar, and magnetic-field vectors. Values for the ambient electron temperature and the induced satellite potential are also presented. These observations are used to postulate a qualitative model of the plasma sheath and a quantitative model of the current exchange between satellite and medium. 29 pages; 4 references.

35. INSTRUMENTATION OF THE IONOSPHERE DIRECT MEASUREMENTS SATELLITE (EXPLORER VIII)

Bourdeau, R. E., Donley, J. L., Whipple, E. C., Jr.

April 1962

National Aeronautics and Space Administration, Washington, D. C.

TN D-414

AD-274,563

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D. C.; see also Paper 61-173-1867, presented at the IAS-ARS Joint National Meeting, Los Angeles, Calif., June 13–16, 1961)

This paper describes the ionosphere direct measurements satellite *Explorer VIII*, with emphasis on the physics of the experiments designed to measure electron density (RF impedance probe), electron temperature (electron temperature probe), positive ion concentration (ion current monitor), and ion mass (retarding potential probe). Experiments were also performed which measured the momentum, energy, and spatial distribution of dust particles. Experimental data presented are typical of data processed to date. Methods are described which were used by systems engineers to fulfill the special requirements imposed by the scientific experiments upon the overall satellite design, and data are reported on the thermal and spin-decay history of the satellite. Measurements of the effects of potential differences at various points on the satellite surface are of interest to spacecraft technologists concerned with the influence of the Earth's magnetic field. A method for determining satellite aspect is also introduced. 34 pages; 2 references.

36. IONOSPHERIC RESEARCH FROM SPACE VEHICLES. APPENDIX. ON THE INTERACTION BETWEEN A SPACECRAFT AND AN IONIZED MEDIUM

Bourdeau, R. E.

***Space Science Reviews*, v. 1, pp. 719–728, 1962–1963**

Much of the ionospheric research from space vehicles employs direct measurement techniques (Entry 632). The success of experiments of this type is dependent upon an evaluation of the effects of the interaction between the spacecraft and the ionized atmosphere immediately surrounding it. This interaction is discussed here. An estimate of the errors which this interaction could introduce into the results can best be made by the respective investigators. However, as a service to readers unfamiliar with this class of experiments, general considerations of this interaction are presented and estimates are given concerning the relative confidence that

can be placed on the electron and ion parameters obtained from plasma probes.

37. EXPLORER VIII SATELLITE MEASUREMENTS IN THE UPPER IONOSPHERE
Bourdeau, R. E., Donley, J. L.
August 1963
National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md.
TM X-54573, X-615-63-165
N64-17,602
(Paper presented at the Royal Society Conference, London, England, May 2–3, 1963)

This report covers upper-ionospheric ion composition, spacecraft-plasma interaction, and electron temperature—all measured by the *Explorer VIII* satellite. Among the topics discussed are: (1) the potential of the *Explorer VIII* satellite; (2) measurements of plasma-to-satellite ion current; (3) measurements of plasma-to-satellite electron current; and (4) elimination of interaction effects in deriving geophysical parameters. Summaries of ion composition results and electron temperature results are included. 45 pages.

38. EXPLORER VIII SATELLITE MEASUREMENTS IN THE UPPER IONOSPHERE
Bourdeau, R. E., Donley, J. L.
June 1964
National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md.
TN-D-2150
N64-22,019
(See also *Proceedings of the Royal Society of London, Series A—Mathematical and Physical Sciences*, v. 281, pp. 487–504, October 6, 1964)

This is an extensive report on upper ionospheric ion composition, electron temperature, and spacecraft–plasma interaction, all measured by *Explorer VIII*. Results from an ion-retarding-potential experiment show that the upper ionospheric composition responds to the neutral gas temperature. Explanations are suggested for differences between the *Explorer VIII* T_e observations and other ground-based and spaceflight measurements of upper ionospheric parameters. The measured satellite–plasma interaction is consistent with theory, lending confidence to the geophysical results described. The observed average satellite potential varied from a few tenths of a volt negative at night, to zero when the measured daytime charged particle density was $10^4/cm^3$, and thence to a few tenths of a volt positive for daytime densities of $10^3/cm^3$. Superimposed on the average potential were experimentally observed potential gradients across the satellite skin — an effect produced by the movement of a conducting body through a magnetic field. The measured orientation sensitivity of three types of current flowing between the satellite and the ionosphere is described. 20 references.

39. MEASUREMENT OF ELECTRON TEMPERATURE AND CONCENTRATION FROM A SPACECRAFT
Bowen, P. J., Boyd, R. L. F., Henderson, C. L., Willmore, A. P.
***Royal Society of London, Proceedings of the, Series A—Mathematical and Physical Sciences*, v. 281, pp. 514–525, October 6, 1964**

Probes installed on *Ariel I* were used to investigate the energy distribution of the electrons and the disturbance of electron density and temperature near the spacecraft due to its motion through the ionosphere. The experimental technique used and the results obtained are described. The method used avoids the disturbing effects of photoemission due to sunlight, or of variations in satellite potential, and is particularly well-suited to measurements using a low-bandwidth telemetry system. The ionospheric electrons are found to have a Maxwellian energy distribution, with any non-Maxwellian, high-energy "tail" including less than 1% of the total. Some measurements of the charge distribution around the satellite are in good agreement with previously predicted values; i.e., the satellite exhibited no "ram" effect, but a very marked depletion of charge was noted in the wake. No associated effect on the electron temperature could be detected. Some evidence is found for the occurrence of plasma oscillations in the wake. 12 references. (*IAA*, A64-27,511)

40. PLASMA PROBES ON SPACE VEHICLES
Boyd, R. L. F.
In "Proceedings of the Fifth International Conference on Ionization Phenomena in Gases, Munich, Germany, August 28–September 1, 1961—Volume II," pp. 1387–1396
Maecker, H., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, 1962
(See Entry 600)

The Langmuir probe and subsequent developments provide a means of making ionospheric measurements such as electron concentration and temperature, and ion mass spectrum, concentration, and temperature. To obtain successful operation of plasma probes on space vehicles, it is necessary to take into account problems which arise in connection with the potential of the fast-moving space vehicle with respect to its environment. A rocket or satellite in the ionosphere takes up a potential with respect to its surroundings such that the sum of the current of positive ions swept up plus the current due to photo and secondary emission is equal to the current of electrons collected. Within a distance of half an Earth radius, a space vehicle may be expected to take up a potential slightly negative with reference to its surroundings. At greater distances the potential may become positive so as to limit the photoemission. In the shadow of the Earth or another object the space vehicle potential will always tend to be negative. Measurements to date show that the potential of space vehicles near the Earth usually varies from a fraction of a volt up to two or three volts negative. The problems involved arise largely because the vehicle is isolated from the Earth and because of its varying aspect. These problems require

very careful study before any instrumentation is built, and the solutions involve the use of special techniques which are unnecessary in the laboratory. The work done to date is reviewed, and special reference is made to the instrumentation planned for the first Anglo–U.S. satellite.

41. THEORY OF A RADIO-FREQUENCY PLASMA PROBE FOR ELECTRON-DENSITY MEASUREMENTS IN THE IONOSPHERE AND EXOSPHERE

Boyd, T. J. M.
Journal of Geophysical Research, v. 68, no. 17, pp. 5089–5092, September 1, 1963

The problems involved in RF plasma probe measurements of electron density in the ionosphere and exosphere are discussed, with special reference to the *Ariel* satellite. Difficulties in data interpretation are discussed in terms of the interaction between the satellite and the medium. Considered briefly are problems caused by the satellite disturbance of the medium, including the charge of the satellite surface, and the impact of ions on the satellite. Other problems discussed include the sheath of ions which forms on any probe in a plasma, and the errors that might be caused by the interaction of the imposed RF voltage with the plasma around the grids. 14 references. (*IAA*, A63-22,362)

42. CAMPO ELETTRICO ATTORNO AD UN SATELLITE IN MOTO NELLA IONOSFERA (THE ELECTRIC FIELD IN THE VICINITY OF A SATELLITE IN MOTION IN THE IONOSPHERE)

Brocchieri, F. B., Caldirola, P., Federighi, U., Maroli, C.
Alta Frequenza, v. 32, no. 4, pp. 258–266, April 1963

A mathematical study was made to determine the electric field in the vicinity of a satellite moving in the ionosphere, since this field has an appreciable effect on the velocity of the satellite. The expression derived from the Poisson equation forms the basis for determining the field, assuming that the velocity of the ions is much lower and that of the electrons much higher than that of the satellite. The expression cannot, however, be reduced (as other authors have assumed) to the simple form applicable to the determination of the field surrounding ions in an electrolyte, since the ratio of potential energy to kinetic energy is of a much higher order. It is shown that the expression can be evaluated either by a successive approximation process or directly by a digital or analog computer. Families of curves of the results are given. (*PA*, 1963, #21,137)

43. COMMENT ON "PERTURBATIONS IN THE IONOSPHERE CAUSED BY A MOVING BODY"

Browand, F. K.
AIAA Journal, v. 1, no. 7, pp. 1748–1749, July 1963

The author comments on a paper by Gurevich (Entry 61) concerning the problem of a spherically shaped body which is penetrating a region of low density, and points out what he believes are incorrect calculations and errors in evaluation.

44. EFFECTS OF CHARGED PARTICLES ON THE MOTION OF AN EARTH SATELLITE

Brundin, C. L.
AIAA Journal, v. 1, no. 11, pp. 2529–2538, November 1963

The charge on a conducting spherical satellite and the drag due to charged particles are estimated for altitudes below the hydrogen region. A model of the upper atmosphere is used in which the principal atmospheric constituent (for both atoms and ions) changes with increasing altitude from atomic oxygen to helium and then to atomic hydrogen. The effects of photoelectric emission and the Earth's magnetic field are included in the calculations. It is found that the contribution of charged particles to the satellite drag may be neglected in the oxygen region. In the helium region the drag due to charged particles may be significant, particularly for large satellites and in cases where the photoelectric emission current is significant. A method of estimating this drag is presented. A comprehensive survey of the literature concerning satellite charge and the resulting drag is included, and the existing contradictions are explained. The conclusions regarding drag are applicable to satellites considered large with respect to the Debye length. 41 references. (*IAA*, A63-25,688)

45. COMPUTER SIMULATION OF THE ELECTRON MIXING MECHANISM IN ION PROPULSION

Buneman, O., Kooyers, G. P.
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
Paper 63-042, presented at the AIAA Conference on Electric Propulsion, Colorado Springs, Colo., March 11–13, 1963

The problem of getting electrons to emerge from an ion engine at the same rate and velocity as the ions is calculated by means of a computer. Time-displacement graphs of electrons and ions, as well as profiles of the potential inside and outside the spaceship, are presented. 21 pages.

46. ON THE DRAG OF A SPHERE MOVING IN A PARTIALLY IONIZED ATMOSPHERE

Chang, H. H. C., Smith, M. C.
June 13, 1958
Rand Corporation, Santa Monica, Calif.
P-1520
(See also *Journal of the British Interplanetary Society*, v. 17, no. 7, pp. 199–205, January–February 1960)

The Coulomb attraction or repulsion of charged particles as it affects the atmospheric drag forces acting on a satellite at altitudes of 500 km or greater is considered. For altitudes of 800 km, the free particle model is appropriate in calculating the increase in drag due to ions that stick to the surface of the satellite and those that pass near the satellite. At the lower altitude of 250 km, the much greater density of neutral particles overshadows completely the effects of Coulomb interactions. For intermediate altitudes between 250 and 800 km, the theory may be useful for determining approximate magnitudes of the Coulomb interactions. 17 pages.

47. DISTURBANCE DUE TO A SATELLITE
Chen, K.-M.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 465–481
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17; see also Preprint 61-70, presented at the AAS Symposium on Interactions of Space Vehicles With an Ionized Atmosphere, Washington, D.C., March 17, 1961)

The disturbance caused by a conducting spherical satellite passing through a plasma medium is considered. The density distributions of the positive ions and the electrons surrounding the satellite are obtained. The potential of the satellite is determined, and the radar return from the disturbed region is evaluated. The theoretical results are compared with observational data.

48. DRAG OF AN ARTIFICIAL EARTH SATELLITE
Chuan, R. L., Chopra, K. P.
American Physical Society, New York, N.Y.
Paper presented at the APS Summer Meeting in the West, Honolulu, Hawaii, August 27–29, 1959

Several physical processes are discussed which may contribute to the drag of an artificial satellite moving in an ionized atmosphere with a pervading magnetic field. These processes involve electromagnetic induction (induction drag), Coulomb scattering of charged particles (Coulomb drag), ionization caused by the satellite (ionization drag), the emission of plasma waves (wave drag), surface interactions with impinging particles (surface drag), etc., in addition to the direct collisions (neutral aerodynamic drag). An insight into these processes can be obtained by performing simple experiments in a low-density wind tunnel under specified conditions.

49. ELECTROSTATIC CHARGING AND DISCHARGING MODELS AND ANALYSIS FOR RANGER SPACECRAFT DURING LAUNCH
Cohn, G. I.
August 1, 1965
Jet Propulsion Laboratory, California Institute of Technology, Pasadena
Technical Report 32-771

Various electrification processes can cause large amounts of charge to appear on a spacecraft during launch. The charging process is limited by various discharge mechanisms such as conduction via the ambient space charge, corona, and arcing. Strong electric and magnetic fields can be created by the charging and discharging processes. The metal shroud surrounding the *Ranger* forms a Faraday cage which shields the payload. However, this shielding is not perfect, and the resulting leakage couples electrical pulses into sensitive electronic devices and circuits in the payload.

The objective of the investigation reported here is to aid the assessment of whether or not the electrical pulses induced in the payload circuitry by charging or discharging processes are sufficiently large to (1) actuate any device when it should not be actuated or (2) cause any device not to be actuated when it should be. To support this objective, the charging and discharging phenomenologies are examined. This provides the basis for constructing approximate equivalent circuits, which are then analyzed. The pertinent properties of the induced electrical pulses are graphed against the circuit parameters, charging current, and breakdown voltage to facilitate extraction of numerical values. A preliminary analysis is also made of the charging current. However, considerable work remains to be done to determine the actual values of charging current, breakdown voltage, and circuit parameters.

50. A SEARCH FOR HF RADAR EFFECTS OF SATELLITES
Croft, T. A., Villard, O. G., Jr.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 389–427
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17; see also *Journal of Geophysical Research*, v. 66, no. 10, pp. 3109–3118, October 1961, and TR 24, Stanford University, Electronics Labs., Stanford, Calif., March 10, 1961, AD-253,136)

Several investigators have interpreted experimental data as evidence that the passage of artificial Earth satellites creates large-scale disturbances in the ionosphere. In an effort to check this hypothesis, a search for such effects in the immediate vicinity of *Sputnik III* and *Echo I* has been conducted with the aid of an HF radar having a comparatively broad beamwidth, both in azimuth and in elevation. Possible satellite-associated disturbances were sought both as direct reflections from the vicinity of the vehicle and as perturbations within the F layer sufficient to alter the structure and appearance of ground backscatter mirrored by that layer. A total of 139 acceptable observations were made.

In all this work, the fundamental assumption was made that if an effect were produced, it would be closely associated with the satellite passage in time and would occur comparatively close to the satellite's track in space. No observed returns could be attributed to direct reflection. Many layer anomalies were found to occur at locations below orbiting vehicles, at times close to the time of vehicle passage. Subsequent study of these anomalies, and comparison with statistical and other characteristics of natural changes, did not provide any basis for believing the anomalies to be satellite-caused.

51. INTERACTION OF A CHARGED SATELLITE WITH THE IONOSPHERE
Davis, A. H., Harris, I.
In "Rarefied Gas Dynamics," pp. 691–699
Talbot, L., Editor
Academic Press, Inc., New York, N.Y., and London, England, 1961
(Paper presented at the Second International Symposium on Rarefied Gas Dynamics, Berkeley, Calif.,

August 3–6, 1960—Entry 606; also available at TN D-704, National Aeronautics and Space Administration, Washington, D.C., September 1961)

Perturbations produced in the ionosphere in the neighborhood of a charged satellite are analyzed. The restriction of linearity, particularly in the region close to the satellite where such approximations are most questionable, is removed from the analysis. As a result, the small regions of high ion density, perhaps corresponding to the ion shock wave predicted in linearized theories, did not occur. A steady state flow is assumed and satellite surface potential is considered a variable parameter. Satellite velocity is hypersonic with respect to the ions, but small compared to electron thermal velocities; thus, the electrons have an equilibrium distribution in the potential field of the satellite. For the solution, an arbitrary (i.e., constant) ion density is assumed and the electrostatic potential around the satellite is determined from Poisson's equation (solved by a relaxation method). The flow pattern of ions in the potential field is then obtained by computing a large number of ion trajectories. In this part of the calculation the ions are not allowed to interact with each other; it is assumed that the satellite surface acts as a sink for ions. The equation of continuity is used to obtain values of the ion density around the satellite once the flow pattern is known. With the new ion density distribution, the entire process is repeated. Although the ions do not interact directly, the self-consistent potential field finally obtained should allow important collective effects to be included properly. Only close collisions near the satellite are neglected, which is a good approximation at ionospheric densities.

Calculations are completed for spherical satellites of radii 10 and 25 Debye lengths with surface potentials ranging from minus 20 to minus 1000 times the electron temperature. In most cases, six iterations were sufficient to obtain convergent results. As expected, there is a region of low ion density behind the satellite. This region, from which ions have been swept out, may be of considerably larger radius than the satellite itself, a result previously predicted in considerations of charge drag. In addition, the focusing effect of the negative potential on the satellite may produce a small region of high ion density just behind the satellite.

These studies should be of value in obtaining accurate estimates of charge drag for bodies of simple shape and in interpreting measurements of ion density close to a satellite or probe arm. The method at present is incapable of predicting dynamic effects, such as plasma oscillations, or of yielding the precise shape of the Mach cone. (*NRC*, 1963, PDL-47, 810)

52. SCIE IPERSONICHE (HYPERSONIC WAKES)

de Socio, L.
***Missili*, v. 4, pp. 5–8, October 1962**
(Paper presented at the Ninth International Congress on Electronics, Rome, Italy, June 18–23, 1962)

Hypersonic-wake equations are examined, taking into account the interactions between the gradients of temperature and electron concentration and the gradient of electric potential. The fundamental parameters affecting the phenomenological behavior of the wakes are demonstrated. It is shown that, in the case considered, the effect of thermal diffusion is small. The energy equation shows how the temperature distribution is not practically controlled by the distribution of the electric potential. (*IAA*, A63-13,101)

53. SOME ELECTRICAL CHARGING PROCESSES FOR VEHICLES IN SPACE AND POSSIBLE CONSEQUENCES

Favale, A.
January 1964
Grumman Aircraft Engineering Corporation, Bethpage, N.Y.
RN 176L, IDEP Report 347-95-00-00-K4-01
AD-433,353

Two types of charge accrual are illustrated quantitatively, and some charge loss phenomena are discussed qualitatively. Two methods which produce electrical charge on vehicles are considered: (1) vehicle charging induced by the Earth's own surface charge, and (2) vehicle charging due to impingement of space radiation. 8 pages.

54. RESONANCE EFFECTS OF ELECTROSTATIC OSCILLATIONS IN THE IONOSPHERE

Fejer, J. A., Calvert, W.
***Journal of Geophysical Research*, v. 69, no. 23, pp. 5049–5062, December 1, 1964**

Plasma resonances observed with the *Alouette* can be attributed to electrostatic oscillations of ionospheric electrons in the vicinity of a satellite. The nature of these oscillations, their dispersion properties, and conditions for their persistence are considered and compared with *Alouette* observations. (*EI*, 1965)

55. ANALYSIS OF TOPSIDE SOUNDER RECORDS

Fitzenreiter, R. J., Blumle, L. J.
***Journal of Geophysical Research*, v. 69, no. 3, pp. 407–415, February 1, 1964**
(Also available as NASA RP-169, National Aeronautics and Space Administration, Washington, D.C., N64-20,018)

Methods are presented for interpreting the data obtained by the *Alouette*, and a technique is outlined for reducing the topside sounder satellite data to electron density distributions with height. The most useful feature for the calculation of electron density profiles is the extraordinary trace; however, to achieve accurate results, the effect of the geomagnetic field must be considered in the data-reduction process. The method of analysis selected assumes that small sections of the profile can be approximated by exponential laminations. This method requires fewer points than other first-order lamination techniques to achieve a given accuracy. It is usually assumed that received echoes correspond to vertical propagation. This assumption is not always valid, and can lead to large errors.

The sounder also excites the medium in the immediate vicinity of the satellite, giving rise to various plasma resonances. A graph is given which summarizes the local effects seen on the ionograms, and can be used for rapid identification of these resonances. 26 references.

56. MEASUREMENT OF ELECTRIC FIELD INTENSITY AT THE SURFACE OF A ROCKET MOVING THROUGH THE IONOSPHERE

Gdalevich, G. L.

***Akademiya Nauk SSSR, Doklady*, v. 146, no. 5, pp. 1064–1067, October 11, 1962**

Measurements of the electrostatic field intensity at the surface of vertically ascending geophysical rockets were made in 1957–1958, employing the electrostatic fluxmeter method. A description is given of three ionospheric experiments and the different techniques used in each case to determine the interaction of the electrostatic charge on the probe surface with the charged particles of the ionosphere. The results of three experiments were found to differ substantially with respect to electrostatic field intensities. Determinations were made to ascertain whether the changes in the output signal were caused by the current being measured (working current) or by modulated direct currents (interference currents). Only in cases where the working current considerably exceeded the interference currents could the electrostatic field intensity changes be attributed to a true difference of intensity. Examination of the experimental data indicated that: (1) in a large part of the trajectory the electrostatic field intensity at the surface of the rocket varies within the limits of 0.2 and 3 V/cm and corresponds to a negative rocket charge, and (2) there are sectors in which the rocket has a positive charge. An analysis of the experimental data indicates the existence of an external electrostatic field in the ionosphere that is in no way produced by the ionospheric rocket. It is suggested that the evaluation of the intensity of this external field be conducted with allowance for the processes which take place near a body in a plasma.

57. MEASUREMENT OF THE ELECTROSTATIC FIELD AT THE SURFACE OF A ROCKET DURING ITS FLIGHT IN THE IONOSPHERE

Gdalevich, G. L.

***Iskusstvennye Sputniki Zemi*, no. 17, pp. 42–58, 1963**
(Translation available as NASA TT-F8527, National Aeronautics and Space Administration, Washington, D.C., October 19, 1963, and in *Artificial Earth Satellites*, v. 17, pp. 43–59, March 1964)

With the exception of a short paper (Entry 56), experimental data on the strength of the electrostatic field near the surface of a rocket in flight have not yet been published. Although the literature does mention electrostatic field measurements on rockets, the methods of measurement are not described and results are not given.

In this paper, the conditions at the surface of a rocket in the ionosphere are examined with reference to measurements of the electrostatic field. The apparatus used to conduct experimental measurements by this method on three vertically launched rockets of the USSR is described, and the results of these experiments are given and discussed. An analysis of the results indicates that a rocket has a negative charge over most of its trajectory, but that some surface areas can have a positive charge. The values of the rocket's charge density, calculated from the measured electrostatic field intensities (assuming the rocket is a homogeneous conducting cylinder), are found to lie between 5×10^{-5} and 10^{-3} esu/cm^2. 12 references.

58. ROCKET EXPERIMENTS AIMED AT DETECTING AN ELECTRIC FIELD IN THE IONOSPHERE

Gdalevich, G. L.

In "Problems of Atmospheric and Space Electricity," pp. 566–572
Coroniti, S. C., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, and New York, N.Y., 1965
(Paper presented at the Third International Conference on Atmospheric and Space Electricity, Montreux, Switzerland, May 5–10, 1963—Entry 590)

During the IGY, rocket experiments were carried out in the USSR for the purpose of detecting an electric field in the ionosphere. An electrostatic fluxmeter method was used similar to that employed by Imyanitov. The apparatus used had the following main features: (1) the use of two sensors (which give voltage proportional to the electrostatic field strength near the rocket surface at the places where the sensors are installed) placed at diametrically opposite points of the cylindrical part of the rocket's surface; (2) simultaneous use of an automatic switch and a synchronous detector. The use of two sensors permits, in principle, the separation of the field strength produced by the body's own charge from the strength component of the outer electric field in the direction of a straight line connecting the points where the sensors are mounted. The simultaneous use of an automatic sensitivity switch and a synchronous detector makes it possible to extend the measuring range and, for measured values of an electric field strength, to distinguish whether the changes of the output signal are caused by the measurement of working current produced by an electric field near the rocket's surface or by an interference current. It was found that for a given altitude there was a difference in readings of the two sensors which has a value at least of the order of tenths of a volt per centimeter.

Two possible explanations of a difference of the order of 0.10 V/cm (measured simultaneously by the sensors) are considered: (1) a direct increase of the outer field strength near the rocket's surface, and (2) a variation of the thickness of layers near sensors due to directed motion of charged particles. 7 references.

59. FREE MOLECULAR HEAT TRANSFER IN INTERACTIONS
Gilbert, L. M., Scala, S. M.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 283–303
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17)

The potential energy stored in the ionosphere in terms of the atomic particles and ionized species is substantial, and the energy released in the recombination processes taking place at the surface of a space vehicle can therefore contribute substantially to the overall heat transfer.

In order to evaluate the importance of these chemical effects, the usual free molecular heat transfer and mass flux expressions are modified in this study to allow for a multicomponent, chemically reacting, mixture of gases. These expressions include the effects which result from the recombination interactions at the solid-gas interface caused by the transport of atomic and ionized particles to the vehicle.

Results of the numerical solutions are presented graphically as functions of the altitude and flight velocity. The magnitudes of the various modes of energy transferred to the vehicle are compared. In particular, it is shown that for many free molecular situations of interest (i.e., flight speeds which equal or exceed the magnitude of the escape velocities), the kinetic terms in the transfer equations are the dominant ones. However, for certain attainable combinations of altitude and flight speed (when all radiative heating is neglected), the total energy transfer can exceed the available kinetic energy by a factor as large as five.

60. DOUBLE ELECTRICAL LAYER AT THE SURFACE OF A SATELLITE
Ginzburg, M. A.
Trudy Instituta Zemnogo Magnetizma Ionosfery i Rasprostraneniya Radiovoln i Ionosfera, no. 17 (27), pp. 187–202, 1960
(Translation available as FTD-TT-62-1380/1+2+4, Air Force Systems Command, Foreign Technical Division, Wright-Patterson AFB, Ohio, January 2, 1963, AD-295, 800; see also *ARS Journal, Russian Supplement*, v. 32, no. 11, pp. 1794–1800, November 1962)

Three existing theories are discussed which describe the distribution of the electric field in the double electrical layer formed upon the surface of a satellite in its interaction with the ionosphere. The difference between the three theories and their results, particularly with respect to the relationship of the potential to the distance from the satellite wall, is examined. An analysis is made of the equation describing the double layer for the classic case of thermodynamic equilibrium and the Langmuir-Bohm equation, both of which use the assumption of a Boltzmann distribution of the electrons. The equation which describes the double layer for the case of a uniform ion density is also analyzed. The effect of the Earth's magnetic field on the ion flux to the satellite is evaluated. 11 references. (*IAA*, A63-10,403)

61. PERTURBATIONS IN THE IONOSPHERE CAUSED BY A TRAVELING BODY
Gurevich, A. V.
Iskusstvennye Sputniki Zemli, no. 7, pp. 101–124, 1961
(Translated from the Russian in *Planetary and Space Science*, v. 9, pp. 321–344, June 1962, and in *Artificial Earth Satellites*, v. 7–8, pp. 101–124, June 1962; see also *ARS Journal, Russian Supplement*, v. 32, no. 7, pp. 1161–1167, July 1962)

The movement of bodies in the upper atmosphere occurs in an extremely rarefied medium, and the mean free path is much greater than the dimensions of the body. Consequently, the usual hydrodynamic methods of investigating the interaction of a moving body with the medium are no longer valid. It is necessary to employ kinetic theory, considering the gas not as a continuous medium but as an aggregation of separate molecules. Secondly, the motion of a body in a plasma is involved, and the interaction of the body with ions and electrons must be considered. The different effects produce different perturbations in the electron and ion concentration. The quasi-neutral state of the plasma is destroyed and an electric field is produced. In calculating the values of the perturbations, it is assumed throughout that the speed of bodies in the ionosphere is much greater than the thermal velocity of the molecules or ions and much less than the thermal velocity of the electrons. Section 1 is concerned with the calculation of the neutral particle concentration near the moving body. In the second section the perturbations of electron and ion concentrations are determined, in addition to the value of the electric field. Section 3 resolves the same problem, taking into account the Earth's magnetic field. (For comment, see Entry 43)

62. THE DISTRIBUTION OF PARTICLES IN A CENTRALLY SYMMETRIC FIELD
Gurevich, A. V.
Geomagnetizm i Aeronomiia, v. 3, no. 2, pp. 185–203, 1963
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 3, no. 2, pp. 151–164, 1963)

Expressions are derived and analyzed for the density and flux of particles in a rarefied gas in a centrally symmetric field. The absorption of particles at the surface of a body is taken into account.

63. DISTURBANCES AROUND A BODY MOVING IN PLASMA IN THE DIFFUSION APPROXIMATION
Gurevich, A. V., Pitaevskii, L. P.
Geomagnetizm i Aeronomiia, v. 3, no. 5, pp. 823–829, 1963
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 3, no. 5, pp. 666–671, 1963)

Using ambipolar diffusion equations, the authors have computed the disturbance of the electron and ion concen-

trations around a body moving rapidly in a plasma in a magnetic field. The results were obtained for distances which are small in comparison with the mean free path of the ions. The scattering of electromagnetic waves incident upon the trail of the body is also discussed. 5 references.

64. STRUCTURE OF THE DISTURBED ZONE IN THE NEIGHBORHOOD OF A LARGE CHARGED BODY IN PLASMA
Gurevich, A. V.
***Geomagnetizm i Aeronomiya*, v. 3, no. 6, pp. 1021–1035, 1963**
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 3, no. 6, pp. 822–832, 1963)

A study was made of the disturbances caused in a plasma by a charged spherical body much greater in size than the Debye radius. Determinations were made of the electric field and the distribution of electrons and ions in the neighborhood of the body for an arbitrary field potential at its surface. The intensity of the electric field was determined. The total flux of ions and electrons at the surface of the body was computed and a probe characteristic derived. 8 references.

65. STRUCTURE OF THE DISTURBED ZONE IN THE VICINITY OF A CHARGED BODY IN PLASMA
Gurevich, A. V.
***Geomagnetizm i Aeronomiia*, v. 4, no. 1, pp. 3–16, 1964**
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 4, no. 1, pp. 1–11, 1964)

An analysis is made of the disturbances produced in plasma by a charged spherical body, small in size compared to the Debye radius. The distribution of the electric field and of the electrons and ions is found for various field potentials at the surface of the body.

66. THE INSTABILITY OF THE DISTURBED ZONE IN THE VICINITY OF A CHARGED BODY IN A PLASMA
Gurevich, A. V.
***Geomagnetizm i Aeronomiia*, v. 4, no. 2, pp. 247–255, 1964**
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 4, no. 2, pp. 192–198, 1964)

A study was made of the stability of a disturbed zone in a plasma in the vicinity of a body charged to a potential, ϕ_0. It is shown that at $T_e > T_i$ and $\phi_0 \sim 0$, where T_e and T_i are the electron and ion temperatures, respectively, an instability occurs with respect to the longitudinal waves. At $T_e \gg 1.7\ T_i$, the entire region of potentials $\phi_0 \gtrsim 0$ is unstable. However, the region of significant negative potentials $\phi_0 < -2.5\ kT_e/e$ is stable for any value of the ratio T_e/T_i. The disturbed zone near very large bodies (i.e., for $R_0 \gg c/\omega_0$, where R_0 is the diameter of a body and ω_0 is the Langmuir frequency) is unstable with respect to transverse electromagnetic waves. 14 references.

67. ELECTRIC FIELD STRENGTH ON THE SURFACE OF A BODY IN A PLASMA
Gurevich, A. V.
***Kosmicheskie Issledovaniia*, v. 2, no. 2, pp. 232–245, March–April 1964**
(Translated from the Russian in *Cosmic Research*, v. 2, no. 2, pp. 196–208, March–April 1964, and also in FTD-TT-64-547/1+2+3, Air Force Systems Command, Foreign Technology Division, Wright-Patterson AFB, Ohio, June 8, 1964, AD-601,554, N64-29,080)

The structure of a charged layer on the surface of a body in a plasma was investigated, and the electric field strength at the body surface was determined. It is shown that these field strength measurements can be used for determining the velocity vectors of ion movement in the ionosphere. 8 references.

68. SUPERSONIC MOTION OF A BODY IN A PLASMA
Gurevich, A. V., Pitaevskii, L. P.
***Geomagnetizm i Aeronomiia*, v. 4, no. 5, pp. 817–824, 1964**
(Translation available as TT-F-9174, National Aeronautics and Space Administration, Washington, D.C., November 1964, and in *Geomagnetism and Aeronomy*, v. 4, no. 5, pp. 637–642, 1964)

A comparison is made of various approximate methods of calculating the ion concentration at great distances from a fast-moving body in a plasma. A dimensionless equation is obtained, which describes the plasma disturbances behind the body. A similarity law of such motions is formulated. 14 references. (*IAA*, A64-28,539)

69. FURTHER COMMENTS ON "PERTURBATIONS IN THE IONOSPHERE CAUSED BY A MOVING BODY"
Gustafson, W. A., Kiel, R. E.
***AIAA Journal*, v. 1, no. 12, pp. 2869–2870, December 1963**

A study was made of the relation between an exact formulation of the problem of the density distribution behind a satellite of circular cross section in free molecule flow as indicated by Browand (Entry 43), and the approximate results presented by Gurevich (Entry 61). An analysis is presented which explains the relatively good agreement between the exact calculations and Gurevich's approximate results. (*IAA*, A64-11,772)

70. PLASMA–VEHICLE INTERACTION IN A PLASMA STREAM
Hall, D. F., Kemp, R. F., Sellen, J. M., Jr.
***AIAA Journal*, v. 2, no. 6, pp. 1032–1039, June 1964**
(Paper 63-055, presented at the AIAA Conference on Electric Propulsion, Colorado Springs, Colo., March 11–13, 1963)

An analytical and experimental examination was undertaken to determine the possibility of an interaction between a vehicle bearing an electrical propulsion device and the resident plasma in space. When the vehicle is stationary within the plasma, the fields, the potentials, and the currents to the vehicle are calculable from conventional Langmuir

probe theory. It is shown that the perturbed region in the plasma may extend outward from the vehicle over distances which are many times greater than the size of the vehicle. At a given vehicle potential the electric field strength at the surface of the vehicle may be greatly enhanced because of the near termination of the lines of electrical force from the vehicle surface. When the vehicle velocity becomes comparable to, or greater than, the ionic velocity, the simple calculational treatment is no longer valid. Under these conditions, an experimental examination using a vehicle in a plasma stream is undertaken. The potentials in the plasma are examined and found to demonstrate an increasing zone of disturbance as the potential difference between the vehicle and the plasma is increased. The geometry of this perturbed region is no longer simply spherically symmetric and is complicated in its behavior, particularly in the directions to the rear of the vehicle. Using a second experimental array, the ion flow patterns in this downstream region are examined. 12 references. (*IAA*, A63-16,903)

71. DETECTION OF ARTIFICIAL SATELLITES BY THEIR INFLUENCE ON THE IONOSPHERE
Hame, T. G., Stuart, W. D.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 373–388
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17; see also Preprint 61-61, presented at the AAS Symposium on Interactions of Space Vehicles With an Ionized Atmosphere, Washington, D.C., March 17, 1961)

Twenty-megacycle WWV bursts received at Columbus, Ohio, have been investigated for correlation in time and with geographical location of particular artificial satellites. The results are presented in terms of time diagrams, scatter diagrams, and statistical analysis. The recorded transmissions from active satellites are used in evaluating these results and for suggesting modifications of the experiments.

In further WWV experiments, elementary frequency sensitivity was introduced into the receiving system so that Doppler effects could be observed, and simultaneous amplitude and frequency spectrum recordings of 10-Mc WWV signals were obtained. The results are analyzed for correlation with satellite passes and the influence of solar activity.

Probable modes of scattering from satellite ionization are discussed, indicating that increased echo areas could be produced by an evacuated satellite trail. It is concluded that under certain circumstances a satellite-related effect may be detected.

72. ELECTRON TEMPERATURES IN THE IONOSPHERE
Hanson, W. B., Johnson, F. S.
***Mémoires de la Société Royale des Sciences de Liège*, Série 5, v. 4, pp. 390–424, 1961**
(Paper presented at the Tenth International Colloquim of Astrophysics, Liège, Belgium, July 11–14, 1960)

The physics of energy loss by electrons was studied. Assuming that the principal ionizing source in the F region is the solar He II 302 Å line with an intensity of 10^{-7} W/cm^2, it is unlikely that the electron temperature significantly exceeds the neutral particle temperature, except in the altitude region 150 to 300 km, where the electron temperature may be as much as 50% higher than the neutral particle temperature. The authors' interpretation of the experimental results obtained by *Sputnik III* differs from that presented by Krasovskii, who estimated a temperature of 15,000°K at 800 km. Two experimental indications showed that the electron temperature is not so high. Mass spectrometer experiments performed in rockets have shown that negative potentials of only a few tenths of a volt are present on rockets in the ionosphere and thus the electron temperature cannot exceed 1000°K. At night the electron temperature should drop to the neutral particle temperature, and the non-Maxwellian high energy tail for the electron velocity distribution should disappear. 22 references. (*MGA*, 1962, 13J-62)

73. EXPERIENCES WITH THE IMPEDANCE PROBE ON SATELLITES
Haycock, O. C., Baker, K. D., Ulwick, J. C.
***IEEE, Proceedings of the*, v. 52, pp. 1029–1033, September 1964**
(See also *1964 IEEE International Convention Record*, v. 12, pt. 8, pp. 165–170, 1964; paper presented at the IEEE International Convention, New York, N.Y., March 23–26, 1964)

A system is discussed which was designed to measure the impedance of a dipole antenna on a satellite orbiting in the ionosphere. The variations in impedance are used to determine the electron density of the ionosphere. Details of the instrumentation are given. To facilitate antenna engineering, experimental results from many satellite flights are presented in the form of antenna impedance. Electron density profiles are included, and the data show interesting spatial and temporal variations. The electron density in the vehicle wake is also considered. 7 references. (*IAA*, A64-26,107)

74. A STUDY OF SOME PROBLEMS IN THE KINETIC THEORY OF RAREFIED GASES IN AN EXTERNAL FORCE FIELD
Hays, P. B.
1964
Michigan, University of, Ann Arbor
Thesis

This thesis is a study of two physically distinct, but mathematically related, problems in the kinetic theory of a gas which is under the influence of a potential force field. The first part is an investigation of the effect of the electrostatic potential field in the vicinity of a moving charged body on a rarefied plasma. The second part deals with the classical problem of the escape of a planetary atmosphere from the gravitational field surrounding a planet.

The electrostatic interactions between a moving metallic body and a rarefied plasma are examined for the limits of very slow motion and very rapid motion. The disturbance to the plasma in the vicinity of a slowly moving body is shown to be made up of the stationary disturbance where the body is at rest, plus a perturbation which is linearly dependent upon the body velocity. The perturbations are shown to obey a simple cosine variation with the angular position in the vicinity of a moving sphere. In this case the radial variation of the ion density and the potential field are determined from an ordinary linear integro-differential equation.

The electrostatic disturbance in the vicinity of the stagnation point of a large, rapidly moving body is demonstrated to be planar and confined to a thin sheath. This sheath is of the order of 10 Debye lengths thick for a negatively charged body. The potential field within the sheath is nearly independent of the composition of the ambient plasma; however, the composition of the plasma varies within the sheath. The variation of the composition through the sheath is due to differential acceleration of the various ion species. 168 pages. (*DA*, 64-12,609)

75. THE ELECTROSTATIC AND ELECTROMAGNETIC DRAG FORCES ON A SPHERICAL SATELLITE IN A RAREFIED PARTIALLY IONIZED ATMOSPHERE
Hohl, F., Wood, G. P.
In "Rarefied Gas Dynamics, Volume II," pp. 45–64
Laurmann, J. A., Editor
Academic Press, Inc., New York, N.Y., 1963
N63-21,590
(Paper presented at the Third International Symposium on Rarefied Gas Dynamics, Paris, France, June 1962—Entry 599)

A theoretical study was made of the electric charge drag forces acting on a spherical satellite in free-molecule flow in the upper atmosphere. An attempt is made to clarify the theory. The analysis is applied to an Earth satellite 4 m in diameter at 1500-km altitude. The calculations yield the charge density distribution and potential distribution in the sheath, the ion trajectories, the increased ion-impact drag, the ion-scattering drag, and the induction drag due to the Earth's magnetic field. These three electric drags total about 3½% of the drag of the uncharged sphere for average conditions between maximum and minimum of sunspot activity. The percentage would be approximately doubled at the maximum, and approximately halved at the minimum. 13 references.

76. SATELLITE CHARGE-UP IN THE OUTER VAN ALLEN BELT
Hundley, R. O.
September 1961
Rand Corporation, Santa Monica, Calif.
P-2441
AD-605,786
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The study of satellite charge-up is extended to include satellites in the outer Van Allen belt. Due to the presence of the high energy Van Allen electrons, the electrostatic potentials acquired by satellites in the Van Allen region may be much larger than that of ionospheric satellites. Numerical results for the satellite potential are obtained, assuming complete absorption of the incident particles, and it is found that for satellites of the size used thus far, potentials of a few kilovolts can be expected, but for satellites of larger size, potentials up to the order of several tens of kilovolts can be expected. The effects of secondary electron emission and photoelectron emission are investigated. It is found that secondary electrons will have only a minor effect, but that for some surface materials the effect of photoelectron emission due to solar radiation may completely cancel the large potentials. 42 pages.

77. SATELLITE CHARGE-UP AS A MEANS OF MAINTAINING THE SHAPE OF ECHO-TYPE SATELLITES IN THE OUTER VAN ALLEN BELT
Hundley, R. O.
December 1961
Rand Corporation, Santa Monica, Calif.
RM-2921-NASA, NASr-21
N62-10,766
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The possibility is considered of using satellite charge-up as a means of maintaining the shape of *Echo*-type satellites in the outer Van Allen belt. The electrostatic repulsive force due to satellite charge-up is calculated, as well as the principal forces causing satellite collapse — namely, the plasma pressure, the radiation pressure, and the gravitational gradient. It is concluded, on the basis of existing experimental data concerning the Van Allen electrons, that the charge-up method of maintaining satellite shape would probably not be useful for opaque satellites. The method might be useful some of the time for partially transparent balloon satellites at the center of the Van Allen belt. However, the method would be, at best, only marginally useful for partially transparent satellites at the lower edge of the outer Van Allen belt. 21 pages; 4 references.

78. THE FLOW ABOUT A CHARGED BODY MOVING IN THE LOWER IONOSPHERE
Hunziker, R. R.
***Journal of the Aerospace Sciences*, v. 27, no. 12, pp. 935–942, December 1960**

The flow about an electrically charged body traveling at high speeds through the lower ionosphere is analyzed. A simple gas model composed of electrons, ions, and neutral particles is used, and the hydrodynamic description given is based on Maxwell's transfer equations for a mixture. The conditions under which local statistical equilibrium can be assumed are discussed, and methods for determining the gas-dynamic force in the subsonic, supersonic, and hyper-

sonic cases are indicated. The reciprocal action of the electric field of the flow on the body is also analyzed, and a formula for the resultant electric force is given. The total force on the body is equal to the sum of the gas-dynamic force and the electric force. The negative potential acquired by a plane body is also calculated. Finally, the lack of validity of Debye's linearization in this case and the solution of the exterior nonlinear problem which characterizes the electric potential and the electron distribution are discussed.

79. METHODS OF COMBATING INTERFERING CURRENTS THAT ARISE AT INPUT OF ELECTROSTATIC FLUXMETER OPERATING IN CONDUCTING MEDIUM

Imyanitov, I. M., Shvarts, Ya. M.
***Iskusstvennye Sputniki Zemli*, no. 3, pp. 77–83, 1959**
(Translations available as TT-F-16, National Aeronautics and Space Administration, Washington, D.C., May 1960, and in *Artificial Earth Satellites*, v. 3, pp. 108–118, 1961; see also *ARS Journal*, v. 30, no. 4, pp. 403–406, April 1960)

An electrostatic rotary-type fluxmeter was used to measure the charge acquired by a satellite through a variety of processes. Methods useful in combating conduction current at the input of the fluxmeter are surveyed. Three methods are discussed: the first uses a synchronous detector at the output of the measuring circuit; the second requires measuring and screening plates to decrease the modulation of the flow of charged particles and absolute value of the current falling on plate surface; the third method suggests the use of a negative feedback on the noise voltage. The calculations involved are discussed.

80. ELECTROSTATIC FIELD STRENGTH MEASUREMENTS WITH SPUTNIK III

Imyanitov, I. M., Shvarts, Ya. M.
***Iskusstvennye Sputniki Zemli*, no. 17, pp. 59–65, 1963**
(Translations available as TT-F-8528, National Aeronautics and Space Administration, Washington, D.C., October 1963, N64-23,036, and in *Artificial Earth Satellites*, v. 17, pp. 60–65, March 1964)

An analysis of the electrostatic field strength measurements by *Sputnik III* indicates the following: (1) The average area of the *Sputnik* surface on which a positive current can flow is, at most, not smaller than the area on which a negative current can flow. Thus the observed longer duration of a positive field, as compared to the duration of a negative field, indicates an average negative charge on the *Sputnik* during those portions of the trajectory where the intensity of the electrostatic field was measured. (2) Changes were observed in the intensity of the electrostatic field that did not correlate with the parameters of the detector related to the course, the Sun, or the magnetic field. Some of these changes are connected with intensive accumulation of electrostatic changes on the *Sputnik*. (3) Improved methods, which permit the exclusion of the effects produced by noise currents, may be used to elucidate the sources of these variations and their relation to the characteristics of the medium. 7 references.

81. MEASUREMENTS OF THE ELECTROSTATIC FIELD STRENGTH NEAR THE SURFACE OF GEOPHYSICAL ROCKETS IN THE UPPER ATMOSPHERE

Imyanitov, I. M., Gdalevich, G. L., Shvarts, Ya. M.
***Iskusstvennye Sputniki Zemli*, no. 17, pp. 66–81, 1963**
(Translations available as TT-F-8529, National Aeronautics and Space Administration, Washington, D.C., October 1963, and in *Artificial Earth Satellites*, v. 17, pp. 66–80, March 1964)

Diagrams are shown of improved measuring apparatus of the type described earlier by Gdalevich (Entry 57), showing the new construction of the pickups and shape of the rotating and stationary screen plates (metal grids). This new apparatus makes it possible to reduce the modulation and absolute magnitude of the radiative and charged-particle flows incident on the surface of the measuring plate. The parameters of the input circuit and special tuning methods make it possible to tune the synchronous detector to the minimum of the noise voltage and thereby improve the signal-to-noise ratio. The noise current can be estimated; this permits an evaluation of the efficiency of the measures taken to combat noise. The influence of the surface space charge on the measurements is considered. Measurements obtained with a stabilized rocket launched November 15, 1961, to a height of 430 km, show that the rocket was negatively charged throughout the flight and measurements of the two detectors were not the same. The average electrostatic field strength near the surface of the rocket (above 100–120 km) was approximately constant at 1.5–1.6 V/cm. Using a table of the values of the thickness of the space-charge layer at different altitudes (1.2–1.5 cm at 1000°K, and 1.7–7 cm at 2000°K), the potential of the rocket was several volts. It is inferred that many fast negative particles must exist in the atmosphere which electrically charge the body. Other launchings suggest that these results are not random. By making certain assumptions, the intensity of the external field is estimated to be on the order of 10^{-3} V/cm, a value only expected in connection with polar aurora.

82. MEASUREMENT OF ELECTROSTATIC FIELD INTENSITY AT THE SURFACE OF GEOPHYSICAL ROCKETS

Imyanitov, I. M., Gdalevich, G. L., Shvarts, Ya. M.
***Akademiya Nauk SSSR, Doklady*, v. 148, no. 6, pp. 1306–1308, February 21, 1963**

An electrostatic fluxmeter of special design was used to measure the electrostatic field strength at the surface of a stabilized geophysical rocket. The block diagram of the device is presented. The results, given in the form of curves, indicate the existence in the ionosphere, at the time of the measurements, of an electric field of an intensity of the order of 10^{-3} V/cm. (*IAA*, A63-14,696)

83. AN IMPROVED METHOD OF MEASUREMENT OF THE STRENGTH OF THE ELECTROSTATIC FIELD AT THE SURFACE OF SPACECRAFT IN THE UPPER ATMOSPHERE
Imyanitov, I. M., Shvarts, Ya. M.
October 6, 1964
Joint Publications Research Service, Washington, D.C.
JPRS-26742 (pp. 119–128), TT 64-41999
N64-32,339
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is one of 12 articles included in the JPRS report entitled "Methods and Instruments for Meteorological Observations." This report consists of English translations of selected articles from Volume IX of "Trudy Vsesoyuznogo Nauchnogo Meteorologicheskogo Soveshchaniya, Pribory i Metody Nablyudency" (Proceedings of the All-Union Scientific Meteorological Conference, Instruments and Methods of Observations), edited by M. S. Sternzat, and published by the Hydrometeorological Publishing House, Leningrad, in 1963.

Measurements of the electrostatic field at the surface of spacecraft are useful in estimating the distortions in sensor measurements of the distribution of charged particles in the vicinity of the spacecraft, and in estimating the braking forces when satellites are used as geodetic reference points. The use of an electrostatic oscillator with a measuring plate (which is part of the surface of the spacecraft) and a shielding plate (which periodically shields the measuring plate from the surrounding space charge) is described. The generated current causes a voltage drop that is measured by a tube circuit. Design considerations necessary to reduce interfering noise currents to acceptable limits are included.

84. ATMOSPHERIC DRAG ON THE SATELLITE
Jastrow, R., Pearse, C. A.
***Journal of Geophysical Research*, v. 62, no. 3, pp. 413–423, September 1957**

The drag exerted on the satellite in its orbit arises partly from collisions with neutral air particles and partly from losses associated with the passage of a charged sphere through an ionized medium. It is found that the charged and neutral effects are comparable under the atmospheric conditions expected at an orbital altitude of 300 miles. (*PA*, 1958, #4688)

85. ARTIFICIAL SATELLITES AND THE EARTH'S ATMOSPHERE
Jastrow, R.
***Scientific American*, v. 201, no. 2, pp. 37–42, August 1959**

Artificial satellites have provided much information concerning the upper atmosphere. This information is reviewed, and the effects of electrical drag are considered. The energy flux of the electrons in the inner belt of particles is high enough to raise the potential on a satellite to some thousands of volts during each pass through the belt. A potential of roughly 1000 V would increase the effective radius of the *Vanguard* satellite by a factor of 10, increasing its cross-sectional area by a factor of 100. The resulting increase in drag at apogee, when the *Vanguard I* traverses the inner zone of particles, would be sufficient to double the mean drag on the satellite. Electrical drag may also be responsible for the drag increases produced by the flares in the orbit of the *Sputnik III* rocket. Further experiments on the particles in the outer belt will yield the data necessary to make a good calculation of satellite voltages, and to separate the effects due to density changes from those caused by electrical drag.

86. SATELLITE POTENTIAL IN AN IONIZED ATMOSPHERE
Jen, N. C.
***AIAA Journal*, v. 3, no. 4, pp. 714–717, April 1965**

A self-consistent field theory involving the Vlasov equation and the Poisson equation is applied to the study of the potential field, the Coulomb drag, and the wake trails of a spherical satellite in an ionized atmosphere. It is considered that undisturbed particles have a Maxwellian distribution of speeds with large mean free paths in comparison with the Debye length. In the vicinity of the sphere, both the incident and the reflected distribution functions are considered. It is found that the electrical potential around a rapidly moving satellite is not spherically symmetrical, which is a new and essential contribution to the existing state of knowledge on this subject. From this nonspherical potential field, the Coulomb drag is easily formulated, and the characteristics of the wakes behind the satellite are readily predicted. The theoretical value as computed for the *Explorer VIII* satellite leads to a potential of -0.156 V, which is in close agreement with the actual observed measurement of -0.15 V. A method is also presented for obtaining results from the nonlinear and self-consistent set of Vlasov–Poisson equations. 9 references.

87. THE REGION BEHIND A BODY MOVING THROUGH A RAREFIED IONIZED ATMOSPHERE
Kornowski, E. T.
1960
Air Force Cambridge Research Center, Electronics Research Directorate, Bedford, Mass.
AFCRC-TR-60-108(I)
AD-236,932
(Paper presented at the Symposium on the Plasma Sheath: Its Effects on Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 18)

Physical arguments indicate that charge density gradients will exist some distance behind, and possibly a short distance to the side of, a body moving at high speed through the ionized layers of the upper atmosphere.

The medium is taken to be highly rarefied gas composed of ions and electrons. An unsteady model is set up wherein the ion and electron density profiles, which are obtained as a function of space and time, correspond to the profiles at a

given cross section aft of the body in the actual problem. The Boltzmann equation is utilized, with electric effects taken into account, and solutions are obtained numerically. Perturbations on the velocity distribution functions are calculated over small increments of time which then yield the magnitude of the electric effect over the next time increment.

Calculations indicate that the charge density gradients extend several body radii downstream. These gradients are inherent to the rarefied flow over any vehicle and can significantly alter its detectability by electromagnetic signals. 8 pages.

88. OBSERVATIONS OF IONIZATION INDUCED BY ARTIFICIAL EARTH SATELLITES
Kraus, J. D., Higgy, R. C., Scheer, D. J., Crone, W. R.
***Nature*, v. 185, no. 4712, pp. 520–521, February 20, 1960**

Enhancements of the strength of continuous wave signals from the station WWV were found at the times of approach of *Sputnik III*. The enhancements were greatest as the satellite passed through the auroral zone. It is postulated that echoes obtained from moving regions near the path of the satellite were caused by ionized clouds scattered by the satellite. (*PA*, 1960, #10,540)

89. THE SATELLITE IONIZATION PHENOMENON
Kraus, J. D., Higgy, R. C., Crone, W. R.
***IRE, Proceedings of the*, v. 48, no. 4, pp. 672–678, April 1960**

A number of observations are presented which show a close correlation between CW-reflected HF signals and passes of artificial Earth satellites. The periodic (nonrandom) occurrence of the signal bursts and the symmetry of some burst sequences are indicative of satellite-related phenomena. The occurrence of a variety of satellite-related Doppler effects is described, and several satellite ionization mechanisms are discussed. The possible relation of the satellite phenomenon to prior solar activity is mentioned.

90. THE RELATION OF THE SATELLITE IONIZATION PHENOMENON TO THE RADIATION BELTS
Kraus, J. D., Higgy, R. C.
***IRE, Proceedings of the*, v. 48, no. 12, pp. 2027–2028, December 1960**

Observations at the Ohio State University Radio Observatory have been reported which indicate a close correlation between the occurrence of satellite-induced ionization and passes of the satellite through the auroral or Van Allen belts. (*AI/S*, 1961, #30,349)

91. OBSERVATIONS OF SATELLITE-RELATED IONIZATION EFFECTS BETWEEN 1958 AND 1960
Kraus, J. D., Tiuri, M. E.
***IRE, Proceedings of the*, v. 50, no. 10, pp. 2076–2081, October 1962**

Three independent sets of satellite observations — which were made over a two-year period (1958–1960) — are described. The results indicate a marked correlation between satellite passes and ionospheric ionization effects. The effects tend to peak at the time of near-approach of the satellite or somewhat earlier, with most of the effects occurring in the interval of 20 minutes before the satellite's passage to 10 minutes after its passage. Other observations of some short-range effects are described which indicate a dependence of the effects on the satellite's heading as a function of the local time, and on its position with respect to the observing location. (*PA*, 1963, #5151)

92. THE SATELLITE IONIZATION PHENOMENON
Kraus, J. D.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 325–372
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17)

Observations are described which provide evidence of satellite-related ionization effects. The observations were made using both CW-reflection and pulse-radar techniques, especially in the 10- to 20-Mc frequency range. Using the CW-reflection technique, the evidence is based to a considerable extent on close time correlations between reflected CW signals and passes of artificial Earth satellites. Such events are considered to have some probability of relation to a satellite only if no other significant reflected signals are observed for long periods. Additional evidence of correlation with satellites may be inferred in the case of CW signal burst groups having a high degree of symmetry (symmetrical burst sequences) or other unique characteristics. A number of examples of CW-reflected signals are described and discussed.

Using the pulse-radar technique, the evidence rests on a time correlation between the radar echo and a satellite pass and on a comparison of the radar range and direction information with the satellite position. Several examples of radar events are presented in which radar echoes are observed that appear to be satellite-related. Although a few of the observed radar echoes may have come from ionization in the vicinity of the satellite, and moving with it, most of the radar echoes which appear to be satellite-related are from fast-moving disturbances. The disturbances tend to cluster near a satellite pass and occasionally follow systematic trends during a pass. Frequently the disturbances are first detected in the vicinity of the satellite and are observed to travel generally nearer the observer at velocities of 50 to 200 km/sec. Although the nature of the disturbances is uncertain, several possibilities are considered.

The relation of the CW-reflection and pulse radar events to disturbed magnetic, ionospheric, auroral, and radiation belt conditions, and also to prior solar activity, is discussed.

Such factors as satellite height, frequency, and radar cross section are also considered. In addition, some evidence of an inter-hemispheric effect is presented.

93. PLASMA MOTIONS INDUCED BY SATELLITES IN THE IONOSPHERE
Kraus, L., Watson, K. M.
In "Avionics Research: Satellites and Problems of Long Range Detection and Tracking," pp. 75–91
Glazier, E. V. D., Rechtin, E., Voge, J., Editors
Pergamon Press, Inc., New York, N.Y., 1960 (available as AGARDograph 40)
(Paper presented at the AGARD Avionics Panel Meeting, Copenhagen, Denmark, October 20–25, 1958—Entry 6; see also *Physics of Fluids*, v. 1, no. 6, pp. 480–488, November–December 1958)

The electrohydrodynamic phenomena associated with the high velocity motion of a charged body in a plasma are investigated with a view to applications to satellite motion in the ionosphere. It is shown that the effect of the electric field due to the charge on the body in inducing collective motion leads to similar results both for high and low density gases. Using a linearized theory, formulas are obtained for the electrohydrodynamic drag and for the increased ionization in the Mach cone behind the body. 12 references.

94. ELECTROHYDRODYNAMIC PROPERTIES OF SATELLITES
Kraus, L.
In "Avionics Research: Satellites and Problems of Long Range Detection and Tracking," pp. 92–100
Glazier, E. V. D., Rechtin, E., Voge, J., Editors
Pergamon Press, Inc., New York, N.Y., 1960 (available as AGARDograph 40)
(Paper presented at the AGARD Avionics Panel Meeting, Copenhagen, Denmark, October 20–25, 1958—Entry 6)

The principles of electrohydrodynamics which describe the motion of a charged body in a plasma are applied to typical satellite motions, and numerical estimates are obtained for various quantities of interest. Among these are the drag, the Mach cone angle, and the increase in ionization across the Mach cone. The drag is compared to that obtained for uncharged bodies in a neutral gas in various regions of the ionosphere. 5 references.

95. THE POTENTIAL OF A METAL SPHERE IN INTERPLANETARY SPACE
Kurt, V. G., Moroz, V. I.
***Iskusstvennye Sputniki Zemli*, no. 7, pp. 78–88, 1961**
(Translated from the Russian in *Artificial Earth Satellites*, v. 7–8, pp. 78–87, June 1962; see also *Planetary and Space Science*, v. 9, pp. 259–268, May 1962)

The problem of determining the potential of a metal sphere in interplanetary space is analyzed and a first order approximation is obtained. The analysis is illustrated using a pure metal sphere which is 130 cm in diameter. Assuming an interplanetary gas temperature of 10,000°K and a photocurrent density of 2.5×10^{-9} A/cm^2, the potential of the clean metal sphere in the illuminated portion of the trajectory should lie within the limits of -2.5 and $+4$ V, providing the ion concentration is > 10 particles/cm^3. The effect of the magnetic field and motion of the sphere becomes manifest in a small change (1–2 V) in potential; this change can be neglected considering the indeterminacy of other factors. In the region of the outer radiation belt, it seems unlikely that the potential will be affected by radiation electrons in the illuminated part of the trajectory, at least during magnetically quiet times. The possibility of large negative potentials (on the order of kilovolts) is not excluded, however, if the usual notions of a high concentration of soft radiation electrons and sufficiently rare interplanetary gas in the outer zone are correct. In the latter case, appreciably negative potentials are possible even with relatively small total electron fluxes. For example, with an ion concentration of 1 particle/cm^3 and an electron flux on the order of 3×10^8/cm^2/sec, the potential would equal ~ -25 V. 21 references.

96. THE CONTROL AND USE OF DRAG-FREE SATELLITES
Lange, B. O.
1964
Stanford University, Stanford, Calif.
Thesis
(See also *AIAA Journal*, v. 2, no. 9, pp. 1590–1606, September 1964)

A scientific Earth satellite which is guided in a drag-free orbit by a shielded, free-falling proof-mass has been proposed by a number of investigators. The outer satellite, which completely encloses the proof-mass, has a jet-activated translation-control system that causes it to pursue the proof-mass in such a way that the two never touch. The feasibility and some of the applications of this scheme are examined.

The principal trajectory errors which are due to vehicle gravity, stray electric and magnetic fields, and sensor forces are investigated. It is found that drag and solar radiation pressure forces may be effectively reduced by three to five orders of magnitude for 100- and 500-st mi orbits, and that the deviation from a purely gravitational orbit may be made as small as 1 m/yr. Such a satellite may be used to make precise measurements in geodesy and aeronomy. 208 pages. (*DA*, 64-13,606)

97. ELECTRODYNAMIC EFFECTS CONNECTED WITH THE MOTION OF A SATELLITE OF THE EARTH
Lehnert, B.
***Tellus*, v. 8, no. 3, pp. 408–409, August 1956**

Data are presented indicating the order of magnitude of the following: (1) mean free path of charged and neutral particles and number of collisions, (2) lifetime of electrons, (3) ion currents, (4) charge on satellite (at speeds of 7.7×10^3 m/sec and height of 500 km), (5) interaction of

satellite with ions and electrons "blasted off" along lines of magnetic field, (6) momentum transfer at and near satellite, (7) electrostatic energy and drag. 13 references. (*MGA*, 1960, 11F-76)

98. THE DRAG ON A CHARGED SATELLITE
Licht, A. L.
***Journal of Geophysical Research*, v. 65, no. 10, p. 3493, October 1960**

In considering the drag on a charged satellite, Wyatt (Entry 377) has omitted the largest contribution to the drag — that due to the ions actually striking the satellite surface. The number of such ions varies with the electric charge on the satellite, so that these impacts make a contribution to the charge drag. (*PA*, 1961, #18,224)

99. SPUTTERING AS A POSSIBLE MECHANISM FOR INCREASE OF IONIZATION IN THE VICINITY OF LOW-ALTITUDE SATELLITES
Magnuson, G. D., Medved, D. B.
***Planetary and Space Science*, v. 5, no. 2, pp. 115–121, June 1961**

It is suggested that for altitudes below 200 km there may be sufficient sputtering produced by ionic, atomic, and molecular impact on the vehicle surface to lead to some increase in ionization above ambient at distances of one mean path or less from the vehicle. The sputtering process injects into the environment atoms of metallic elements whose ionization potentials are one-half to one-third those of the ambient species. Collision energies in the center-of-mass system vary from ionization thresholds, E_i, to two to three times E_i. The resulting ionization in the surroundings may then be calculated if values for β, the probability of any collision leading to ionization, are known. On the basis of the crude model presented, β should be greater than or equal to 10^{-6} for this mechanism to be of interest.

100. EXPERIMENTAL STUDY OF THE INTERACTION OF A MOVING BODY WITH A PLASMA
Meckel, B. B.
In "Rarefied Gas Dynamics," pp. 701–714
Talbot, L., Editor
Academic Press, Inc., New York, N.Y., and London, England, 1961
(Paper presented at the Second International Symposium on Rarefied Gas Dynamics, Berkeley, Calif., August 3–6, 1960—Entry 606)

An experimental investigation was undertaken to determine some of the effects of interactions of a body moving at high velocity through a low-pressure, partially ionized gas. An apparatus is described which simulates the motion of a body traveling through an ionized gas. In the approach used, a plasma is accelerated past the body, rather than moving the projectile through the plasma. In order to properly diagnose the beam characteristics, it is necessary to develop methods of determining particle densities, energies, and directional motions for the entirety of the test chamber. This is done by using moveable Langmuir probe techniques, fine microbalance detectors, and other varied electrode-collector devices. These and other methods are used to determine the charge accumulation, to detect the wake, and to investigate the drag produced by the electrostatic interaction. 12 references. (*IAA*, A63-11,345)

101. SECONDARY ELECTRON EMISSION AND THE SATELLITE IONIZATION PHENOMENA
Medved, D. B.
***IRE, Proceedings of the*, v. 49, no. 6, pp. 1077–1078, June 1961**

The observations of Kraus and colleagues (Entries 89 and 90) on the large anomalous electromagnetic scattering from artificial Earth satellites are reviewed. These observations are assumed to be connected in some manner with a satellite-induced ionization phenomena in the medium traversed by the vehicle.

Several independent and distinct mechanisms have been proposed and analyzed for the production of local electron and ion densities varying from ambient in the neighborhood of a satellite. Some of these theories are discussed. A model is outlined for ionization buildup based on secondary electron emission, which is valid for two ranges of altitude: (1) 90 to 250 km, and (2) altitudes greater than 1000 km.

102. EXCITATION AND IONIZATION FLOW FIELDS ASSOCIATED WITH UPPER ATMOSPHERE VEHICLES
Medved, D. B., Ball, J. S., Frazer, W. R.
In "Rarefied Gas Dynamics, Volume II," pp. 23–32
Laurmann, J. A., Editor
Academic Press, Inc., New York, N.Y., 1963
(Paper presented at the Third International Symposium on Rarefied Gas Dynamics, Paris, France, June 1962—Entry 599)

The interaction of a satellite with the ambient medium in producing excitation (radiation) and/or ionization fields is considered for very low altitude vehicles (200 km or lower). The problem is simplified by reducing it to a consideration of a point source which is generating particles and moving through this ambient medium at the satellite velocity. Since the collision energies are in the neighborhood of the threshold value for the inelastic processes, only the first two or three collisions are considered, although a general formulation of the nth-collision problem has been obtained using a random-walk calculation.

103. SHEATHS FROM SECONDARY ELECTRON EMISSION AND PHOTOEMISSION
Medved, D. B.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 305–321
Singer, S. F., Editor

Pergamon Press, Inc., Oxford, England, and
New York, N.Y., 1965
(See Entry 17; see also Preprint 61-67, presented at the AAS Symposium on Interactions of Space Vehicles With an Ionized Atmosphere, Washington, D.C., March 17, 1961)

The processes of charge accumulation and production of electron sheaths around satellites are reviewed. It seems most unlikely that any unique, simple, physical model can completely account for all the observations reported, particularly in view of the wide altitude range involved. A model for satellite ionization buildup is described which is based on secondary electron emission and is valid for two specific altitude ranges. Secondary electron emission, in the general sense used here, signifies the emission of electrons from the vehicle surface initiated by any neutral sources, such as (1) neutral atoms and molecules in the ground or excited states, or (2) energetic photons above the photoelectric threshold ($\lambda < 4000$ Å). The two altitude ranges are defined by these two processes. The first process defines a range between 90 and 250 km, and the second corresponds to altitudes greater than 1000 km.

104. DISTURBANCES OCCURRING IN THE GASEOUS MEDIUM DURING THE FLIGHT OF A SATELLITE
Mirtov, B. A.
***Iskusstvennye Sputniki Zemli*, no. 2, pp. 17–28, 1958**
(Translated from the Russian in *Artificial Earth Satellites*, v. 2, pp. 20–31, 1960; see also *Annals of the International Geophysical Year*, v. 12, pt. I, pp. 372–380, 1960)

In its rapid flight in a rarefied gas medium, a satellite produces streams of molecules which move together with it at very high velocities relative to the molecules of the surrounding medium. It is necessary to distinguish two types among these streams: streams arising from the release of molecules by the satellite itself (desorption from the surface and leakage from inside), and streams of molecules of the medium recoiling from the satellite according to the laws of elastic collision. These streams have a mean molecular velocity of 8.5 9 km/sec and 13–16 km/sec, respectively. Because of these streams, the medium surrounding the satellite experiences perturbations which result in (1) density disturbances; (2) thermochemical reactions and ionization that arise from head-on collisions (because the molecules coming from the satellite have sufficient energy for this); and (3) the formation of a "rear cone" or molecular shadow behind the satellite, into which only fast molecules of the surrounding medium can penetrate, since the velocity of the satellite exceeds the thermal velocity of the molecules of the surrounding medium by an order of magnitude.

Because of these disturbing effects, satellite experiments designed to measure such parameters as ion composition, ion concentration, and gas density may yield incorrect results (which do not correspond to the actual condition of measured parameters of the undisturbed atmosphere). The purpose of this work is to evaluate several distorting factors capable of affecting the measurement of the indicated values.

105. IDEALIZED SHEATH THEORY AND SATELLITE CHARGE-UP IN THE VAN ALLEN REGION
Modesitt, G. E.
April 1962
Rand Corporation, Santa Monica, Calif.
RM-3096-PR

As an aid in the determination of the electric potential of naturally charged satellites, Langmuir and Mott-Smith's concept of the idealized sheath is studied in some detail by the use of distribution functions. It is shown that the functions are discontinuous in velocity variables and lead to the same results as the particle trajectory theory. The limitations of the sheath theory and its connection with the space-charge-limited diode theory are discussed. It is shown that, under certain assumptions, the potential on a satellite of diameter smaller than the local Debye length will reach 3500 V negative in the more intense regions of the Van Allen electron belt. The equilibrium potential decreases with increasing size of the satellite, with a limiting value of −35,000 V for satellites much greater than the Debye length in diameter. (*AI/A*, 1963, #70,530)

106. THE EFFECT OF THE ELECTRIC FIELD ON DISTURBANCES AROUND A BODY MOVING IN A PLASMA
Panchenko, Yu. M., Pitaevskii, L. P.
***Geomagnetizm i Aeronimiia*, v. 4, no. 2, pp. 256–259, March–April 1964**
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 4. no. 2, pp. 199–202, 1964)

Expressions are derived for calculating the electron and ion concentrations at great distances from a body moving in a plasma. It is assumed that the plasma is highly rarefied, and that the velocity of the moving body is much larger than the thermal velocity of the ions.

107. FLOW OF A HIGHLY RAREFIED PLASMA PAST BODIES
Pashchenko, N. T.
***Archiwum Mechaniki Stosowanej*, v. 16, no. 2, pp. 521–528, 1964 (in Russian)**
(Paper presented at the Sixth Scientific Conference of the Polish Academy of Sciences, Institute of Basic Technical Problems, Division of Mechanics of Fluids, Zakopane, Poland, September 2–9, 1963)

A solution is presented for the problem of a charged body in a stationary flow of a highly rarefied plasma. The field of body potential and the forces acting on the body are determined on the assumption that the body charge is small and the Debye radius is small relative to the characteristic body size. The Vlasov equations of self-consistent field are used to derive the equations of distribution functions for each component and the potential of the electrical field. 12 references. (*IAA*, A65-15,279)

108. PARTICLE MOTION IN THE EQUATORIAL PLANE

Pisacane, V. L.
AIAA Journal, v. 2, no. 8, pp. 1361–1364, August 1964

A theoretical analysis is presented to describe the motion of bound particles in the equatorial plane of a concentric gravitational and dipole magnetic field. Exact expressions are obtained for the angular drift, angular drift velocity, and period of the particle about the dipole axis in terms of the normal complete elliptic integrals. More tractable results are obtained by a first-order approximation to the trajectory of the particle. The analysis is applicable to the motion of charged satellites or charged particles in the exosphere. The approximate results which were obtained can be extended by using higher-order approximations.

109. EXPERIMENTAL INVESTIGATION OF ELECTRIC DRAG ON SATELLITES

Pitts, W. C., Knechtel, E. D.
AIAA Journal, v. 2, no. 6, pp. 1148–1151, June 1964
(Paper 64-32, presented at the AIAA Aerospace Sciences Meeting, New York, N.Y., January 20–22, 1964; also available as RP-280, National Aeronautics and Space Administration, Washington, D.C.)

Accurate knowledge of the satellite drag coefficient is a prerequisite in the prediction of satellite lifetimes and in the determination of the upper atmosphere density from orbital decay rates. For these purposes it is generally assumed that the drag is the same as that of an uncharged satellite in an ionized medium. The results are presented of experimental measurements of the interaction between the satellite charge and the ambient ions. The magnitude of the drag is determined, and it is established which of the various assumptions used in the theories are plausible. A physical description of the electric drag is also given, and the following conclusions are drawn: (1) the electric drag can be significant compared to the uncharged satellite drag; (2) any theory for electric drag must include both hard collisions of ions on the surface and the shielding effect of the plasma sheath; and (3) a simple empirical relation is available that permits rapid estimation of electric drag over practical ranges of interest.

110. EXPERIMENTAL INVESTIGATION OF ELECTRIC DRAG ON SPHERICAL SATELLITE MODELS

Pitts, W. C., Knechtel, E. D.
February 1965
National Aeronautics and Space Administration, Ames Research Center, Moffet Field, Calif.
TN D-2619
N65-15,548

Electric drag is defined as the difference between the drag of a charged satellite and the drag of an identical satellite with no charge. The drag increment is a consequence of the effective increase in size of the satellite resulting from scattering of ambient ions by the satellite potential. Electric drag was measured on conducting spheres in a streaming mercury plasma. It is shown that electric drag can be a significant portion of the total drag if the fraction ionization is sufficiently high. 40 pages.

111. IONIZATION IN HYPERSONIC WAKES. REVIEW OF MICROWAVE PROBE INSTRUMENTATION AND SUMMARY OF PRELIMINARY DATA

Primich, R. I., Hayami, R. A.
December 1962
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
TR 62-209 D, Technical Report on Hypervelocity Range Research Program, DA-04-495-ORD-3567
AD-294,868

An outline is given of the progress which was made in the development of the focused microwave probe as a plasma diagnostics tool, and its application to the study of ionization in hypersonic wakes. A major part of the development was concerned with instrumentation, the theoretical analysis of the interaction of the probe field with a plasma, data reduction, and interpretation of the results in terms of magnitudes and spatial variations of electron density and collision frequency. 64 pages; 24 references.

112. WAKE OF A SATELLITE TRAVERSING THE IONOSPHERE

Rand, S.
Physics of Fluids, v. 3, no. 2, pp. 265–273, March–April 1960

The particle treatment is applied to a study of the structure of the wake behind a charged body moving supersonically through a low-density plasma. For the case of a body having dimensions considerably smaller than a Debye length, a solution is obtained which is very similar in structure to the solution obtained by using the linearized fluid dynamics equation. For the case of a disk having radial dimensions much larger than a Debye length, two conical regions are found in the wake. At the surface of each of these cones, over thicknesses of the order of a Debye length, the ion and electron densities are increased over the ambient values. Formulas are obtained for the electrohydrodynamic drag on a wire and on a large disk. (*PA*, 1960, #9023)

113. DAMPING OF THE SATELLITE WAKE IN THE IONOSPHERE

Rand, S.
Physics of Fluids, v. 3, no. 4, pp. 588–589, July–August 1960

Landau damping of the ion plasma oscillations which constitute the wake of a line charge moving supersonically through a low-density plasma is studied. Maxwellian distribution functions in the ambient plasma have been assumed for both electrons and ions. It is found that the damping is critical to the question of whether the electrohydrodynamic

wake produced by a satellite in the ionosphere is observable, unless the electron temperature is at least an order of magnitude greater than the ion temperature.

114. REMARK CONCERNING THE CHARGE OF A SATELLITE

Rawer, K.
In "The Upper Atmosphere Above F2-Maximum," pp. 321–322
Poeverlein, H., Editor
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Paris, France, 1959 (available as AGARDograph 42)
(Paper presented at the Symposium of the Ionospheric Research Committee AGARD Avionics Panel, Paris, France, May 22–28, 1959—Entry 603)

In an earlier paper (Entry 84), Jastrow and Pearse estimate that high energy electrons of 70 eV may exist in appreciable quantity in the orbit of a satellite. Since there is no evidence of rapid deceleration, the author takes exception to this estimate. The photoeffect of solar radiation is also discussed.

115. PLASMA EFFECTS ON SATELLITES

Rawer, K.
In "Radio Astronomical and Satellite Studies of the Atmosphere," pp. 385–399
Aarons, J., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1963
(Paper presented at the Conference on Radio Astronomical and Satellite Studies of the Atmosphere, Corfu, Greece, June 1962)

An analysis is presented of that part of the interaction between a metallic satellite and the surrounding ionospheric plasma which influences the electrostatic potential of the satellite. The effects considered are the flux of electrons and ions, eventually controlled by additional magnetic and electric fields, and the photoeffect produced by solar radiation. The resulting potential should normally be negative in the ionosphere, but has a diurnal variation. At higher altitudes where the plasma density is small, positive values should occur when the satellite is sunlit. 15 references. (*IAA*, A63-25,996)

116. EVOLUTION OF AN INHOMOGENEOUS RAREFIED PLASMA AND ASSOCIATED HIGH FREQUENCY ELECTROMAGNETIC RADIATION

Ritt, R. K.
April 1962
Michigan, University of, Radiation Laboratory, Ann Arbor
Report 2764-10-T, DA 36-039-sc-75041
AD-290,219

A highly simplified model is presented of the electron distribution to the rear of, and slightly behind, an object traveling through a rarefied, totally ionized gas at a velocity much greater than the rms velocities of the ions and much less than the RMS velocities of the electrons. It has been shown, by Dolph and Weil (1959) and by Sawchuk (1962), that there is a "hole" behind such an object in which the ion density is very low in comparison to the ion density outside the hole and that the electron-ion configuration is electrically neutral. The first simplification is to replace this hole with a well-defined vacuum, and to make the problem essentially one-dimensional by letting the hole be the region between two parallel planes. The manner in which the hole "fills up" is then investigated. Only the electron motion is considered, since it is assumed that the ions are stationary for the time interval involved. 52 pages; 3 references.

117. THE DISTRIBUTION OF CHARGED PARTICLES NEAR A MOVING SPACECRAFT

Samir, U., Willmore, A. P.
***Planetary and Space Science*, v. 13, pp. 285–296, 1965**

Electron and ion temperatures and densities obtained by Langmuir probes installed on the *Ariel I* satellite and a *Black Knight* rocket have been used to study disturbances caused by a supersonic body moving through the ionosphere. A wake depleted of ions and electrons was observed. Evidence is given for the existence of a turbulence in the wake in which strong rapid oscillations occur. A comparison is made with present theories and with similar measurements from the *Explorer VIII* satellite.

118. WAKE OF A CHARGED PROLATE SPHEROID AT ANGLE OF ATTACK IN A RAREFIED PLASMA

Sawchuk, W.
In "Rarefied Gas Dynamics, Volume II," pp. 33–44
Laurmann, J. A., Editor
Academic Press, Inc., New York, N.Y., 1963
(Paper presented at the Third International Symposium on Rarefied Gas Dynamics, Paris, France, June 1962—Entry 599; see also Report 2764-9-T, University of Michigan, Radiation Lab., Ann Arbor, March 1962, AD-290,218)

Time independent electron-ion density distributions in the surrounding flow field and the surface potential of a perfectly conducting prolate spheroid moving in a rarefied plasma are determined. Free molecular flow concepts and Poisson's equation are used to effect a solution. It is assumed that the ion flow is not greatly influenced by the satellite potential field, and the ion density is found by integrating Maxwell's distribution function over limited velocity space which has bounds that are determined from the geometry of a shadow cone in configuration space. It is assumed that the electrons are in an equilibrium state, and the electron density distribution is obtained from a solution of Poisson's equation.

Results of numerical calculations for a prolate spheroid having a major axis of 4 m and a minor axis of 2 m, and moving at 8 km/sec at an altitude of 500 km, are plotted for angles of attack of 0, 45, and 90 degrees.

119. RESULTS FROM A ROCKET-BORNE LANGMUIR PROBE EXPERIMENT
Serbu, G. P.
July 1961
National Aeronautics and Space Administration, Washington, D.C.
TN D-570
AD-260,030
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Data were obtained from a rocket-borne Langmuir probe experiment at altitudes of up to 220 km above Fort Churchhill, Canada, in a quiet daytime ionosphere. The electron temperatures deduced from the probe data are in good agreement with the accepted neutral gas temperatures at altitudes above 140 km. Improper corrections for the positive ion component of the diffusion current to the rocket are thought to be the cause for the much higher electron temperatures measured below 140 km, since that component is adversely affected by the high rocket velocity. The rocket-to-plasma potential was measured as ½ to 1 V negative. 9 pages.

120. RESULTS FROM THE IMP-I RETARDING POTENTIAL ANALYZER
Serbu, G. P.
In "Space Research V," pp. 564–574
King-Hele, D. G., Muller, P., Righini, G., Editors
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1965
(Paper presented at the Fifth International Space Science Symposium, Florence, Italy, May 12–16, 1964—Entry 594; also available as TM-X-55004, X-615-64-109, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md., May 1964)

Some preliminary experimental results are presented which were obtained with a planar-geometry retarding potential analyzer which was flown on the *Imp I* satellite. The plasma energy spectrum for both ions and electrons was measured in the range from 0 to 100 eV. Charged particle density measurements have been obtained continuously from 1000 km to 30 Earth radii.

The results show a sharp decrease of about an order of magnitude in charged particle density at about 4.5 R_e, which is similar to the decrease deduced from whistler observations. The electrons exhibited thermal energies for geocentric distances less than 4.5 R_e. The average electron energy then increased gradually to values above 100 eV at about 8 R_e. The observed satellite potential was less than 1 V positive.

121. SOME IONOSPHERIC MEASUREMENTS WITH SATELLITE-BORNE ION TRAPS
Sharp, G. W., Hanson, W. B., McKibbin, D. D.
In "Space Research IV," pp. 454–470
Muller, P., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1964
(Paper presented at the Fourth International Space Science Symposium, Warsaw, Poland, June 4–10, 1963—Entry 10; see also *Journal of Geophysical Research*, v. 69, no. 13, pp. 2747–2763, July 1, 1964)

This paper presents data obtained with two ion traps with planar geometry, flown in polar-orbiting oriented satellites, one in October 1961, and the other in April 1962. Several of the results are at variance with the present understanding of the ionosphere. The measurements were confined to the altitude region from 200 to 500 km. The measured ion concentrations varied from about 10^6 ions/cm^3 to less than 2×10^3 ions/cm^3. The vehicle potential varied from less than 1 V negative to 20 V negative. In general, the negative potential of the satellite was high when the ion concentration was low. At high latitudes, the data on occasion indicate large horizontal gradients, the ion concentration sometimes changing by factors greater than 2 in a few kilometers, and on one occasion apparently changing by a factor of at least 50 in a horizontal distance of about 200 km. The temperature of the ions obtained from the ion trap data is shown to be higher than expected from present models of the ionosphere. The possibility is considered that the satellite might have affected the immediate ionospheric environment in such a way as to invalidate some of the measurements. 5 references. (*IAA*, A64-25, 045)

122. ELECTROSTATIC PLASMA OSCILLATIONS GENERATED BY A HIGH ALTITUDE VEHICLE
Shea, J. J., Anton, H. F.
January 30, 1962
Cosmic, Inc., Washington, D.C.
Semiannual Report 1 for July 1–December 31, 1961, Report 24, AF 19(628)-203
AD-446,174

This report summarizes a program which is directed toward the quantitative determination of the range of utilization, for ballistic missile defense purposes, of electrostatic plasma oscillations which may be induced by the passage of an object through the upper atmosphere at altitudes in the approximate range 300 to 2000 km. Specifically, the program includes (1) a theoretical investigation directed toward establishing the mechanism of wave generations, determining the energy, frequency, propagation modes, etc., of these waves, and correlating the energy calculations with results obtained from the *Echo I* and *Explorer VIII* satellites; and (2) an experimental investigation leading to the design, construction, testing, and calibration of a sensitive electrostatic detector suitable for laboratory experiments. 35 pages.

123. METHOD FOR DETERMINING THE ELECTRICAL POTENTIAL OF BODIES LOCATED IN A PLASMA
Shvarts, Ya. M.
***Iskusstvennye Sputniki Zemli*, no. 4, pp. 161–164, 1960**
(Translated from the Russian in *ARS Journal, Russian Supplement*, v. 31, no. 9, pp. 1321–1323, September 1961, and in *Artificial Earth Satellites*, v. 4, pp. 397–401, 1961)

The employment of rockets and artificial Earth satellites for geophysical investigations necessitates the measurement of their electrical potential, since this affects the indications of the instruments. Several methods have been employed. The present paper introduces another approach to the problem of determining the potential of bodies located in a plasma, including rockets and satellites. This approach is based on the space-charge theory, which provides an expression for the electrostatic field strength at the surface of insulated bodies in terms of the potential of the body, the thickness of the space-charge layer, and two coefficients depending on the gas density. Limiting conditions are defined for bodies moving at high velocity, thus excluding the tail section where electrons mainly occur. It is shown that the electrical potential can be obtained from simultaneous measurement of the electrostatic field strength and of the current density of positive ions. (*PA*, 1962, #9121)

124. ON THE OPERATING CONDITIONS OF THE ELECTROSTATIC FLUXMETER IN THE UPPER ATMOSPHERE

Shvarts, Ya. M.

***Trudy Glavnoi Geofizicheskoi Observatorii*, Leningrad, no. 136, pp. 83–95, 1962**

Factors leading to the development of an electrostatic field at the surface of a sounding body in the upper atmosphere or in interplanetary space are: (1) the exterior electrostatic field; (2) the charge of the body, and (3) the difference in potential between points on the surface of the body as a result of its motion within a magnetic field.

Electrification of the sounding body in the upper atmosphere may be caused by the current of thermal ions, I_p, the current of thermal electrons, I_e, the current of high-energy electrons of the radiation belts, I_{er}, and the current of high-energy ions in the radiation belts, I_{pr}. The action of solar ultraviolet and X radiation, and of high-energy electrons and ions, causes the sounding body to emit photoelectrons, creating the current, I_{fe}, and secondary electrons, which create the current, I_{se}.

At equilibrium the sum of these currents is equal to zero:

$$I_p + I_e + I_{er} + I_{pr} + I_{fe} + I_{se} = 0$$

Equilibrium is established when the potential of the body reaches a certain value which differs from the potential of the surrounding plasma. The body is surrounded by a volume charge from which the intensity of the electric field can be determined. The above formula relates to an immobile body in interplanetary space filled with plasma. The value of the potential of the body and the thickness of the charge layer are taken from the work of Gringauz, Kurt, and Moroz. The field intensity is computed, and the results are given in tabular form for various potentials and concentrations.

A moving body in a magnetic field is characterized by potential differences on its surface, which depend upon the size and shape of the body. The electric field of the sounding body depends on its own charge and on the concentration of charged particles in the surrounding space, especially in the ionospheric F_2 layer.

The current density in individual parts of the surface of the body cannot be equal to zero in the equilibrium state, when the total current on the sounding body is zero, because of the following factors: (1) the motion of a sounding body with a velocity equal to that of thermal ions, causing an inequality of total current in individual areas on the body; (2) the difference in potential in surface areas, caused by the motion of the body in a magnetic field; (3) the photoemission created by the illumination of the body surface; and (4) the streams in the upper atmosphere.

125. MEASUREMENT OF THE ELECTRIC CHARGE OF A SATELLITE

Singer, S. F.

March 31, 1959

Maryland, University of, Physics Department, College Park

Final Report on Grant NSF/IGY-32.2/216

A literature survey was undertaken to ascertain the best values for the environmental parameters in a satellite orbit. These parameters include the gas temperature, the average velocities of ions and electrons and their respective temperatures, the gas density, and the degree of ionization. From these data, an estimate of the electrostatic potential of a satellite is determined. Photoemission of electrons from the satellite skin is the primary investigation undertaken. The hot-probe technique is given careful consideration, and the components for such a probe are described. (*AI/A*, 1959, #1394)

126. CHARGE ON A BODY MOVING IN AN IONIZED ATMOSPHERE WITH PERVADING MAGNETIC FIELD

Singer, S. F., Chopra, K. P.

American Physical Society, New York, N.Y.

Paper presented at the APS Summer Meeting in the West, Honolulu, Hawaii, August 27–29, 1959

A body moving in an ionized atmosphere with a pervading magnetic field may acquire charge through collisions with ions and electrons, photo-ejection of electrons, and induced electric currents due to the motion across the magnetic lines of force. The phenomena which occur at slow speeds differ from those which occur at fast speeds of the body. In the intermediate case the calculations would be quite involved. A knowledge of the nature and amount of charge on a body is of interest in the problems concerning the dynamics of dust particles, meteors and meteorites, whistling atmospherics, and the motion of artificial Earth satellites. The relative importance of the various processes of charging under specified conditions is discussed. Some insight can be gained by performing simple experiments in a low-density wind tunnel. A method of estimating satellite charge (currently in progress at the University of Maryland) is briefly described.

127. FORCES AND TORQUES DUE TO COULOMB INTERACTION WITH THE MAGNETOSPHERE
Singer, S. F.
In "Torques and Attitude Sensing in Earth Satellites," pp. 99–105
Singer, S. F., Editor
Academic Press, Inc., New York, N.Y., 1964
(See Entry 16)

An analysis is made of the Coulomb forces and torques produced by interactions between an electrostatically charged satellite or space vehicle and the ions and electrons of the ionized gas through which it is moving. The drag forces acting on a charged body moving through a plasma are examined. The results are discussed in terms of specific vehicle applications, including the design of an Earth satellite with a large antenna, and the general application of charge-drag effects for the control of torques acting on space vehicles. Possible applications of these effects to further research are also noted. 7 references. (*IAA*, A64-25,296)

128. AN ION GYROFREQUENCY PHENOMENON OBSERVED IN SATELLITES
Smith, R. L., Brice, N. M., Katsufrakis, J., Gurnett, D. A., Shawan, S. D., Belrose, J. S., Barrington, R. E.
Nature, v. 204, pp. 274–275, October 17, 1964

A discrete VLF noise (below 1 kc) recorded after the reception of atmospherics by the satellites *Alouette I* and *Injun III* is reported. The noises were detected aurally during the playback of the tapes. They show an initial rapid rise in frequency, followed by a very nearly constant value. This maximum frequency was 520 cps (*Alouette*) and 400 cps (*Injun*). It is suggested that these noises may be related to an ion gyrofrequency resonance, since the maximum frequency observed is approximately equal to the gyrofrequency for protons in the plasma surrounding the satellites at their respective altitudes (1000 and 1800 km). (*IAA*, A64-23,613)

129. SATELLITE WAKES
Thaler, W. J.
In "Recent Advances in Astro-Geophysics: A Topical Symposium based on Lectures delivered at the Summer Conference for College Professors on Physics and Astronomy, Georgetown University, Washington, D.C.," pp. 29–38
Georgetown University, Georgetown College Observatory, Washington, D.C., 1961
N64-15,281

A satellite wake is defined as the perturbation produced in the vicinity of the satellite in the ionosphere or in the interplanetary gas. Perturbations of particle concentration and the electric field are discussed, and experimental data on the scattering of radio waves by satellite trails are presented.

130. IONOSPHERIC DISTURBANCES ASSOCIATED WITH ECHO I AS STUDIED WITH 19-MEGACYCLE-PER-SECOND RADAR
Tiuri, M. E., Kraus, J. D.
Journal of Geophysical Research, v. 68, no. 19, pp. 5371–5385, October 1, 1963

Observations at 19 Mc made at the Ohio State University Radio Observatory between November 1961 and March 1962 are described which show a correlation between anomalous pulse-radar echoes and passes of the *Echo I*. The correlation is especially noteworthy between the starting times of the anomalous echoes and the passage of *Echo I* through the antenna beam, most echoes starting in the 20-min interval prior to passage of the satellite. The effects of the time of day, the orbit range, the equator-crossing longitude, and the latitude of the satellite are also investigated. Some possible mechanisms are discussed. 11 references.

131. IONISATION DURCH ERDSATELLITEN (IONIZATION BY EARTH SATELLITES)
Triskova, L.
Beiträge zur Geophysik, v. 68, no. 4, pp. 246–249, 1959

Experimental studies were made of the ionization produced by artificial Earth satellites. The process of ionization was investigated. In particular, consideration was given to the ionization produced by molecules accelerated by collision with the satellite. 6 references. (*MGA*, 1960, 11D-144)

132. IONIZATION THROUGH EARTH SATELLITES
Triskova, L.
March 7, 1963
Joint Publications Research Service, Washington, D.C.
JPRS-18010 (pp. 27–36)
N64-11,629
(Also available as OTS-63-21273, U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is one of three articles on electromagnetics translated from *Studia Geophysica et Geodaetica*, Prague, v. 6, no. 4, pp. 369–399, 1962.

From the theory developed in this paper and from measurements of satellite signals, it is concluded that a satellite causes an increase of ionization in the vicinity of its path of travel. An analysis of the signals confirms the existence of an ionized formation ahead of the satellite. After consideration of the ionization mechanism involved, it is concluded that the concentration of the ionization formation is dependent on the cross section of the satellite, on its speed, and on the composition of the atmosphere at the altitude of the flight. An ionization mechanism is described which can be applied to satellites at altitudes up to 350 km.

133. A THREE-DIMENSIONAL CALCULATION OF THE EFFECTS OF INSUFFICIENT SPACE CHARGE NEUTRALIZATION ON ION ROCKETS
von Roos, O.
American Rocket Society, New York, N.Y.
Paper 1385-60, presented at the ARS Conference on Electrostatic Propulsion, Monterey, Calif., November 3–4, 1960

A three-dimensional calculation of the space-charge distribution adjacent to an ion rocket and its influence on the thrust of the vehicle is described. Starting with a set of self-consistent equations for the particle densities of both the ions and electrons, the contributions to the thrust due to momentum transfer through the surface of the spaceship and the effects of image forces are discussed. Two cases are considered: in the first case, electrons and ions are ejected in opposite directions; in the second, they are ejected in the same direction. The thrust obtained in each case is compared with the nominal thrust (the thrust calculated ignoring space-charge effects). (*AI/A*, 1961, #3320)

134. INVESTIGATION OF SATELLITE-RELATED IONOSPHERIC ANOMALIES
Vrataric, F.
October 1961
Diamond Ordnance Fuze Laboratories, Washington, D.C.
DOFL-PR-61-10
AD-265,849
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

An investigation of satellite-related ionospheric anomalies was conducted. Monitoring results of CW-reflected waves and a back-scatter radar are discussed, and similar experiments and related reports are reviewed. Results of this investigation indicate that anomalies occur too frequently to enable the detection of satellite ionization effects with any degree of confidence. A bibliography of related works is included, and a method of obtaining transmission signatures is described. 49 pages; 44 references.

135. WAKE OF CHARGED BODY MOVING IN A PLASMA
Walker, E. H., Singer, S. F.
American Physical Society, New York, N.Y.
Paper presented at the APS Annual Meeting, New York, N.Y., January 27–30, 1960

When a charged body moves through a plasma pervaded by a magnetic field, Coulomb scattering near 90 deg puts ions into "quasi-trapped" orbits. With the magnetic field nearly parallel to the body's velocity vector, these ions remain in the vicinity of the body for some time before being scattered again. As a result, a charge cloud may build up around the body. The density distribution of the charge cloud can be calculated by setting up and solving the appropriate diffusion equations. This discussion covers the dependence of the equilibrium distribution on the charge and size of the body, the strength of the magnetic field, and the density and temperature of the plasma. The time constants associated with buildup and decay are investigated because of their importance in the discussion of motion through nonuniform plasmas or nonuniform magnetic fields. The authors' theory is applied to the problem of Earth satellites moving through the outer ionosphere, and the formation of satellite "ghosts" is discussed.

136. WAKE OF A CHARGED BODY MOVING IN A PLASMA
Walker, E. H., Singer, S. F.
American Physical Society, New York, N.Y.
Paper presented at the APS Spring Meeting, Washington, D.C., April 25–28, 1960

The authors' earlier theory (Entry 135) has been extended to the case where the magnetic field and velocity vector of the body are no longer parallel, and where the field is non-homogeneous. In this manner the case of a charged satellite moving in the Earth's outer ionosphere is approached. As distinct from the case of the parallel and homogeneous field, the charge cloud now detaches from the satellite but produces peculiar condensations of plasma (termed "ghosts") which bear a fixed relation to the satellite. Under nonsteady-state conditions this relationship changes and ghosts can travel with respect to the satellite. Some of the interesting properties of these ghosts are discussed, particularly as they relate to radar observations. More detailed results are presented concerning the distribution of charge around the satellite. This work may be applied to the study of the electric drag of an Earth satellite.

137. PLASMA SHEATH AND SCREENING AROUND A RAPIDLY MOVING BODY
Walker, E. H.
March 1961
Maryland, University of, College Park
Report, AFOSR-460, AF 49(638)-899
AD-253,850
(Also available as Preprint 61-65, presented at the AAS Symposium on Interactions of Space Vehicles With an Ionized Atmosphere, Washington, D.C., March 17, 1961; see also Entries 15 and 138)

The distribution of the potential and the charge density is derived quite generally for a stationary charged sphere and for a charged body moving rapidly through a plasma. Previous treatments were restricted to the cases where (1) the body's potential was small, being limited to less than five times the plasma temperature, or (2) the body was small compared to the Debye length, or (3) the body was moving slowly compared to the ion velocity. 27 pages.

138. PLASMA SHEATH AND SCREENING AROUND A STATIONARY CHARGED SPHERE AND A RAPIDLY MOVING CHARGED BODY
Walker, E. H.
June 1964
Maryland, University of, College Park
Thesis, NASA-CR-56226
N64-23,930
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.; see also Entries 15, 137, 139)

The potential and charge density distributions are derived for both a stationary charged sphere and a charged body moving rapidly through a plasma. The potential and charge

density are calculated as functions of position about a stationary charged sphere, using both monoenergetic and Maxwellian velocity distributions for the ions and electrons of the ambient plasma. The ion and electron voltage–current probe characteristics are obtained and the equilibrium potential is calculated as a function of the radius of the body. For a rapidly moving body, a self-consistent method for solving the screening problem is developed that requires no iterative calculations. Equations for the solution of the screening of axially symmetric bodies are derived for plasmas in which the thermal motion of the ions can be neglected and for plasmas with a Maxwellian velocity distribution. The potential and density variations in the wake, the probe characteristics, and the impact and electric drag characteristic curves for various bodies are also calculated. 171 pages. (*DA*, 65-647)

139. SCREENING OF A MOVING BODY IN A PLASMA
Walker, E. H.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 61–162
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17; see also Entries 137 and 138)

The potential and charge density distributions are derived quite generally for both a stationary charged sphere and a charged body moving rapidly through a plasma. Previous treatments were restricted to cases where either the body's potential was small (at most only two or three times kT/e), or the body was small compared to the Debye length.

The potential and charge density are calculated as functions of position about a stationary charged sphere, using both monoenergetic and Maxwellian velocity distributions for the ions and electrons of the ambient plasma. The potential decreases with distance more slowly than in the case of local thermodynamic equilibrium; the density of the ions, if the body is negative (or of electrons, if positive), is generally much smaller than given by the barometric formula and varies in a complicated way. The ion and electron voltage–current probe characteristics and the equilibrium potential are also calculated as functions of the radius of the body. The Mott-Smith and Langmuir equations for the ion current, if the body is negative (or electrons, if positive), prove to be unsatisfactory unless the sheath thickness is expressed as a function of the potential and radius of a body. The appropriate expression is given for the sheath thickness of a spherical body in terms of the nondimensional potential and body radius.

Eigenvalue solutions are obtained if the charged body neutralizes most of the ions and electrons that strike its surface, i.e., if the reflection coefficients for the surface of the body are small. Under these conditions the potential is found to vary more slowly than r^{-2} for small values of the potential.

For a rapidly moving body, a self-consistent method for solving the screening problem is developed which does not require iterative calculations. Equations for the solution of the screening of axially symmetric bodies are derived for plasmas in which the thermal motion of the ions can be neglected and for plasmas with a Maxwellian velocity distribution. Calculations are made for the potential and density variation in the wake, the probe characteristics, and the impact and electric drag characteristic curves for various bodies. These calculations show that there is a trough in the ion density surrounding a highly charged body. The drag calculations show that under certain conditions a negative drag is obtained if the potential on the body is large and if the ions are neutralized and elastically reflected at the surface of the body.

140. DECAY OF SPIN IN SPUTNIK I
Warwick, J. W.
***Planetary and Space Science*, v. 1, no. 1, pp. 43–49, January 1959**

A secular change was noted in the spin-fading rate during the three weeks of observation of the radio transmissions from *Sputnik I*. This effect allows a determination of atmospheric density near the perigee point. For an assumed atmospheric scale height of 30 km, a value of 3.8×10^{-13} g/cm^3 is derived for the density at 220 km. Some fluctuations in the spin decay appear to be real, and may result from small changes in the orientation of the spin axis within the satellite. An alternative interpretation in terms of charge drag resulting from motion of the satellite through the ionospheric plasma requires a charge of at least 10^4 V on the satellite. This charge might be acquired in the auroral zone. 5 references. (*MGA*, 1960, 11.12-599)

141. THE ION-TRAP RESULTS IN "EXPLORATION OF THE UPPER ATMOSPHERE WITH THE HELP OF THE THIRD SOVIET SPUTNIK"
Whipple, E. C., Jr.
January 1961
National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md.
TN D-665
N62-71,239
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

In interpreting the ion trap data obtained from *Sputnik III*, unexpectedly high electron temperatures were computed by Krassovskii. It was concluded, on the basis of experimental current–voltage characteristics of the collector, that the effective electron temperature at an altitude of 795 km was not less than 15,000°K, corresponding to a vehicle potential of −6.4 V with respect to the plasma. If, however, it is noted that a retarding potential corresponding to the average kinetic energy will stop only about half the incident ions, new values of 8800°K and −3.9 V are obtained for the effective electron temperature and the vehicle potential, respectively. 4 pages.

142. A DEVICE FOR MEASURING ELECTRIC FIELD IN THE PRESENCE OF IONIZATION
Wildman, P. J. L.
***Journal of Atmospheric and Terrestrial Physics*, v. 27, no. 3, pp. 417–423, March 1965**

When investigating the electrical structure of regions more than about 30 km above the Earth's surface with the aid of rockets and satellites, the interactions between the vehicle and its surroundings cause complications when large numbers of charged particles are present. Information about ambient conditions may be deduced by studying these interactions.

It is not yet known whether any steady or long period electric fields exist either in the conducting regions of the ionosphere up to about 800 km above the Earth or at greater distances, where the electron or ion concentrations may be as low as a few particles/cm^3. The existence of low electric fields in the ionosphere has been postulated both in the formation of aurorae and in the maintenance of the potential difference between the Earth and ionosphere. Beyond these regions fields may exist which are screened from the Earth by the ionosphere.

If the potential difference between a number of points on and near a vehicle can be determined, then fields as low as a few tenths of a volt per meter may be determined directly, and fields perhaps a hundred times smaller may be deduced taking into account the motions of the plasma close to the surface of the vehicle. It is possible to measure these potential differences using stepped voltages applied to probes used for density and temperature measurements of electrons and ions. However, since disturbing voltages are applied to external portions of the vehicle, this may interfere with other experiments on the same vehicle and may also change ambient electrical conditions for a proportion of the time. Although bulkier than these probes, the device described fits flush with the skin of the vehicle, if desired, and all exposed parts are at vehicle potential. This device allows the determination of electrostatic fields when a charged particle flux is acting upon the field sensors, and can also be used to determine the value of the flux.

143. THE ELECTRIC DRAG FORCES ON A SATELLITE IN THE EARTH'S UPPER ATMOSPHERE
Wood, G. P.
In "Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration, Chicago, Ill., November 1–3, 1962," pp. 337–345
National Aeronautics and Space Administration, Office of Scientific and Technical Information, Washington, D.C., December 1962 (available as NASA SP-11, Volume 2)

A theoretical study was made of the drag forces resulting from the electric charge on a spherical satellite in free-molecule flow in the upper atmosphere. The analysis was applied to an Earth satellite 4 m in diameter at an altitude of 1500 km; the lightweight hollow sphere was constructed of two layers of thin plastic and two layers of aluminum foil. The calculations yielded charge density and potential distributions in the sheath, the ion trajectories, the increased ion-impact drag, and the induction drag due to the Earth's magnetic field.

The Coulomb drag due to scattering was essentially zero; that due to increased ion impingement was 2.3% of the drag of the uncharged sphere under average conditions during a solar cycle. The percentage was approximately doubled for the degree of ionization prevailing at the maximum of the solar cycle of sunspot activity and approximately halved at the minimum. The values for Coulomb drag did not take into account photoemission. Assuming the expected photoemission effect for an aluminum surface, the values decrease. They may be taken, therefore, to be the upper limits occurring when the satellite is in the Earth's shadow. The induction drag due to the electric generator action of the satellite was 1.2% of the drag of the uncharged sphere for the orientation for which the induction drag is a maximum. The three electric drags totaled ~3.5% of the drag of the uncharged sphere under average conditions. 10 references. (*NRC*, 1963, PDL-49,851)

144. THE IONIZATION OF GASES ENTRAINED BY A SATELLITE IN THE UPPER ATMOSPHERIC LAYERS
Yatsenko, S. P.
***Iskusstvennye Sputniki Zemli*, no. 7, pp. 60–63, 1961**
(Translated from the Russian in *Artificial Earth Satellites*, v. 7–8, pp. 57–62, June 1962)

An attempt was made to determine the cause of ionization of water vapor desorbed from the surface of satellites. Purely qualitative observations, such as the shape of the curve of gas formation, are considered. The probable cause of ionization is attributed to recharging, and the mechanism is described. 5 references. (*MGA*, 1963, 14.1-119)

145. THE PLASMA SHEATH IN A MAGNETIZED PLASMA
Zachary, W. W.
August 17, 1962
Electromagnetic Research Corporation, College Park, Md.
Interim Report, NASA CR-55100, NAS-585-5
N64-12,394
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Equations are derived for determining the properties of the plasma sheath (particularly the particle density and potential distributions) formed about vehicles moving through the ionosphere. The derivation begins with a generalization of the method used by Kadomtsev and Ichikawa (the use of a variant of Bogolubov's method to derive a Fokker-Planck equation containing spatial dependent effects in the collision terms) to fit the case of a non-neutral two-component plasma in the presence of a static magnetic field. Methods for solving the derived equations are presented, and a theoretical derivation of the dependence of the sheath thickness on the medium parameters is discussed. 20 pages.

146. STUDY OF DRAG OF CHARGED BODIES IN A PLASMA
May 31, 1961
Maryland, University of, College Park
Final Report for April 1, 1960–May 31, 1961, AFOSR-1159, AF 49(638)-899
AD-261,570
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A brief summary is presented of the calculations made during the period covered by this report. 3 pages.

147. EXPERIMENTAL PROGRAM TO DETERMINE PROPERTIES OF IONIZATION WHICH IS PRODUCED BY SPACE VEHICLES
June 30, 1961
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Final Report 1108-6, AFCRL-751, AF 19(604)-7274
AD-264,035
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Research to determine the density, duration, and extent of ionization produced in the ionosphere by artificial satellites and space vehicles is summarized. A theoretical analysis of single-frequency artificial Earth satellite radio transmissions provided basic equations and methods for gaining information concerning the electron density at the satellite. Analyses of such phenomena as magnetic disturbances, ionospheric irregularities, and satellite signal scintillation were accomplished. Other studies, such as expected high-frequency reflection from suggested distributions around the satellite, were evaluated. The ionosphere seems to possess irregularities that sometimes scintillate the signal from the satellite so greatly that it is impossible to measure the rate of Faraday rotation. This scintillation has a high degree of correlation with spread F and sporadic E, but only a low amount of correlation with magnetic and solar indices. Further research on the electron density of the ionosphere and its variations is required. It is possible that satellite–ionosphere interactions, especially during periods at high geomagnetic activity, will create a disturbance having a large radar echo area. 18 pages; 25 references.

(For related entries, see Ionospheric Research—Instrumentation and Data)

REENTRY AND PLASMA SHEATH EFFECTS

148. ANTENNA NOISE TEMPERATURE IN PLASMA ENVIRONMENT
Bachynski, M. P., French, I. P., Cloutier, G. G.
***IRE, Proceedings of the*, v. 49, no. 12, pp. 1846–1857, December 1961**

The total noise power at a receiving antenna of a hypersonic space vehicle is determined on the assumption that the engulfing plasma sheath is a uniform slab of plasma. The noise emission from the plasma is treated as a boundary value problem, and a complete solution is obtained. The analysis takes into account the effects of the hot vehicle surface and other external noise sources. The effect of an anisotropic plasma sheath is also studied for magnetic field orientations normal to and parallel to the plasma. (*IAA*, 62-2476)

149. COMMUNICATIONS IN THE PRESENCE OF PLASMA MEDIA
Bachynski, M. P., Cloutier, G. G.
In "Dynamics of Manned Lifting Planetary Entry," pp. 206–298
Scala, S. M., Harrison, A. C., Rogers, M., Editors
John Wiley & Sons, Inc., New York, N.Y., 1963
(Paper presented at the Third Symposium on Dynamics of Manned Lifting Planetary Entry, Philadelphia, Pa., October 29–31, 1962)

This is a review of the basic concepts of plasma kinetics. The interaction of the particle constituents which determine the plasma properties is described, and the interaction of electromagnetic waves with plasmas is outlined. Developments in the theory of propagation of electromagnetic waves in nonuniform plasmas and in the performance of RF sources in ionized media are presented. The effects of the plasma sheath on radio communications are assessed, and techniques for opening "windows" in the plasma in order to establish and maintain communications are described. 49 references. (*IAA*, A63-23,654)

150. ELECTROMAGNETIC WAVE PENETRATION OF REENTRY PLASMA SHEATHS
Bachynski, M. P.
***Journal of Research of the National Bureau of Standards, Section D—Radio Propagation*, v. 69D, no. 2, pp. 147–155, February 1965**

Methods of enabling electromagnetic waves to propagate through the sheath of plasma created by a high speed vehicle reentering a planetary atmosphere are reviewed and compared. The possibilities considered are: (1) employing very high frequency waves or low frequency waves, (2) treating magneto-ionic wave modes by imposing static magnetic fields, and (3) modifying the plasma by chemical seeding and aerodynamic effects. Not one of the techniques is without major limitations, and considerable experimental study is still required to establish the feasibility of the various methods. (*PA*, 1965, #13,633)

151. REENTRY OBSERVABLES IN THE NEAR WAKE OF A SLENDER ABLATING TEFLON BODY
Baum, E.
January 1964
Electro-Optical Systems, Inc., Pasadena, Calif.
Research Note 22, DA-04-495-AMC-28-(Z)

Equilibrium compositions and temperatures are calculated for the laminar shear layer of a Teflon conical body, including profiles at the wake neck. Electron densities are found to be about two orders of magnitude below those in the shear layer of an equivalent cold-wall nonablating body. This can be attributed principally to a lower peak temperature in the Teflon shear layer and to electron attachment to atomic fluorine.

152. MISSILE AEROPHYSICS PHENOMENA OF ELECTRONIC IMPORT
Bershader, D.
August 20, 1957
Lockheed Missile and Space Company, Sunnyvale, Calif.
LMSC-2215
AD-606,339
(Paper presented at IRE WESCON, San Francisco, Calif., August 20, 1957; also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Some features of the environment surrounding missile-type vehicles in hypersonic flight are described. Emphasis is placed on the physical basis for the phenomena observed or thought to exist. The problem of attenuation of communication signals to and from high speed vehicles by ionization induced near the surface is discussed. 22 pages.

153. PLASMADYNAMICS
Bershader, D.
***Astronautics and Aerospace Engineering*, v. 1, no. 11, pp. 94–97, November 1963**

Literature covering recent advances in plasmadynamics is reviewed. Investigations are reviewed concerning nonequilibrium ionization in thermal plasmas as well as plasma sheaths and wakes associated with hypersonic reentry vehicles. Solid state plasma studies and studies of plasma diagnostics and the Schlieren technique are briefly considered. 21 references. (*IAA*, A64-10,160)

154. FINITE RATE PLASMA GENERATION IN THE LAMINAR AIR BOUNDARY LAYER OF SLENDER REENTRY BODIES
Blottner, F. G., Lenard, M.
In "Transactions of the Eighth Symposium on Ballistic Missile and Space Technology, San Diego, Calif., October 16–18, 1963—Volume II," pp. 4–33
Air Force Systems Command, and Aerospace Corporation, Los Angeles, Calif., 1963
N64-15,252

Calculations are performed for the electron densities in the plasma sheath surrounding a slender reentry vehicle. The computations depend on the accurate description of the inviscid shock layer surrounding the vehicle and the chemical equilibrium caused by the rate of ionization, since most of the energy is imparted to the air by the shock and pressure forces rather than by surface friction or shear forces (the case for blunt reentry bodies). In the case of a small-tipped, slender-shaped vehicle, the energy is imparted to the air by means of surface friction; consequently, the boundary layer will be a significant source of high-temperature air. 14 references.

155. PLASMA PHYSICS AND HYPERSONIC FLIGHT
Bond, J. W., Jr.
***Jet Propulsion*, v. 28, no. 4, p. 235, April 1958**

Effects of the presence of free electrons in a hypersonic shock layer are reviewed. Shock front structure and boundary layer structure are briefly discussed, and some of the differential plasma properties are mentioned.

156. SHOCK LAYER ELECTRON DENSITIES CONSIDERING THE EFFECTS OF BOTH CHEMICAL REACTIONS AND FLOW FIELD VARIATIONS
Bortner, M. H.
***Planetary and Space Science*, v. 3, pp. 99–103, February 1961**
(Paper presented at the Physical Chemistry in Space Flight Conference, Philadelphia, Pa., September 1–3, 1959—Entry 21)

A method is developed for calculation of the time variation of electron density in the nonequilibrium shock layer of a reentry vehicle. The method includes the effects of changes in both temperature and density. The temperature and the density are each affected by both chemical reaction and the expansion of the gas in the flow field. These changes, in turn, affect the rate of the chemical reactions. Calculations on a simplified system of four reversible chemical reactions were made along given streamlines. This was accomplished by applying an iterative method to a set of simultaneous equations for the rate of change of concentrations of the various species. An example is given of a calculation in which the electron density is far below the equilibrium value for a considerable period of time. (*PA*, 1962, #2755)

157. A PROPOSED SCATTERING RANGE FOR SIMULATED ECHO AREA MEASUREMENTS OF PLASMA-COATED OBJECTS
Brackey, T. A., Peters, L., Swarner, W. G., Thomas, D. T.
January 27, 1962
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Report 1116-17, Scientific Report 10, AFCRL-62-144, AF 19(604)-7270
N62-11,195

A scattering range is proposed for use in experimentally simulating echo area measurements of dielectric bodies and dielectric-coated bodies with dielectric constant less than one.

These investigations were initiated due to interest in plasma coatings of satellites in the ionosphere. The optimum parameters of the scattering range and the liquid to be used as the ambient medium are discussed.

While no conventional dielectric has the required properties, a mixture of rutile (42% by volume) in transil oil was found to have the required properties for use as the ambient medium. Settling problems can be greatly alleviated with little change in electrical properties by adding petrolatum to the mixture. 14 pages; 14 references.

158. ROCKET ANTENNA VOLTAGE BREAKDOWN INDUCED BY FIRING EXPLOSIVE BOLTS
Cairns, F. V.
***IEEE, Proceedings of the*, v. 51, no. 10, p. 1360, October 1963**

A brief description is given of the changes in signal strength from a 220-Mc rocket telemetry transmitter which were caused by the firing of explosive bolts from the rocket. A sudden decrease of signal strength (about 6 dB) occurred at the instant that the explosive bolts were fired. The signal strength recovered in three steps. The causes of these changes in signal strength are discussed. (*IAA*, A63-25,113)

159. ELECTROMAGNETIC WAVE SCATTERING BY PLASMA SYSTEMS WITH APPLICATIONS TO THE REENTRY PROGRAM. DOWN-RANGE ANTI-MISSILE MEASUREMENT PROGRAM (DAMP)
Carswell, A. I., Nuttall, J., Paquette, G.
December 1962
Radio Corporation of America, Missile and Surface Radar Division, Moorestown, N.J.
RCA-DTM-62-24, DA-36-034-ORD-3144 RD
AD-295,045, N64-20,351

This is a review of certain topics relevant to an understanding of radar returns from the plasma associated with reentry bodies. The interaction of electromagnetic waves with plasma is summarized using the effective dielectric coefficient approach. Also discussed are methods of calculating the scattering of electromagnetic waves from dielectric bodies of simple shapes, with particular emphasis on cylinders. Work on radar observations of meteor trails is reviewed and the problems arising in the tracking of a reentering body are discussed. Future work in this field is suggested. An extensive list of references is included as a bibliography. The experimental results described are a part of an analytical program directed toward better understanding of the effects of plasma and wake on radar electromagnetic propagation. 122 pages.

160. MEMORANDUM ON ELECTROMAGNETIC PROPERTIES OF THE HYPERSONIC PLASMA SHEATH
Chang, W. S. C.
June 30, 1960
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Report on Radome Optics Study (Cm-to-Mm Range), Report 786-29, AF 33(616)-5410
AD-240,445

An attempt was made to analyze, both theoretically (macroscopically and microscopically) and experimentally, the hypersonic plasma sheath from five points of view: (1) the conductivity and the permittivity of the plasma for weak signals; (2) nonlinear properties of the plasma for moderately strong signals and the breakdown process for very strong signals; (3) the transmission, reflection, and diffraction characteristics of the sheath; (4) the noise and plasma radiations; and (5) the radar echo areas and the Doppler frequency shifts of the plasma. Because of the lack of experimental data and the complexity of hypersonic flight conditions, the analyses are incomplete; however, the conclusions and the best available analysis and estimates obtained as a result of current work are presented. 96 pages.

161. SCATTERING OF ELECTROMAGNETIC WAVES BY AN ANISOTROPIC PLASMA-COATED CONDUCTING CYLINDER
Chen, H. C., Cheng, D. K.
***IEEE Transactions on Antennas and Propagation*, v. AP-12, pp. 348–353, May 1964**

A study is made of the scattering of electromagnetic waves by an infinitely long anisotropic plasma-coated conducting cylinder. The source is assumed to be a magnetic current filament which gives rise to an incident magnetic field having an axial component only. Starting from Maxwell's equations, complete expressions are obtained for the scattered electric and magnetic fields. As a special case, it is shown that, as the radius of the conducting cylinder approaches zero, the problem is reduced to that of scattering from an anisotropic plasma column. An anisotropic plasma-coated cylinder is an appropriate, simplified model for a missile as it reenters the Earth's atmosphere. 11 references. (*IAA*, A64-19,859)

162. STUDIES IN RADAR CROSS SECTIONS. XLIII. PLASMA SHEATH SURROUNDING A CONDUCTING SPHERICAL SATELLITE AND THE EFFECT ON RADAR CROSS SECTION
Chen, K.-M.
October 1960
Michigan, University of, Radiation Laboratory, Ann Arbor
Report 2764-6-T, DA 36-039-sc-75041
AD-250,805

The means for computing the radar cross section of objects in a variety of different environments was investigated. An extension of the investigation included the standard boundary value problems, the emission and propagation of electromagnetic and acoustic waves, and phenomena connected with ionized media. An experimental program was considered which embraces (1) measurement of antennas and radar

scatterers in order to verify data determined theoretically; (2) investigation of antenna behavior and cross-section problems not amenable to theoretical solution; (3) problems associated with the design and development of microwave absorbers; and (4) low and high density ionization phenomena. The plasma sheath surrounding a conducting spherical satellite was studied. The density distributions of the positive ions and the electrons in space were obtained, and the potential of the charged satellite was determined. An evaluation was made of the change of the radar cross section of the satellite caused by the plasma sheath. 38 pages.

163. ELECTROACOUSTIC WAVES EXCITED BY A SPACE VEHICLE IN IONIZED ATMOSPHERE AND ITS EFFECT ON RADAR RETURN
Chen, K.-M.
***Journal of Research of the National Bureau of Standards, Section D—Radio Propagation*, v. 69D, no. 2, pp. 235–242, February 1965**

When an electromagnetic wave from the ground is incident on a conducting space vehicle in the ionosphere, a current and charge are induced on the vehicle. The induced current and charge in turn generate two scattered fields in the ionosphere: the electromagnetic (EM) and an electroacoustic (EA) wave. Part of the EA wave is converted to an EM wave across the discontinuity of the ionosphere and reaches the ground. This causes the radar return of a space vehicle in the ionosphere to be greatly enhanced. The case is considered of a conducting cylinder in a plasma, illuminated by an EM wave. The induced current and charge on the cylinder are determined, and the scattered EM and EA waves are calculated. The corresponding radar cross sections due to EM and EA waves are defined. It is shown that the enhancement of the radar return due to an EA wave bears some resemblance to the large outbursts of the reflected HF signals from the satellites observed by Kraus. (*PA*, 1965, #13,630)

164. A BRIEF INVESTIGATION OF THE EFFECT OF AN IONIZED LAYER AROUND A VEHICLE ON THE TRANSMISSION OF MICROWAVE SIGNALS
Chen, S.
April 15, 1961
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Report on Ion Sheath Research, Report 1021-4, AF 33(616)-6782
AD-260,113
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

An approximate analysis of the power transmission coefficient of an ionized layer surrounding a spherically blunted nose cone-type vehicle was performed for three frequencies (30, 33, and 36 kMc). The best available aerodynamic data at various stations of the vehicle were used. It was found that (except for the stagnation region) better than approximately 89% of the incident power in the case of normal incidence can be transmitted through the layer. In general, the higher the signal frequency for the frequency range under investigation, the higher the transmission. The effect of the ionized layer on the antenna field pattern can be predicted by using the Lorentz reciprocity relationship. The beam tilt of an antenna pattern caused by the presence of the ionized layer was computed for the case of an ideally narrow, pencil-type beam. Again, using the best available aerodynamic data, a beam tilt of less than 0.6 deg can be expected for the signal frequencies within the range of 30 to 36 kMc. 10 pages; 6 references.

165. THERMIONIC SCREENING OF BODIES IN THE ATMOSPHERE AND INTERPLANETARY SPACE
Chopra, K. P., Shen, C. S.
April 5, 1963
National Aeronautics and Space Administration, Goddard Institute for Space Studies, New York, N.Y.
TM X-50226, RP-124
N63-20,178
(See also *Journal of the Atmospheric Sciences*, v. 20, no. 5, pp. 359–365, September 5, 1963)

The problem of thermionic emission of electrons from a hot spherical object surrounded by a plasma is formulated and analyzed. It is assumed that in the absence of other mechanisms (1) the spherical body acquires an electric potential in the processes of thermionic emission of electrons from the surface of the object and accretion of the charged particles from the plasma; and (2) the surface potential, distribution of the potential, and the electron density in the screening cloud have spherical symmetry about the object. To satisfy these assumptions, the spherical surface must be at a uniform temperature and either at rest or moving at a low speed relative to the mean thermal speed of the plasma electrons. Even where these assumptions do not strictly hold, the analysis provides at least an order-of-magnitude estimate of this phenomenon in front of the hottest part of the object. The analysis is applied to objects in space which become hot by entering a planetary atmosphere or by approaching a hot star, and numerical examples are given. 32 pages; 3 references. (*NRC*, 1963, PDL-49,697)

166. STUDY OF PLASMA-INDUCED VOLTAGE BREAKDOWN AT LOW PRESSURE
Chown, J. B.
July 1961
Stanford Research Institute, Menlo Park, Calif.
Final Report, SRI Project 3369, AF 33(600)-41517

A crucial factor affecting the radiation from a hypersonic vehicle during reentry is the breakdown of air modified by high ambient ionization. An experimental investigation was made of the power-handling capability of antennas operating in the presence of a thermally generated plasma. The plasma properties are related to the breakdown level of the antenna.

167. STUDY OF THE EFFECTS OF ENVIRONMENTAL CONDITIONS ON THE BREAKDOWN OF ANTENNAS AT LOW PRESSURES ON A SUPERSONIC VEHICLE
Chown, J. B., Keenan, M. G.
September 1961
Stanford Research Institute, Menlo Park, Calif.
Final Report, AFCRL-940

The breakdown characteristics of antennas under supersonic flight conditions at altitudes up to 80 mi are investigated. Three *Nike-Cajun* rockets were instrumented and fired from Eglin Gulf Test Range on November 4, 1960, and on March 14 and 24, 1961. Significant results were obtained only from the March 14 firing.

Details of the instrumentation and the data obtained are discussed. Data are given on (1) the RF power required to initiate and extinguish breakdown, (2) surface temperatures, and (3) pressure on the surface of the conical nose. A comparison of breakdown data with previously obtained laboratory data and with the theory of breakdown phenomena reveals discrepancies which remain unresolved due to the limited quantity of flight data available for analysis. (*AI/A*, 1962, #5178)

168. A STUDY OF THE TRANSMISSION OF RADIO SIGNALS FROM A HYPERSONIC VEHICLE
Chuan, R. L., Kuehl, H. H., Kaprielian, Z. A.
June 30, 1960
University of Southern California Engineering Center, Los Angeles, Calif.
USCEC Report 71-101, ERD TR 60-176, AF 19(604)-5722
AD-242,971

In order to acquire some understanding of the mechanisms whereby the propagation of an electromagnetic signal is affected by the pressure of a partially ionized gas layer (the ion sheath) adjacent to a hypersonic vehicle, a program of research combining theoretical and experimental efforts was initiated. The first year's tasks consisted of (1) the modification of a low-density hypersonic wind tunnel to produce flows at Mach number 14 at an equivalent altitude of about 300,000 ft and a velocity of about 15,000 ft/sec; (2) a study of scaling parameters to render possible the extension of model studies to full-scale flight conditions; (3) theoretical studies of the effects of a uniform plasma sheath on the radiation of a finite cylinder; (4) determination of the electronic and aerodynamic configurations for the wind tunnel experiments; and (5) exploratory studies of the use of a microwave interferometer for the determination of electron density. 28 pages.

169. THE EFFECTS OF A PLASMA SHEATH ON THE IMPEDANCE PROPERTIES OF SOME SLOT ANTENNAS. PART I: ANALYTICAL FORMULATION
Cutler, S.
December 1959
Technical Research Group, New York, N.Y.
TRG-127-SR-1, Scientific Report 1, AFCRC TN-59-993, AF 19(604)-4574
AD-234,593

The impedance properties of a slot antenna radiating into a plasma layer in space are obtained by determining the equivalent admittance of a slot radiating into a layer of complex refractive index. Equations are derived which give the equivalent admittance for the simplified case of a single slot formed by the open end of a waveguide radiating into the layer of complex refractive index in a planar half-space. The solution of this problem can be used to obtain the impedance properties for practical antennas. The admittance is given in a variational expression in terms of the slot field. 27 pages; 11 references.

170. METHODS OF APPROXIMATING THE ION FIELD SURROUNDING ADVANCED MISSILES
Daniels, R. L.
1960
Air Force Cambridge Research Center, Electronics Research Directorate, Bedford, Mass.
AFCRC-TR-108(I)
AD-236,932
(Paper presented at the Symposium on the Plasma Sheath: Its Effects on Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 18)

An extensive study of current aerodynamic and thermodynamic methods of calculating hypersonic flow fields has indicated techniques for evaluating problems of electromagnetic propagation from reentry bodies and nuclear-propelled vehicles. The effects of thermal nonequilibrium, secondary radiations, boundary layer, ionization, dissociation, and initial overshoot are considered. The general technique consists of determining free electron concentrations in the shock front and then determining changes that occur along streamlines due to electron attachment and detachment, recombination, and temperature-density variations of the flow field. Error estimates are also discussed. Application of these methods to two specific vehicles—a hypersonic reentry body and a supersonic nuclear missile — are discussed in detail. 14 pages; 7 references.

171. ANTENNA WINDOW: A TECHNIQUE FOR PROPAGATION THROUGH A PLASMA SHEATH
DeLosh, R. G.
September 1, 1961
Bendix Corporation, Bendix Systems Division, Ann Arbor, Mich.
Interim Engineering Report 1 for June 1–September 1, 1961, AF 33(616)-8420
AD-263,157
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A study is being made of the electromagnetic properties of a plasma in a magnetic field for the express purpose of finding a solution to the reentry communications blackout prob-

lem. Phase I will consist of measuring the absorption and reflection of microwave energy from a slab of plasma permeated by a quasi-stationary magnetic field. Phase II will consist of a flight test of a magnetic window device on a hypersonic reentry vehicle, and will provide the ultimate test of the magnetic window concept. The present effort is directed toward refining the experimental apparatus and experimental techniques. 33 pages.

172. ANTENNA WINDOW: A TECHNIQUE FOR PROPAGATION THROUGH A PLASMA SHEATH
DeLosh, R. G., LaPointe, C.
December 1, 1961
Bendix Corporation, Bendix Systems Division, Ann Arbor, Mich.
Interim Engineering Report 2 for September 1–December 1, 1961, Report BSR-620, AF 33(616)-8420
AD-267,934
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Several aerodynamic analyses were performed for the *Trailblazer II* vehicle. Included in the analyses were: (1) calculation of stagnation point electron density and collision frequency for an 80-deg launch, 20-lb payload vehicle; (2) study of plasma layer thickness at the stagnation point; and (3) determination of the effect of a magnetic field on the plasma layer thickness. The shock tube was improved to obtain higher shock wave velocities and, hence, higher electron densities; several refinements were made on the microwave plasma diagnostic devices, and provision was made for accurately controlling the initial shock tube conditions. Preliminary measurements made of the magnetic window effect indicated that a magnetic field can reduce microwave attenuation to a negligible value. 26 pages.

173. SCATTERING FROM PLASMA CYLINDERS WITH RADIAL VARIATIONS IN ELECTRON DENSITY
de Ridder, C. M., Edelberg, S.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 286–319
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass., April 10–12, 1962—Entry 12)

Interest in electromagnetic scattering from plasma cylinders with radial variations in electron density is not new. For many years this problem has been investigated in order to understand the phenomena occurring in meteor trails. These investigations have usually been confined to the underdense portions of the trail. More recently it has become necessary to learn more about the physical and chemical phenomena occurring in the plasma trails behind reentering hypersonic vehicles. Electromagnetic scattering data are collected by radars in field experiments and by microwave devices in free-flight hypervelocity ballistic ranges. In order to better understand these data, a more complete study of scattering from radially varying plasmas has been undertaken. This study assumes broadside incidence of electromagnetic energy upon an infinite plasma cylinder of electron density which varies in the radial direction according to some monotonic function, with its peak on the cylinder axis.

In order to obtain practical results, a computer program has been written for the IBM 7090. Outputs from this program have been obtained for three types of radial variations: a quadratic polynomial, and two sixth degree polynomials, one of which allows the electron density to approach the surface of the cylinder with zero slope. These are compared with the results for the homogeneous cylinder. The peak value of electron density, which always occurs on the cylinder axis, is varied from underdense to overdense, thus permitting greater flexibility in interpreting experimental data. Other parameters which have been varied are collision frequency and cylinder radius. The latter has been varied over a broad-enough range so that Rayleigh and geometrical optics approximations are feasible. Consideration is given to the application of this information and the results of hypersonic flow calculations to the interpretation of data from radars in the field and microwave devices in ballistic ranges. 7 references.

174. PROBLEMI DI RIVELAMENTO E DI COMUNICAZIONE NELLA NAVIGAZIONE SPAZIALE (PROBLEMS OF TRACKING AND COMMUNICATION IN SPACE NAVIGATION)
de Socio, L.
***Missili*, v. 4, pp. 39–46, December 1962**
(Paper presented at the Tenth International Communication Congress, Genoa, Italy, October 7–12, 1962)

The atmospheric phase of manned and unmanned space flight is considered, with emphasis on the plasma interference effects caused by the ionized layer surrounding the vehicle. Transmission of electromagnetic waves through this layer is discussed. The effect of this ionized layer on the operation of the radar systems is noted. (*IAA*, A63-16,689)

175. ON THE CHANGE IN RADAR CROSS SECTION OF A SPHERICAL SATELLITE CAUSED BY A PLASMA SHEATH
Dolph, C. L., Weil, H.
***Planetary and Space Science*, v. 6, pp. 123–132, June 1961**
(Paper presented at the Symposium on the Plasma Sheath: Its Effects on Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 22)

A uniform neutral dilute ionized gas is assumed to be perturbed by a sphere moving through it. The radar return from the disturbed region is obtained by integrating the Compton scattering from the electrons, taking phase into account, but ignoring secondary scattering and attenuation. The electron density distribution for this computation is obtained by integration of the zeroth-order velocity distribution function for neutral particles as a solution of the Boltzmann transport equation. Numerical results are obtained for the

perturbation of electron distribution by a sphere traveling at 8 km/sec and at an altitude of 500 km, and for the radar cross section of this perturbed region when viewed broadside. 13 references. (*PA*, 1962 #4879)

176. FIELD EXPERIMENTS PERTAINING TO HYPERSONIC WAKES AND TRAILS

Edelberg, S.
American Rocket Society, New York, N.Y.
Paper 2661-62, presented at the ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., November 13–18, 1962

Optical radiation and radar results pertinent to reentry field experiments are discussed. Following qualitative study of the amplitudes and spectrum information available from the *Trailblazer* optical radiation experiments, detailed interpretations of radar data of the *MA-6* and *Trailblazer* reentries were reviewed. These interpretations, which yielded information on the electron density characteristics of the laminar and turbulent trails and on the Doppler and fluctuation velocities of the turbulent blobs, are discussed within the context of available radar scattering theory, and are compared with hypersonic reentry information obtained from theoretical studies and laboratory experiments. (*AI/A*, 1963, #70,814)

177. RADIO TRANSMISSION THROUGH THE PLASMA SHEATH AROUND A LIFTING REENTRY VEHICLE

Ellis, M. C., Jr., Huber, P. W.
January 1961
National Aeronautics and Space Administration, Washington, D.C.
TN D-507
AD-248,791

Plasma signal attenuation concepts related to hypersonic reentry are reviewed. Attenuation experiments are described in which telemetry and microwave signals are transmitted through a simulated flight plasma. Computations of plasma conditions about typical reentry shapes are made to show the effects of body bluntness, angle of attack, velocity, and altitude on the plasma frequency and the collision frequency in the shock layer. It is concluded that signal frequencies of the order of 10,000 Mc are required to avoid sudden signal blackout during a critical part of a lifting reentry flight. 22 pages.

178. INTERACTION OF HIGH-POWER MICROWAVES WITH A REENTRY VEHICLE PLASMA SHEATH

Epstein, M.
In "Transactions of the Eighth Symposium on Ballistic Missile and Space Technology, San Diego, Calif., October 16–18, 1963—Volume II," pp. 97–119
Air Force Systems Command, and Aerospace Corporation, Los Angeles, Calif., 1963
N64-15,256

An exact solution has been derived for the propagation of electromagnetic waves through an inhomogeneous plasma slab. Although the solution is expressed in terms of an infinite series, an accurate approximation can be obtained using only the first two terms, if the slab is sufficiently thin. The result is used in developing an approximate analysis of the interaction between a strong electromagnetic wave and a thin plasma sheath. The results of the analysis indicate that, even at power levels below breakdown, the absorption of electromagnetic energy by the plasma may significantly alter the propagation characteristics of the plasma. The presence of plasma in the irradiated region is found to markedly affect the character of the breakdown process. Small amounts of plasma are found to eliminate breakdown in the usual sense. The electron density increases rapidly, but continuously, as the incident power is increased. 4 references.

179. CALCULATED RADIO ATTENUATION DUE TO PLASMA SHEATH ON HYPERSONIC BLUNT-NOSED CONE

Evans, J. S., Huber, P. W.
December 1963
National Aeronautics and Space Administration, Langley Research Center, Langley Station, Va.
TN D-2043
N64-11,900

Electron concentration and collision frequency in the flow field are evaluated for conditions corresponding to maximum observed attenuation during the flight of the *RAM A1* vehicle. Equilibrium, frozen, and finite-rate flow assumptions are made concerning both chemical and ionic processes. Boundary layer concepts are applied to modify the results near the body. Signal attenuation through the plasma layer at 240 Mc is computed by numerical integration of the propagation equation for electromagnetic radiation. 30 pages; 22 references.

180. AIR IONIZATION IN THE HYPERSONIC LAMINAR WAKE OF SHARP CONES

Fernandez, F. L., Levinsky, E. S.
***AIAA Journal*, v. 2, pp. 1829–1832, October 1964**

A comparison is made of the relative influences of the boundary layer and the laminar wake on the reentry radar observables. Scaling laws are developed for clean-air ionization in the laminar wake. An examination of several numerical laminar wake solutions shows that species diffusion and fluid entrainment are much weaker than in the laminar boundary layer with a catalytic wall, and that the most important single parameter is the peak static enthalpy. The results also show that a nearly constant static enthalpy level is maintained along the wake centerline. The results of the approximate solutions are compared with the more exact calculations. Scaling laws for the effect of body size, shape, and altitude on wake electron production are given, and are compared with boundary-layer electron density values, assuming that peak wake and boundary-layer enthalpies are equal. 10 references. (*IAA*, A64-26,559)

181. COMPUTER PROGRAM FOR BLUNT-NOSED REENTRY BODIES
Finley, W. L.
November 1963
Rome Air Development Center, Griffiss AFB, N.Y.
RADC-TDR-63-412
AD-424,962, N64-12,208

The electronic computer program presented is one of several that have been created to aid in quickly finding numerous solutions to the problem of propagating an EM signal at normal incidence through the plasma sheath of a wide variety of hypersonic bodies; the solutions are obtained for speeds of 10,000 to 40,000 ft/sec at altitudes ranging from sea level to 350,000 ft. The objective of this program is to provide numerical information concerning the aerothermodynamic and electronic characteristics of the plasma sheath which extends well beyond the boundary layer into the inviscid flow field on blunt nosed bodies. The program is also intended to provide unsophisticated numerical estimates (in decibels) of the EM signal loss through the plasma sheath (due to reflection and absorption) for a plane wave at normal incidence to a single interface model of the plasma sheath. 54 pages.

182. MAGNETO-PLASMAS AND REENTRY RADIO BLACKOUT
Fisher, S. T.
IEEE, Proceedings of the, v. 51, no. 6, pp. 1029–1030, July 1963

The use of a magnetic field to bring about transmission of electromagnetic waves through the plasma sheath which surrounds a reentering space vehicle is discussed. The use of right-hand, circularly polarized waves in conjunction with a steady, longitudinally oriented magnetic field offers the only promising approach to transmission through a plasma sheath which has a plasma frequency much higher than the signal frequency. It is proposed that the reflection coefficient of the transmitting antenna be monitored and the magnetic field be adjusted continuously for minimum reflected power. (*IAA*, A63-22,381)

183. CHEBYSHEV METHOD FOR THE CALCULATION OF RADAR CROSS SECTION OF PLASMA WAKES
Fong, K.
In "Transactions of the Eighth Symposium on Ballistic Missile and Space Technology, San Diego, Calif., October 16–18, 1963—Volume II," pp. 65–81
Air Force Systems Command, and Aerospace Corporation, Los Angeles, Calif., 1963
N64-15,254

This paper presents the Chebyshev method by which the field equation of a radially varying plasma wake is numerically solved. Using the computed values, along with values for the Bessel and Hankel functions, the radar cross section of the cylindrical wake can be computed. The numerical method proposed alleviates the slow convergence problems caused by use of power series, since the use of the Chebyshev series assures a strong convergence. 6 references.

184. PROPAGATION OF ELECTROMAGNETIC WAVES THROUGH REENTRY-INDUCED PLASMAS. APPENDIX — ELECTROMAGNETIC WAVE PROPAGATION AND ATTENUATION IN PLASMAS
Friel, P. J., Rosenbaum, B.
In "Advances in the Astronautical Sciences—Volume 11," pp. 399–430
Jacobs, H., Editor
American Astronautical Society, New York, N.Y., 1963
(Paper presented at the AAS Eighth Annual Meeting, Washington, D.C., January 16–18, 1962)

The absorption and reflection of UHF telemetry signals in the ion layer are examined. The dependence of absorption and reflection upon frequency is further studied to determine whether there is a practical frequency that can be used for transmission throughout the reentry phase of the trajectory.

185. A TECHNIQUE FOR OBTAINING THE ELECTRICAL CONDUCTIVITY VELOCITY PROFILE
Fuhs, A. E.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 337–353
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass., April 10–12, 1962—Entry 12)

An important macroscopic property of the plasma sheath is its electrical conductivity, σ, which is not constant but varies spatially. On the flank of a reentry vehicle the electrical conductivity will be a function of a distance, y, normal to the surface. The electrical conductivity profile, $\sigma(y)$, influences electromagnetic wave propagation and scattering.

An instrument which measured the product of electrical conductivity and the velocity, v (averaged through the boundary and shock layers), has previously been flown aboard a reentry vehicle. The σv-profile meter described in this report is an extension of the program, and is intended to obtain additional experimental information concerning the plasma sheath. 5 references.

186. ADMITTANCE OF A WAVEGUIDE RADIATING INTO STRATIFIED PLASMA
Galejs, J.
IEEE Transactions on Antennas and Propagation, v. AP-13, no. 1, pp. 64–70, January 1965

A slot covered by a stratified plasma is assumed to radiate into a wide waveguide instead of free space. The slot admittance approximates the free space admittance of the slot for waveguide diameters exceeding 6 to 10λ. For thick plasma layers the computed slot admittance checks with earlier admittance calculations for a laterally unbounded plasma. When approximating a plasma profile of a typical hypersonic reentry, a multilayer plasma model in a wide waveguide appears to provide a more accurate slot admittance than a single-layer approximation in a laterally unbounded geometry.

187. ON PROCESSING THE RADAR RETURN FROM AN IONIZED TRAIL
Gersch, W.
1964 IEEE International Convention Record, v. 12, pt. 2, pp. 227–233, 1964
(Paper presented at the IEEE International Convention, New York, N.Y., March 23–26, 1964)

Techniques for processing the radar return from the moving ionized trail radar target associated with an atmospheric reentry vehicle are considered. A phenomenological model of the ionized trail radar target is developed which is the equivalent of a filter with a space-varying, time-varying impulse response. Three processing techniques are considered: the matched filter processor, a generalized correlation computer, and a periodogram processor that is used only with a pulse train radar waveform. Using the periodogram processor and a transmitted signal consisting of a train of narrow pulses, a procedure is demonstrated for identifying the parameters of impulse response of a deterministic range-velocity-distributed radar target. The response of the matched filter and generalized correlation computer processors is computed for the stochastic radar target model. The results are expressed in terms of the transmitted signal ambiguity function and the ionized trail radar target scatter function. 12 references. (A64-22,443)

188. INTERACTION OF ELECTROMAGNETIC WAVES WITH THE PLASMAS OF HYPERSONIC FLOWS
Glick, H. S.
American Rocket Society, New York, N.Y.
Paper 2174-61, presented at the ARS Space Flight Report to the Nation, New York, N.Y., October 9–15, 1961

A hypersonic shock tunnel is described in which the interaction of electromagnetic waves with the plasma sheath surrounding a hypervelocity vehicle may be studied. The communication "blackout" problem for a vehicle in sustained hypersonic flight in the upper atmosphere is examined to illustrate the capabilities of the shock tunnel. The plasma physics necessary for the calculation of interactions of electromagnetic waves and plasmas and the importance of chemical kinetics are summarized with regard to the present status of theory and experiment. It is shown that due to the complexity of the aerodynamic, chemical-kinetic, and electrodynamic phenomena, useful small-scale experiments are not possible for many problems of interest. Full duplication of flight conditions is available over a region that includes a major fraction of the typical trajectory of a glide reentry vehicle. 13 pages. (*NRC*, 1962, PDL-42,169)

189. ANALYSIS OF ELECTROMAGNETIC WAVE PROPAGATION THROUGH REENTRY INDUCED PLASMA SHEATHS
Gold, R. R.
In "Transactions of the Eighth Symposium on Ballistic Missile and Space Technology, San Diego, Calif., October 16–18, 1963—Volume II," pp. 83–96
Air Force Systems Command, and Aerospace Corporation, Los Angeles, Calif., 1963
N64-15,255

An exact solution is obtained to the general problem of propagation of plane harmonic electromagnetic waves across a stratified plasma layer. The variation of the plasma properties in the direction normal to the layer is arbitrary, and oblique incidence is considered with no applied magnetic field. A constant magnetic field applied normal to the layer is included for the case of normal incidence. The solution is based on an integral equation formulation of the problem and is expressed as an infinite series. It is particularly useful when the ratio of slab thickness to free space wavelength (L/λ_0) is small. The resultant relatively simple algebraic expressions for the reflection and transmission coefficients give an excellent approximation in many applications of current interest. 6 references.

190. SEEING THE NEAR WAKE DURING REENTRY
Goldburg, A., Hromas, L. A., McLain, C. E., Menkes, J.
Astronautics and Aeronautics, v. 3, no. 3, pp. 38–45, March 1965

A summary is given of the fireball and shock wave observations made by Glenn, Carpenter, Schirra, and Cooper during the atmospheric reentries of their *Mercury* capsules. The sources of information are the tape transcripts in which the flow fields and fireballs are described as they were seen, and the comments made by the astronauts during a personal conference with the authors. The authors conclude that luminosity in the flow appeared at an altitude between 350,000 and 300,000 ft. Furthermore, the fireball was about half the size of the body diameter and about three body diameters behind the spacecraft, and was produced by the convergence of the flow field into the wake neck. Glenn and Cooper saw the fireball as an orange-yellow ball; Schirra saw it as greenish-blue and doughnut-shaped; and Carpenter saw a yellow-colored doughnut with greenish flares. The attempt to photograph the fireball with color motion picture film failed when Cooper had to fly the spacecraft manually during reentry. 26 references. (*IAA*, A65-19,145)

191. SIMULATION OF A THIN PLASMA SHEATH BY A PLANE OF WIRES
Golden, K. E., Smith, T. M.
IEEE Transactions on Nuclear Science, v. NS-11, no. 1, pp. 225–230, January 1964
(Paper presented at the 10th International Symposium on Plasma Phenomena and Measurements, San Diego, Calif., October 29–November 1, 1963—Entry 609)

A method is presented for simulating a thin plasma sheath, of the type encountered in some aerospace applications, by using a single plane of equally spaced wires. It is shown that the surface impedance of such a periodic structure can be made equal to that of a thin plasma sheath. In this treatment, the respective surface impedances are related through three dimensionless parameters. A simple technique for obtaining

high losses is also discussed whereby collision frequencies in the neighborhood of the operating frequencies are realizable. Experimental data for both the lossy and lossless cases are compared with the theoretical model in the X-band region. 11 references. (*IAA*, A64-14,505)

192. A STUDY OF ARTIFICIAL DIELECTRICS
Golden, K. E.
May 15, 1964
Aerospace Corporation, Los Angeles, Calif.
SSD-TDR-64-90, TDR-269-4280-10-4, AF 04(695)-269
AD-601,325
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The simulation of a plasma sheath by the use of an artificial dielectric is studied and applied to an antenna geometry which is similar to some configurations encountered in aerospace applications. The antenna configuration is equivalent to a horn in an infinite ground plane with an unbounded plasma layer in front of the horn. The plasma layer is simulated by a rodded medium, and the radiation patterns of the antenna system are studied experimentally at 9, 10, and 11 kMc. The characteristics of a rodded medium are obtained both theoretically and experimentally. It is shown that a rodded medium simulates not only the isotropic characteristics of a plasma sheath but also the anisotropic characteristics of a plasma in an infinite steady magnetic field. 71 pages.

193. SPECULAR REFLECTION OF A PLANE WAVE BY A PLASMA-CLAD CONDUCTING BODY OF REVOLUTION. DOWN-RANGE ANTI-MISSILE MEASUREMENT PROGRAM
Gottlieb, A. D., Steinberg, J.
August 1963
Radio Corporation of America, Missile and Surface Radar Division, Moorestown, N.J.
RCA-DTM 63-05, DA 36-034-ORD-31442
AD-416,212, N64-20,568

An expression was developed to find the strength, at a distance (R), of an electromagnetic field reflected specularly from a plasma-clad conducting body of revolution. This work was performed as a part of the overall DAMP task undertaken to (1) increase understanding of the performance of ballistic missiles during the terminal phase of flight and (2) enhance comprehension of the metric techniques useful in evaluating missile performance. The ultimate objective of this report is to define far-field effects produced by the interaction between electromagnetic waves and their propagation-medium discontinuities due to plasma and wake. 24 pages.

194. RADIO FREQUENCY CHARACTERISTICS OF THE PLASMA SHEATH
Gould, R. W.
***Physics Letters*, v. 11, no. 3, pp. 236–237, August 1, 1964**

The physical basis underlying the assumption of a sheath capacitance is discussed and used to explain the difference between electron densities measured by resonance probes and Langmuir probes at frequencies $\omega < \omega_p$. Another important consideration is the finite time it takes for electrons to be reflected by the sheath. If the sheath field changes during this time, the reflections are no longer elastic and the electron energy is increased at the expense of the oscillating field. (*PA*, 1964, #29,931)

195. ELECTROMAGNETIC WAVE INTERACTION AT A PLANE, SEMI-INFINITE, ANISOTROPIC PLASMA BOUNDARY
Graf, K. A., Bachynski, M. P.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 49–72
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass., April 10–12, 1962—Entry 12)

The nature of electromagnetic wave propagation in bounded plasma is determined not only by the physical properties of the plasma, but by the shape and nature of the boundaries as well. This has long been recognized in association with the investigation of ionospheric propagation and, more recently, with the problem of communication through the plasma sheaths of reentering space vehicles. In previous studies by others, the reflection of radio energy from the ionosphere has been of particular interest. Other special cases of the interaction of electromagnetic waves with sharply bounded, uniform, anisotropic plasmas have also been considered. All these treatments are limited to linear polarization or normal incidence of the electromagnetic wave.

In this paper the study of electromagnetic wave interaction with a sharply bounded, anisotropic plasma is extended to include arbitrary angles of incidence and three "representative" orientations of the static magnetic field. From a consideration of the boundary conditions, the polarization of an incident wave required to launch only a single given wave into a doubly refracting, anisotropic plasma is obtained. Extensive numerical results of the energy refracted into the plasma are presented for both the aforementioned polarizations and horizontally and vertically polarized incident plane waves. Finally, the polarization of the incident wave which launches the most energy into the plasma is derived. 11 references.

196. A MICROWAVE–PLASMA INTERACTION MODEL TO STUDY THE HEAD-ON RADAR CROSS SECTION OF BLUNT BODIES UNDER REENTRY CONDITIONS
Gravel, M., Waymel, M.
August 1964
Canadian Armament Research and Development Establishment, Defence Research Board, Valcartier, Quebec
CARDE-TR-507
AD-449,712, N64-28,016

A physical optics model is being developed to study the influence of the plasma sheath on the head-on radar cross

section of blunt bodies. According to this model, the large variations in radar cross section observed experimentally in hypersonic ranges with small metal spheres would be primarily the result of an interference between two signals: (1) the signal reflected at the vertex from the surface of the opaque region of the plasma sheath, and (2) the signal reflected from the part of the surface of the sphere which is not covered by an opaque plasma. As the velocity of the sphere increases, the opaque region spreads over the surface to produce Fresnel interferences that are successively destructive and constructive, until the sphere is completely eclipsed by overdense layers. The theoretical analysis also leads to the determination of an angular electron distribution within the plasma sheath that agrees well with theoretical flow-field calculations made subsequently. 21 pages; 10 references.

197. RF PROPERTIES OF THE PLASMA SHEATH
Harp, R. S., Kino, G. S., Pavkovich, J.
***Physical Review Letters*, v. 11, no. 8, pp. 310–312, October 1963**

The RF properties of a plasma sheath were investigated to determine (1) if self-oscillating RF fields exist in the sheath, and (2) if an externally applied RF field penetrates through the sheath and into the plasma. Measurements were made of both the RF and the DC fields in the sheath. The results obtained are compared with the values predicted by theoretical calculations. Measurements of the phase of the field are being planned; these should provide information on the real and imaginary field components and, therefore, on the loss due to Landau damping in the plasma sheath.

198. RADIATION THROUGH CYLINDRICAL PLASMA SHEATHS
Harris, J. H.
***Journal of Research of the National Bureau of Standards, Section D—Radio Propagation*, v. 67D, pp. 717–733, November–December 1963**

An analytic determination is made of the radiation fields of a magnetic line source which is axially oriented on a conducting cylinder in a plasma environment. The plasma environment is taken to be a series of homogenous cylindrical layers, none of which is contiguous with the cylinder. It is demonstrated that a quite significant distortion of the field pattern is effected by the presence of a lossless plasma sheath. Characteristics of the radiation fields are discussed, and radiation patterns, computed in a plane through the axis of the cylinder and the line source, are presented. The patterns are found to have large, narrow-amplitude fluctuations that can be attributed to leaky waves. (*IAA*, A64-10,343)

199. THE USE OF MAGNETIC FIELDS IN THE ELIMINATION OF THE REENTRY RADIO BLACKOUT
Hodara, H.
***IRE, Proceedings of the*, v. 49, no. 12, pp. 1825–1830, December 1961**

A study was undertaken to determine the feasibility of using a magnetic field to eliminate radio blackout caused by the plasma sheath surrounding a reentering vehicle. The transmission and reflection losses that occur at a plasma–air interface are analyzed, and it is shown that, in the special case of the absence of collisions, maximum transmission occurs when the signal frequency is half the gyrofrequency. In this case, the ratio of transmitted power to incident power is approximately equal to the ratio of plasma frequency to gyrofrequency. It is concluded that the application of a static magnetic field of about 500 G could eliminate radio blackout. 19 references. (*IAA*, 62-2553)

200. ELECTRONIC TRACKING ERRORS VERSUS PLASMA EFFECTS
Hoffman, J.
August 1964
Mitre Corporation, Bedford, Mass.
TM-3865, ESD-TDR-64-74, AF 19(628)-2390
AD-606,317
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Simple models are utilized to calculate the order of magnitude of errors generated by reentry and flame plasma effects in typical tracking systems. 38 pages.

201. PLASMA FREQUENCY AND RADIO ATTENUATION
Huber, P. W., Nelson, C. H.
In "Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration, Chicago, Ill., November 1–3, 1962," pp. 347–360
National Aeronautics and Space Administration, Office of Scientific and Technical Information, Washington, D.C., December 1962 (available as SP-11, Volume 2)

The problem of radio-frequency attenuation due to the interaction of an electromagnetic wave and a plasma layer is reviewed, with particular attention to that aspect dealing with communications during the reentry phase of space flight missions. The need for concerted effort on the problem is first brought out by the projection of radio blackout data from current missions to that of second-generation missions. The electromagnetic plasma parameters are discussed in relation to their influence on the wave propagation properties. It is shown that theoretical models of wave–plasma interaction (absorption and reflection) can be synthesized to approximate the reentry plasma-layer problem, which is interaction with relatively dense plasmas having gradients of finite extent with respect to a signal wavelength. Flight results are compared with those obtained with a simplified conceptual model. Various means by which the attenuation problem may be alleviated or circumvented are reviewed, and the capabilities for laboratory and flight model tests are outlined. 35 references.

202. THE ENTRY COMMUNICATIONS PROBLEM
Huber, P. W., Sims, T. E.
***Astronautics and Aeronautics*, v. 2, no. 10, pp. 30–38, 40, October 1964**

The fundamental nature of the cause and effect of radio blackout during spacecraft entry into a planetary atmosphere is considered. The interaction of electrons with the RF wave is discussed, and a quantitative evaluation of the attenuation is made. Approaches to the reentry plasma near-field transmission problem are suggested. Nonequilibrium regimes and their classifications are presented, and reference is made to radio attenuation measurements carried out by Langley Research Center, the ground tests and flight experiments, the equipment used, and the results of four flights to investigate the velocity regime below 20,000 ft/sec. 5 references. (*EI*, 1965)

203. AN EXPERIMENTAL DETERMINATION OF ANTENNA PATTERN DISTORTION DUE TO A PLASMA LAYER
Jacavanco, D. J., Meltz, G.
Air Force Cambridge Research Laboratories, Bedford, Mass.
AFCRL-64-18
AD-436,821
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Measured radiation patterns of a plasma-covered antenna are compared with an approximate "leaky-wave" analysis. The results clearly show a shift in the optical "critical angle," and the appearance of several side lobes is predicted by theory. The plasma is produced in a He–Xe admixture at 0.4 torr by a capacitively coupled, 10-Mc continuous wave source. Electron densities in excess of $5 \times 10^{11}/cm^3$ are measured by a standard microwave interferometer by manually balancing a bridge, or by automatically displaying a set of interference "fringes" after a pattern is recorded. 11 pages.

204. PLASMA PRODUCED ANTENNA PATTERN DISTORTION
Jacavanco, D. J.
June 1964
Air Force Cambridge Research Laboratories, Bedford, Mass.
AFCRL-PSRP-28, AFCRL-64-511
AD-605,271
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report describes an experimental attempt to determine and measure the antenna pattern distortion produced by a layer of plasma. A brief theoretical and experimental summary of the problem is given, and the theory pertaining to this particular experimental geometry is discussed. The complete experiment, including the generation and measurement of the plasma, the vacuum system, and the antenna pattern measuring equipment, is described in detail. Results are presented and compared with the theoretical predictions. The merits of the experiment are weighed and future plans are given. 30 pages.

205. BREAKDOWN AND DETUNING OF TRANSMITTING ANTENNAS IN THE IONOSPHERE
Jackson, J. E., Kane, J. A.
August 24, 1959
Naval Research Laboratory, Washington, D.C.
NRL Report 5435, Upper Atmosphere Research Report 36

Impedance measurements made on a 7.75-Mc rocket-borne antenna during several rocket flights indicate that at altitudes above 110 km a capacitance change occurs; the magnitude of the change can be used to determine ambient electron densities. In the 50- to 100-km region, the antenna undergoes an RF glow discharge resulting in a severe resistive loading and reduction of radiated power. The properties of this breakdown were investigated both theoretically and by laboratory experiments. The use of a DC bias on the antenna was found helpful in preventing breakdown. The knowledge acquired from this project is being applied to the development of improved RF probe techniques for the direct measurements of electron densities in the ionosphere. 23 pages; 20 references. (*MGA*, 1960, 11E-72)

206. RADIATION OF AN ELECTRIC DIPOLE INTO AN IONIZED SHEATH
Katzin, M.
December 15, 1957
Electromagnetic Research Corporation, College Park, Md.
Final Report, R-60175-7, AF 04(645)-24

The radiation of an insulated electric dipole surrounded by a cylindrical, strongly ionized sheath is treated. The effect of a highly ionized sheath on the radar cross section of a metallic sphere is considered briefly. For a high ionization density, it is shown that a good approximation is the radar cross section of a metallic sphere of the same radius as the sheath.

207. EFFECTS OF REENTRY PLASMA SHEATH ON ANTENNA CHARACTERISTICS
Katzin, M., Marini, J. W., Koo, B. Y.-C.
June 30, 1960
Electromagnetic Research Corporation, College Park, Md.
Final Report, Report 61527-3, AF 04(647)-269
AD-438,964
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report deals with various effects on antenna characteristics caused by the plasma which forms around a reentry vehicle. A general formulation is developed for spherically inhomogeneous plasmas. It is shown that, since only the radial functions are affected by the inhomogeneity, results for the uniform plasma case can be extended to the nonuniform case by the substitution of the appropriate radial functions. The effect of noise generated by the plasma on the problem of signal reception aboard a hypersonic reentry vehicle is discussed. The effective noise temperature of the plasma depends on the attenuation of the plasma. Thus, the optimum frequency for reception will usually be significantly lower than for transmission. An optimization procedure is described. 86 pages.

208. RF IMPEDANCE PROBE FOR REENTRY PLASMA SHEATH MEASUREMENTS
Katzin, M., Parsons, A. D., Ringwalt, D. L.
December 31, 1963
Electromagnetic Research Corporation, College Park, Md.
Semiannual Technical Summary Report, BSD-299-4, BSD-TDR-64-22
AD-430,999

Preliminary records from the reentry vehicle flight on November 1, 1963, showed that the Mark I impedance probe obtained 17 seconds of useful flight data during reentry. An internal failure which resulted in fuse blowout rendered the instrument inoperative thereafter. Examination of the records reveals the buildup of ionization during the reentry period. Some interesting dynamic effects evidently associated with reentry vehicle dynamics can be seen. The instrument was able to follow changes in the environment at least as rapid as the telemetry switching rate. On March 2 the production prototype was completed and submitted for environment tests.

209. EFFECTS OF REENTRY PLASMA SHEATH ON ANTENNA CHARACTERISTICS
Katzin, M., Koo, B. Y.-C.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 73–88
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass,, April 10–12, 1962—Entry 12)

The various effects on antenna characteristics which are produced by the plasma sheath which forms around a reentry vehicle are considered. Previous studies have dealt with the case of a strongly ionized plasma. In this paper, some interesting properties of this form of antenna are deduced for weak plasma sheaths. Computations are made which apply to a homogeneous plasma. These are extended to the case of a spherically inhomogeneous plasma.

The effect of noise generated by the high-temperature plasma is discussed in relation to the receiving problem aboard a hypersonic reentry vehicle. It is shown that the effective noise temperature of the plasma depends on the attenuation of the plasma. As a consequence, the optimum frequency for reception usually will be significantly lower than for transmission. An optimization procedure is described.

210. CALCULATION OF THE ECHO AREAS OF AN *N*-LAYER PLASMA CYLINDER AND SPHERE
Kawano, T., Peters, L., Jr.
May 1963
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Report 1116-33, AFCRL-63-387, AF 19(604)-7270
AD-423,019

The echo areas of inhomogeneous plasma bodies are studied by the application of the modified geometrical-optics method. The formulas for the echo area of an n-layer plasma cylinder were deduced from those for the echo areas of three more simple plasma cylinders. Equations for the scattered fields due to the specular rays from the i-th layer of an n-layer body are given. The total field scattered by this multilayered body is simply the phasor sum of the above components. 20 pages.

211. A SURVEY OF METHODS FOR TREATING ELECTROMAGNETIC SCATTERING BY REENTRY WAKES
Keitel, G. H.
June 1964
Stanford Research Institute, Menlo Park, Calif.
TR 22, SD-103
AD-445,729

Electromagnetic scattering by axially uniform cylindrical columns of ionization is examined (both for normal and off-normal incidence) for the homogeneous, Gaussian, and parabolic electron distributions, and for the limiting case, the metallic cylinder. The effect of turbulence in the underdense column is considered and related to the autocorrelation (or spectrum) of the turbulence. The effect of turbulence in the overdense column is approximated by a roughness on an "equivalent metallic cylinder," which permits the estimation of that component of the radar cross section. A relationship is developed for the circular scattering coefficient of an infinite cylinder and the radar cross section of an axially varying cylinder. This analysis is applied to certain typical reentry wakes, resulting in estimated curves of radar cross sections as a function of frequency, aspect angle, and assumed models. 89 pages.

212. INTERACTION BETWEEN A RADIO WAVE AND A PLASMA IN THE PRESENCE OF A UNIFORM MAGNETIC FIELD
Koga, T.
January 1961
University of Southern California Engineering Center, Los Angeles
USCEC Report 83-204, AFOSR-283, AF 49(638)-831
AD-253,452

The effect of movements of ions cannot be neglected because of the imposed magnetic field. Boltzmann-type equations for ions and electrons are proposed for a plausible model of plasmas in which molecules are partly ionized. By introducing "generalized moments" of the distribution functions of electrons and ions, it is easy to solve the equations and obtain the conductivity of a plasma in an oscillating electric field. The propagation of a radio wave in the plasma is investigated. There are several frequencies which characterize the phenomenon: (1) the electron and the ion Larmor frequencies, (2) the frequency of the radio wave, (3) the plasma frequency and a similar frequency defined with respect to the ions, and (4) the electron and the ion collision frequencies. The first approximation is treated in which the plasma frequency is negligibly small compared with radio-wave frequency; i.e., the electric field induced by the group dis-

placements of electrons and ions is neglected. As special cases, Alvén's theory of hydromagnetic waves and Margenau's theory of radio waves in plasmas with no imposed magnetic field are included in the theory. For the second approximation, the field induced by the group displacements of electrons and ions may be taken into account. 45 pages.

213. SPUTNIK I'S LAST DAYS IN ORBIT

Kraus, J. D., Dreese, E. E.
***IRE, Proceedings of the*, v. 46, no. 9, pp. 1580–1587, September 1958**

Observations are presented which were made at the Ohio State University Radio Observatory during the last days of *Sputnik I's* orbiting, using a simple CW reflection technique. The satellite ionization phenomenon is discussed, and a possible mechanism is presented to account for the observed ionization. The data suggest that the breakup of an artificial satellite upon its reentry into the denser atmosphere is a complex phenomenon in which a series of events may occur over a period of days. Graphs are presented of the average height of the satellite and its associated fragments as a function of time, and some conclusions are drawn as to the details of the actual breakup phenomenon.

214. THE GASDYNAMIC ENVIRONMENT OF SPACE VEHICLES

Leadon, M.
In "Space Vehicle Guidance and Control: Proceedings of the Third Winter Institute on Advanced Control, Gainesville, Fla., February 15–19, 1965," pp. 7-1–7-21
University of Florida, Department of Electrical Engineering, Gainesville, 1965

The ion and electron sheaths that form over bodies moving at hypersonic speeds through the atmosphere (such as reentry bodies) are described. For blunt bodies the most intense heat is generated in the stagnation region, but for slender bodies of small nose radius the maximum temperatures may be found in the boundary layer which develops along the sides. Nitrogen gas injection may suppress ionization or promote recombination in a boundary layer, but only by very intense (and therefore uneconomical) blowing can regions exterior to the boundary layer be affected. 6 references. (*IAA*, A65-19,058)

215. RADAR CROSS SECTIONS OF ANISOTROPIC BODIES

Lee, W. C.-Y.
1963
Ohio State University, Columbus
Thesis

Electromagnetic scattering from an anisotropic body is studied from the standpoint of geometrical optics. An example of an anisotropic body is the ionized sheath or trail which forms in the vicinity of a satellite. Because of the Earth's magnetic field, such a region will be anisotropic. Hence a study of scattering by anisotropic bodies is of interest.

The method of geometrical optics has proved to be a powerful tool in antenna studies and in electromagnetic scattering from isotropic bodies. In this dissertation, the geometrical optics method is extended to include electromagnetic scattering from homogeneous anisotropic plasma bodies. For an anisotropic body of arbitrary shape, the usual boundary value solution is prohibitively difficult. The modified geometrical optics method discussed here appears to be the only practical solution.

The method offered in the dissertation for solving for the electromagnetic scattering from an anisotropic body appears to be unique at the present time. Although the calculation may be lengthy, the method is straightforward and can be applied to a homogeneous anisotropic body of arbitrary shape. 206 pages. (*DA*, 64-7035)

216. RADIATION MEASUREMENTS FROM THE PLASMA SHEATH SURROUNDING HYPERSONIC PROJECTILES

Lemay, A.
In "The High Temperature Aspects of Hypersonic Flow," pp. 555–567
Nelson, W. C., Editor
Pergamon Press, Ltd., Oxford, England, 1964 (distributed through The Macmillan Company, New York, N.Y.; available as AGARDograph 68)
N64-26,154
(Paper presented at the AGARD-NATO Symposium Meeting sponsored by the Fluid Dynamics Panel, Belgium, April 3–6, 1962)

Results of measurements of passive radiation from the plasma sheath surrounding a hypersonic projectile are presented for various reentry flight conditions. The measurements fall into three broad categories corresponding to three main types of experiment performed – those of total intensity of radiation from the stagnation region within given spectral bandwidths, obtained using photodetectors; those of spectral distribution of intensities for the integrated radiation from the plasma as a whole, obtained using conventional spectrographs; and those of spacial distribution of intensities within a given spectral bandwidth, obtained using an image converter camera. The results are of particular interest in the study of relaxation and ablation phenomena, and yield some preliminary information on wake structure.

217. CHEMICALLY REACTING BOUNDARY LAYERS

Lenard, M.
March 1964
General Electric Company, Missile and Space Division, Valley Forge Space Technology Center, Space Sciences Laboratory, Philadelphia, Pa.
R64SD14, AF 04(694)-222

Numerical calculations of the chemically reacting, laminar air boundary-layer equations are presented for several flight conditions and different wall temperatures. Computations are made at several points along cone-shaped reentry bodies.

Thermodynamic and transport properties are completely general and use the latest available information. The solutions are based on the assumption of local similarity. The resulting electron densities are noted.

218. IONIZATION OF CESIUM AND SODIUM CONTAMINATED AIR IN THE HYPERSONIC SLENDER BODY BOUNDARY LAYER
Lenard, M.
August 1964
General Electric Company, Missile and Space Division, Valley Forge Space Technology Center, Space Sciences Laboratory, Philadelphia, Pa.
R64SD22

An approximate procedure is used to predict the effect on air ionization of small amounts of cesium and sodium in the ablating surface material of pointed cones. Ionization is assumed to occur due to finite-rate, gas-phase chemical reactions in the laminar boundary layer. An 11-species, 16-reaction chemical system is assumed.

219. PLASMA SHEATH CHARACTERISTICS ABOUT HYPERSONIC VEHICLES
Lew, H. G., Langelo, V. A.
April 6, 1960
General Electric Company, Space Sciences Laboratory, Philadelphia, Pa.
TIS-R60SD356, AF 04(647)-269
AD-236,880
(Paper presented at the IRE-ARS 14th Annual Spring Meeting, Cincinnati, Ohio, April 12–13, 1960)

Vehicle-induced interferences to signal transmission are considered, and some results for a typical reentry body are presented. The shock layer for such a body and the effects of nonequilibrium are investigated. The ionized wake behind the body is discussed for both the continuum and rarefied gaseous states. Finally, the attenuation of a plane wave through the ion sheath is estimated.

220. A ROUGH ESTIMATE OF THE ATTENUATION OF TELEMETERING SIGNALS THROUGH THE IONIZED GAS ENVELOPE AROUND A TYPICAL REENTRY MISSILE
Lin, S. C.
February 1956
Avco-Everett Research Laboratory, Everett, Mass.
Research Report 74, AF 04(645)-18
AD-221,395

A rough estimate was made of the attenuation of telemetering signals which pass through the ionized gas layer surrounding a typical long-range missile reentering the Earth's atmosphere at hypersonic speeds. The results indicate that in the frequency range used by the standard telemetering systems (e.g., the RDB system, $f \approx 200$ Mc), it would be difficult to send any signal through the ionized gas throughout the critical part of the trajectory. If the electron-ion recombination rate proves to be sufficiently rapid, microwave frequencies ($f \approx 3 \times 10^{10}$ cps) will probably be satisfactory. According to the present estimate, even if the electron-ion recombination rate is very slow, microwaves would still provide satisfactory transmission at sufficiently high altitudes ($\sim$150,000 ft or more). The low-frequency end of the spectrum ($f \lesssim 1$ Mc) can probably be utilized for transmission below the ionosphere. 43 pages.

221. RADIO ECHOES FROM THE IONIZED TRAILS GENERATED BY A MANNED SATELLITE DURING REENTRY
Lin, S. C., Goldberg, W. P., Janney, R. B.
April 1962
Avco-Everett Research Laboratory, Everett, Mass.
Research Report 127, BSD-TDR-62-54, AF 04(694)-33

The ionized trails produced during reentry by the *MA-6* capsule, which carried John Glenn on his first orbital flight on February 20, 1962, have been analyzed. The observations, made from San Salvador Island, employed apparatus similar to that used by radio astronomers in the study of meteor echoes. It was clearly demonstrated that the ionized trail generated by a large hypersonic object, such as a reentering manned satellite, would produce strong radio echoes over great distances and over a wide range of aspect angles—even during the early phase of reentry. It is possible that this strong echoing characteristic of the wake could be utilized in the future as a navigational aid for reentering satellites and spacecraft. (*AI/A*, 1962, #5601)

222. RADIO ECHOES FROM MANNED SATELLITE DURING REENTRY
Lin, S. C.
***Journal of Geophysical Research*, v. 67, no. 10, pp. 3851–3870, September 1962**

Five clearly separated ionized trails produced during reentry by the *MA-6* capsule, on February 20, 1962, were observed 370 nt mi uprange from the landing point. The most prominent trail was visible to radar for a total duration of about 20 sec, and displayed an equivalent isotropic scattering cross section of about 10^6 m^2 at its peak. (*EI*, 1963)

223. THEORY OF IONIZED TRAILS FOR BODIES AT HYPERSONIC SPEEDS
Lykoudis, P. S.
October 5, 1961
Rand Corporation, Santa Monica, Calif.
RM-2682-1-PR (Revision of RM-2682, AD-257,938), AF 49(638)-700
AD-269,285
(See also "Proceedings of the Heat Transfer and Fluid Mechanics Institute," pp. 176–192, Stanford University Press, Stanford, Calif., 1961; also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The characteristics of the gaseous trail remaining behind a body moving through the atmosphere at hypersonic speeds are discussed. Means are sought for ascertaining those variables that can be measured and used to predict the characteristics of the body causing the trail – essentially its shape and weight. In the case of thermodynamic equilibrium, a universal solution is found for the velocity and enthalpy distributions at a station behind the body where the pressure has reached its ambient free-stream value. This solution is given in terms of the coordinate defining the shape of the bow shock wave. The nondimensional velocity and enthalpy profiles depend strongly on the drag coefficient alone. The thermal conduction part of the trail is also studied. An analytic solution is found for variable thermal conductivity. The length of the trail based on a minimum ionization level is calculated at different altitudes for actual reentry. As a good approximation, this length is directly proportional to the local atmospheric density, the drag coefficient, and the cross-sectional area of the object, for a constant flight velocity and for a relatively blunt body with boundary-layer effects neglected. The influence of the trailing shock on the conduction portion of the trail is discussed. A preliminary study is also made of the trail under chemically frozen conditions. 62 pages; 26 references.

224. ELECTROMAGNETIC PROPAGATION THROUGH SHOCK-IONIZED AIR SURROUNDING GLIDE REENTRY SPACECRAFT
McCabe, W. M., Stolwyk, C. F.
***IRE Transactions on Space Electronics and Telemetry*, v. SET-8, no. 4, pp. 257–266, December 1962**

Methods are examined by which an approximation of the radio interference effects (caused by thermal ionization) may be obtained when only the trajectory and body configuration are known. A procedure is described by which analysis of propagation effects for elemental bodies may be used to approximate the conditions to be expected in the corresponding region of the more complex vehicle. In the analysis, the direction of propagation is, for the purpose of simplicity, considered normal to the vehicle surface. In an actual case, however, the direction of propagation is determined by the location of ground stations relative to the flight path and the attitude of the vehicle in space. More accurate analysis to include these factors requires that the increased propagation path through the ionized layer be considered in determining attenuation loss. Determination of reflection losses must include the effect of oblique incidence. A sample problem is presented in the appendix to demonstrate the procedure. 15 references. (*IAA*, A63-11,462)

225. SCATTERING OF RADAR WAVES BY AN UNDERDENSE TURBULENT PLASMA
Menkes, J.
American Institute of Aeronautics and Astronautics, New York, N.Y.
Paper 64-20, presented at the AIAA Aerospace Science Meeting, New York, N.Y., January 20–22, 1964

The scattering of electromagnetic waves by a turbulent plasma has occupied the interest of ionospheric physicists for a long time. A reentering ballistic missile leaves an ionized trail in its wake which provides a target to a radar in a manner quite similar to the trail of a meteor. It is assumed that the description of the target is as complete as is necessary to perform the calculations indicated.

226. THE REDUCTION OF ELECTROMAGNETIC BACKSCATTER FROM A PLASMA-CLAD CONDUCTING BODY
Murphy, E. L.
September 23, 1963
Massachusetts Institute of Technology, Lincoln Laboratory, Lexington
TR 329, ESD-TDR-63-589, AF 19(628)-500
AD-430,589, N64-17,364

A conducting body embedded in a collisionless ionized cloud is discussed, and the possibility that the cloud acts to decrease the backscatter cross section of the object is considered. Although an obvious process would be refraction, a less obvious process exists that can be described on the same mathematical basis as the plasma resonance or space charge effect described by Herlofson for meteors. The essential change here is to include a conducting core within the plasma. Not only are the resonance shapes and locations affected, but it is then possible for a backscatter cross section to decrease considerably below the value of the conducting core itself. This "resonance-dip" phenomenon is described in detail for the problem of a cylindrical or spherical conducting core surrounded by a uniform concentric dielectric layer. 26 pages; 7 references.

227. THE PLASMA SHEATH EFFECT ON RADAR CROSS SECTION OF A HYPERSONIC SPHERE AS PREDICTED BY LOSSLESS GEOMETRICAL OPTICS
Musal, H. M., Jr.
March 1, 1960
Bendix Corporation, Bendix Systems Division, Ann Arbor, Mich.
Research Note 1, DA-11-022-ORD-3130, NOrd-18930, and DA-11-022-ORD-2649
AD-268,800

A first-order approximation was made of the high-altitude plasma sheath effect on the nose-on radar cross section of a hypervelocity sphere in the atmosphere. The geometrical optics approach was used, employing ray path power-density addition. On the basis of this first-order analysis, upper and lower limits on the nose-on radar cross-section variation and characteristics transitional behavior can be predicted. It must be remembered that the ray path power-density addition technique averages the electromagnetic wave interference phenomena; therefore the results do not show scintillation effects that arise from this cause. Such effects are predicted from a second-order approximation employing ray path field-

intensity addition. On the basis of this second-order analysis, it is shown that the nose-on radar cross section may fluctuate from a maximum value slightly greater than the static radar cross-section value to a minimum value of zero, due to the plasma sheath effect. 11 references.

228. ON THE THEORY OF THE RADAR PLASMA ABSORPTION EFFECT
Musal, H. M., Jr.
July 1963
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
TR-63-217A, DA-04-495-ORD-3567(Z)
AD-421,889, N64-20,562

A brief review is given of the hypersonic aerodynamics, chemical physics, plasma physics, and electromagnetic wave scattering phenomena involved in the study of plasma effects on radar cross sections. The effect of the plasma sheath on the radar cross section of a hypersonic body can be considered separately from the effect of the plasma trail left behind the body. Several theoretical models of electromagnetic wave scattering from plasma-covered bodies are formulated and analyzed. The theoretical results of these analyses show both absorption and enhancement effects that could be caused by the plasma sheath. Theoretical predictions of plasma sheath effects calculated from the analyses of the theoretical models are compared with experimental results. The measured absorption and enhancement are both significantly greater than was predicted by the theoretical results. 191 pages.

229. THE RADAR ABSORPTION EFFECT CAUSED BY VERY THIN PLASMA SHEATHS
Musal, H. M., Jr., Blore, W. E.
July 1964
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
CTN-64-02, DA-04-495-ORD-3567(Z)
AD-444,071, N64-31,136

It is shown theoretically that anomalous absorption may be a diffraction effect caused by the gradient of the electron density in the plasma sheath around the body; i.e., the effect occurs when the body is only partially covered by an overdense plasma sheath. This plasma layer can be very thin compared to the wavelength of the radar wave and still cause a significant decrease in the radar cross section. These results are illustrated by several theoretical graphs showing the dependence of the radar cross section of a metal sphere partially covered by a plasma layer on the size, thickness, and properties of the layer. 21 pages; 9 references.

230. ELECTROMAGNETIC WAVE SCATTERING FROM DIELECTRIC-COATED METAL BODIES
Musal, H. M., Jr.
August 1964
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
CTN-64-05, DA-04-495-ORD-3567(Z)
AD-448,062, N65-12,754

The general definition of the radar cross section of a body, including the electromagnetic field intensities of the incident and scattered waves, is reviewed. It is shown how the scattered wave is determined by the induced electromagnetic field at the surface of the body which is caused by the incident electromagnetic wave. The physical optics approach that relates the induced electromagnetic field to the incident electromagnetic wave at the surface of the body is reviewed, and the resultant radar cross-section formula is given. The modification of this approach that accounts for the phase and amplitude perturbations caused by a thin dielectric coating over the metal surface is presented, and the resultant formula for the radar cross section is then derived. 24 pages.

231. ELECTROMAGNETIC WAVE REFLECTION FROM A METAL-BACKED NONUNIFORM PLASMA LAYER FOR NONNORMAL INCIDENCE
Musal, H. M., Jr.
August 1964
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
CTN-64-06, DA-04-495-ORD-3567(Z)
AD-449,859, N65-12,742

This study presents a technique for the calculation of the reflection coefficient for a plane, transverse, electromagnetic wave incident nonnormally on a nonuniform plasma layer with a metal-backed wall. An arbitrarily polarized, incident electromagnetic wave is considered that is composed of transverse electric and transverse magnetic modes. The reflection coefficient for each of these different modes is then found separately through the solution of a pair of second-order linear differential equations, with given initial conditions at the metal wall, over the interval defined by the thickness of the plasma layer. 15 pages.

232. STUDY OF RADIATION AND RECEPTION OF ELECTROMAGNETIC ENERGY FROM AIRCRAFT AND GUIDED MISSILES
Nanevicz, J. E.
September 22, 1964
Stanford Research Institute, Menlo Park, Calif.
Report for August 1964, MPL-31, SRI-3977, AF 19(628)-325

This monthly progress report is one of a series which began in February 1962. The studies are concerned with the following objectives: (1) to investigate antenna breakdown phenomena affecting HF antennas in space and to determine the restrictions these phenomena impose on spacecraft communications; (2) to investigate the static charging of rocket vehicles, possible applications for static charge measurements, and the effect of static charge in modifying the electromagnetic environment of the vehicle; and (3) to investigate methods of propagating through the plasma sheath surrounding a hypersonic reentry vehicle.

233. **RADIATION FROM SEMI-INFINITE SLOT-EXCITED PLASMA-SHEATH CONFIGURATIONS**
Oliner, A. A., Tamir, T.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 32–48
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass., April 10–12, 1962—Entry 12)

It is well known that the actual plasma sheath surrounding a high-speed vehicle has a very complicated structure: it is finite in length, its thickness and plasma properties vary along its length, it possesses a radial variation, etc. Nevertheless, it is necessary to adopt a simple and tractable model for the plasma sheath in order to obtain even approximate theoretical information regarding its influence on electromagnetic radiation.

The cylindrical, spherical models are discussed and compared with the planar model. An examination is made of the performance changes produced when the planar structure is made semi-infinite in length, rather than infinite. Since the resulting model is still far from an accurate description of the actual plasma sheath, even though it is a step in the direction of a more realistic model, only an approximate technique is employed, which is sufficient to determine the main effects. 4 references.

234. **ON THE ANTENNA RADIATION THROUGH A PLASMA SHEATH**
Olte, A., Hayashi, Y.
June 1964
Michigan, University of, Radiation Laboratory, Ann Arbor
Report-5825-1-F, NASA-CR-59905
N65-13,281
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The influence of the plasma sheath on the slot antenna properties is considered. It is shown that opening a slot in a thin, overdense plasma sheath reestablishes, in many cases, the radiation of an elementary cylinder antenna. The changes in the impedance of a cavity-backed slot antenna with the onset of a plasma sheath are formulated on the basis of an energy theorem. 106 pages.

235. **NONLINEAR TRANSMISSION CHARACTERISTICS OF THE PLASMA SHEATH**
Papa, R. J.
May 1963
Air Force Cambridge Research Laboratories, Microwave Physics Lab., Bedford, Mass.
AFCRL 63-133
AD-407,089
(See also *IEEE Transaction on Antenna and Propagation*, v. AP-11, pp. 593–594, September, 1963)

A determination is made of the transmission characteristics of antennas located on hypersonic vehicles which are surrounded by a shock-induced sheath of ionized gas. A step-by-step numerical integration of Maxwell's equations is used to compute the reflection and transmission coefficients of the nonlinear slab of plasma. The approximation consists of replacing the inhomogeneous, nonlinear plasma slab with a set of homogeneous, linear sheets. 99 pages.

236. **RF THEORY OF THE PLASMA SHEATH**
Pavkovich, J., Kino, G. S.
In "Comptes Rendus de la VIe Conférence Internationale sur les Phénomènes d'Ionisation dans les Gaz, Volume III," pp. 39–44
Hubert, P., Crémieu-Alcan, E., Editors
SERMA, Paris, France, 1963
(Paper presented at the Sixth International Conference on Ionization Phenomena in Gases, Paris, France, July 8–13, 1963—Entry 592; also available as ARL 64-15, Aerospace Research Laboratories, Wright-Patterson AFB, Ohio, January 1964, AD-431,855, N64-16,777)

A theoretical treatment is given for the variation of RF fields within the plasma sheath. The analysis is based on an integration of the collisionless Boltzmann equation, with the assumption that the static potential varies parabolically in the sheath. It is shown that an effective impedance for the sheath can be defined, and that over the range in which the numerical results are calculated this impedance always has a real, positive part. The real part of this impedance is associated with Landau damping. A set of curves is given of the field through the sheath.

237. **NUMERICAL CALCULATIONS RELATED TO THE PROPERTIES OF THE PLASMA SHEATH**
Pavkovich, J.
January 1964
Aerospace Research Laboratories, Wright-Patterson AFB, Ohio
ARL 64-17, AF 33(616)-8121
AD-431,854, N64-16,795
(Also available as 64-7675, University Microfilm, Inc., Ann Arbor, Mich.)

A detailed RF theory of the sheath is presented. The complete collisionless Boltzmann equation is used to derive a linear integral equation for the RF electric field through the sheath; the analysis is one dimensional. This integral equation is solved numerically for a semi-infinite uniform plasma bounded by a sheath defined by a parabolic DC potential. A Maxwellian distribution of velocities is assumed for all computations. The results show that it is reasonable to assume that the normal component of displacement is continuous, but that extra waves are set up near the boundary which decay as the uniform plasma is approached. The waves are somewhat like the cutoff waves excited in the neighborhood of a waveguide discontinuity, and thus give rise to a sheath impedance. 184 pages.

238. ECHO AREA OF A PLASMA-COATED SPHERE
Peters, L., Jr., Green, R. B.
***Planetary and Space Science*, v. 6, pp. 133–141, June 1961**
(Paper presented at the Symposium on the Plasma Sheath: Its Effects on Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 22)

A report is given of several approximate methods for determining the echo area of various bodies immersed in plasma. The effects of transmission, reflection, and focusing are considered. Means of modeling plasma sheaths, which are valid for both echo area and transmission characteristics, are presented. Some problems with relatively simple geometry—e.g., the plasma sphere and the metallic sphere coated with plasma —are considered in detail. Methods are indicated for extending these results to missile shapes other than the sphere and to more general ion distributions.

239. FURTHER STUDIES OF THE RADAR CROSS SECTION OF PLASMA CLAD BODIES
Peters, L., Jr., Swarner, W. G., Thomas, D. T.
March 15, 1962
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Report 1116-19, Scientific Report 12, AFCRL-62-183, AF 19(604)-7270
N62-12,040

Approximate methods based on the pertinent scattering mechanisms are given for determining the radar cross sections of plasma-clad bodies. These methods are extensions of a method proposed at the First Plasma Sheath Symposium (Entry 238). A superposition principle is used which combines the scattered fields from the sheath alone and from a modified metallic body. Appropriate modifications of the scattered fields of the modified metallic body are discussed with respect to the physical phenomena involved. A comparison of approximate radar cross sections of spherical bodies clad in concentric spherical sheaths with the exact multipole expansion solutions shows excellent agreement for all sizes and dielectric constants, except for small restricted regions. An approximate method based on macroscopic properties is given for determining the radar cross section of dielectric bodies. This method is superior in accuracy, simplicity, and range of validity to previous methods, thereby removing a serious restriction of the superposition method—the need for exact solutions for dielectric bodies, solutions which do not exist for most shapes. 37 pages; 8 references.

240. FURTHER STUDIES OF THE RADAR CROSS SECTION OF PLASMA CLAD BODIES
Peters, L., Jr., Swarner, W. G., Thomas, D. T.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 320–336
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass., April 10–12, 1962—Entry 12)

At the First Symposium on the Plasma Sheath, an approximate solution for the echo area of plasma-clad spheres was introduced (Entry 238). This was later extended at the American Astronautical Society Symposium on Interactions of Space Vehicles With an Ionized Atmosphere (Entry 241). Further studies of this approximation are treated in this paper. Basically, the plasma is treated as a dielectric material of relative dielectric constant less than unity. Consequently, exact solutions for scattering from dielectric-clad spheres can be used to validate the approximate solutions. Because of the extreme length of the exact solution, an IBM 704 computer was used to obtain numerical results. However, the capacity of the computer limited the size of spheres which could be considered. The approximate solution has the advantage of giving simplified numerical results without use of a computer, and can be applied to nonclassical shapes. 8 references.

241. COHERENT SCATTERING OF A METALLIC BODY IN THE PRESENCE OF AN IONIZED SHELL
Peters, L., Jr., Swarner, W. G.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 447–463
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17; see also Preprint 61–69, presented at the AAS Symposium on Interactions of Space Vehicles With an Ionized Atmosphere, Washington, D.C., March 17, 1961, and Report 1116-4, Scientific Report 2, Ohio State University Research Foundation, Antenna Laboratory, Columbus, March 7, 1961, AD-256,359)

The problem of scattering of electromagnetic waves by a satellite which acquires an ionized coating while traversing the ionosphere is considered. An ion or electron shell may have considerable effect on the echo area of a satellite. This effect has been examined for several models. A spherical satellite becomes charged and acquires a concentric sheath of the opposite charge. The scattering cross section is obtained by considering the ionized sheath to have the macroscopic properties of a dielectric material. The resultant boundary condition problem is solved exactly. Also, alternative approximate solutions which are useful for determining the scattering cross sections of bodies of arbitrary shape have been developed.

An interesting result is noted; i.e., the configuration is nearly invisible for some cases. For example, a decrease of approximately 50 dB in echo area of a metallic sphere is obtained for a sphere 0.05λ in radius and a sheath of relative dielectric constant 0.75 and thickness 0.035λ.

Another model is examined for which significant echo areas are obtained by two mechanisms. The first occurs when the radar frequency falls below the plasma frequency of the shell, and the second, when the evacuated trail acts as a dielectric rod antenna. 16 references.

242. PLASMA SHEATH EFFECTS ON ROCKET ANTENNAS
Pfister, W., Ulwick, J. C.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 271–281
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17; see also Preprint 61–62, presented at the AAS Symposium on Interactions of Space Vehicles With an Ionized Atmosphere, Washington, D.C., March 17, 1961)

An antenna impedance probe is being developed by the Air Force Cambridge Research Laboratories for the measurement of electron density and collision frequency. Two Aerobee 150 rockets equipped with the experiment and a retarding potential probe have been successfully flown. Both flights provided data on the effect of a plasma on the antenna impedance experiment. Although the ion sheath around the antenna had been changed by a DC sweep voltage between rocket body and antenna, no effect on the impedance could be detected up to the highest reliable measurements at 140-km altitude. At greater heights outgassing of rocket fuel caused a reduction of electron density around the antenna by a process of attachment. Quantitative estimates indicate that the leaking gas, most likely the liquid fuel, is a very effective attaching agent.

243. THE ELECTRICAL PROPERTIES OF THE AIR AROUND A REENTERING BODY
Pippert, G. F., Edelberg, S.
Institute of the Aerospace Sciences, New York, N.Y.
Paper 61-40, presented at the 29th Annual IAS Meeting, New York, N.Y., January 23–25, 1961

The electrical properties of reentry plasmas, such as electron density and collision frequency, were studied. The effects of these properties on radar returns from the plasma column and on transmission through the plasma from the reentry vehicle are reviewed. Microwave plasma diagnostic work in hypervelocity ballistic ranges is discussed. Methods of obtaining plasma properties from radar data, and the limitations involved, are analyzed in relation to some available experiments. 24 pages. (*IAA*, 61-1503)

244. DISTURBANCES PRODUCED IN PLASMA BY A RAPIDLY MOVING BODY
Pitaevskii, L. P.
***Geomagnetizm i Aeronomiia*, v. 1, no. 2, pp. 194–208, 1961**
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 1, no. 2, pp. 172–183, 1961; see also *AIAA Journal, Russian Supplement*, v. 1, pp. 994–1000, April 1963)

This study concerns the scattering of electromagnetic waves in the disturbed region formed around a body moving in an electron–ion plasma in a permanent magnetic field. Expressions for the Fourier components are derived using the kinetic equations. It is assumed that the velocity of the body is much greater than the thermal velocity of the ions and that the Larmor radius of the ions is much greater than the dimensions of the body. The effective cross section of the scattering of electromagnetic waves with a wavelength much greater than the dimensions of the body is found from these formulas. 12 references.

245. CONCERNING DISTURBANCES PRODUCED BY A BODY MOVING IN A PLASMA
Pitaevskii, L. P., Kresin, V. Z.
***Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 40, pp. 271–281, January 1961**
(Translated from the Russian in *Soviet Physics—JETP*, v. 13, pp. 185–191, July 1961)

An expression is derived for the Fourier components, n_q, of the disturbance to the electron density produced by a body moving in a plasma, in the limit as the wave vector approaches zero, i.e., $q \to 0$. It is shown that the exact expression for n_q contains terms proportional to $1/q$, which are absent in the first approximation of perturbation theory. The formulas are employed in various particular cases to calculate the effective cross section for scattering of electromagnetic wavelengths much greater than the characteristic dimension of the body.

246. EFFECT OF COLLISIONS ON THE DISTURBANCES AROUND A BODY MOVING IN A PLASMA
Pitaevskii, L. P.
***Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 44, pp. 969–979, March 1963**
(Translated from the Russian *Soviet Physics—JETP*, v. 17, pp. 658–664, September 1963)

Formulas for the Fourier components, n_q, of the disturbances of the electron density around a body moving in a plasma in a magnetic field are deduced in various limiting cases by taking into account the collisions of ions with one another and with other particles. The calculation is performed on the basis of the kinetic equations with exact collision integrals. The relation between the expressions for n_q and the plasma dielectric constant is found by taking into account spatial dispersion.

247. SOME CALCULATIONS OF THE PHASE SHIFT AND ATTENUATION RATES OF THE HYPERSONIC PLASMA SHEATH
Plugge, R. J., Chen, S., Long, R. K.
January 31, 1961
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Report on Ion Sheath Research, Report 1021-3, AF 33(616)-6782
AD-260,075
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Electromagnetic parameters of the plasma sheath surrounding hypersonic vehicles are evaluated for plane-wave propagation, using small-signal macroscopic approximations. These

parameters, i.e., relative permittivity, relative conductivity, ordinary index of refraction, extinction or absorption coefficient, attenuation rate, phase coefficient, and reflection coefficient for the electric field, are computed at typical telemetering frequencies from 250 to 30,000 Mc. The results are plotted as functions of the altitude and speed of the vehicle. Parameters for longitudinal propagation of transverse electromagnetic waves in a magnetoplasma are also computed. 125 pages.

248. PLASMA SHEATHS SURROUNDING RADIATING ANTENNAS
Rashad, A. R. M.
In "Record of the International Space Electronics Symposium, Las Vegas, Nev., October 6–9, 1964," pp. 9-b-1–9-b-7
Institute of Electrical and Electronics Engineers, Space Electronics and Telemetry Group, New York, N.Y., 1964

The plasma sheath surrounding a thin cylindrical antenna radiating in the ionosphere is analyzed. The Maxwell, Boltzmann, and Vlasov equations are solved to find the density distribution, n, of both ions and electrons in the sheath. It is assumed that the sheath medium is an inhomogeneous anisotropic plasma. It is found that n depends on the radial distance from the antenna and on the Debye length. Simple formulas for the sheath thickness are derived from the diffusion theory, if the ionization effects and boundary surface fluctuations are neglected. The analysis shows that longitudinal and transverse plasma waves can exist in the sheath. These waves are excited by the antenna-applied RF voltage. Isothermal sound waves can appear also, but only at frequencies below the plasma frequency. As a result of this study, the radiation pattern of the antenna can be calculated more accurately than was possible with previous procedures. 10 references.

249. SOME PROPERTIES OF PLASMAS FORMED BY REFLECTION OF ELECTROMAGNETICALLY DRIVEN SHOCKS
Rausa, G.
***IEEE Transactions on Nuclear Science*, v. NS-11, no. 1, pp. 170–175, January 1964**
(Paper presented at 10th International Symposium on Plasma Phenomena and Measurements, San Diego, Calif., October 29–November 1, 1963—Entry 609)

The program described was designed to determine the applicability of an electromagnetic shock tube to the study of problems in the field of reentry physics, i.e., (1) microwave interactions with plasma sheaths; (2) ionization growth and decay; and (3) at higher shock velocities, the determination of the intensity and spectrum of radiation from shock heated gases. Specifically, the plasma generated in a conical tube (immersed electrode) was investigated to determine its limitations with regard to the study of the aforementioned problems. The plasma under investigation included that associated with the reflected as well as the incident wave. 21 references. (*IAA*, A64-14,499)

250. COMPARISON OF THE IONIZED SHOCK LAYER ABOUT TWO- AND THREE-DIMENSIONAL BLUNT SHAPES AT HYPERSONIC SPEEDS
Ridyard, H. W.
***Planetary and Space Science*, v. 6, pp. 10–23, June 1961**
(Paper presented at the Symposium on the Plasma Sheath: Its Effects on Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 22)

A comparative study of the ionized shock layer about simple two- and three-dimensional blunt shapes was conducted at a Mach number of 15 and an altitude of 100,000 ft. Various shock layer profiles of the aerodynamic and thermodynamic flow quantities and electron densities are given for the inviscid and viscous regions of the flow. It is seen that the largest electron concentrations are present at the blunt nose of the configurations. Both the shock layer thicknesses and electron densities for the two-dimensional bodies are greater than for the three-dimensional bodies. The Gravalos numerical method was used to determine the inviscid flow results. The nonlinearities in the variations of the resulting flow quantities make it difficult to predict these results accurately by use of simple approximation methods. 13 references. (*PA*, 1962, #4878)

251. EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF A HYPERSONIC ENVIRONMENT UPON ELECTROMAGNETIC RADIATION
Rotman, W., Meltz, G.
1960
Air Force Cambridge Research Center, Electronics Research Directorate, Bedford, Mass.
AFCRC-TR-60-108(I)
AD-236,932
(Paper presented at Symposium of the Plasma Sheath: Its Effects On Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 18)

An experimental investigation to determine the effects of the plasma sheath, which surrounds a reentry vehicle, upon the transmission and reception of radio signals is discussed. The experiment and its instrumentation are described, and the quantities that will be measured are enumerated. The expected results are briefly discussed.

252. EXPERIMENTAL INVESTIGATION OF THE ELECTROMAGNETIC EFFECTS OF REENTRY
Rotman, W., Meltz, G.
March 1961
Air Force Cambridge Research Laboratories, Bedford, Mass.
AFCRL-87 (Revised)
AD-271,699

The instrumentation and expected results of a forthcoming missile test are described. An instrumented, nonablative nose cone will be flown in a reentry trajectory to investigate the

effects of the vehicle plasma sheath upon the transmission and reception of radio signals. The initial results of a plasma simulation experiment and of flow field and antenna pattern computations are summarized in graphs and briefly discussed. 22 pages; 16 references.

253. RESONANCE SCATTERING OF RADIO WAVES BY EARTH-SATELLITE WAKES
Saiasov, Iu. S., Zhizhimov, L. A.
***Radiotekhnika i Elektronika*, v. 8, pp. 499–502, March 1963**
(Translated from the Russian in *Radio Engineering and Electronic Physics*, v. 8, pp. 442–445, March 1963)

The peculiarities of the resonance scattering of radio waves in a satellite trail are analyzed qualitatively. An idealized model of a plane wave perpendicularly incident upon an infinite cylindrical discontinuity is used in which the electron concentration depends only on the cylinder radius. It is postulated that the electric vector of the incident wave is parallel to the z-axis of the cylinder. The reflection factor of a plane incident wave is determined from a model of a one-dimensional plasma discontinuity analogous to the one-dimensional potential well in quantum mechanics. It is shown that the resonance scattering of radio waves follows different patterns depending on the symmetry of the satellite wake, and that resonance scattering does not take place if the trail length and the relative changes in electron concentration are small. (*IAA*, A63-16,357)

254. VOLTAGE BREAKDOWN OF ANTENNAS AT HIGH ALTITUDES
Scharfman, W. E., Morita, T.
***IRE, Proceedings of the*, v. 48, no. 11, pp. 1881–1887, November 1960**

The factors influencing the power-handling capability of antennas at high altitude are considered. The physical mechanisms involved, including the roles of attachment, free diffusion, ambipolar diffusion, and nonuniform field distribution in the breakdown process, are qualitatively described. These factors are illustrated by breakdown curves for various antenna configurations under both CW and pulse conditions. Normalized data – useful for estimating breakdown fields when the conditions for scaling are fulfilled – are presented. The effects of missile environment on breakdown characteristics are discussed, and an experiment that involves artificially introducing ionization near the surface of the antenna is described. Methods are considered for increasing the power-handling capability, and typical results are given showing the increase in power that can be achieved.

255. RADIATION FROM AN ELECTRIC DIPOLE IN A PLASMA COLUMN
Seshadri, S. R.
August 7, 1964
Sylvania Electric Products, Inc., Applied Research Laboratory, Waltham, Mass.
Scientific Report 4, AFCRL-64-695, AF 19(628)-2410
AD-609,304, N65-15,291

During reentry into the Earth's atmosphere, antennas situated on space vehicles are surrounded by a layer of plasma. As a consequence, the radiation characteristics of these antennas are considerably modified. Therefore it is of interest to study the radiation characteristics of antennas surrounded by a plasma. The idealized problem of radiation from an axially oriented electric dipole in an infinite cylindrical plasma column is treated with a view to obtaining the general nature of modification of antenna characteristics introduced by the plasma sheath.

256. SHOCK-WAVE IONIZATION AND ITS EFFECT ON SPACE COMMUNICATIONS
Sisco, W. B., Fiskin, J. M.
June 5, 1958
Douglas Aircraft Company, Inc., Missile and Space Systems Division, El Segundo, Calif.
Engineering Paper 656
(Paper presented at the National Symposium on Extended Range and Space Communications, Washington, D.C., October 6–7, 1958)

Within a planetary atmosphere, a space vehicle moving at hypersonic velocities on an exit or reentry course will be surrounded by a shock-induced ionized sheath. Even in the realm of "free molecular flow" in the atmospheric fringe, an increase in the ion density can be expected ahead of a rapidly moving vehicle. Consequently, communication with a vehicle will be affected. This report deals with air as the atmosphere, since it is of immediate concern. However, the principles will apply equally to any other planetary atmospheres. 21 pages.

257. DIRECT *IN SITU* MEASUREMENTS OF WAKE CHARACTERISTICS OF REENTRY VEHICLES
Stephenson, R. L., Hammond, S. B., De Vries, K. L., Burt, D. A.
March 16, 1964
Utah, University of, Upper Air Research Laboratory, Salt Lake City
Scientific Report 1, AFCRL-64-276, AF 19(628)-3243
AD-441,549, N64-23,981

A study was conducted to determine the feasibility of making *in situ* measurements in the wake of a reentry vehicle. Two methods of sensor positioning were considered: (1) ejecting a free capsule into the wake, and (2) ejecting and dragging a package that would remain physically connected to the reentry vehicle. Different types of sensors were studied for measuring various characteristics of the wake. It is concluded that a physically attached drag device could be constructed and flown. The drag device would position sensors for the measurement of electron densities. 33 pages.

258. EFFECTS OF REENTRY IONIZATION ON THE ASSET COMMUNICATION SYSTEM
Stolwyk, C. F., Hinrichs, C. A.
In "Record of the International Space Electronics Symposium, Las Vegas, Nev., October 6–9, 1964," pp. 6-f-1–6-f-12

Institute of Electrical and Electronics Engineers, Space Electronics and Telemetry Group, New York, N.Y., 1964

The shock-induced ionization effects observed during the flight of the first *ASSET* communication vehicle in September 1963 are discussed. A brief description of the satellite and the associated communication system is provided. The VHF attenuation experienced in the flight is presented parametrically as a function of flight parameters. Several simple plasma models are used to illustrate their various predictive capabilities. Reflectometer and antenna breakdown due to ionization is discussed. The flight is assessed as a unique opportunity to measure the propagation effects of shock ionization associated with glide reentry. The results show a fair agreement between the observed attenuation and that predicted from simplified analytical models. (*IAA*, A65-11,470)

259. SCATTERING OF ELECTROMAGNETIC WAVES FROM THE DISTURBANCE CAUSED BY A RAPIDLY MOVING BODY IN PLASMAS

Suh, S. K.
August 1964
Brown Engineering Company, Inc., Huntsville, Ala.
BrownEng-R-111, DA-01-021-AMC-85Z
AD-606,290
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The scattering of electromagnetic waves by a body moving in a plasma is discussed in detail. A general theory covering scattering phenomena is developed, with emphasis on a perturbation method which can be used to obtain a reasonably accurate differential cross section under two different physical conditions. The general theory is extended in order to investigate the following two problems: the scattering of electromagnetic waves from the disturbance caused by a rapidly moving body in the ionosphere, and the scattering of electromagnetic waves from the turbulent wake produced by a reentry vehicle. In the first problem, kinetic equations are used to find the frequency spectrum of the electron density fluctuations in terms of which the differential scattering cross section can be expressed. In the second problem, the differential scattering cross section is obtained in terms of the correlation function for turbulence, which can be estimated by using the correlation length. 31 pages.

260. RADAR CROSS SECTIONS OF DIELECTRIC OR PLASMA COATED CONDUCTING BODIES

Swarner, W. G.
1962
Ohio State University, Columbus
Thesis
(See also *IEEE Transactions on Antennas and Propagation*, v. AP-11, pp. 559–569, September 1963)

Radar cross sections for a variety of spherical and cylindrical scatterers having dielectric or plasma shells are obtained by using both the exact boundary value solutions and approximate methods based on physical principles. The plasma is assumed to have the macroscopic properties of a lossless dielectric with a relative permittivity less than that of free space.

Exact boundary value solutions are given for the bistatic echo area of homogeneous dielectric spheres, conducting spheres, and concentric dielectric-coated conducting spheres in both the E plane and the H plane, and for two concentric infinite circular cylinders of arbitrary composition, illuminated by a plane wave (at normal incidence) having either parallel or perpendicular polarization with respect to the axis of the cylinder.

A superposition approximation for the radar cross section of a dielectric-coated conducting body is obtained by considering the scattered field to be the phasor sum of two principal components, the field scattered by the air–dielectric interface and the field scattered by an equivalent conducting body which differs from the actual body because of the lens action of the shell. This approximation yields very good agreement with the exact solutions for both spherical and cylindrical dielectric-clad scatterers with radii ranging from the Rayleigh region through the resonant region, and for bistatic scattering as well as for backscatter.

The echo area of a conducting sphere with a nonconcentric spherical dielectric shell calculated by means of the superposition approximation is in excellent agreement with experimental measurements, thus demonstrating the validity of this method in a case for which the exact solution cannot be obtained. 108 pages. (*DA*, 63-2564)

261. ANALYSIS OF RADIO SIGNAL INTERFERENCE EFFECTS DUE TO IONIZED LAYER AROUND A REENTRY VEHICLE

Taylor, W. C.
***Planetary and Space Science*, v. 6, pp. 1–9, June 1961**
(Paper presented at the Symposium on the Plasma Sheath: Its Effects on Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 22)

In the theoretical section of this paper, the electromagnetic properties of the ionized shock layer about a missile reentering the atmosphere are discussed. Also treated is the problem of predicting the transmission through the shock layer of electromagnetic waves originating on the vehicle. The important quantitative aspects for calculating the extent of the attenuation problem are outlined. Theoretical curves are given which allow rapid prediction of the attenuation effects in the shock layer due to air ionization for specified temperature and density. If other sources of free electrons are significant (e.g., ablation products), separate determination of the density distribution must be made. Specific results are given on certain *Polaris* configurations and trajectories which were computed using this method; these predictions are

based upon two specific transmitter frequencies. Although the method utilizes the Lorentz theory, and the plane wave homogeneous sheet assumption is made, the resulting estimates are shown to agree satisfactorily with signal strength records of actual reentry tests. A quantitative discussion is given concerning the approximations inherent in the use of the Lorentz theory of conductivity in view of "strong fields" near a transmitter and the velocity dependence of collision cross sections. A section is devoted to possible solutions of the transmission problem suggested by the parameters available in various ranges of temperature and density; particular attention is paid to transmitter frequency and position of the aerial. A method is demonstrated for extrapolating the results of a minimum of predictions for a given combination of radiator and reentry body to include predictions for a wide range of altitudes and velocities. (*PA*, 1962, #4883)

262. ANALYSIS AND PREDICTION OF RADIO SIGNAL INTERFERENCE EFFECTS DUE TO IONIZED LAYER AROUND A REENTRY VEHICLE
Taylor, W. C.
***Planetary and Space Science*, v. 7, pp. 286–300, July 1961**
(Paper presented at the Fourth AFBMD/STL Symposium on Advances in Ballistic Missile and Space Technology, Los Angeles, Calif., August 24–27, 1959, and at the IRE National Symposium on Space Electronics and Telemetry, San Francisco, Calif., September 28–30, 1959)

Principally, this report treats the problem of transmission of electromagnetic waves through the thermally ionized layer of gases in the shock layer around a hypersonic missile. Simplified theory, methods, and graphic aids for approximate predictions of the problem are given, and some specific results for a typical hemisphere-cylinder vehicle shape are presented. While details of the theory allowing computation of temperature and the concentration of electrons and neutral particles are not included, a method which has been used is outlined and referenced.

It is concluded that a 200-Mc signal will experience significant attenuation due to air ionization when peak reentry velocities exceed about 11,000 or 12,000 ft/sec. Although it may not be true in every case, it is predicted that an increase in signal frequency above the 200-Mc region for a midsection-radiated wave will decrease attenuation for missiles in the intermediate, or shorter range. 21 references.

263. SCATTERING BY PLASMA AND DIELECTRIC BODIES
Thomas, D. T.
1962
Ohio State University, Columbus
Thesis

In response to recent interest in space programs, research was initiated to investigate the scattering by plasma and dielectric bodies. For this research, plasma bodies are considered to be dielectric bodies with relative permittivity less than unity. Exact boundary-value solutions exist for a few very special shapes, and several approximate solutions are available for limited regions of size and permittivity. However, no approximate methods were found for obtaining the scattering from dielectric bodies of arbitrary shape with dimensions in the resonant region, i.e., size comparable to a wavelength.

A modified geometrical optics approximation is presented which can be used to obtain scattering results for these bodies in the resonant region. The backscattering aspect is of particular interest here. Ray-tracing techniques are used to find the emergent rays contributing to the scattering, i.e., the backscattering rays which have only a few internal reflections, and, in exceptional cases, stationary rays whose final direction is near the backscattering direction. The amplitude and phase of the fields associated with each ray are calculated by using classical geometrical optics where possible, with modifications and the use of physical optics where necessary. In the final step the component fields of each emergent ray are added to give the total fields.

Applications of this method include calculations of backscattering from various special shapes: the infinite circular cylinder, the sphere, a thin spherical shell, and a prolate spheroid. For the cylinder, sphere, and thin spherical shell, exact values from the boundary value solution are used for comparison; for the prolate spheroid, models were built and measured. In all cases the results were good for bodies ranging in size from 0.8 to 4.0λ, which covers the resonant region. The method can also be applied to larger bodies. These results and the generality of the method indicate the value of this method in calculating the scattering from dielectric bodies of arbitrary shape. 102 pages. (*DA*, 63-2566)

264. COMMUNICATION BLACKOUT AT REENTRY
Tischer, F. J.
In "Proceedings of the Fifth International Symposium on Space Technology and Science, Tokyo, Japan, September 2–7, 1963," pp. 751–758
Hayashi, T., Editor
AGNE Corporation, Tokyo, Japan, 1964

Procedures are outlined for computing (1) the approximate attenuation of radio signals transmitted through the shock layer of a large reentry vehicle, and (2) the communication blackout time. A review of the computation methods and of the availability of the data needed in these computations indicates that approximate methods (with simplifications applied in most of the phases of the computation) represent, at present, one of the most fruitful approaches for obtaining estimates of the communications blackout at reentry. For this reason, approximate equations are derived for the reentry attenuation. The derived equations are then applied to the reentry of a manned space capsule into the Earth's atmosphere. 8 references. (*IAA*, A65-14,347)

265. AEROPHYSICAL ASPECTS OF SLENDER BODY REENTRY
Vaglio-Laurin, R., Bloom, M. H., Byrne, R. W.
American Rocket Society, New York, N.Y.
Paper 2674-62, presented at the ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., November 13–18, 1962

Complete flow fields and measurable parameters about slender hypersonic reentry configurations are quantitatively analyzed and are compared with the more familiar blunt-body pattern. Methods of analysis are reviewed, and typical quantitative results are presented, particularly for 10-deg half-angle blunted cones. Special attention is given to the following aspects of the problem: (1) turbulent boundary layer over the body, including the effects of ablation and mass entrainment; (2) engineering and mathematical studies of the near wake, including temporary recovery; and (3) analysis of the turbulent far wake, including an assessment of an eddy viscosity model, a closed-form solution for velocity decay, and a quantitative discussion of electromagnetic and optical observables. 70 pages; 30 references. (*IAA*, A63-12,680)

266. ELEMENTARY SOLUTIONS FOR THE NORMAL TRANSMISSION OF ELECTROMAGNETIC SIGNALS THROUGH NONUNIFORM PLASMA LAYERS
Vandrey, J. F.
***IEEE Transactions on Antennas and Propagation*, v. AP-11, pp. 709–711, November 1963**

A number of easily accessible elementary solutions of the wave equation in suitably constructed media are studied with respect to their use in theoretical studies of the reentry communication problem. Particular attention is paid to the normal transmission of plane-polarized waves through collisionless plasmas with an electron density varying only in the direction of propagation. Diagrams showing electron density distributions and transmission and reflection properties of a partly supercritical plasma layer with symmetrical electron distribution are included. (*IAA*, A64-11,813)

267. RESONANCES OF A SPHERICAL VOID IN A COMPRESSIBLE ISOTROPIC PLASMA
Wait, J. R.
***Journal of Geophysical Research*, v. 69, no. 19, pp. 4189–4191, October 1, 1964**

The effect of the finite temperature of a plasma or an ion sheath surrounding a space vehicle antenna is considered. The void is taken to be spherical in shape and sharply bounded; the interior is completely rid of electrons, while the exterior is a homogeneous isotropic plasma. The effect of an acoustic wave is to increase the resonant frequency by a small increment proportional to the acoustic velocity. To within the first order, the finite temperature of the plasma will not influence the damping of resonances; furthermore, because of the smallness of the Debye length relative to the dimensions of the void, resonance frequencies will not be significantly modified over those computed on the basis of the cold plasma. (*EI*, 1965)

268. REFLECTION OF RADIO WAVES FROM BOUNDARIES
Walker, E. H.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 437–446
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17)

Satellite wakes present sharp boundaries to radio waves that are incident upon them. Also, the wake produced by a satellite is not free to disperse in all directions, but is constrained by the Earth's magnetic field so as to form a large and sharply defined boundary surface which persists long after the passage of the satellite. In order to show the relation between such satellite wakes and the Kraus effect, the subject of the reflection of radio waves by sharp boundary surfaces is treated. Although these wakes have been considered by many authors to be insufficient to account for the Kraus effect, it is shown that the reflection coefficient for these boundaries becomes significant under favorable conditions of observation. The geometry and very large size of the wakes result in an inverse square law relating the power-to-signal strengths for radar observations, rather than an inverse fourth-power law.

269. THE IMPEDANCE OF AN ELECTRICALLY SHORT ANTENNA IN THE IONOSPHERE
Whale, H. A.
In "Proceedings of the International Conference on the Ionosphere Held at Imperial College, London, July 2–6, 1962," pp. 472–477
Stickland, A. C., Editor
The Institute of Physics, and The Physical Society, London, England, 1963 (distributed by Chapman & Hall, Ltd., London, England)
(See Entry 605)

The use of RF impedance probes for the measurement of ionospheric electron densities is investigated. On the basis of measurements made during rocket flights, it is found that the impedance of a short antenna operating above the local plasma frequency can be predicted if the following factors are considered: (1) the formation of an ion sheath around the antenna and the vehicle, (2) the enhancement of this sheath when large RF voltages are applied to the antenna, and (3) the loading which apparently arises from electroacoustic waves excited in the medium by the RF field close to the antenna. Design data are presented and are used to calculate the effect of the ionosphere on both the resistive and reactive components of the impedance of a short antenna. (*IAA*, A63-16,090)

270. ION SHEATH EFFECTS NEAR ANTENNAS RADIATING WITHIN THE IONOSPHERE
Whale, H. A.
***Journal of Geophysical Research*, v. 69, no. 3, pp. 447–455, February 1, 1964**
(Also available as TN D-1746, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md., May 1963, and through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A theoretical treatment of the electron displacement in the vicinity of a linear cylindrical antenna immersed in the ionosphere is developed which explains the surprisingly thick ion sheaths observed experimentally when large RF voltages are applied to the antenna. The force that displaces the electrons is obtained from numerical solutions to the nonlinear differential equation describing their motion, and the results are found to be consistent with the observations. 9 references.

271. RF ANTENNA BREAKDOWN CONDITIONS IN THE PRESENCE OF THE PLASMA SHEATH
Whitmer, R. F., MacDonald, A. D.
***Planetary and Space Science*, v. 6, pp. 149–154, June 1961**
(Paper presented at the Symposium on the Plasma Sheath: Its Effects on Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 22)

Aerials on nose cones and reentry vehicles are known to be susceptible to voltage breakdown at relatively modest microwave field strengths. The voltage required to produce breakdown is calculated, as a function of altitude, for typical nose cones reentering the atmosphere. The effects of the ionized sheath are included, and it is shown that the sheath can greatly modify the usual breakdown conditions. The effects of ambipolar diffusion within the sheath are of major importance and can modify the breakdown voltage as much as 50%. This correction is discussed in detail. When the electron density within the sheath approaches the density needed to cut off the microwave signal, a further correction to the breakdown voltage is required. Breakdown conditions for CW and pulsed operation are discussed as functions of Mach number, nose cone angle, frequency, and pulse width. The limitations of the present theory are briefly discussed. The theory is greatly limited by the lack of knowledge of certain basic plasma parameters. Methods for obtaining these parameters on in-flight tests are discussed. (*PA*, 1962, #4884)

272. MUTUAL COUPLING OF TWO THIN INFINITELY LONG SLOTS LOCATED ON A PERFECTLY CONDUCTING PLANE IN THE PRESENCE OF A UNIFORM PLASMA LAYER
Yee, J. S.
***IRE, Proceedings of the*, v. 49, no. 12, pp. 1837–1845, December 1961**

The effect of a plasma sheath upon the admittance parameters of the antennas of a hypersonic reentry vehicle is analyzed. The model used consists of two infinitely long thin slots on a ground plane covered by a uniform plasma layer, which is assumed to be a lossless gaseous dielectric slab having a dielectric constant less than unity but greater than zero. The coupling effects are described in terms of a mutual admittance parameter. The problem is formulated by spatial Fourier transforms which, upon inversion, yield the desired results. The transform integral for the case of a thick layer is evaluated by the method of steepest descent. The results are explained in terms of multiple reflections of rays by the sharply defined plasma–air interface. 15 references. (*IAA*, 62-2475)

273. SCATTERING FROM A CYLINDER COATED WITH AN INHOMOGENEOUS DIELECTRIC SHEATH
Yeh, C., Kaprielian, Z. A.
***Canadian Journal of Physics*, v. 41, no. 1, pp. 143–151, January 1963**

As a space vehicle reenters the atmosphere, a plasma sheath surrounding the vehicle is generated. It is well known that the sheath is inhomogeneous. However, to make this problem suitable for theoretical analysis, most investigators assume that the sheath is homogeneous. To investigate the validity of this assumption, the idealized problem of the scattering of plane waves by a conducting cylinder coated with a stratified dielectric sheath is considered. The wave equation is separated using the vector wave-function method of Hansen and Stratton, and it is then applied to the plane wave scattering problem. The backscattering cross section is defined and obtained. Analytical expressions for the scattering coefficients of a thin inhomogeneous sheath are also given. Numerical computations are carried out for a specific variation of the dielectric sheath. Results are compared with the homogeneous sheath problem; the dielectric constant of the homogeneous sheath is taken to be the average value of that for the inhomogeneous sheath. It is found that, in general, rather distinct differences are observed except when the sheath is very thin. (*PA*, 1963, #7703)

274. RADIATION FROM AN AXIALLY SLOTTED CYLINDER COATED WITH AN INHOMOGENEOUS DIELECTRIC SHEATH
Yeh, C., Kaprielian, Z. A.
***British Journal of Applied Physics*, v. 14, no. 10, pp. 677–681, October 1963**

Most investigators assume that the plasma sheath surrounding a space vehicle during reentry is homogeneous. An investigation of the validity of this assumption is made which is based on the radiation characteristics of a slotted-cylinder antenna. Expressions are obtained for the radiated fields of an axially slotted, infinite cylinder coated with a radially inhomogeneous, dielectric sheath, and the radiation patterns are plotted. 6 references. (*EI*, 1964)

275. ELECTROMAGNETIC RADIATION THROUGH A COLD CYLINDRICAL PLASMA SHEATH WITH AN AXIAL STATIC MAGNETIC FIELD
Yeh, W. H.
August 1963
University of Southern California Engineering Center, Los Angeles
Report 82-214, EE 30, AFCRL-63-347, AF 19(604)-6195
AD-423,426
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Expressions are obtained for the radiated fields of an arbitrary slot on a conducting cylinder coated with a cold plasma sheath in an axial, static magnetic field. It is well known from the plane wave analysis that the presence of a static magnetic field considerably affects the transmission characteristics of the signal through the plasma sheath. The effects of a static magnetic field on the radiation of a plasma-coated slot antenna are considered. Extensive numerical computations are carried out for the special case of an infinite axial slot. It is found that, if the plasma frequency is moderate, a small, axial, static magnetic field could significantly change the radiation patterns of the slotted antenna. The radiation patterns are found to be asymmetric. 23 pages.

276. SOME ASPECTS OF TURBULENT SCATTERING OF ELECTROMAGNETIC WAVES BY HYPERSONIC WAKE FLOWS
Yen, K. T.
December 1963
General Electric Company, Missile and Space Division, Space Science Laboratory, Valley Forge Space Technology Center, Philadelphia, Pa.
R63SD58, DA-30-069-ORD-1955

The present analytical study of the turbulent scattering of electromagnetic waves is directed to certain features of the phenomenon considered as peculiar to hypersonic wakes. Effects of flow intermittency, nonisotropy of the turbulence structure, and finite width of the wake on the scattering cross section (in its frequency and aspect-angle dependence) are of primary concern.

Phenomena of turbulence relevant to the scattering problem are briefly discussed. In particular, it is shown that electron density fluctuations of a turbulent nature, in addition to those caused by turbulence, will be produced by the intermittency behavior of turbulent wake flows. This fluctuation is found to depend on the mean electron density distribution, and Townsend's intermittency δ-function.

Phenomenological consideration of the physical process by which the turbulent electron density fluctuations are likely to be produced in hypersonic wakes yields an expression for the intensity of the fluctuations in terms of the gradient of the mean electron density distribution, the intensity of the turbulent velocity fluctuation, and a turbulence scale of the turbulent velocity field. 35 pages; 32 references.

277. INFORMATION TRANSFER FUNCTIONS THROUGH PLASMAS
April 1964
Hallicrafters Company, Chicago, Ill.
Final Report, RADC-TDR-63-548, AF 30(602)-3069
AD-600,821
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The degradation in information content undergone by surveillance and communication signals transmitted through the plasma sheath was calculated for some specific reentry conditions. A comparative analysis was made for all present-day types of modulations, assuming a flush-mounted slot antenna located near the stagnation point of the reentry vehicle and operating near, but above, the plasma frequency. The analysis is based on a transfer function which relates the space-time Fourier transforms of the antenna exciting field to the received radiation field. The end results, presented graphically in terms of both error probability and transinformation vs. input signal-to-noise ratio, are based on the calculated pulse distortion undergone by the signal as it traverses the plasma sheath. The results of the study indicate that, for the plasma model under consideration, the performance of all modulated signals is degraded, with the greatest degradation occurring for amplitude keying and the least degradation occurring for phase shift keying. 136 pages.

278. DECELERATION OF SPACE VEHICLES
April 18, 1961
Library of Congress, Air Information Division, Washington, D.C.
AID Report 61-51
AD-255,793
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report is a translation and discussion of an article from *Tekhnika-Molodezhi*, no. 1, p. 37, 1961, by G. Pokrovskiy. The electric charge on the nose of a rapidly flying body changes the magnitude of the body's deceleration. The application of this effect in the development of a deceleration engine for space vehicles is discussed. The possibility of using the kinetic energy of a space body to produce deceleration is also considered. Reentry processes for both electrically conductive meteors and dielectric meteors are explained. It is suggested that the ideas outlined by Pokrovskiy be given further consideration, since the establishment of an analogy between reentry processes of meteors and those of rockets may be of value in developing new principles and design philosophies for the solution of critical reentry problems. 2 pages.

279. REENTRY PHYSICS PROGRAM
1959
Massachusetts Institute of Technology, Lincoln Laboratory, Lexington
Semiannual Technical Summary Report for October 1, 1958–June 30, 1959, AF 19(604)-4559
AD-228,431

A program of research on the physics of reentry has been undertaken. The principal objectives of the current program are: (1) to determine the effects of the ionization produced by a reentering body on the electromagnetic scattering characteristics of the body; (2) to determine the effects of the ionization produced by a reentering body on the transmission of electromagnetic radiation from sources in the body; (3) to measure the intensity and the spectrum of electromagnetic and optical radiation resulting from the reentry process; and (4) to develop adequate theoretical models for the experimentally observed phenomena and to correlate the experimental data with measurements obtained by laboratory methods. The experimental and theoretical activities of the program include the study of (1) reentry shock formation and flow fields; (2) electronic properties of reentry plasmas, including the study of ion production and removal mechanisms; and (3) electromagnetic interactions with reentry plasmas. Hypersonic range facilities and associated instrumentation provide experimental support for all of these study programs. The field experiment portion of the program, which involves the use of a specially designed reentry vehicle, is intended to test the results of theory and laboratory measurements under reasonably controlled conditions in the atmosphere. The vehicles are being launched from the NASA Wallops Island facility. 109 pages.

280. REENTRY PHYSICS PROGRAM
February 8, 1961
Massachusetts Institute of Technology, Lincoln Laboratory, Lexington
Semiannual Technical Summary Report for July 1–December 31, 1960, AF 19(604)-7400
AD-252,669

Among the subjects covered in this report are the following: flow field studies; electronic properties of reentry plasmas; electromagnetic interactions with reentry plasmas; and electron removal rate and wake temperature. 67 pages.

281. REENTRY PHYSICS AND PROJECT PRESS PROGRAMS
August 30, 1961
Massachusetts Institute of Technology, Lincoln Laboratory, Lexington
Semiannual Technical Summary Report 5 for January 1–June 30, 1961, AF 19(604)-7400
AD-262,543
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report covers the research program on the electronic properties of reentry plasmas, as well as related flow field studies.

282. ANNUAL SUMMARY REPORT
June 1, 1961
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Report 1116-8, AFCRL-749, AF 19(604)-7270
AD-264,034
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Research was conducted to determine the scattering properties of a rapidly moving vehicle in the presence of a perturbed ionized environment by investigating the change in radar echo area caused by the presence of a plasma sheath. Approximate methods based on physical concepts were evolved for determining the echo area of conducting spheres surrounded by concentric dielectric shells. The approximate echo areas were in good agreement with exactly computed results; however, several discrepancies did occur. The exact bistatic echo areas of conducting spheres are being computed for use in determining approximate methods for computing the bistatic echo area of spherical configurations. Computations of the echo area of concentric circular cylinders of infinite length are expected to further demonstrate the validity of the approximations. Methods of solution are described for the near end-fire echo area of long, thin bodies with a dielectric shell. 21 pages; 20 references.

283. PLASMA NOISE MEASUREMENTS
November 30, 1964
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Annual Summary Report for November 1, 1962–October 31, 1963, Report 1573-5, AF 33(657)-10523
AD-429,411, N64-18,354

A research program is described which was undertaken to determine the effect of radio noise generated by the hypersonic plasma sheath. Thermal noise is of major importance under conditions of light plasma formation such as exist when various methods of plasma control are used. Laboratory measurements of thermal and interference noise in the frequency range 400–10,000 Mc are described. 20 pages.

284. ELECTROMAGNETIC WAVE PROPAGATION AND RADIATION CHARACTERISTICS OF ANISOTROPIC PLASMAS
April 1961
Radio Corporation of America, Moorestown, N.J.
Report on Down-Range Antiballistic Measurement Program (DAMP), DA 36-034-ORD-3144
AD-257,296
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Electromagnetic properties of homogeneous anisotropic plasmas are studied. The propagation characteristics of electromagnetic waves in anisotropic plasmas are examined for propagation parallel with and perpendicular to the applied DC magnetic field. The existence of very low frequency passbands due to ion effects is noted. The Faraday rotation due to the Earth's magnetic field is considered for the ionosphere and the plasma sheath of a reentry vehicle. A generalized and exact form of Kirchhoff's law is used to obtain the absorptivity of a plasma from its electromagnetic properties. The

absorptivity of an isotropic and anisotropic plasma slab is computed for normal incidence, and the effects of electron collision frequency, slab thickness, stop-bands, and boundary effects on the radiation spectrum are presented.

285. INVESTIGATION OF THE NATURAL INTERFERENCE EFFECTS UPON HIGH THRUST PILOTED AND PILOTLESS VEHICULAR ELECTRONICS SYSTEM PERFORMANCE. PART I. VEHICLE-INDUCED INTERFERENCE. PART II. INTERFERENCE DUE TO UNDISTURBED ENVIRONMENT. PART III. CONCLUSION AND RECOMMENDATIONS
August 1961
Wright Air Development Division, Wright-Patterson AFB, Ohio
WADD TR 61-191 (Volume I), AF 33(616)-6957
AD-262,913
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The effects of natural interferences on the performance of vehicular electronic systems in space are evaluated. There are two major types of natural interferences: those due to the undisturbed environment and vehicle-induced interferences.

Vehicle-induced interferences result from the ionized flow field (shock layer, boundary layer, and the near wake) surrounding the vehicle. Methods of analysis for the plasma sheath characteristics, which take into account the effects of impurities due to ablation, are given for the condition of chemical equilibrium. Nonequilibrium effects at high altitudes are also considered. The electrical properties of the plasma sheaths which exist when an electromagnetic wave interacts with the ionized species are treated, and the imposition of a magnetic field on the plasma sheath is investigated as a possible means of alleviating communications blackout. The behavior of an antenna immersed in a hot ionized plasma is treated, taking into account the antenna radiation pattern and impedance, the breakdown, and plasma noise. The hot gas effects on antenna window materials are studied, and these materials are evaluated in terms of known requirements. The shock layer attenuation for various types of spacecraft is calculated and presented in detail for various signal frequencies, antenna locations, and trajectory conditions. The results compare favorably with telemetry flight data.

Interference effects due to undisturbed environments include (1) free space path loss, (2) absorption and attenuation through the atmosphere, (3) angular deviation, (4) polarization rotation, (5) multipath effects, (6) effects of auroral, solar, and magnetic storms, (7) ambient radio noise due to either extraterrestrial or terrestrial sources, (8) the effects of environmental radiation, and (9) vehicle electrification. Although the effects are evaluated with regard to a boost-glide system, the results are presented in a form suitable for application to other vehicles. 390 pages.

(For related entries, see Ionospheric Research—Instrumentation and Data)

ROCKET EXHAUST EFFECTS

286. THERMAL IONIZATION OF ROCKET EXHAUST PLASMAS
Balwanz, W. W., Navid, B. N.
July 30, 1962
Naval Research Laboratory, Washington, D.C.
Interim Report, NRL-5808
N62-15,048

Thermal or equilibrium processes contribute to the total ionization of the exhaust plasmas attending a missile in flight. Such equilibrium ionization is the principal contributor to the total ionization in some cases of interest. Calculations of the equilibrium values of ionization for various rocket propellant components are presented in graphical form to make numerical values readily available and to simplify their utilization. 24 pages; 8 references.

287. THE PREDICTION OF ROCKET EXHAUST INTERFERENCE WITH RADIO SIGNALS
Balwanz, W. W., Weston, J. P.
American Rocket Society, New York, N.Y.
Paper 2591-62, presented at the ARS Conference on Ions in Flames and Rocket Exhausts, Palm Springs, Calif., October 10–12, 1962

Four major classifications of parameters which influence the propagation of command, guidance, and telemetry signals between a rocket and a ground station are discussed. The first classification deals with the exhaust plasma; the second, with interaction between plasma and electromagnetic waves; the third, with the antenna radiation pattern as influenced by plasma and electromagnetic waves; and the fourth, with applications to operational systems. Models for various phases of flight provide a method of predicting system performance. Data for the models are furnished by theory, actual flight records, and sea-level measurements on small-scale and operational motor exhausts, as well as by studies at simulated altitude and during simulated flight on the exhaust of scale-model motors and by experiments on laboratory flames. 38 pages; 30 references. (*IAA*, A63-11,697)

288. COMMENT ON PAPER BY HENRY G. BOOKER, "A LOCAL REDUCTION OF F-REGION IONIZATION DUE TO MISSILE TRANSIT"
Barnes, C., Jr.
***Journal of Geophysical Research*, v. 66, no. 8, p. 2538, August 1961**

A possible explanation for hole formation in the wake of a missile is advanced which differs from that previously sug-

gested by Booker (Entry 289). The exhaust gases, after emerging from the nozzle into the near vacuum of the F layer, will expand immediately by a factor of more than 10^7, until pressure equilibrium is reached. This expansion will actually cool the exhaust, and will also reduce its ion density. The expanded exhaust will form a hole through the layer in which the density will be less than one-tenth that of the surrounding atmosphere.

289. **A LOCAL REDUCTION OF F-REGION IONIZATION DUE TO MISSILE TRANSIT**
Booker, H. G.
***Journal of Geophysical Research*, v. 66, no. 4, pp. 1073–1079, April 1961**

An unusual echo received by local ionospheric sounders for a period of about one-half hour subsequent to the firing of *Vanguard II* is described and interpreted. A hole was punched through the F region by hot gases from the missile's exhaust, after which diffusion along the Earth's magnetic field realigned the hole along the lines of flux. The hole was then filled in by re-ionization under the influence of solar radiation. A possible relation to spread F and star scintillation is discussed. 7 references. (For comment by Barnes, see Entry 288.)

290. **THE ROLE OF ELECTRON ATTACHMENT IN A ROCKET EXHAUST**
Buss, J. H.
February 1, 1961
Space Technology Laboratories, Inc., Los Angeles, Calif.
STL/TM-61-0000-19011
AD-607,817
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Numerous investigations have shown that a large number of free electrons are present in a rocket exhaust. Because these electrons interfere with telemetry, they have been the subject of several studies undertaken to determine the source of the electrons and to inhibit their production. The puzzling feature of the problem has been the failure of thermodynamics to predict the measured concentration of free electrons in the exhaust. This anomaly can be partially explained by a theory which treats the impurities in the fuel (notably sodium and potassium), rather than the fuel itself, as the source of these electrons. Recently tested new fuels were found to have a concentration of free electrons which cannot be predicted by this simple impurity ionization theory. This fact has led to a reexamination of the impurity theory. Some calculations are given which show that there is a plausible explanation for the breakdown of the theory. 16 pages.

291. **NONEQUILIBRIUM IONIZATION IN FLAMES**
Calcote, H. F.
In "Ionization in High-Temperature Gases," pp. 107–144
Shuler, K. E., Fenn, J. B., Editors
Academic Press, Inc., New York, N.Y., and London, England, 1963
(See Entry 14; see also Paper 2583-62, presented at the ARS Conference on Ions in Flames and Rocket Exhaust, Palm Springs, Calif., October 10–12, 1962)

The work on ionization in flames is reviewed, with emphasis on the author's own contributions to the field. The analysis covers studies on the flame deflection in electric fields and Langmuir probe studies of ion concentrations and recombinations, ion rate of formation, and dissociative recombination. Information on mechanisms of ion formation and decay in flames is applied to problems of radar attenuation in rocket exhausts. A brief summary of current research is included.

292. **STUDIES ON IONIZATION PHENOMENA ASSOCIATED WITH SOLID PROPELLANT ROCKETS**
Capener, E. L., Chown, J., Nanevicz, J. E., Dickinson, L. A.
American Institute of Aeronautics and Astronautics, New York, N.Y.
Paper 65-182, presented at the AIAA Sixth Solid Propellant Rocket Conference, Washington, D.C., February 1–3, 1965

An investigation is made of the influence of propellant composition and motor design on the attenuation of microwaves and visible light by the plasma emitted by a rocket. The propellants studied include nonaluminized and aluminized composite propellants using both polyurethane- and polybutadiene-based binders. Ionization probes are used to measure the electron density within the combustion chamber (chamber pressure = 300 psi), while electron density downstream is determined using conventional two-frequency microwave diagnosis. It is found that equilibrium conditions are obtained up to an expansion ratio of ~70, while frozen flow occurs at higher ratios, confirming the theoretical predictions. Also in conformity with theoretical expectations, it is observed that initially ionization is below the theoretical equilibrium value and that it increases progressively with time. Electron leakage to ground from an insulated motor is also found to be progressive with time. Light transmission is found to be appreciably hindered by rocket exhaust. Transmission of light through conventional aluminized propellants at ambient pressure does not appear feasible, but a window at 4000 to 5000 Å may exist for nonaluminized propellants. 38 pages; 8 references.

293. **IONOSPHERIC MODIFICATION OF MISSILE EXHAUST**
Dalgarno, A.
December 1962
Geophysics Corporation of America, Bedford, Mass.
Scientific Report 10, GCA-TR-62-15-G, SD-112
N63-14,039

Changes in the high F region and the D, E, and F regions of the ionosphere, which may be created by the introduction of rocket-exhaust contamination, are evaluated as to the

kind of changes and the orders of magnitude. Secondary effects and collision frequency resulting from contamination are discussed. 16 pages.

294. **INFLUENCE OF IONS ON ROCKET COMBUSTION**
Dimmock, T. H.
1963
Thiokol Chemical Corporation, Reaction Motors Division, Denville, N.J.
Final Report for March 1, 1958–March 21, 1963, AFOSR-5493, AF 49(638)-305
AD-256,015, N64-16,341

The ionization profile along the axis of a seeded, Mach 3, high-altitude rocket exhaust has been mapped by microwave and probe techniques. The ionization density in the jet was as high as 10^{13} electrons/cm^3 and was found to vary half an order of magnitude between the expansion and shock regions. The relaxation in the jet was evaluated from the measured data. Since the ionization was found to follow the gas density profile, it was concluded that the relaxation time was at least as long as the transit time between the shock waves, and that the residence time in the shock zone was sufficient to sustain this ionization. Cases in which the residence time is less than the thermalizing time are also illustrated. The thermodynamic properties in the jets were measured by pressure and temperature probes and by line reversal spectroscopy. 63 pages.

295. **IONIZATION PROFILES IN LOW PRESSURE EXHAUSTS**
Dimmock, T. H., Kineyko, W. R.
In "Physico-Chemical Diagnostics of Plasma," pp. 423–441
Anderson, T. P., Springer, R. W., Warder, R. C., Jr., Editors
Northwestern University Press, Evanston, Ill., 1964
(Paper 63-388, presented at the AIAA Fifth Biennial Gas Dynamics Symposium on Physico-Chemical Diagnostics of Plasmas, Evanston, Ill., August 14–16, 1963; also available as Report 63-388, Thiokol Chemical Corporation, Reaction Motors Division, Denville, N.J., August 1963, AFOSR-J1089, AF 49(638)-305, AD-421, 129)

An experimental investigation of ionization relaxation processes in seeded, high-temperature, supersonic exhausts was conducted in order to consider the effects of ambient pressure and chemical composition on this relaxation, and to study some of the parameters which control the electromagnetic interaction process in the high-altitude exhaust. A Mach 3 rocket exhaust was studied at an equivalent altitude of 20–25 miles. The variations in the ionization density and dielectric properties of the jet were mapped, and the relaxation and attenuation properties of the exhaust were studied. It was found that the profile of ionization along the jet depends upon the conditions at the exit plane and upon the gas residence time in the shock diamond and the gas transit time between shocks. The data allow two possible relaxation mechanisms: (1) shock-induced ionization which decays slowly according to the jet time-scale, and (2) frozen ionization which is controlled only by chamber and nozzle conditions and follows the density profile identically. The ionization in the jet was seen to exceed the Saha value at all points in the jet of the premixed stoichiometric rocket. This is evidence of an electron density greater than the equilibrium value. A spectrographic analysis of the jet shows that the energy distribution in the excited states is also modified; excited lines are obtained which are not evident in the mantle of an atmospheric propane/air flame. Such nonequilibrium is attributed largely to an after-reaction of fuel-rich jets with the surrounding environment, since it is most prominent with shrouded vortex jets. 17 pages. (*IAA*, A63-21,646)

296. **RESEARCH IN THE CHEMI-IONIZATION PROCESSES IN THE INTERACTION OF MISSILE EXHAUST PRODUCTS WITH ATMOSPHERIC CONSTITUENTS AND DETECTABILITY OF SUCH PROCESSES BY RADIO FREQUENCY SOUNDING**
Fontijn, A.
July 1964
AeroChem Research Laboratories, Inc., Princeton, N.J.
Final Report, Report TP 98, AF 19(628)-3302
AD-443,559, N64-30,487

The upper atmospheric modification of rocket exhaust–radar interaction is briefly discussed. A probable cause of this phenomenon is the production of free electrons due to chemi-ionization in oxygen atom–hydrocarbon reactions. Reasons are given explaining why chemi-ionization may cause a more intense ionization trail in rocket exhaust gases than that caused by upper atmospheric acetylene releases. This report describes the results of a laboratory study program undertaken to explain the mechanism of upper atmospheric chemi-ionization and to obtain quantitative information on chemi-ion production. Rocket exhaust gas components such as CO_2 were shown to quench CH. Hence, if present in suitably high concentrations, these components can decrease the rate of production of free electron radar targets. Conclusions are based on results obtained from two experimental facilities. Individual ion species were identified by a mass spectrometer in an atomic diffusion flame system. The reaction temperature in these investigations varied from 300–700°K and the pressure range was from 1–10 torrs. 32 pages.

297. **CHARGE BUILDUP ON SOLID ROCKETS AS A FLAME BURST MECHANISM**
Fristrom, R. M., Oyhus, F. A., Albrecht, G. H.
***ARS Journal*, v. 32, no. 11, pp. 1729–1730, November 1962**

A solid propellant rocket may act as an electric generator similar to a Van de Graaff or Kelvin electrostatic machine. The mechanism for charge buildup would be the ejection of charged carbon and other particles in the rocket exhaust. Calculations indicate that such a charge buildup might approach a potential of 10^6 V if allowed to proceed without interruption. Sparks from such a source would be capable of re-igniting fuel-rich propellant exhaust gases (during a flight) in regions where sufficient air had mixed to render the gases

combustible. The mechanism could explain the repeated occurrence of flame bursts in rocket exhaust gases during certain missile flights. To test this hypothesis, the charge accumulating on a rocket motor case was measured during a static firing; a charge of 133.2×10^{-6} C was measured on a recorder attached to the rocket case across a 10-Ω resistor. This would correspond to voltage buildup of approximately 5×10^{5} V on an isolated missile of approximately 250×10^{-12} F capacity. The voltage was of the order expected. In missile test flights, the installation of static charge dissipating wire brushes in the missile appeared to reduce the frequency and intensity of flame bursts but did not completely eliminate them.

298. ANALYSIS OF THE EFFECTS OF ROCKET EXHAUST FLUCTUATIONS ON FSK TELEMETRY
Geiger, A. A.
American Institute of Aeronautics and Astronautics, New York, N.Y.
Paper 65-184, presented at the AIAA Sixth Solid Propellant Rocket Conference, Washington, D.C., February 1–3, 1965

The spectral analysis of PCM/FM missile flight-test telemetry data is presented to illustrate the effect of the rocket exhaust flame on the PCM data. The spectral history of PCM data received at different aspect angles shows that the flame creates strong, band-limited noise in the FM demodulated PCM spectrum. This effect is caused by turbulence and density fluctuations in the rocket exhaust flame, which scatter the transmitted electromagnetic wave. The theory of scattering by a turbulent medium is applied to the line-of-sight forward scattering of radio waves by the turbulence in the rocket exhaust plasma. The mean square amplitude and phase fluctuation of the received signal is calculated and shown to be related to the plasma turbulence density autocorrelation function, the plasma electron density, electron collision frequency, and the RF wave frequency. The received signal contains amplitude and phase modulation due to the scattered signal and the additive receiver and antenna noise. The optimum receiver for the received PCM/FM signal with random amplitude and phase, but with assumed known distributions, is shown to be a two-filter noncoherent receiver with envelope detectors. The error probability of the received PCM signal with fluctuation noise at the output of this receiver is given. 25 pages; 13 references.

299. PREDICTING RADAR ATTENUATION
Holland, J. M., Jessup, H. A.
American Institute of Aeronautics and Astronautics, New York, N.Y.
Paper 65-180, presented at the AIAA Sixth Solid Propellant Rocket Conference, Washington, D.C., February 1–3, 1965

The exhaust gas from solid propellant rocket motors attenuates the transmitted signal, affecting communication with the missile; it also reflects the transmitted signal, tending to increase the missile's apparent size when observed by enemy radars. The basic problems of the prediction and control of these effects (through knowledge of propellant chemistry and motor design parameters) are discussed, and experimental verification of the basic theoretical model for the attenuation phenomena is presented.

The solution of Maxwell's equation in ionized media, including effects of attenuation, refraction, and reflection from the boundary of the ionized region (cross section), is discussed in relation to experimental verification of the model from test firings of a representative series of composite high-performance propellants. The studies resulted in a workable model of the interaction of the electromagnetic wave with the exhaust plume, with possible implications regarding the future design of motors for air-launched missiles. It is concluded that the interactions of electromagnetic radiation with solid rocket plumes are of some significance in the communication with, and detection of, any missile. It is also concluded that these interactions are predictable and, to some extent, controllable. 7 references; 29 pages.

300. A TECHNIQUE FOR THE EXPERIMENTAL DETERMINATION OF THE ELECTRICAL CONDUCTIVITY OF PLASMAS
Hollister, D. D.
***AIAA Journal*, v. 2, no. 9, pp. 1568–1571, September 1964**

A technique is presented by which the electrical conductivity of a plasma can be measured by observing a diminution of radio frequency magnetic flux through the plasma. This technique has found application in the measurement of conductivity of stationary plasmas, flowing steady-state plasmas, and plasmas produced in the electromagnetic shock tube. The rudiments of the theory of operation of a device using this technique are presented, and a measurement of plasma conductivity is described for the case of the hot exhaust gas of a deflagrating sample of solid rocket fuel expanding in a vacuum.

301. LOCAL IONOSPHERIC DISTURBANCE CREATED BY A BURNING ROCKET
Jackson, J. E., Whale, H. A., Bauer, S. J.
***Journal of Geophysical Research*, v. 67, no. 5, pp. 2059–2061, May 1962**

A solid-fuel rocket was launched from Wallops Island, Virginia, on October 19, 1961, to collect data on the ionospheric electron density from Faraday rotation measurements. Ionosonde records were obtained from a local station. An interpretation of the influence of a burning rocket on the ionosphere was obtained by comparing the results obtained from the ionosonde, the Faraday rotation method, and the high altitude profile. A figure shows the electron density derived from Faraday rotation and also the initial undisturbed electron density profiles obtained by reduction of ionograms. Third-stage ignition occurred at an altitude of 120 km, and resulted in distorted Faraday cycles, which are interpreted as a large increase in density. During the rest of

the third-stage burning period, at an altitude of 120 to 220 km, the Faraday data show reduction in electron densities. During the fourth-stage burning, the electron density increased during the ignition, but there was reduction later. The analysis shows that the rocket-induced disturbance was local initially, extending only a few kilometers horizontally. 3 references.

302. I — THE ELECTRICAL CONDUCTIVITY OF WEAKLY IONIZED GASES. II — ESTIMATES OF INTERFERENCE DUE TO VERNIER EXHAUST TO BE ENCOUNTERED BY RADAR AND ALTIMETER SYSTEMS DURING A LUNAR LANDING
Molmud, P.
American Rocket Society, New York, N.Y.
Paper 2586-62, presented at the ARS Conference on Ions in Flames and Rocket Exhausts, Palm Springs, Calif., October 10–12, 1962
(See also *AIAA Journal*, v. 1, pp. 2816–2819, December 1963)

Some elementary solutions of the wave equation are presented for electromagnetic waves in an ionized gas, which demonstrate the importance of conductivity in controlling absorption. Improper computation of conductivity by conventional, over-simplified theory may lead to order-of-magnitude errors in estimating absorption. The conventional theory for conductivity is reviewed, and the correct theory is discussed. Examples cited show that although the conventional theory may be employed in certain cases, in others the exact theory must be used. The expression for the conductivity of a weakly ionized mixture of gases is formulated and analyzed in the low-, intermediate-, and high-pressure regions. The conductivity of the mixture is shown to be reducible to the sum of conductivities of gases of constant cross section but of complex wave frequencies. On the basis of the results obtained, the conventional method used for analysis of certain diagnostic measurements on rocket exhausts is criticized. In addition, the effects of vernier-rocket exhaust on the performance of the Doppler and altimeter systems of the lunar landing vehicle are considered. Gross exaggeration in estimating the ionization of the vernier exhaust leads to exceedingly small—in fact, almost nondetectable—effects on the Doppler and radar systems. 37 pages; 35 references.

303. MODIFICATION OF THE EARTH'S UPPER ATMOSPHERE BY MISSILES
Pressman, J., Tank, W., Connell, J., Brown, H. K., Reidy, W., Dalgarno, A., Millman, S., Warneck, P.
December 1962
Geophysics Corporation of America, Bedford, Mass.
Final Report, GCA-TR-62-18-G, SD-112
AD-296,488, N63-12,770

A study was made of possible changes in the upper atmosphere that might occur on a long-term basis as a result of large-scale deposition of exhaust material. This study was reported in 11 scientific papers, which are reviewed here. The data compiled indicate the strong probability that an accelerated rocket program may cause future local or widespread modifications of the upper atmosphere. These modifications include changes in composition, temperature structure, light emission, electron density, and airglow. A theoretical program to evaluate this problem is presented. 64 pages; 7 references.

304. EFFECT OF ION ENGINE EXHAUST ON THE PROPAGATION OF ELECTROMAGNETIC WAVES
Rashad, A. R. M.
American Institute of Aeronautics and Astronautics, New York, N.Y.
Paper 65-186, presented at the AIAA Sixth Solid Propellant Rocket Conference, Washington, D.C., February 1–3, 1965

A theory is presented concerning the effect of the ion engine exhaust on the propagation, interaction, and scattering of incident electromagnetic waves originating from a nearby dipole antenna. The exhaust is represented as a cylindrical beam. Two cases of interest are studied: the case of an exhaust beam in an axial DC magnetic field (B_z) for $B_z = 0$, and that of a finite value for B_z. The electromagnetic field equations are obtained for TM modes in the first case, and for TE modes in the second case. The analysis also considers the changes in the beam temperature due to its interaction with the surrounding medium. This temperature change is found to be anisotropic in the case $B_z \neq 0$. The fluctuations in the coefficients of a tensor dielectric constant due to the temperature changes are studied in detail, as well as the effect of such fluctuations on the electromagnetic field expressions. 11 pages; 30 references.

305. IONIZATION IN ROCKET EXHAUST PLUMES
Rosner, D. E.
April 1964
Aerochem Research Laboratories, Inc., Princeton, N.J.
AEROCHEM-TP-85
AD-447,304, N65-11,429

Aerodynamic, thermodynamic, and chemical kinetic factors governing electron concentrations in the exhaust plumes of rocket motors are discussed. The quantitative prediction of radar attenuation trends with changes in trajectory and/or propulsion system characteristics is emphasized. 80 pages.

306. IONIZATION IN AFTERBURNING ROCKET EXHAUSTS
Smith, F. T.
August 1961
Stanford Research Institute, Menlo Park, Calif.
Quarterly Report 2 for May 6–August 6, 1961, BSD-TR-61-26, SRI-PU-3544
AD-603,297
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Existing knowledge of jet flow and mixing (including turbulence) in the continuum regime of fluid dynamics is surveyed in relation to the afterburning rocket exhaust stream. Recent experimental information on ionization in flames is outlined, and consequences for ionization in rocket exhausts are suggested. 21 pages.

307. IONIZATION IN AFTERBURNING ROCKET EXHAUSTS

Smith, F. T., Gatz, C. R.
November 8, 1961
Stanford Research Institute, Menlo Park, Calif.
Final Report, BSD-TR-61-76, AF 04(647)-751, SRI-PU-3544
AD-445,837

When a rocket exhaust encounters the atmospheric environment, afterburning and other interactions may produce ionization. Phenomena controlling these interactions are surveyed, and areas needing further research are indicated. The most important known ionization reactions in afterburning involve atomic oxygen; these reactions are important at altitudes up to and above 100 km. With hydrocarbons, the best known ionizing reaction is $CH + O \rightarrow CHO^+ + e$. Alkali metals (at a few parts per million) will also be ionized rapidly by transfer of energy from excited combustion intermediates. Both mechanisms may produce high electron densities. For reliable prediction, further research on reaction rate constants and on the mixing process is required. Available techniques for measuring ionization in combustion systems are surveyed. Criteria are suggested for evaluating the importance of impact ionization in molecular encounters between a fast-moving exhaust and the atmosphere. 79 pages.

308. CHEMISTRY OF IONIZATION IN ROCKET EXHAUSTS

Smith, F. T., Gatz, C. R.
In "Ionization in High-Temperature Gases," pp. 301–316
Shuler, K. E., Fenn, J. B., Editors
Academic Press, Inc., New York, N.Y., 1963
(See Entry 14; see also Paper 2581-62, presented at the ARS Conference on Ions in Flames and Rocket Exhausts, Palm Springs, Calif., October 10–12, 1962)

Theoretical and experimental studies contributing to the understanding of ionization in rocket exhausts are reviewed. Sources of ionization which are discussed include thermal ionization of atoms and solid particles and ion-producing interactions between the exhaust gases and the ambient atmosphere. Nonequilibrium effects in the rapidly expanding exhaust gases are also considered. 23 references.

309. PREDICTION OF MICROWAVE ATTENUATION CHARACTERISTICS OF ROCKET EXHAUSTS

Smoot, L. D., Underwood, D. L., Schroeder, R. G.
American Institute of Aeronautics and Astronautics, New York, N.Y.
Paper 65-181, presented at the AIAA Sixth Solid Propellant Rocket Conference, Washington, D.C., February 1–3, 1965

The extent to which a radar signal is attenuated (by free electrons) when passing through a hot rocket exhaust is investigated. A technique for estimating microwave attenuation characteristics of rocket motors is described and is applied to typical solid propellant systems. The microwaves studied are confined to radar frequency bands. The prediction of microwave attenuation is based on the knowledge of electron density, collision frequency, and microwave frequency. The problem of predicting electron density is divided into several parts, each treated individually, and then combined to provide the final solution. When applied to the prediction of electron density, the technique involves the treatment of the effects of thermal ionization of alkali metals, detachment and recombination processes during nozzle expansion, and – in the exhaust plume – the influence of solid particles, inviscid plume expansion, plume-air mixing, afterburning, and missile velocity and altitude. The accurate description of nozzle recombination processes is the most sensitive factor to be assessed. The collision frequency is calculated using existing techniques and data. The effects of propellant composition, motor configuration, and missile trajectory are examined, and the predicted and measured attenuation values for static sea-level motor firings are compared. The principal causes of radar attenuation are seen to be the thermal ionization of alkali metals together with nonequilibrium processes during afterburning. 60 pages; 42 references.

310. EFFECT OF SOLID PARTICLES ON ELECTROMAGNETIC PROPERTIES OF ROCKET EXHAUSTS

Sodha, M. S., Palumbo, C. J., Daley, J. T.
***British Journal of Applied Physics*, v. 14, no. 12, pp. 916–919, December 1963**

A general analysis is presented of the electromagnetics of rocket exhaust plasmas, as well as the physics of a technique for reduction of electron density by the addition of solid particles to the exhaust. The role of solid particles in modifying the electromagnetic properties of the exhaust is analyzed in considerable detail, and representative numerical results based on an approximate model are presented. It is shown that the presence of solid particles of low work function material can account for the very high electron densities in rocket exhausts and that the electron density can be considerably reduced by the addition of solid particles of a material having a high work function. 11 references. (*IAA*, A64-12,606)

311. THE ROLE OF ALUMINUM AND ITS OXIDES AS SOURCES OR MODERATORS OF ELECTRONS IN SOLID PROPELLANT ROCKET EXHAUSTS

Spokes, G. N.
December 31, 1963

Stanford Research Institute, Menlo Park, Calif.
Quarterly Status Report 6 for October 1–December 3, 1963,
SRI-PAU-4134 (Part 2), AF 04(694)-128
AD-434,699
(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

Evidence is presented for the occurrence of reactions which liberate ions from surfaces. Ions thus ejected from a wall in an atmosphere of active nitrogen include NO^+, N^+, N_2^+, N_3^+, N_4^+. Surface chemionization reactions of this kind could be important in the production of excess ionization in rocket exhausts. A model is given for the propagation of electromagnetic waves through gas-particle plasmas. A refined approach was adopted for theoretical study of electron distributions about particles emitting thermionic electrons. Some preliminary results are given. 50 pages.

312. THE ROLE OF ALUMINUM AND ITS OXIDES AS SOURCES OR MODERATORS OF ELECTRONS IN SOLID PROPELLANT ROCKET EXHAUSTS

Spokes, G. N.
March 31, 1964
Stanford Research Institute, Menlo Park, Calif.
Quarterly Status Report 7 for January 1–March 31, 1964,
SRI-PAU-4134, AF 04(694)-128, AF 19(628)-1651
AD-602,218
(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

Preliminary machine computations of electron distributions about a thermionically emitting particle are presented. Work on ion sampling from chemical plasmas has shown that the process involves competition between hydrodynamic flow and the local electric fields at a sampling aperture. Further results are presented for flames and for nitrogen afterglows. 74 pages.

313. A FARADAY ROTATION MEASUREMENT ON THE IONOSPHERIC PERTURBATION PRODUCED BY A BURNING ROCKET

Stone, M. L., Bird, L. E., Balser, M.
Journal of Geophysical Research, v. 69, no. 5,
pp. 971–978, March 1, 1964

The angle of rotation of linearly polarized waves radiated from missiles launched at Cape Kennedy was measured at a site in Yankeetown, Florida. The site was located so that the propagation path passed along the disturbed region in the missile plume. The electron content of the path was computed from the measured Faraday rotation and was compared with that computed from ionograms for the undisturbed ionosphere. This process was carried out for five *Atlas* flights. Results consistently indicated a deficiency in the electron density along the path in the region, generally of about an order of magnitude. 8 references.

314. TURBULENT DIFFUSION OF A REACTING WAKE

Webb, W. H., Hromas, L. A.
American Institute of Aeronautics and Astronautics,
New York, N.Y.
Paper 64-42, presented at the AIAA Aerospace Science
Meeting, New York, N.Y., January 20–22, 1964

In order to identify the important features of nonequilibrium processes in the hypersonic turbulent wake, an integral solution for the diffusion of species in the wake has been developed. The technique applied is essentially an extension of the method proposed by Lees and Hromas for the equilibrium wake. Each species is represented by two parameters: the axis concentration, and a characteristic Howarth-Dorodnitsyn scale width. To obtain the variation of these quantities with downstream distance, the species diffusion equations (including chemical kinetic terms) are integrated across the wake and, in addition, are satisfied along the wake axis. In the chemical kinetic model studied, particular attention is paid to the processes of far downstream electron decay, and appropriate oxygen attachment, charge neutralization, and charge exchange reactions are considered. Some new approximate but explicit solutions for species diffusion in the wake are obtained. Scaling laws exhibited by these solutions are discussed. Detailed numerical calculations are also given for several slender and blunt bodies. The effect of ionized or dissociated species in the inviscid stream on the wake kinetics of blunt bodies is included in the calculations. The presence in the wake of foreign (ablation) species, either as ionizing species or as species with large electron affinities, is considered, and the possible effect of these species on experimental data is evaluated. 13 pages; 19 references.

315. MICROWAVE ATTENUATION CHARACTERISTICS OF SOLID PROPELLANT ROCKET EXHAUST PRODUCTS

Wood, W. A., DeMore, J. E.
American Institute of Aeronautics and Astronautics,
New York, N.Y.
Paper 65-183, presented at the AIAA Sixth Solid Propellant
Rocket Conference, Washington, D.C., February 1–3, 1965

Experimental radar-attenuation measurements were made on the exhaust products from both PBAA and plastisol-nitrocellulose-type composite propellants. Focused-beam measurements were made both near (1 to 2 nozzle diameters) and far downstream (20 to 30 nozzle diameters) from the nozzle exit planes of motors loaded with these propellants. Multiple frequency measurements that permit calculation of free-electron concentrations and collision frequencies were also made. In addition, a traversing mechanism was used which allows measurement of attenuation as a function of distance from the nozzle. Perhaps the most important phase of this work is the determination of nozzle exit attenuation independent of afterburning effects. The secondary combustion reactions between CO and H_2 in the exhaust gases and entrained oxygen are delayed by placing a nitrogen sheath around the exhaust plume. 22 pages.

ELECTRICAL HAZARDS

316. TECHNIQUES AND DEVICES FOR THE PROTECTION OF ELECTRICAL AND ELECTRONIC SYSTEMS FROM LIGHTNING TRANSIENTS
Buies, R. E., Fisher, F. A.
March 1964
Air Force Systems Command, Research and Technology Division, Air Force Weapons Laboratory, Kirtland AFB, N. Mex.
WL-TDR-64-26, AF 29(601)-5402
AD-437,816
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report presents a survey of techniques and devices for the protection of missile systems from the effects of lightning transients. The susceptibility of a missile site to lightning strokes is considered, and the areas within the system where direct strokes and/or induced effects may cause failures in equipment are discussed. The primary concern is with semiconductor devices and associated circuits, but the problems of power distribution are included for a complete analysis. It is suggested that analysis of storm damage reports might yield criteria which could serve as a basis for device testing and the development of new applications for devices, with complete protection as an objective. 43 pages; 11 references.

317. BALL LIGHTNING AS A PLASMA PHENOMENON
Carpenter, D. G.
***AIAA Student Journal*, v. 1, pp. 25–27, April 1963**

Ball lightning as a plasma phenomenon was investigated on the assumption that air is nitrogen gas. The study was based on Maxwell's equations, continuity of charge, conservation of relative charge, and Boltzmann's two fluid transport equations. The initial condition is postulated that a rod of electric current exists in the center of a swirl of turbulent air. There are no sources of electric potential. Therefore, the flow of the charged particles is linear along the axis of the rod and rotational about it. It is concluded that: (1) ball lightning is composed of a magneto-vortex ring surrounded by a radiation field composed primarily of β rays (this radiation field is the region observed during occurrence of this phenomenon); (2) all ball lightning characteristics can be explained by this model of core ring and a unique enveloping radiation field; (3) the use of ball lightning as a weapon would be greatly limited by inherent instabilities; and (4) with the possible exceptions of lightning and aurora borealis, ball lightning is probably the most concentrated form of naturally occurring radiation which exists within a planetary atmosphere. 10 references. (*IAA*, A63-1793)

318. RADIO-FREQUENCY LEAKAGE INTO MISSILES
Duncan, R. H., Harrison, C. W., Jr.
***IEEE Transactions on Antennas and Propagation*, v. AP-11, no. 6, pp. 652–657, November 1963**

Missile functions are often initiated by the detonation upon command, from either a wire or radio circuit, of sensitive electroexplosive devices. The possibility exists of inadvertent detonation of these devices caused by the leakage of RF energy into the missile from high-power radar or communications facilities. This paper treats the idealized problem of RF energy leakage through a slot in an infinite cylinder as a perturbation on the scattering problem for the same object with no slot. It is shown that interior response depends on three factors: the exterior skin current density from the scattering problem; the transmitting admittance of the slot; and an eigenfunction expansion of the interior field when unit voltage is impressed across the slot. It is proposed that the form of this solution may be applicable and conceptually useful in treating other problems either theoretically or experimentally.

319. LIGHTNING PHENOMENA INVESTIGATION
Klapper, J. J., Rohlfs, A. F., Ludewig, F. A., Fisher, F. A.
March 1964
General Electric Company, Syracuse, N.Y.
Final Report, WL-TDR-64-21, AF 29(601)-5402
AD-440,274, N64-26,271

The lightning phenomena investigation program was designed to determine induced voltage and currents in certain selected missile-site cables as a result of a lightning discharge on or near the instrumented SM-78 site. The characteristics of the lightning discharge which produced the induced signals were measured; in addition, background meteorological measurements were made to facilitate the analysis of the storm event and the resulting data. Limited oscillographic surge data are presented on the only three storms that occurred in the vicinity of the instrumented site. Data obtained during the six-month continuous monitoring period are also presented for the meteorological parameters, point discharge current, and the atmospheric electric gradient. 84 pages.

320. NEW WEAPON "X" — BALL SHAPED THUNDERS (GLOBULAR FIREBALLS)
Konieczny, J. R.
***Wojskowy Przeglad Lotniczy*, no. 2, pp. 72–75, 1963**
(Translation available as FTD-TT-63-806/1+2, Air Force Systems Command, Foreign Technology Division, Wright-Patterson AFB, Ohio, October 3, 1963, AD-423,834, N64-12,620)

Recent investigations in the field of plasma physics indicate that the time is approaching when it will be possible to produce artificial spherical "thunders" and to use them as defensive and offensive weapons. These "thunders" (called globular fireballs) are thought to originate in the atmosphere after strong electric discharges. Tests are being conducted in an

effort to produce these fireballs and to utilize them as an antimissile defense.

321. LOW PRESSURE ELECTRICAL DISCHARGE STUDIES
Krebs, W. H., Reed, A. C.
December 17, 1959
Space Technology Laboratories, Inc., Los Angeles, Calif.
STL/TR-59-0000-09931, AF 04(647)-309
AD-605,984
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report concerns electrical breakdown of air at low pressures or high altitudes (70,000 to 250,000 ft) due to secondary emission. Information pertinent to the problem of low frequency (0 to 1000 cps) sparking was compiled through a literature survey, and a bibliography was compiled concerning electrical breakdown at both low and high frequencies. A test program yielded the following results: (1) No statistically significant deviation from Paschen's law was detected. (2) The addition of water vapor to the air constituting the test environment caused a significant lowering of the minimum sparking voltage. Recommendations are made relative to test programs for missile electrical components employing voltages higher than 200 V. 78 pages.

322. MEASUREMENT OF ELECTROMAGNETIC RADIATION HAZARD TO WEAPON FUSING CIRCUITS
Lemco, I., Buckland, R. T., Lloyd, W.
Institution of Electrical Engineers, Proceeding of the, v. 110, no. 9, pp. 1701–1705, September 1963

The hazard is discussed which is caused by induced RF currents in weapon circuits that may occur when the weapon to be launched is situated near the transmitting antenna. Two methods of measuring the hazard are described. (*EI*, 1963)

323. NATURAL INTERFERENCE CONTROL TECHNIQUES. PART I. LIGHTNING PROTECTION OF AEROSPACE ROCKET VEHICLE LAUNCHING SYSTEMS
Newman, M. M., Stahmann, J. R.
April 1963
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 407, Quarterly Report, ASD-TDR-63-370, AF 33(657)-10904
AD-409,692
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Lightning protection can be provided either by diverting a direct strike to some distance away, or by shielding the sensitive equipment to withstand a direct stroke of lightning. Lightning strokes to diversionary rods or towers still leave intense transient magnetic fields to contend with, as well as possible large ground currents in control cables. Shielding of all conductors and associated "black boxes" of equipment is theoretically possible if resistance of cable sheaths and connector joints can be kept sufficiently low. The two approaches can be usefully combined to achieve maximum protection. A possible combination approach in a ground installation is to "invite" nearby strokes to a central high point over a "bird cage" wire assembly surrounding the launching system, thus guiding the lightning current symmetrically, thereby cancelling the magnetic fields inside. This offers a practical method of approaching the effectiveness of a complete "Faraday cage" for most cases of lightning-to-ground strokes which are nearly vertical. Slanting strokes or nearby strokes and intense electromagnetic waves would require additional horizontal interconnecting wires. Illustrative test demonstrations indicate that additional lightning protection may be necessary, even for buried cables, in cases of dry, sandy terrain. 17 pages.

324. NATURAL INTERFERENCE CONTROL TECHNIQUES. PART II. LIGHTNING SIMULATORS FOR AEROSPACE VEHICLE STUDIES AND ELECTROMAGNETIC EFFECTS
Newman, M. M., Robb, J. D., Stahmann, J. R., Gensch, R. H.
October 1963
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 414, ASD-TDR-63-370 (Part 2), AF 33(657)-10904
AD-425,010
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A mobile lightning simulator of modular construction was designed for full-scale tests of aircraft and aerospace vehicle launching sites. The modules may be used parallel or in series to simulate peak currents up to the order of 200 kA which are required to simulate the more severe lightning damage to aerospace vehicles. Voltages are of the order of 10 MV and will also be available to obtain a better scale factor in lightning studies for determining regions of highest stroke contact probability and for developing diverter techniques. A working model of the simulator has been constructed which demonstrates the principles of operation as well as the feasibility and usefulness of such a unit. A full-size wooden mockup of a section of one of the modules was also constructed to aid in design work. This mockup will be used to determine hardware configurations, voltage clearances, and similar details. 25 pages.

325. REDS MAY USE LIGHTNING AS A WEAPON
Ritchie, D. J.
Missiles and Rockets, v. 5, no. 35, pp. 13–14, August 24, 1959

Soviet high-voltage experiments on artificial lightning are reported. G. I. Babat, head of the Soviet Institute of Energetics, is quoted as hinting at possible military applications.

Babat is said to propose generation of balls of lightning above cities by means of two parabolic antennas. Such a flame ball could be moved by directing the ground antennas, and could be used against aircraft or missiles. (*MGA*, 1963, 14.1-443)

326. EFFECTS OF VEHICLE ELECTRIFICATION ON APOLLO ELECTRO-EXPLOSIVE DEVICES
Vance, E. F., Seely, L. B., Nanevicz, J. E.
December 1964
Stanford Research Institute, Menlo Park, Calif.
Final Report, SRI Project 5101

In the course of the lunar mission, the *Apollo* vehicle will be exposed to electrification processes that include (1) rocket-engine charging, (2) frictional charging from ice crystals in the lower atmosphere and dust in the upper atmosphere and in space, (3) photoelectric charging in space, and (4) plasma processes in the Earth's atmosphere and in space. The effects of vehicle charging on the *Apollo* pyrotechnic system are analyzed, and potentially dangerous situations are pointed out.

327. STUDY ON MINIMIZATION OF FIRE AND EXPLOSION HAZARDS IN ADVANCED FLIGHT VEHICLES
October 1961
Lockheed Aircraft Corporation, Burbank, Calif.
Report for June 1960–August 1961 on Design Criteria for Fire and Explosion Hazards in Advanced Flight Vehicles, Report 15156, ASD-TR-61-288, AF 33(616)-7387
AD-269.559
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Although this report is concerned primarily with nonelectrical hazards, possible causes of fire and explosion in advanced flight vehicles were studied, covering vehicles ranging from Mach 3 airplanes to long-time, long-range space vehicles. Static discharges from the skin of a vehicle are considered as ignition sources, and various static electricity sources are discussed. Methods are outlined for the discharge of static electricity on missiles and their stands, for safe landing of missiles, and for stationary lightning protection of missiles. 186 pages.

MAGNETIC EFFECTS

328. CHARGE AND MAGNETIC FIELD INTERACTION WITH SATELLITES
Beard, D. B., Johnson, F. S.
***Journal of Geophysical Research*, v. 65, no. 1, pp. 1–8, January 1960**

An investigation has been made of the interaction of a satellite with the ionized medium through which it is moving and with the magnetic field of the Earth. As a result of the differing incident velocities of ions and electrons, a negative potential will be induced on the satellite; however, it is smaller than expected. Satellite motion across the magnetic lines of the Earth will induce a voltage on the satellite of as much as 0.2 V/m of satellite length perpendicular to the magnetic field, and this may affect the interpretation of measurements of satellite potential. The magnetic drag resulting from the induced currents is proportional to the cube of the satellite dimensions and may exceed the mass drag for satellites larger than 50 m in diameter; this can occur only above 1200-km altitude, where the charge density exceeds the neutral density. Thus the magnetically induced current is an insignificant cause of drag. Although some useful power can be extracted from the induced current, it is not a very promising source of auxiliary power for presently conceived vehicles.

329. COMMENT ON WYATT'S ANALYSIS OF CHARGE DRAG
Beard, D. B., Johnson, F. S.
***Journal of Geophysical Research*, v. 65, no. 10, pp. 3491–3492, October 1960**

The authors' analysis (preceding abstract) of the charge drag on a satellite is defended against Wyatt's criticisms (Entry 377). Wyatt calculated the charge drag as the small difference between two large and approximate quantities and found it to be independent of the ionospheric ion density and inversely dependent on the area of the satellite surface. The authors find these features physically unacceptable. (*PA*, 1961, #18,223)

330. INDUCTION DRAG ON SATELLITES
Beard, D. B.
In "Aerodynamics of the Upper Atmosphere," pp. 17-1–17-10
Masson, D. J., Compiler
The Rand Corporation, Santa Monica, Calif., 1959, 1962 (available as R-339)
(Paper presented at the Symposium on Aerodynamics of the Upper Atmosphere, Santa Monica, Calif., June 8–10, 1959—Entry 9)

The charge interaction of positive ions and negative electrons with the satellite surface is analyzed under various conditions, on the basis of some pertinent velocities and distances, such as cyclotron period and radius for electrons, cyclotron radius for ions, Debye shielding distance, and collision frequency for electrons. The electric field component perpendicular to the magnetic field is of interest since plasma conductivity is essentially governed by the magnetic field. The satellite motion and the induced voltage are examined to determine the integral of the current. Examination of the resulting satellite drag indicates a torque which would cause tumbling unless the neutralized particle was reflected iso-

tropically from a sphere, and the power loss is proportional to the curve of the satellite dimension while the drag is proportional to the square. If the neutral density is less than the ion density and the satellite is larger than 50 m, the inductive drag will exceed the ordinary neutral or ion drag. The usefulness of electrical power generation is indicated by the result that a satellite which is 100 m in diameter could generate ~100 W of electrical power if its skin were composed of conducting strips separated by insulating layers. (*MGA*, 1960, 11.12-533)

331. THE CLASSIFICATION OF ARTIFICIAL EARTH SATELLITE PATHS ABOUT THE MASS CENTER

Beletskii, V. V.
***Iskusstvennye Sputniki Zemli*, no. 6, pp. 11–32, 1961**
(Translated from the Russian in *Planetary and Space Science*, v. 9, pp. 47–65, 1962; see also Translation 966, Royal Aircraft Establishment, Farnborough, Great Britain, September 1961)

The method employed for classifying secular perturbations in the motion of a satellite around the mass center affords a qualitative and quantitative investigation of the path and a classification of the paths as a function of the various initial data and conditions of motion. Investigations of the rotation of the third Soviet satellite have indicated that electromagnetic effects can also play a substantial part if power systems such as solar batteries are carried on the satellite.

332. SOME PROBLEMS OF MOTION OF ARTIFICIAL SATELLITES ABOUT THE CENTER OF MASS

Beletskii, V. V.
In "Dynamics of Satellites," pp. 158–167
Roy, M., Editor
Academic Press, Inc., New York, N.Y., 1963
(Paper presented at the International Union of Theoretical and Applied Mechanics Symposium, Paris, France, May 28–30, 1962)

The problems of satellite motion about the center of mass are discussed. The satellite motion with respect to the center of mass is divided into two basic types, depending on whether the kinetic energy of the satellite rotation is small or large as compared to the action of outer forces. Some results are given of an investigation of satellite motion about the center of mass, taking into account only the main disturbing factors. It was found that the motion of *Sputnik III* about the center of mass represents regular precession with slowly changing parameters, and that the revealed secular motion of the kinetic moment vector agrees well with the theory. It was also revealed that dissipative electromagnetic effects causing the drag of *Sputnik III* rotation played a significant role. 12 references. (*IAA*, A64-12,663)

333. ELECTROMAGNETIC DOCKING OPERATIONS IN SPACE

Benedikt, E. T.
In "Advances of the Astronautical Sciences—Volume 9," pp. 309–409
Burgess, E., Editor
American Astronautical Society, New York, N.Y., 1963
(Paper presented at the AAS Fourth Western Regional Meeting, San Francisco, Calif., August 1–3, 1961)

The possibility is discussed of using electrodynamic interactions to effect the terminal phases of an orbital rendezvous operation without establishing a material connection between the two vehicles.

The relative motion of two neighboring satellites can be regarded as being governed by a fictitious gravitational field which is a linear, anisotropic function of their relative position. The resulting acceleration is of the order of magnitude $(2\pi/T_*)^2\, r$, where T_* is the local value of the circular satellite period and r is the separation of the vehicles. The smallness of the quantity suggests that the above interactions can be overcome (whenever r is not too great) by the electrodynamic interactions which are obtainable by circulating currents of adequate intensity in the vehicles. When such currents are set up in artificial Earth satellites, the latter will be subjected to additional forces and torques, due to the existence of the terrestrial magnetic field. Because of the geometric gradient, the forces will be too small to materially affect the motion of the vehicles.

During the initial phases of the docking operation, the geomagnetic torques will generally be strong enough to overcome the mutual orienting effects of the electrodynamic interaction. However, the latter will gradually increase and become predominant during the terminal phases of the approach, eventually causing the vehicles to be coupled in an attitude corresponding to minimum magnetic energy. The effects of torques of gravitational origin can be disregarded. The duration of the electromagnetic docking operation is estimated at less than one-tenth of the local satellite period. The weight and power requirements (estimated on the basis of typical vehicle and maneuver data) prove to be tolerable, even if required special equipment (coils, power sources) is to be mounted in the vehicle. A great savings in weight could be effected by a vehicle design in which the required system of electrical conductors is made into an integral part of the structure.

334. EXPLORER X PLASMA MEASUREMENTS

Bonetti, A., Bridge, H. S., Lazarus, A. J., Rossi, B., Scherb, F.
1962 (?)
Massachusetts Institute of Technology, Cambridge
Report, NASA-CR-58670
N64-29,562

A plasma moving with a velocity of about 300 km/sec was first observed when the satellite reached a distance of about 22 Earth radii. During the remainder of the observations (which terminated about 40 hours later, at a distance of 42 Earth radii), periods in which substantial plasma fluxes were recorded alternated with shorter periods in which the plasma flux was below or just above the detection limit. There was a striking correlation between the plasma flux

and the magnetic field; in the absence of plasma the magnetic field direction was nearly radial from the Earth, whereas in the presence of plasma the field was irregular and generally formed large angles with the Earth satellite direction. 124 pages; 34 references.

335. AN MHD SOLUTION FOR A REENTRY VEHICLE CHANNEL
Brunner, M. J., Yager, P. A.
January 17, 1961
General Electric Company, Space Sciences Laboratory, Philadelphia, Pa.
TM 176, AF 04(645)-24
AD-442,616

When an electrically conducting fluid flows through a properly oriented magnetic field, currents and electric body forces will be produced. If the fluid is made to flow in a channel, the force produced may be utilized to create a torque on the body connected to the channel. This torque, when properly applied about the center of gravity of the vehicle, will orient the vehicle in a desired trimmed condition. The actual forces which will produce the desired trajectory corrections for control will be accomplished by the aerodynamic forces which occur when the vehicle is at angle of attack. This is called MHD control. The method particularly attractive for reentry vehicle application is that of powering the MHD coil from the plasma surrounding the reentry vehicle. Since the MHD channel can absorb power from the conducting fluid, the magnetic field may be powered by the MHD generator itself. The application of interest is to utilize the hot conducting gases surrounding the reentry vehicle to produce enough power within a confined channel to power an electromagnet, which in turn will generate the desired magnetic field. The body force (electric and pressure) thus produced is a drag force which always opposes the flow direction. When relatively large control forces are required for a large portion of flight, self-power generation appears to be the ideal method for minimizing weight, since large powers are required for the operation of the coil. 31 pages.

336. EVALUATION OF HALL AND ION SLIP EFFECTS FOR MAGNETOHYDRODYNAMIC REENTRY VEHICLE CHANNELS
Brunner, M. J., Yager, P. A.
April 18, 1961
General Electric Company, Space Sciences Laboratory, Philadelphia, Pa.
TM 191, AF 04(645)-25
AD-442,614

The electrical conductivity is determined for unseeded high temperature air for a wide range of temperatures and pressures, and for a typical flight path for unseeded and seeded air for various typical local pressure ratios. The Hall and ion slip effects are determined in order to obtain an effective electrical conductivity for use in MHD devices having magnetic fields. 40 pages.

337. THE EFFECTS OF HALL AND ION SLIP ON THE ELECTRICAL CONDUCTIVITY OF PARTIALLY IONIZED GASES FOR MAGNETOHYDRODYNAMIC REENTRY VEHICLE APPLICATION
Brunner, M. J.
ASME, Transactions of the, Series C—Journal of Heat Transfer, v. 84, no. 2, pp. 177–184, May 1962

The presence of a partially ionized gas around a hypersonic vehicle permits the application of MHD devices during reentry. The operation of such MHD devices on a reentry vehicle will largely depend on the magnitude of the electrical conductivity of the gas between the electrodes. In some cases it may be necessary to seed the air in order to insure high conductivity. The operation of the reentry vehicle at relatively low gas densities and high magnetic fields will produce Hall and ion slip effects which may materially reduce the effective conductivity between the electrodes. The electrical conductivity for air, including Hall and ion slip effects, is presented for a wide range of pressures and temperatures and for a typical reentry vehicle, with and without seeding. The electrical conductivity is evaluated for equilibrium conditions, considering the number density and collision cross sections for electrons, neutrals, and ions. The Hall and ion slip effects are evaluated from the degree of ionization, the cyclotron frequency, and the time between collisions for electrons, neutrals, and ions. 11 references.

338. THE PERFORMANCE OF A MAGNETOHYDRODYNAMIC REENTRY VEHICLE CHANNEL
Brunner, M. J.
AIEE, Transactions of the, Part I—Communication and Electronics, v. 81, no. 61, pp. 209–216, July 1962

The overall performance of a reentry vehicle channel throughout the trajectory is described for various vehicle applications as a function of the trajectory, the channel, and the vehicle geometry. Various design aspects are discussed, including the coil channel, electrodes, seeding requirements, Hall and ion slip effects. A typical MHD channel and coil design is included. Solutions of the MHD equations are evaluated through the channel as a function of inlet Mach number, voltage parameter, magnetic-interaction parameter, and channel aspect ratio.

339. THE RESONANT FREQUENCIES OF CAVITIES IN A MAGNETO-IONIC MEDIUM
Budden, K. G.
Canadian Journal of Physics, v. 42, no. 1, pp. 90–102, January 1964

The resonant frequencies for a hollow cylindrical or spherical cavity in a magneto-ionic medium are derived using a simple model in which the boundary of the cavity is sharp and the outside medium is homogeneous and loss free, but anisotropic. The effects of electron temperature and of nonlinearity are ignored. The problem is complementary to a similar problem treated by Herlofsen (1951), who discussed the resonant frequencies of a uniform cylindrical or spherical

mass of isotropic plasma surrounded by a vacuum. It is found that the resonant frequencies are not equal to the characteristic frequencies of the plasma, as usually described by the formulas $X = 1$, $X = 1 \pm Y$, but are more complicated functions of the plasma frequency and the electron gyro frequency. It is concluded that for a plasma sheath or cavity of any structure with a sharp or gradual boundary region, the resonant frequencies will, in general, differ from the characteristic frequencies of the undisturbed plasma. For a cylindrical cavity the resonant frequencies depend upon the angle between the axis of the cavity and the constant magnetic field. The results may have applications to the interpretation of plasma "spikes" observed with space vehicles, and to the theory of the radar cross section of a space vehicle within the ionosphere. (*PA*, 1964, #8929)

340. IS AERODYNAMICS BREAKING AN IONIC BARRIER?
Busemann, A.
In "Electromagnetics and Fluid Dynamics of Gaseous Plasma," pp. 1–18
Fox, J., Crowell, M., Editors
Polytechnic Press, Brooklyn, N.Y., 1962
(Paper presented at the Polytechnic Institute of Brooklyn Microwave Research Institute Symposium Series XI, New York, N.Y., April 4–6, 1961)

Present knowledge of the behavior of ion and electron fields produced by high-velocity bodies is surveyed. These phenomena may dictate future vehicle configuration and open a new aerodynamic technology. Topics covered include the heat-shielding problem of reentry, magnetic forces in plasmas of low conductivity, lift by the Hall effect, and the DC accelerator. (*IAA*, A63-15,810)

341. PLASMA RESONANCES IN THE UPPER IONOSPHERE
Calvert, W., Goe, G. B.
***Journal of Geophysical Research*, v. 68, no. 22, pp. 6113–6120, November 15, 1963**

Plasma resonances detected in the upper atmosphere with the *Alouette* topside sounder satellite were examined. The resonant frequencies were found to be f_N and $(f_N^2 + f_H^2)^{1/2}$, where f_N is the plasma frequency and f_H is the electron gyrofrequency. The two resonances are attributed to electron oscillations along and across the Earth's magnetic field, respectively. (*PA*, 1964, #10,752)

342. ALOUETTE IONIC, MAGNETIC-FIELD, AND PLASMA STUDIES
Calvert, W., Rishbeth, H., Van Zandt, T. E.
***American Geophysical Union Transactions*, v. 45, no. 2, pp. 398–401, June 1964**

Results are reported of investigations conducted at the Central Radio Propagation Laboratory, U.S. National Bureau of Standards, concerning ionic composition, magnetic-field-aligned irregularities, and plasma resonances excited by a sounding transmitter. (*EI*, 1964)

343. EFFECT OF THE GEOMAGNETIC FIELD ON THE ORBIT OF A CHARGED SATELLITE
Cappellari, J. O., Jr.
1961
Purdue University, Lafayette, Ind.
Thesis

The motion of an electrically charged body in the Earth's combined magnetic and gravitational fields is studied with respect to the effects on the trajectory of the body. The satellite is considered as a point mass, and the Earth's magnetic field is ideally represented as a magnetic dipole situated at the Earth's center.

Closed-form solutions are obtained for any initial motion in the geomagnetic equatorial plane, including rotational effects (assuming that the magnetic dipole axis coincides with the rotational axis). These solutions are generally expressed in terms of elliptic integrals of the first and third kinds. Generally speaking, the solutions are periodic in nature, with the mass restricted to motion between two limiting circles. However, in certain special cases, nonperiodic solutions are obtained. For example, for K (the ratio of the Earth's rotational speed to the satellite's initial rotational speed) sufficiently large, there are shown to exist certain ranges of values of the parameter α (primarily a measure of the charge to mass ratio of the satellite) for which the charged body will "escape" the Earth.

Numerical results are presented for a number of specific cases which were chosen to illustrate the possible types of resultant orbits.

For the case of an initially inclined orbit, under suitable assumptions, a solution is obtained which is analogous to the solution given by Brouwer for the oblate Earth. 105 pages. (*DA*, 61-5701)

344. NOTE ON INDUCTION DRAG
Chopra, K. P.
***Journal of Geophysical Research*, v. 62, no. 1, pp. 143–436, March 1957**

Some aspects of induction drag are discussed. The quoted expressions for translational and rotational induction drags of a sphere of infinite electrical conductivity moving in an incompressible fluid of finite electrical conductivity in the presence of a magnetic field are derived. An analogy with the viscous drag is drawn, and it is shown that, unlike ordinary viscosity, the hydromagnetic or inductive viscosity is anisotropic in nature. A condition for this latter viscosity to play an important role is also obtained. The limitations of the results obtained are discussed. It is shown that the results hold good for small bodies or weak induction currents. When applied to large bodies or strong currents, the appropriate corrections for electromagnetic and electrostatic shielding effects must be used. An order of magnitude calculation shows that, for bodies of cosmical dimensions, the correction is precisely of the same order as the induction effect itself.

345. DRAG OF A SPHERE MOVING IN A CONDUCTING FLUID IN THE PRESENCE OF A MAGNETIC FIELD
Chopra, K. P., Singer, S. F.
In "1958 Heat Transfer and Fluid Mechanics Institute, Preprints of Papers," pp. 166–175
Stanford University Press, Stanford, Calif., 1958
(Paper presented at the Heat Transfer and Fluid Mechanics Institute Meeting, Berkeley, Calif., June 19–21, 1958)

A body moving in a conducting liquid or in a plasma will experience a drag. Three types of drag are discussed which vary in importance depending on the circumstances of the motion, the properties of the body, and the properties of the medium. Considered first is the induction drag which is basically due to the Joule dissipation of energy caused by induced currents either in the medium or in the body. A further distinction is made as to whether the body is a magnetized sphere moving in an electrically conducting fluid, or an electrically conducting sphere moving in a conducting fluid in the presence of an external magnetic field.

In general, a body moving in a plasma will acquire an electric charge. If, in addition, there exists a strong source of UV radiation, then the charge may become positive because of the preponderant effects of photoemission. In any case, the trajectories of electrons and ions of the medium will be affected by the charge of the body and will transfer momentum to the body. This Coulomb drag can be calculated, and is found to be important for small dust particles moving in the interplanetary gas or the upper layers of the atmosphere.

Also considered is the motion of a highly charged particle in a plasma in the presence of an external magnetic field. Under such conditions the motion of the body may excite plasma waves which can propagate through the medium with a frequency below the critical frequency and with a phase velocity less than the material velocity of the body. Under these conditions the particle loses energy to the waves and therefore experiences a drag force. This phenomenon bears a certain resemblance to Cerenkov radiation and to the operation of traveling wave tubes.

346. EXCITATION OF PLASMA WAVES BY BODIES MOVING IN AN IONIZED ATMOSPHERE
Chopra, K. P.
January 1961
Brooklyn, Polytechnic Institute of, Department of Aerospace Engineering and Applied Mechanics, New York, N.Y.
PIBAL Report 627, AF 49(638)-445
AD-252,225
(Paper presented at the Second Annual Meeting of the Plasma Physics Division of the American Physical Society, Gatlinburg, Tenn., November 2–5, 1960; see also *Planetary and Space Science*, v. 5, pp. 288–291, 1961)

A body moving in an ionized atmosphere acquires an electric charge through the accretion of charged particles and the emission of electrons by high-energy photons. The moving charged body may then interact with the charged particles of the atmosphere and any pervading magnetic field to excite plasma waves. Of particular interest is the situation in which the body collects an ionized cloud in front of it. The motion of this ionized cloud in the atmosphere induces an electrostatic instability and causes a column of ionized gas to move ahead of the body. The electrostatic instability is conducive to the excitation of electrostatic oscillations which, if already present, are further enhanced. A magnetic field along the direction of motion assists in the formation of the ionized cloud. If the pervading magnetic field is of suitably weak strength, it may excite extraordinary electromagnetic waves. A pervading transverse magnetic field of suitable strength may cause the excitation of magnetohydrodynamic waves.

347. REVIEW OF ELECTROMAGNETIC EFFECTS ON SPACE VEHICLES
Chopra, K. P.
***Journal of the Astronautical Sciences*, v. 9, pp. 10–17, Spring 1962**
(Paper presented at the AAS Symposium on Interactions of Space Vehicles With an Ionized Atmosphere, Washington, D.C., March 17, 1961)

A survey is made of the various electromagnetic effects on a space vehicle moving through an ionized atmosphere pervaded by a magnetic field. The effects caused by electric currents induced both inside the space vehicle and in the surrounding medium are discussed, and the latter are analyzed by considering the atmosphere first as a continuum and then as a noncontinuum. The significance of the nature of the ionized medium in the immediate proximity of the space vehicle is noted, and a physical model is formulated in which the ionized cloud is composed of a spherical ion belt surrounding a negatively charged vehicle with an ionized column at its front. The characteristic features of this model are the high drag and large radar cross sections of the space vehicles, the acceleration of electrons in the frontal column to high energies prior to impact, and the excitation of plasma waves. These features may be useful for the interpretation of satellite observations. 23 references. (*IAA*, 62-7371)

348. ZERO THRUST VELOCITY VECTOR CONTROL FOR INTERSTELLAR PROBES: LORENTZ FORCE NAVIGATION AND CIRCLING
Forward, R. L.
***AIAA Journal*, v. 2, no. 5, pp. 885–889, May 1964**
(See also Paper 64-53, presented at the AIAA Aerospace Science Meeting, New York, N.Y., January 20–22, 1964)

An examination is made of the fundamental equations and conditions governing the interaction of an interstellar probe with the magnetic fields existing in interstellar space. The interactions investigated are: (1) the Lorentz force on a moving charge, (2) the eddy currents induced in a moving conductor, (3) the Meissner-effect repulsion of a supercon-

ductor, and (4) the magnetic gradient force on a permanent magnetic dipole. The most promising effect for obtaining a usable amount of velocity change is the Lorentz force. By increasing the self-capacitance of the probe with a long, thin cable, and by using a radioisotope as the voltage source, the charge-to-mass ratio of the probe can be made very large. Since the ion densities in interstellar space are very low, a substantial voltage can be easily maintained. Because of the large distances and the long times involved, it is found that the weak forces can build up to an appreciable change in the direction of the velocity vector of the probe. The change is large enough to allow for extensive midcourse corrections on a multi-ton, one-way charged probe, and can also be used to return a smaller probe to its starting point.

349. FORCES DUE TO THE MAGNETIC FIELD OF THE ELECTRICAL CONDUCTIVITY METER

Fuhs, A. E., Betchov, R.
***AIAA Journal*, v. 1, no. 3, pp. 704–705, March 1963**

Forces produced by the interaction of the moving conductor with the applied magnetic field are determined. These forces, which are measured by an instrument flown aboard a reentry vehicle, are desirable effects for MHD attitude control. The calculated and measured forces agree within a factor of 4. It is shown that the presence of a conductivity meter is unlikely to perturb the trajectory of the reentry vehicle. (*IAA*, A63-14,490)

350. EDDY CURRENT TORQUE COMPENSATION IN A SPIN STABILIZED EARTH SATELLITE

Grasshoff, L. H.
***ARS Journal*, v. 31, no. 3, pp. 290–293, March 1961**
(Also available as TM 232-13, Radio Corporation of America, Astro-Electronics Division, Princeton, N.J., October 16, 1958)

This analysis demonstrates the feasibility of compensating for eddy-current torque by electromagnetic means. The vector torque produced by eddy currents in a conducting body rotating in the Earth's magnetic field bears a unique relationship to the spin vector and the field vector. A simple coil arrangement is discussed which produces a vector torque and effectively cancels the eddy-current torque, thus eliminating the spin decay and precession due to induced eddy currents. (*IAA*, 61-4695)

351. INERTIAL SPHERE SYSTEM FOR COMPLETE ATTITUDE CONTROL OF EARTH SATELLITES

Hering, K. W., Hufnagel, R. E.
***ARS Journal*, v. 31, no. 8, pp. 1074–1079, August 1961**

An electrically conducting sphere placed in a rotating magnetic field will experience a torque about the axis of rotation. This torque arises from eddy-current drag between the field and the sphere, and can be used to control satellite attitude. Accumulated satellite angular momentum will appear as rotation of the sphere and will be automatically "dumped" by eddy-current interaction with the Earth's magnetic field. The sphere can be positioned without mechanical contact with the satellite by high frequency alternating magnetic fields. Very precise attitude guidance, slewing operations, and momentum "dumping" can all be achieved with one device. Three-axis control with one sphere eliminates gyroscopic interaction. The electrical efficiency thus obtained compares favorably with other system types.

352. EFFECT OF THE EARTH'S MAGNETIC FIELD ON THE MOTION OF AN ARTIFICIAL SATELLITE

Jefimenko, O.
***American Journal of Physics*, v. 27, pp. 344–348, 1959**

The effect of the Earth's magnetic field on the motion of an artificial satellite moving in a circular orbit in the plane of the magnetic equator of the Earth is discussed. Approximate formulas are obtained for the current induced in the satellite and for the resulting induction drag. The current in a conducting satellite of an average size at an altitude of several hundred kilometers is estimated to be of the order of milliamperes. The induction drag may exceed the friction drag for satellites of large dimensions and for elongated satellites.

353. CYCLOTRON HARMONIC SIGNALS RECEIVED BY THE ALOUETTE TOPSIDE SOUNDER

Johnston, T. W., Nuttall, J.
***Journal of Geophysical Research*, v. 69, no. 11, pp. 2305–2314, June 1, 1964**

The long-lived returns (spikes) at multiples of the electron cyclotron frequency, often observed in *Alouette* ionograms, may be due to the action of the antenna field on electrons in the antenna sheath whose motions are influenced by the steady nonuniform electric field of the sheath and the ambient magnetic field. Lockwood's mechanism invokes nonuniformities in the oscillating antenna field to produce bunches of electrons moving in circular orbits. Bunching may be due to the nonuniform static electric field of the antenna sheath, which will induce cyclotron harmonic components in the motion of electrons in this region. 15 references.

354. MAGNETORQUER — A SATELLITE ORIENTATION DEVICE

Kamm, L. J.
***ARS Journal*, v. 31, no. 6, pp. 813–815, June 1961**

The magnetorquer attitude control motor generates torque by action of the Earth's magnetic field on electric currents in a satellite. It consists of three orthogonal coils to carry current, a three-axis magnetometer to measure the Earth's field, and a computer. Functions of the magnetometer and the computer are described, and advantages of the system are outlined. (*EI*, 1961)

355. MAGNETOHYDRODYNAMIC EFFECTS ON BOW SHOCK
Kunkel, W. B.
August 5, 1958
Space Technology Laboratories, Inc., Los Angeles, Calif.
STL-GM-TR-0165-00449, AF 04(647)-165
AD-604,993
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

356. MAGNETIC DAMPING OF ROTATION OF THE VANGUARD I SATELLITE
LaPaz, L.
***Science*, v. 131, no. 3397, pp. 355–357, February 5, 1960**

The explicit integration of integrals of the type basic to a comparison of the observed and predicted values of the Earth's mean total magnetic field reveals an error in the numerical integration recently employed by R. H. Wilson, Jr., (Entry 375) in making such a comparison for the special case of *Vanguard I*. The correction of this error destroys the satisfactory agreement which was found between the value implied by rotational damping and the theoretical value. (For reply by Wilson, see Entry 376.)

357. NOTE ON WAVES THROUGH GASES AT PRESSURES SMALL COMPARED WITH THE MAGNETIC PRESSURE, WITH APPLICATIONS TO UPPER-ATMOSPHERE AERODYNAMICS
Lighthill, M. J.
***Journal of Fluid Mechanics*, v. 9, pt. 3, pp. 465–472, November 1960**

Most treatments of MHD waves have confined physical interpretation to cases when the Alfvén velocity, α_1, is small compared with the sound velocity, α_0. In this paper, consideration is given the "low-beta situation," in which α_1 is much larger than α_0. Then, except for two modes with wave velocity α_1, the only possible waves are longitudinal, and are propagated unidirectionally along lines of magnetic force with velocity α_0. These can be interpreted as sound waves, confined to effectively rigid magnetic tubes of force. Hall current effects do not alter these conclusions (in contrast to the high-beta situation), and finite conductivity introduces only small dissipation.

An application is made to the flow pattern around a body moving through the F_2 layer of the ionosphere, where, although neutral particles have a very large mean free path, charged particles interact electrostatically and, it is argued, may be regarded as forming a continuous fluid having a movement which is independent of that of the neutral particles. A body moving at satellite speed or below would then excite the above-mentioned unidirectional sound waves. These considerations suggest that the movement would be accompanied by a V-shaped pattern of electron density, which might be in part responsible for some anomalous radar echoes that have been reported.

358. LOW LATITUDE FIELD ALIGNED IONIZATION OBSERVED BY THE ALOUETTE TOPSIDE SOUNDER
Lockwood, G. E. K., Petrie, L. E.
***Planetary and Space Science*, v. 11, pp. 327–330, March 1963**

Some of the phenomena observed in topside ionograms recorded near the magnetic equator are described, and the conclusions drawn from the observations are summarized. The minimum range of the spread echoes is explained by the reflection of radio waves from overdense irregularities located below the satellite, on a surface defined by the rotation of a magnetic field line about the magnetic polar axis. The maximum range of the spread echoes is determined by the backscatter of the wave. The similar diurnal behavior of the equatorial anomaly and the spread echoes indicates a common origin. 9 references.

359. EXCITATION OF CYCLOTRON SPIKES IN THE IONOSPHERIC PLASMA
Lockwood, G. E. K.
***Canadian Journal of Physics*, v. 43, no. 2, pp. 291–297, February 1965**

The occurrence of resonances in the ionosphere, at frequencies which are harmonics of the gyrofrequency, has been detected by the topside sounder satellite, *Alouette I*. It has been observed that the occurrence of cyclotron spikes on ionograms is a function of the angle between the antenna and the Earth's magnetic field. The number of cyclotron spikes observed is a maximum when the appropriate antenna is parallel to the Earth's magnetic field.

360. MEASUREMENTS OF DRAG AND WAKE STRUCTURE IN MAGNETO-FLUID DYNAMIC FLOW ABOUT A SPHERE
Maxworthy, T.
June 1962
Jet Propulsion Laboratory, California Institute of Technology, Pasadena
TR 32-236
N62-14,045
(Paper presented at the Heat Transfer and Fluid Mechanics Institute, Seattle, Wash., June 13–15, 1962; also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The drag experienced by metal spheres of several different diameters has been measured by determining their terminal velocities as they fall vertically through an electrically conducting fluid and an axial magnetic field. Induction coils were used to detect the moving, perturbed magnetic field associated with the sphere, allowing accurate determination of the sphere's position in space and time and the gross nature of the perturbed field. For the range of parameters considered (Reynolds numbers from 2000 to 11,000 and Hartmann numbers from 0 to 150), the drag coefficient scales with Ha/Re only. It is expected that, as the Reynolds number range is extended, it too will become an important parameter.

Analysis of the induction coil outputs shows that, in a certain region of the *Ha/Re–Re* plane, turbulent fluctuations behind the spheres are suppressed. At the same time, a disturbance ahead of the spheres becomes increasingly apparent and has been observed 20 sphere diameters ahead of the body. The nature of the law of growth and decay of disturbances ahead of and behind the body has been determined in one case. The observations tend to confirm much of the recent theoretical work on the existence and structure of such disturbances. 10 pages; 6 references.

361. **ELECTROMAGNETIC COUPLING DUE TO APERTURES IN MISSILE BODIES**
Merchant, C.
May 30, 1961
Jansky and Bailey, Inc., Washington, D.C.
Technical Report 5455, N178-7604
AD-257,304
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The problem of electromagnetic coupling between the interior and exterior of cylindrical missile bodies due to apertures in the missile body was studied. Expressions were derived which can be used to determine the electromagnetic field at any point (interior and exterior) in terms of a field incident to the missile. 12 pages.

362. **OBSERVED TORQUE-PRODUCING FORCES ACTING ON SATELLITES**
Naumann, R. J.
In "Dynamics of Satellites," pp. 237–256
Roy, M., Editor
Academic Press, Inc., New York, N.Y., 1963
(Paper presented at the International Union of Theoretical and Applied Mechanics Symposium, Paris, France, May 28–30, 1962)

Some experimental satellite orientation data are discussed in order to explain the nature and origin of the torques responsible for the observed motion about the center of mass. To solve the orientation equations, it is necessary to determine the nature of the torque-producing forces. This is done by observing the change in orientation of several *Explorer* satellites where the drag force is sufficiently small that orbital dependence on orientation is negligible. It was found that permanent magnetic moments in the satellites were the dominant effect responsible for the observed changes in orientation. Gravitational torques are also significant. The changes in orientation of the satellites considered were well explained by these two effects; hence, it is concluded that other effects are not significant for similar satellites. Various approximations used in this study greatly reduce the effort required to integrate the orientation equations and do not require the simultaneous solution of the orbital equations. The findings, however, are applicable to the simultaneous solution of both the orbital and orientation sets of equations. 19 references. (*IAA*, A64-12,677)

363. **AN INVESTIGATION OF THE OBSERVED TORQUES ACTING ON EXPLORER XI**
Naumann, R. J.
In "Torques and Attitude Sensing in Earth Satellites," pp. 191–206
Singer, S. F., Editor
Academic Press, Inc., New York, N.Y., 1964
(See Entry 16)

Possible causes of the torques observed to perturb the angular momentum vector of the *Explorer XI* satellite are analyzed. Methods used to determine the orientation of the satellite are reviewed, and torques required to produce the observed motions are calculated. Actual torques acting on the satellite are considered, including those due to a gravity gradient, the aerodynamic effects, a permanent magnetic moment, an induced magnetic moment, and the Coulomb electrical drag on the satellite. It is found that torque due to a permanent magnetic moment may be responsible for the observed motion. 15 references. (*IAA*, A64-25,303)

364. **CHARGE EXCITATION OF PLASMA MOTION IN A MAGNETIC FIELD**
Pappert, R. A.
***Physics of Fluid*, v. 3, no. 6, pp. 966–972, November–December 1960**

The wake of a massive point charge traversing a low-density plasma of vanishing ion temperature, in a constant external magnetic field, is investigated by means of linearized Boltzmann theory. The speed of the exciting charge is taken to be less than the root-mean-square thermal speed of the electrons, and the electron thermal energy is taken to be much less than the ion energy associated with the ambient flow velocity (the ion flow velocity as seen in a reference frame moving with the external charge). The magnetic field is taken along the direction of motion of the exciting charge. One of the effects of the magnetic field is the production of oscillations of both the charge density and the potential. Over some regions of space the frequency of these oscillations is approximately equal to the ion cyclotron frequency. These conditions conform with satellite interactions in the ionosphere.

365. **MAGNETIC FIELD DISTURBANCES AROUND A BODY MOVING IN A PLASMA**
Pitaevskii, L. P.
***Geomagnetizm i Aeronomiya*, v. 3, no. 6, pp. 1036–1047, 1963**
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 3, no. 6, pp. 833–842, 1963)

Expressions based on kinetic theory are derived for the Fourier components of magnetic field disturbances around a body moving in a rarefied magnetized plasma. Formulas are also obtained for the Fourier components of disturbed charged particle concentrations, taking into account the effect of magnetic field disturbances on the motion of electrons and ions. 8 references. (*IAA*, A64-14,423)

366. EFFECTS OF THE EARTH'S MAGNETIC FIELD ON THE ORBIT OF A CHARGED SATELLITE
Shapiro, I. I., Jones, H. M.
Journal of Geophysical Research, v. 66, no. 12, pp. 4123–4125, December 1961

The changes in the orbital elements of a charged satellite due to the $\vec{v} \times \vec{B}$ force ($\vec{B}$ = geomagnetic field) were examined. It is concluded that the ascending nodes of the Project West Ford dipoles may be detectably perturbed by this force. (*PA*, 1962, #4865)

367. INTERACTION BETWEEN FLUXES OF RAREFIED PLASMA AND THE MAGNETIC FIELDS OF SPACE OBJECTS
Sigov, Yu. S.
Kosmicheskiye Issledovaniya, v. 2, no. 6, pp. 948–951, 1964
(Translation available in FTD-TT-64-1316 (pp. 221–227), Air Force Systems Command, Foreign Technology Division, Wright-Patterson AFB, Ohio)

This paper is a brief exposition of some results of a numerical solution of the stationary problem of the structure of a plane boundary layer between a magnetic field and rarefied plasma. A detailed mathematical formulation of the problem was published earlier by the author.

368. PLASMA COMPRESSION EFFECTS
Singer, S. F., Walker, E. H.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 483–501
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17)

A novel phenomenon which leads to the creation of large clouds of compressed plasma is discussed. According to theory, it is caused by the interaction of an electrically charged body with the surrounding ambient plasma in the presence of a magnetic field. The cloud consists of ions which have been scattered into quasi-trapped orbits. A detailed study is made of the injection and removal of these ions. Under nonsteady-state conditions the ion cloud may detach itself from the body and give rise to "ghosts." It is quite possible that this phenomenon is the cause of the unusual "bursts" and radar echoes observed to be associated with passes of Earth satellites.

369. A THEORETICAL STUDY OF THE TORQUES INDUCED BY A MAGNETIC FIELD ON ROTATING CYLINDERS AND SPINNING THIN-WALL CONES, CONE FRUSTUMS, AND GENERAL BODY OF REVOLUTION
Smith, G. L.
1962
National Aeronautics and Space Administration, Langley Research Center, Langley Station, Va.
TR-R-129
N63-12,596

The electromagnetic field equations are applied to nonferromagnetic conducting thin-wall cylinders, cones, and cone frustums. The equations are then applied to the general thin-wall body of revolution slowly spinning in a homogeneous magnetic field, in order to calculate the induced eddy currents and resulting torques. The solutions to these cases can be directly applied to the calculation of the magnetic torques tending to damp the rotation of spinning and tumbling satellites. 17 pages; 7 references.

370. THE TORQUE AND ANGULAR VELOCITY INDUCED BY THE GEOMAGNETIC FIELD ON A SPINNING CONDUCTING SATELLITE
Smith, G. L.
May 1963
Virginia Polytechnic Institute, Blacksburg, Va.
Thesis
N63-16,741

One source of torque on near-Earth satellites is the interaction of the Earth's magnetic field with eddy currents induced in the electrically conducting parts of a spinning satellite. An analysis of this torque and the resulting spin motions is presented. The electromagnetic field equations are applied to spinning and tumbling cylinders, spinning thin-wall cones, cone frustums, and the general body-of-revolution. The eddy currents are thus determined for each case, and from this the torque is calculated. The torque which acts on a spinning satellite while in orbit is studied. An expression is derived for the torque vector as a function of the orbit parameters. The time history of the spin vector subject to this torque is investigated. 81 pages; 8 references.

371. EFFECTS OF MAGNETICALLY INDUCED EDDY-CURRENT TORQUES ON SPIN MOTIONS OF AN EARTH SATELLITE
Smith, G. L.
April 1964
National Aeronautics and Space Administration, Langley Research Center, Langley Station, Va.
TN D-2198
N64-18,956
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

One of the sources of torques on near-Earth satellites is the interaction of the Earth's magnetic field with eddy currents induced in the electrically conducting parts of a spinning satellite. Initially, it is assumed that the geomagnetic field is that of a space-fixed dipole. The equation for the average torque, due to this effect, acting on a satellite of known properties is derived and presented. This equation shows the variation of the torque with the orbital parameters. The time history of the spin vector as influenced by this torque has been investigated. For the general case, the spin vector can be resolved into three orthogonal components which are damped exponentially at three different rates. The

analysis is extended to include the effect of the tilt of the geomagnetic dipole axis with respect to the Earth's spin axis. 29 pages.

372. DIPOLE RESONANCES IN A HOMOGENEOUS PLASMA IN A MAGNETIC FIELD

Sturrock, P. A.
***Physics of Fluids*, v. 8, no. 1, pp. 88–96, January 1965**

Radar observations recently made from a satellite orbiting above the ionosphere provide evidence for resonances of a plasma in a magnetic field which may be excited and detected by a dipole. The plasma may be said to be resonant for a particular mode and frequency if the group velocity is zero. These resonances are studied theoretically on the assumptions that the dipole is of infinitesimal extent and that the plasma is excited by a charge or current impulse. The former assumption restricts the validity of the results to the asymptotic response of the plasma; the latter assumption is not a restriction. The analysis shows that (1) the oscillations decay asymptotically as an inverse power of time, and (2) the response would be significantly stronger than is observed if measurements were made with a stationary dipole, indicating that the observed duration of the resonances is to be ascribed to the finite velocity of the satellite with respect to the exospheric plasma. (*PA*, 1965, #8998)

373. RADIATION FROM A UNIFORMLY MOVING CHARGE IN AN ANISOTROPIC PLASMA

Tuan, H. S., Seshadri, S. R.
***IEEE Transactions on Microwave Theory and Techniques*, v. MTT-11, no. 6, pp. 462–471, November 1963**

An analysis is given of the radiation characteristics of a charge moving uniformly in an incompressible, idealized (dielectric) plasma in the direction of an external magnetic field. It is found that, in general, the radiation consists of an ordinary and an extraordinary mode, the latter arising from the finiteness of the external magnetic field. The radiation is always found to be in the lower end of the frequency spectrum. For an infinite magnetic field, the radiation consists of all frequencies lower than the plasma frequency. This radiation is of the Cerenkov type, and its angular spectrum is evaluated for two sets of parameter values. The problem considered is relevant to the study of the low-frequency radiation observed from space vehicles passing through ionized regions in interplanetary space. 11 references. (*IAA*, A64-13,051)

374. RADIATION FROM A UNIFORMLY MOVING DISTRIBUTION OF ELECTRIC CHARGE IN AN ANISOTROPIC, COMPRESSIBLE PLASMA

Tuan, H. S., Seshadri, S. R.
***IEEE Transactions on Antennas and Propagation*, v. AP-13, no. 1, pp. 71–78, January 1965**

The radiation characteristics of a linear distribution of electric charge moving with a uniform velocity in a homogeneous electron plasma of infinite extent are investigated for the case in which a uniform static magnetic field is impressed externally throughout the medium. The linear distribution of charge and its direction of motion are assumed to be parallel and perpendicular, respectively, to the direction of the external magnetic field. There are two possible modes of waves of small amplitude, namely, the modified electromagnetic mode and the modified electron plasma mode. The uniformly moving charge distribution excites the modified electron plasma mode. The emitted radiation has no frequencies lower than the plasma frequency. For a particular value (for the electrons) of the ratio of the gyromagnetic frequency to the plasma frequency, the frequency and the angular spectrum of the emitted radiation are determined for two values of the velocity of the charge.

375. MAGNETIC DAMPING OF ROTATION OF SATELLITE 1958β2

Wilson, R. H., Jr.
***Science*, v. 130, no. 3378, pp. 791–793, September 1959**

From over 200 observations of the decreasing spin rate of *Vanguard I* made during the year since its launching, eddy-current induction theory yields 0.115 ± 0.001 G as the mean magnetic field normal to the spin axis of the satellite. This measured value agrees with that deduced from Bauer's model of the Earth's dipole field. 7 references. (For comment and reply, see Entries 356 and 376.)

376. REPLY TO "MAGNETIC DAMPING OF ROTATION OF THE VANGUARD I SATELLITE"

Wilson, R. H., Jr.
***Science*, v. 131, no. 3397, pp. 356–357, February 5, 1960**

Continued numerical improvement of all parts of the previous report (Entry 375), based on later accumulation and rediscussion of data, has revealed several small random adjustments, including the arithmetical correction discussed by LaPaz (Entry 356). The consequent result remains a satisfactory agreement of the ground-observed geomagnetic dipole field with that deduced from rotational retardation of the *Vanguard I* satellite.

377. INDUCTION DRAG ON A LARGE NEGATIVELY CHARGED SATELLITE MOVING IN A MAGNETIC-FIELD-FREE IONOSPHERE

Wyatt, P. J.
***Journal of Geophysical Research*, v. 65, no. 6, pp. 1673–1678, June 1960**

An induction drag experienced by a charged satellite during its traversal of the ionosphere has been theoretically postulated by several authors. Previous "exact" treatments of the problem are inapplicable to large systems, and the semi-empirical approach of Jastrow and Pearse (Entry 84) may yield somewhat questionable results. The present description initially considers the satellite as a completely permeable

spherical shell of charge, thus avoiding the difficult boundary conditions introduced by the "exact" linearized treatment. The effects of permeability are then shown to be approximately removable by means of an iterative process. A final result, apparently valid to within an order of magnitude, is obtained for the drag force arising solely from electrical effects. Its magnitude is considerably less than that obtained by Jastrow and Pearse. (*PA*, 1960, #14,473)

378. ON THE PROBLEM OF THE INTERACTION BETWEEN A SATELLITE AND THE EARTH'S MAGNETIC FIELD
Zonov, Yu. V.
***Iskusstvennye Sputniki Zemli*, no. 3, pp. 169–179, 1959**
(Translation available as TT F-37, National Aeronautics and Space Administration, Washington, D.C., May 1960, and in *Artificial Earth Satellites*, v. 3, pp. 169–179, 1961)

The problem of the motion of the artificial Earth satellite relative to its own center of mass is complicated and requires that a large number of factors be taken into account. The phenomena related to the interaction between the satellite and the Earth's magnetic field are considered. The electric processes in the satellite hull are examined, since these processes can influence, to one extent or another, the results of certain scientific experiments carried out on the satellite.

The results of an investigation of the interaction between the satellite and the Earth's magnetic field are reported. The following factors are considered: (1) the currents induced by the translational motion of the satellite relative to the magnetic field, (2) the currents induced by the change in the speed of rotation of the satellite about its own axis due to eddy currents, and (3) the disturbing forces exerted by the magnetic field on a satellite which has no rotation of its own.

AIRCRAFT

GENERAL EFFECTS: STATIC CHARGE AND IONIZATION

379. ELECTRIFICATION OF AEROSPACE VEHICLES
Austin, C. R.
In "Proceedings of the National Aerospace Electronics Conference, Dayton, Ohio, May 11–13, 1964" pp. 64–73
NAECON, Dayton, Ohio, 1964

The latest known facts on aerospace vehicle electrification are briefly outlined and reviewed. Among the topics discussed are: (1) the mechanisms and rates of autogenous and exogenous charging of flight vehicles at altitudes from ground level to orbital space, (2) the nature and noise content of discharges which result from charge accumulation, (3) the degree of degradation which static dischargers cause electronic systems, and (4) techniques for reducing electronic system susceptibility.

Additional studies and experimentation are required for a full understanding of vehicle electrification processes and discharge phenomena applicable to flight vehicles operating at speeds and altitudes in excess of Mach 2 and 100,000 ft, respectively. Although a number of theories covering this area are available, there is very little experimental data to support the theoretical work. 19 references.

380. MEASUREMENT PROGRAM TO DETERMINE STATIC ELECTRICITY CHARGING CURRENTS IN HELICOPTER MAIN ROTOR BLADES
Baron, S., Cholakian, E., Coonan, T.
June 1964
Army Transportation Research Command, Fort Eustis, Va.
TRECOM-TR-64-14, Technical Report for June 1962–August 1963, DA 44-177-TC-844
AD-605,828, N64-31,952

An SH-3A main rotor blade was electrically insulated from the rotor head and connected to measuring apparatus to determine the extent of the contribution of the main rotor blades to the electrostatic charge on a helicopter. Testing was performed on test stands and on an SH-3A helicopter under various environmental conditions. It was found that in clear air conditions (no snow, sand, rain, etc.) electrostatic charging current due to the main rotor blades is relatively small compared to the helicopter's total current; however, in environmental conditions (snow, sand, rain, etc.) the main rotor blades are the major contributors of electrostatic charging current. 43 pages.

381. CHARGES STATIQUES ET DÉCHARGES ÉLECTROSTATIQUES SUR LES AVIONS (STATIC CHARGES AND ELECTROSTATIC DISCHARGES ON AIRPLANES)
Corbillon, P.
Secrétariat Général à l'Aviation Civile et Commerciale, Bulletin de Liaison et de Documentation, no. 95, pp. 35–37, March 15, 1958

The phenomena relating to atmospheric electrostatic discharges are surveyed, taking into account the present knowledge of the subject. The consequences of electrostatic discharges to materials and staff are mentioned, and the importance of the action of static charges and electrostatic discharges on airplanes is pointed out. Protective measures to adopt against electric phenomena resulting from the charges in the atmosphere are recommended for cases of static charges and electrostatic discharges. 3 references. (*MGA*, 1960, 11.4-302)

382. AIRCRAFT ELECTROSTATIC MEASUREMENT INSTRUMENTATION AND OBSERVATIONS OF CLOUD ELECTRIFICATION
Fitzgerald, D. R., Byers, H. R.
February 28, 1962
Chicago, University of, Weather Forecasting Research Center, Ill.
Final Report, AFCRL-TR-62-805, AF 19(604)-2189
N62-14,592

Four electric field meters have been installed on a C-130A aircraft to provide measurements of three components of the cloud electrostatic field vector and the aircraft charge. An analog computer allows real-time display and recording of these components. This system has been used to study electrical charge production in convective clouds as an aid to the understanding of lightning charge centers. 59 pages; 14 references.

383. THE THEORY OF THE ELECTROMAGNETIC FIELDS AROUND AN AIRPLANE. PART III
Hill, E. L.
1952
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 236, Appendix I (AD-1719), AF 18(600)-183
AD-7585

The coupling between the interior and exterior fields provided by openings in the skin of the actual airplane (such as the cockpit, dome, and window) is discussed. A method is developed for the analysis of the problem for low and medium frequencies by a procedure based on successive approximations. Application of the theory to shielding problems is also discussed. 20 pages.

384. THE MECHANISM OF ELECTROSTATIC CHARGING
Imyanitov, I. M.
Akademiya Nauk SSSR, Doklady, v. 121, no. 1, pp. 93–96, 1958

An explanation is given of the effect of accumulation of charge on relatively large bodies moving in a medium consisting of small bodies, e.g., airplanes in flight. (*PA*, 1959, #1402)

385. STUDYING THE DISTRIBUTION OF AN INDUCED AND NATURAL ELECTRIC CHARGE ON THE SURFACE OF AN AIRCRAFT
Imyanitov, I. M., Kolokotov, V. P.
December 1959
Wright Air Development Center, Technical Information Center, Wright-Patterson AFB, Ohio
F-TS-9891/V
(Also available as OTS-PB-61-11152, U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is the first of the two articles in this report; the articles were selected for translation from the 1956 issue of *Trudy Glavnoi Geofizicheskoi Observatorii (Transactions of the Main Geophysical Observatory)*. The second article is referenced in Entry 737.

386. THEORY OF ELECTROSTATIC CHARGING OF BODIES IN AIR CURRENTS
Imyanitov, I. M., Starovoitov, A. T.
Zhurnal Tekhnicheskoi Fiziki, v. 32, no. 6, pp. 759–765, June 1962
(Translated from the Russian in *Soviet Physics—Technical Physics*, v. 7, no. 6, pp. 554–558, December 1962)

A study is made of the kinetics of electrostatic charging of bodies in air currents, taking into account the conductivity of the medium and the corona discharge current. It is shown that the charging mechanism, in which allowance is made for the contact potential difference between the body and the particles of the air stream, is adequate to explain the high potential found. The values of the potentials calculated from the parameters of the current occurring in the atmosphere are in agreement with values of the potentials acquired by airplanes in flight. (*PA*, 1963, #21,688)

387. LIGHTNING STRIKES AND ST. ELMO'S FIRE ON AIRPLANES
Morse, A. R.
Canadian Aeronautics and Space Journal, v. 8, no. 10, pp. 285–292, December 1962

Hazards to aircraft arising from lightning are discussed and various protective measures are considered. A study of St. Elmo's fire indicates that there are two possible causes: friction charging by particles striking the aircraft, and induced charging when the aircraft flies into the electric field caused by atmospheric conditions. Radio interference caused by these types of charging is described, and preventive measures are suggested. The interrelation between lightning, St. Elmo's fire, and radio interference is discussed in terms of the protective measures. (*EI*, 1963)

388. ON THE ELECTRIFICATION OF A BALLOON IN THE COURSE OF FLIGHT OF A ROCKOON
Okazaki, S., Okamoto, S., Aihara, K.
In "Proceedings of the Second International Symposium on Rockets and Astronautics, Tokyo, 1960," pp. 249–251
Tamaki, F., Editor
Yokendo Bunkyo-Ku, Tokyo, Japan, 1961

To prevent spontaneous explosion, a rotating field meter and telemetering equipment were devised for measuring the amount of electric charge on a balloon during inflation with hydrogen, as well as during its flight. Electrification occurs due to violent rubbing of different parts of the balloon during its release. As the balloon flies higher the charge decreases—probably because of the higher conductivity of the surrounding air. (*MGA*, 1962, 13.10-455)

389. HELICOPTER STATIC ELECTRICITY MEASUREMENTS
Seibert, J. M.
June 1962
Army Transportation Research Command, Fort Eustis, Va.
Interim Report, TCREC-TR 62-72
N62-17,229

Helicopter static electricity measurements under varying conditions were made at the Arctic Test Board, Fort Greely, Alaska; the Aviation Board, Fort Rucker, Alabama; and the U.S. Army Transportation Materiel Command Flight Test Office, Edwards AFB, California. The highest voltage accumulation was measured at the Arctic Test Board, with downwash blowing snow in the rotor blade path. Personnel from the Arctic Test Board report that conditions which produce maximum voltage accumulation in the Arctic were not encountered. Measurements made at Fort Rucker, Alabama, were of the same magnitude as those obtained during other measurements under similar conditions. The data obtained at Edwards AFB, California, indicate a larger current generation and voltage accumulation during operations in blowing dust than that experienced in relatively clear air. The maximum voltage accumulation measured on this program was 200,000 V, and the maximum charging current was 50 μA. 13 pages.

390. THE PROBLEM OF MEASURING THE ELECTRICAL CONDUCTIVITY OF AIR IN THE FREE ATMOSPHERE
Zachek, S. I.
Trudy Glavnoi Geofizicheskoi Observatorii, Leningrad, no. 157, pp. 94–120, 1964

Various factors affect the measurement of air conductivity during airplane flights in clouds and in regions with strong electrostatic fields. A detailed discussion is presented of methods which make it possible to offset the effects of (1)

the charge of the airplane, and (2) the strong electromagnetic fields in the atmosphere and in cloud and rain particles. An instrument is described for measuring the electrical conductivity of the air. The circuit and design make it possible to appreciably decrease the interference caused by clouds and rain drops. The limits of measurement range from 5×10^{-6} to 2500×10^{-6} esu (conductivity). The theory of the instrument is described and the instrument error is evaluated. It was found that the instrument must incorporate inertial filters and a secondary aspiration condenser, forming a differential circuit with the principal aspiration condenser and decreasing the influence of electrification currents of the inner electrode. The influence of the charge of the airplane itself or strong atmospheric electrostatic fields on the measurements can be eliminated by the use of systems compensating for the intrinsic charge of the plane and reacting on the sign of the induced charge. This can be accomplished by applying corresponding potentials to the aspiration condensers mounted above and below the fuselage, or by placing intakes in the nose of the airplane. This compensation can also be made by introducing corrections computed using formulas which are cited. Diagrams, block diagrams, and circuit diagrams are given which show the system, the individual components, and some of the results.

ANTENNA PHENOMENA

391. THE CORONA BREAKDOWN OF AERIALS IN AIR AT LOW PRESSURES
Cullen, A. L., Dobson, J.
***Royal Society of London, Proceedings of the, Series A—Mathematical and Physical Sciences*, v. 271, pp. 551–564, February 12, 1963**

Radio-frequency corona breakdown of the air surrounding a transmitting aerial operating under conditions of reduced pressure occurs for a comparatively low value of radiated power. The theory of diffusion-controlled breakdown is discussed and used to deduce the critical field strength for breakdown at the tip of a prolate spheroidal unipole antenna. Two independent methods are used to determine the electric field strength at the tip of the unipole. In the first, the voltage on the coaxial transmission line feeding the unipole is measured at a ¾ wavelength from the unipole base. In this way, the current entering the unipole base is found; hence, the electric field at the tip can be calculated. The second method employs a small microphone actuated by the attractive force of the electric field and square-wave modulation of the RF oscillator. The two methods give satisfactory agreement. In breakdown experiments, two unipoles of different base diameter were used. The satisfactory agreement between theory and experiment suggests that useful solutions of the diffusion equation for breakdown of aerials with shapes other than spheroidal are possible. Slightly different composition of the atmosphere and movement of a vehicle through the air, with the possible formation of shock waves at high speeds, could cause substantial variations in the breakdown strength. 16 references. (*NRC*, 1963, PDL-47,033)

392. VOLTAGE BREAKDOWN MEASUREMENTS ON QUADRALOOP, SHROUD AND RECTANGULAR SLOT ANTENNAS AT HIGH ALTITUDES
Leong, R.
August 1963
Ballistic Research Laboratories, Aberdeen Proving Ground, Md.
BRL-MR-1514
AD-430,483

Experiments concerned with voltage breakdown characteristics of rocket antennas were conducted using an evacuated chamber to reproduce the pressure environment. The antennas studied were the 234-Mc telemetering quadraloop antenna, the 36.44- and 145.76-Mc shroud antennas, and the 1680-Mc rectangular slot antennas. The received signal strength records obtained during recent rocket flights have indicated a decrease in signal between 25- and 75-mi altitude. This probably was caused by ionization of the air around the antennas. Information is presented on radiation efficiency and voltage standing-wave ratio of the antennas before and after breakdown. Included is a study of the application of foam to cover the quadraloop antenna in an effort to prevent voltage breakdown. 38 pages.

393. VOLTAGE BREAKDOWN OF INSULATORS IN "FLOATING SECTIONS" OF AIRCRAFT ANTENNA
Newman, M. M., Robb, J. D., Anderson, J. R.
May 1952
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 232, Appendix II (Part A-II of Final Engineering Report, AD-13,326–AD-13,329), NOa(s)-12017
AD-13,328

Electrolytic tank tests were conducted on a scale model of an RB-37 aircraft with a typical antenna system suspended between a mast and the vertical stabilizers. With a simulated aircraft charge of 500 kV, a corresponding measured potential of 91 kV was obtained for the floating section of the antenna relative to the aircraft. Potentials of about 35 kV were measured in full-scale tests. The DC potential to be expected on a floating section is a function of the existing voltage gradient and the mean distance of the section from the fuselage. The use of floating sections should be avoided, if possible, or the insulators in these sections should be designed for the potentials which are anticipated on the specific installation.

394. **CORONA INTERFERENCE REDUCTION BY POLARITY DISCRIMINATION**
Newman, M. M.
October 1952
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 239, Appendix I (AD-10,242–AD-10,244), AF 18(600)-74
AD-10,243

A simple rectifier method discriminating between signal and impulse noise was developed on the basis of the single polarity of the most severe interfering corona transients on antennas. With high interference and signal levels, a simple crystal rectifier without amplification gave 25-dB improvement ratios; no cross-modulation effects from strong adjacent-channel stations were noted. 8 pages.

395. **STUDY OF ELECTRICAL BREAKDOWN CONDITIONS IN THE AERODYNAMIC FLOW FIELD OF A HYPERSONIC VEHICLE**
Rudin, M., Pegent, B., Noble, C. E., Jr.
January 30, 1963
Vidya, Inc., Palo Alto, Calif.
Report 63-94, Final Report for August 1, 1961–July 31, 1962, Nonr-3581(00)
N63-14,637

A numerical technique has been formulated for solving the antenna-breakdown equation in the presence of gaseous flow for typical antenna electric field and aerodynamic flow field configurations. The results of computations for nonflow conditions agree well with existing data. Breakdown conditions were computed for sample cases of antenna type, vehicle shape, and velocity–altitude combinations. The results in air show that once ambipolar diffusion has been established, an increase in the vehicle velocity at a fixed altitude usually will result in an increase in the breakdown field strength. This increase is found to be caused principally by the increase of gas density near the antenna and, to a much lesser degree, by the effect of the boundary-layer flow velocity in sweeping electrons out of the high electric field regions. 174 pages; 39 references.

396. **RADIO INTERFERENCE FROM CORONA DISCHARGES**
Tanner, R. L.
April 1953
Stanford Research Institute, Menlo Park, Calif.
Technical Report 37, AF 19(604)-266
AD-12,600

Corona discharge studies are described that were devoted specifically to the mechanisms by which electromagnetic disturbances that cause interference with radio reception are produced. The means by which these disturbances are coupled into a receiver are treated, as well as the nature of the dependence of this coupling upon the geometrical configuration of the body on which the discharge occurs. A fundamental coupling theorem is developed which is based directly on Maxwell's field equations. The theorem can be applied in studying the noise signals coupled into the receiver from a discharge occurring at some remote corner of an aircraft. In addition, it is applicable to the converse situation: The dipole moment of the discharge can be inferred from the current pulse measured at the base of a discharge point and from certain supplemental electric field investigations for the discharge electrode system.

The experimental investigation of the transient nature of negative, point corona pulses was carried out with the aid of a newly developed oscilloscope which is capable of defining pulses having rise times of 7 mμsec. The coupling theory was applied in determining from the oscillographic data the effective dipole moments of the discharge. The overall results were applied to various configurations (the fixed wire, the prolate-spheroidal, and the cylindrical dipole antennas). Devices currently in use for the suppression of precipitation static are also discussed in the light of the theory developed. 69 pages; 74 references.

397. **PRECIPITATION CHARGING AND CORONA-GENERATED INTERFERENCE IN AIRCRAFT**
Tanner, R. L., Nanevicz, J. E.
April 1961
Stanford Research Institute, Menlo Park, Calif.
Technical Report 73, AFCRL-336, AF 19(604)-3458
AD-261,029
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Triboelectric charging, occurring when an aircraft is operated in precipitation, raises the aircraft potential until corona discharges occur from points of high DC field on the aircraft. These corona discharges generate noise which is coupled into receiving systems. A study was made of the spectral character of the corona noise source and included an investigation of the manner in which the source spectrum is affected by altitude. Since the noise spectrum magnitude depends upon the total current discharged, methods for determining the discharge current were devised. The problem of determining the distribution of current among the extremities of the antenna was investigated. 251 pages; 73 references.

398. **AN ANALYSIS OF CORONA-GENERATED INTERFERENCE IN AIRCRAFT**
Tanner, R. L., Nanevicz, J. E.
***IEEE, Proceedings of the*, v. 52, no. 1, pp. 44–52, January 1964**

A study was made of the problem of interference generated by corona discharges from points of high DC field on the aircraft as a result of its operation in precipitation. The coupling between the antenna and the noise source is discussed in terms of a reciprocity relationship. Because the geometry of an aircraft is complicated and a purely theoretical approach to the determination of coupling factors is not

possible, a technique was developed for measuring absolute values of the coupling factor as a function of frequency and position on the aircraft. A study was made of the spectral character of the corona noise source. This included the effects of altitude on the source spectrum. To test the validity of the theory and the results of the laboratory work, calculations are made to predict the noise currents induced in the test antennas employed in a flight test program. The results of these predictions are compared with the noise spectra measured in flight. 15 references. (*IAA*, A64-13,664)

399. A STUDY OF CORONA DISCHARGE NOISE IN AIRCRAFT ANTENNAS
Vassiliadis, A.
August 1960
Stanford Research Institute, Menlo Park, Calif.
TR-70, SRI Project 2494, AFCRL-TN-60-1107, AF 19(604)-3458

This study was undertaken to investigate the characteristics of corona discharge noise. The method used to determine the noise pulse characteristics is divided into two parts: the first is the study and measurement of the corona discharge pulse shapes and statistics; the second involves an evaluation of the electromagnetic coupling to a particular antenna.

400. A STUDY OF CORONA DISCHARGE NOISE IN AIRCRAFT ANTENNAS
Vassiliadis, A.
1961
Stanford University, Stanford, Calif.
Thesis

One of the more serious problems in aircraft communications is the radio noise interference which is caused by corona discharges on the aircraft. Although corona discharge noise has been known for a long time and attempts to eliminate the interference date back to 1937, very little is known concerning the exact nature of the noise pulses at the antenna terminals. Thus, the basic reason for this study is to investigate the characteristics of this noise.

When an aircraft flies through clouds, it develops a high negative charge due to the triboelectric effect of the impact of the ice particles in the cloud. Eventually, the electric field at the extremities (such as the wing tips) becomes sufficiently high for negative point corona discharges to occur. The discharge, which consists of numerous high energy pulses of current, causes electromagnetic interference which couples to an aircraft antenna. The character of the noise pulses at the antenna depends not only on the original characteristics of the corona but also on the aircraft structure and aircraft resonances which influence the frequency spectrum of the pulses.

The method used to determine the noise pulse characteristics may be divided into two parts: the first is the study and measurement of the corona discharge pulse shapes and statistics; the second involves an evaluation of the electromagnetic coupling to a particular antenna. 113 pages. (*DA*, 61-1258)

401. PRECIPITATION STATIC AND ATMOSPHERIC INTERFERENCE REDUCTION
June 1952
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 232, Final Engineering Report for May 1950–May 1952, NOa(s)-12017
AD-13,326

A study was made of the degree of coupling between aircraft antennas and precipitation static or corona from points on the aircraft having a small radius of curvature. Results showed that the coupling could be reduced by optimum placing of the antennas for a particular aircraft design. When this method fails to reduce interference sufficiently, a blanking-scheme-type rejector may be helpful. Two minimum-intelligible-signal blankers, models 1B and 2, were tested by means of simulated atmospheric interference from static generators. Improvement ratios of the order of 50 dB were obtained which exceeded the performance of noise limiters located in the audio stage. Although the models tested were not suitable for flight use, they demonstrated a technique which is capable of reducing noise consisting of discrete pulses having pulse-rate frequencies of about 100,000 or higher. Recommended measures for improving the blankers include removing the effects of large undesired carriers by increasing the overload limits. 43 pages.

ELECTRICAL HAZARDS

402. DANGER TO JET AIRCRAFT FROM LIGHTNING
Appleman, H. S.
July 1, 1964
Air Weather Service, Scott AFB, Ill.
TR-179
AD-602,765, N64-27,854

The latest available information on lightning hazards to jet aircraft is reported. The temperature and altitude range at which most strokes are encountered and the type of damage likely to be incurred are discussed. The possibility of fuel-tank explosions due to lightning and electrostatic discharges is considered in some detail. Although the possibility of such explosions is small, aircraft using JP-4 fuel are generally more vulnerable to this hazard than those using gasoline or kerosene. It is concluded from this and other hazards associated with JP-4 that jet passenger aircraft, at least, should use kerosene fuels where possible. 8 pages.

403. ELECTRIC DISCHARGES DURING SIMULATED AIRCRAFT FUELING
Bruinzeel, C.
***Institute of Petroleum, Journal of the*, v. 49, pp. 125–135; (discussion) pp. 135–139, May 1963**

Large-scale tests have shown that when highly refined aviation fuels are pumped through microfilters and hoses into aircraft wing tanks, potential gradients may develop inside which easily exceed spontaneous breakdown. A study of the hazard of electrical discharges near air–fuel interfaces in the vicinity of tank inlet systems indicates that the most critical periods appear to be the first stage of the fueling operation and the stage in which tanks are nearly full. The energy content of discharges is discussed. The relationship between sparking phenomena and increasing fuel conductivity is considered. (*EI*, 1963)

404. THE STUDY OF ELECTROSTATIC CHARGE GENERATION DURING LOW TEMPERATURE REFUELING OF AIRCRAFT
Bruinzeel, C., Luttik, C., Vellenga, S. J., Gardner, L.
October 1, 1963
National Research Council of Canada, Ottawa
Aeronautical Report LR-387

During January to March 1963, low temperature fueling tests were carried out at the RCAF Station, Winnipeg, Manitoba, using RCAF aircraft and fueling equipment. High electric field strengths were measured in the vapor space of a T-33 aircraft tip tank, the wing tank of a Yukon CC-106 aircraft, and in a small experimental tank. Discharges were observed at normal refueling flow rates in T-33 aircraft and in the test tank. Some were sufficiently powerful to present a serious explosion hazard should the vapor be in a flammable region, confirming the theory that previous explosions of aircraft should be attributed to electrostatic discharges. 76 pages. (*EI*, 1964)

405. ELECTROSTATIC SPARK IGNITION-SOURCE HAZARD IN AIRPLANE CRASHES
Busch, A. M.
October 1953
National Advisory Committee for Aeronautics, Washington, D.C.
TN 3026
AD-19,690

The hazard of igniting airplane crash fires by electrostatic sparks, generated when detached airplane parts fly through clouds of dust and fuel mist, was investigated. Within the limits of variables studied, the rates with which airplane wreckage collected a charge were directly proportional to the rate that clay dust or fuel mist was intercepted. Maximum rates of experimental electrification were used to relate energy accumulation to wreckage sizes and trajectories and to estimate minimum hazardous wreckage sizes and trajectories. Comparison of sizes and trajectories of wreckage shown in motion pictures of airplane crashes with these estimated sizes and trajectories indicates that the hazard is small. Of the remedial measures considered, polyethylene coatings were found to offer promise of protection against electrostatic spark ignition. 28 pages; 15 references.

406. THE CONTROL OF STATIC ELECTRICITY IN AIRCRAFT FUELING
Carruthers, J. A.
***Air BP* (International Aviation Service of the British Petroleum Company, Ltd.), no. 18, pp. 18–22, 1961**

The production of static electricity in aircraft fueling systems and the safety problems arising from it were studied. Methods used to minimize possible hazards from static electricity are considered. (*IAA*, 61-4155)

407. THE GENERATION OF STATIC ELECTRICITY DURING AIRCRAFT REFUELING
Gardner, L.
1963
National Research Council of Canada, Division of Mechanical Engineering and National Aeronautical Establishment, Ottawa
Quarterly Bulletin 4 (pp. 31–61)
(See also *Canadian Aeronautics and Space Journal*, v. 10, pp. 193–202, September 1964)

A general outline is presented of current knowledge concerning the electrostatic charging and discharging processes occurring during aircraft refueling. Electrostatic charge generation in fuels during transfer operations is caused by the separation of ions at an interface within the fuel system. The addition of water to the fuel system — in particular, the use of depth-type filtration equipment — increases charging considerably. The reason for this is that the water and filter introduce large surfaces where ion absorption and separation can occur. The results of several programs of the National Research Council of Canada in this field are presented. 10 references. (*IAA*, A64-16,039)

408. INVESTIGATION OF MECHANISMS OF POTENTIAL AIRCRAFT FUEL TANK VENT FIRES AND EXPLOSIONS CAUSED BY ATMOSPHERIC ELECTRICITY
Gerstein, M.
January 1964
National Aeronautics and Space Administration, Washington, D.C.
TN D-2240, NASr-59
N64-15,528
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A study was conducted to determine the important mechanisms involved in the ignition of fuel vapors issuing from a fuel tank vent under conditions of atmospheric electrical activity. The study included a literature review and experimental and analytical investigations of (1) the mixing of the fuel vent effluent with ambient air for three vent configura-

tions at simulated flight conditions; (2) the electrical environment in the vicinity of an aircraft during lightning activity, including measurements of the far field pressures associated with a high energy discharge; (3) ignition and flame propagation through channels smaller than the normal quenching distance, using high energy spark sources; and (4) simulated lightning discharges as to their capability of producing flames that can propagate through a typical fuel vent with and without a flame arrester. 185 pages.

409. ELECTROSTATIC DISCHARGES IN AIRCRAFT FUEL SYSTEMS
Harris, D. N., Ludwig, A. L., Karel, G.
Society of Automotive Engineers, Inc., New York, N.Y.
Paper 583B, presented at the SAE National Aerospace Engineering and Manufacturing Meeting, Los Angeles, Calif., October 8–12, 1962

The results of the Coordinating Research Council's Phase II program (Entry 424) are summarized. The purpose of the program was to study electrostatic phenomena during the fueling of both a full-scale mockup of a typical jet aircraft wing tank and a small-scale rig representing a single compartment of an integral wing tank. The tests were performed with equipment typical of modern aircraft fueling installations, and typical aviation turbine fuels as supplied by the manufacturers were used. 6 pages. (*IAA*, A63-10,200)

410. STATISCHE ELEKTRICITEIT BIJ AARDOLIEPRODUKTEN (STATIC ELECTRICITY IN PETROLEUM PRODUCTS)
Klinkenberg, A.
***Ingenieur*, v. 75, no. 47, pp. M51–55, November 22, 1963**

Recent developments concerning the mechanism of charging of hydrocarbon liquids in turbulent flow are reviewed. Safeguards provided by raising the conductivity are discussed. An investigation of static electricity is reported. The possibility that an electric hazard exists in fueling jet and turbine powered aircraft with ordinary or long-range kerosenes is examined. (*EI*, 1964)

411. SOME ATMOSPHERIC ELECTRIC INSTRUMENTS FOR USE IN AIR FORCE OPERATIONS
Moore, C. B., Leavitt, P. R., Vonnegut, B., Vrablik, E. A.
January 31, 1962
Arthur D. Little, Inc., Cambridge, Mass.
Final Report, AFCRL-62-233, AF 19(604)-7413
AD-273,307
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Knowledge concerning the origin and properties of lightning is reviewed. Requirements are given for a lightning warning device operating from the electrostatic component of the potential gradient change. Successful lightning counters are examined, and a design of a lightning detector recommended for Air Force use is presented. Also reported is the development of a corona current detector for use in warning of the onset of electrification in nearby clouds. A method using conductivity decreases for forecasting the onset of fogs is reviewed. The results are reported of observations of electrical conductivity, aerosol concentration, and visibility. 81 pages.

412. LIGHTNING PROTECTION FOR AIRCRAFT AND RELATED RADIO-INTERFERENCE REDUCTION
Newman, M. M., Stahmann, J. R., Robb, J. D., Magladry, R. E., Merriman, J. H.
July 1955
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 322, Interim Report 5 for April–June 1955, AF 33(616)-2459
AD-80,969

A combination of electrolytic tank studies and studies of HV discharges to a scale-model military-type jet aircraft indicated that lightning strokes to the side of a wingtip fuel tank are not a serious hazard, and that there is approximately an equal probability of frontal strokes to the wingtip fuel tank or nose. These results were substantiated by flight reports. Most discharges to wingtip tanks appeared to be swept back along the tank surface by the motion of the aircraft relative to the discharge channel, producing small pit marks, and then to hang on to the rear of the tail cone, often puncturing it. Elimination of the frontal lightning discharge hazard was considered possible by the construction of a double wall or by the use of heavier aluminum in the frontal tank section. The atmospherics recording system was modified by the addition of a new optical system, a new film recording system, and frequency changes. A balanced pulse generator which is independent of number and duration of discriminator pulses was developed for switching the shorting gate. 16 pages.

413. INVESTIGATION OF MINIMUM CORONA TYPE CURRENTS FOR IGNITION OF AIRCRAFT FUEL VAPORS
Newman, M. M., Robb, J. D.
June 1960
National Aeronautics and Space Administration, Washington, D.C.
TN D-440

An earlier investigation carried out over the period from December 1954 to December 1956 (Entry 417) showed that lightning hazards definitely exist in relation to aircraft fuel tanks. The present report, which is essentially a limited supplementary study on minimum corona-type currents that might cause fuel vapor ignition in fuel vent areas, established a much lower range of ignition currents that could present an indirect lightning hazard. Laboratory studies were made of minimum sparking currents versus time durations, in relation to possible fuel vapor ignition from potentials induced from lightning discharge currents at discontinuities along the aircraft skin. 12 pages.

414. AIRCRAFT PROTECTION FROM THUNDERSTORM ELECTROMAGNETIC EFFECTS. PART I. FIN CAP AND RADOME ANTENNA SYSTEM LIGHTNING PROTECTION
Newman, M. M., Robb, J. D.
March 1962
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 401, ASD-TDR-62-438, AF 33(616)-7828
AD-276,641, N64-13,874
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Reports from over 700 incidents of thunderstorm-lightning strikes to aircraft are tabulated, and, although the data on jets are not yet complete, the greatest incidence of strikes is found to occur at temperatures near 0°C and at altitudes of about 10,000 ft, with some lightning incidents at 40,000 ft. Point-of-strike frequencies are also tabulated. Applications of artificial lightning generators and model studies to determine point-of-strike probabilities and to reproduce natural lightning in-flight effects are discussed. Specific topics included are the use of HF lightning arresters to protect the antenna and radio equipment, and the use of graded resistance diverter rods to provide localized point-of-strike control. The development of radome protection is also discussed in detail, with particular emphasis on foil strip protection systems and proper use of bonding wires. 37 pages.

415. AIRCRAFT PROTECTION FROM THUNDERSTORM ELECTROMAGNETIC EFFECTS. PART II. AIRCRAFT FUEL VENTS
Newman, M. M., Robb, J. D.
July 1962
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 404, ASD-TDR-62-438 (Part II), AF 33(616)-7828
AD-294,650

The shape and location of aircraft fuel vents determine the electrical gradient at the vent outlet and, therefore, the aircraft potential under thunderstorm conditions in which electrical discharges can take place from the vent surface. Electrical discharges from a vent can attract approaching lightning discharges or can themselves be a possible source for fuel vapor ignition. Electric field plots showing the gradients about four typical vent shapes are presented along with plots and data of the shielding effect of vent screens, such as those used for flame arresters. While certain vent types appear to be superior from the electrical standpoint, it must be recognized that this is only one part of the overall problem, and that related problems (e.g., icing and fuel trapping in areas adjacent to the vent) must also be carefully considered in vent design. 19 pages. 5 references.

416. LIGHTNING PROTECTION MEASURES FOR AIRCRAFT FUEL SYSTEMS. PHASE I
Newman, A. M., Robb, J. D., Stahmann, J. R.
May 1964
Federal Aviation Agency, Washington, D.C.
FAA-ADS-17, FA-64WA-4955
AD-603,232, N64-26,277

Lightning is receiving increased recognition as a possible hazard to aircraft. An intensive four-month program covered in this report demonstrates the existence of possible ignition sources in a typical aircraft wing tank section as well as some feasible ignition source reduction measures. The tests, carried out on a typical jet transport fuel system, disclosed ignition possibilities produced by lightning that were essentially common to all aircraft. Direct stroke discharges to such points as fuel filler caps, access doors, and semi-insulated rivets, sparks and molten aluminum showers inside the fuel tank, and discharge streamers provided ignition sources near the vent openings. Sparking was also possible at semi-insulated joints and fastenings in areas that might contain trapped fuel vapors adjacent to the fuel tank. In order to obtain maximum possible induced effects from wiring near fuel gage wiring, strokes were directed to points near the flux gate unit and into a broken navigation light bulb. Induced effects on fuel gage wiring did not prove excessive by a factor of about 10 on the particular wing tested. 101 pages.

417. LIGHTNING HAZARDS TO AIRCRAFT FUEL TANKS
Robb, J. D., Hill, E. L., Newman, M. M., Stahmann, J. R.
September 1958
National Advisory Committee for Aeronautics, Washington, D.C.
TN-4326

The hazards of lightning strokes to aircraft fuel tanks were investigated in artificial-lightning-generation facilities constructed to duplicate closely the natural-lightning discharges to aircraft. There is a primary hazard whenever there is direct puncture of the fuel-tank wall, whereas the ignition of fuel by hot spots on tank walls due to lightning strokes is unlikely. Ninety percent of the natural-lightning strokes recorded have occurred in the temperature range of −10 to +10°C, where many of the jet fuels are flammable but where aviation gasoline is overrich. Also, 10% of the strokes recorded have been to the wings, which are the principal fuel-storage areas for modern aircraft. 58 pages; 2 references. (*MGA*, 1960, 11.7-76)

418. AIRPLANE CHARGING CURRENTS IN AN ACTIVE THUNDERSTORM
Stimmel, R. G.
October 1956
Wright Air Development Center, Communication and Navigation Lab., Wright-Patterson AFB, Ohio
WADC-TN-56-450
AD-119,091

Data from a test during which lightning struck an F-80A airplane flying through a thunderhead at a 39,000-ft altitude are reviewed, with speculative analyses of the electrical environment during a 50-sec record of extremity corona currents and charging patch currents prior to the stroke. The time

sequence of data is not significantly different from that observed during an earlier instance of a lightning strike to a B-25 research airplane flying nearer the freezing level of a thunderstorm. 8 pages.

419. BLITZE, KUGELBLITZE, ELMSFEUER (LIGHTNING, BALL LIGHTNING, AND ST. ELMO'S FIRE)
Toepler, M.
***Wissenschaftliche Zeitschrift der Technischen Hochschule bei Dresden*, v. 9, no. 1, pp. 102–112, 1959–1960**

Lightning, ball lightning, and St. Elmo's fire are discussed. An attempt is made to draw a clear distinction between the three categories, particularly between ball lightning and St. Elmo's fire, and to explain their mechanisms. The relationship between St. Elmo's fire and DC corona is treated. 23 references. (*EI*, 1960)

420. LIGHTNING AND AIRCRAFT. I — A BASIS FOR DISCUSSION
Turner, A. W.
***Air Line Pilot*, v. 33, pp. 7–11, October 1964**

A general discussion is presented concerning lightning and its effect on aircraft. Schonland of South Africa has shown that a lightning stroke from cloud to ground is a complex sequence of events. The first visible evidence of activity is in the form of a "stepped leader," a faintly luminous trail of ionized gas reaching downward from the cloud, which ultimately makes a conductive path, permitting a very large surge of electrons down the path to create a lightning bolt. Although lightning strikes on aircraft are generally considered more of a nuisance than a hazard, the possibility of lightning igniting combustible vapors in fuel tanks does exist and requires more research. Lightning is believed to strike an aircraft only when it happens to be in, or very near, the natural path of a lightning bolt. The problem can be resolved by either keeping aircraft away from lightning areas or taking steps to minimize possible damage. (*IAA*, A64-27,105)

421. LIGHTNING AND AIRCRAFT. II — FURTHER THOUGHTS AND CONSIDERATIONS
Turner, A. W.
***Air Line Pilot*, v. 33, pp. 10–15, 23, November 1964**

The effects of lightning on aircraft structure and components are discussed. Aircraft extremities, such as flight-control surfaces and propeller tips, and antennas of various kinds are vulnerable. Nonconductive shells (such as radomes) are frequently struck because of their location and because the metallic parts under them send out streamers. Radomes can be protected by applying consumable conductors, such as braided wire or thin metallic strips, to their surfaces; for permanent protection, they can be enclosed in Faraday cages. Lightning strikes can magnetize ferrous parts, induce troublesome secondary currents, and temporarily blind the crew. Statistics on lightning strikes to aircraft show that altitude plays a minor role. Lightning can be avoided by circumventing thunderstorms and clouds with high vertical development. Because most strikes occur at near-freezing temperatures, flight levels with temperatures above or below freezing should be selected. Problems of static dischargers are discussed, and the myth that static dischargers discourage lightning strikes is discredited. It is possible that, for very high power radars, ionization could be a significant factor in attracting strikes. (*IAA*, A65-11,120)

422. THE LIGHTNING BOOK
Viemeister, P. E.
Doubleday and Company, Inc., Garden City, N.Y., 1961

An outline covering lightning research from the earliest investigations to the present time is followed by a discussion, based partly on findings of the government-sponsored Thunderstorm Project of the late 1940s, of the origin of thunderstorms and lightning. Problems presented by lightning to aircraft — e.g., St. Elmo's fire — are included. 316 pages. (*IAA*, A63-13,080)

423. ELECTROSTATIC PROBLEM IN AIRCRAFT FUELING
Winter, E. F.
***Royal Aeronautical Society, Journal of the*, v. 66, no. 619, pp. 429–446, July 1962**

A summary is presented of work which was undertaken by Shell Research Ltd., England, over the past six years to check the safety of existing fueling operations and to determine the extent to which present and future fueling requirements might lead to significant hazards. Fuel properties which determine electrostatic phenomena during fueling are studied, and conditions which arise during pumping into the receiving tank are examined. Among the subjects covered are (1) charge generation during flow through aircraft fueling equipment, (2) full-scale fueling tests, and (3) means of preventing electrostatic hazard. (*EI*, 1962)

424. ELECTROSTATIC DISCHARGES IN AIRCRAFT FUEL SYSTEMS, PHASE II
July 1961
Coordinating Research Council, Inc., New York, N.Y.
CRC Project CA-22-59
(See also Entry 409)

A study was made of electrostatic phenomena during fueling of a jet aircraft wing tank and a small-scale rig representing a single compartment of an integral wing tank, using batches of typical aviation turbine fuels. The charge densities in the fuel, the electrostatic field strengths in the vapor spaces of the tanks, and the occurrence of discharges were measured as functions of operating conditions. High field strengths were attained over a wide range of operating conditions, resulting in discharges in many cases. 83 pages. (*EI*, 1961)

425. INVESTIGATION OF MECHANISM OF POTENTIAL AIRCRAFT FUEL TANK VENT FIRES AND EXPLOSIONS CAUSED BY ATMOSPHERIC ELECTRICITY
December 26, 1961

Lockheed-California Company, Burbank, Calif.
LAC-379280, Progress Report 1 for September 5–December 5, 1961
N62-10,978
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The nature of the potential fuel tank vent fire and explosion hazard is discussed in relation to present vent exit design practice, available knowledge of atmospheric electricity as a source of ignition energy, and the vent system vapor space environment. Flammable mixtures and possible ignition sources may occur simultaneously as rare phenomena, according to existing knowledge. The state of science must be extended in order to make possible a vent design which is aimed specifically at minimizing fire and explosion hazards.

In the experimental investigation being continued, data will be obtained on (1) fuel–air mixture profiles at the vent exit; (2) shock-wave energy densities in the near field of a lightning strike; (3) flame quenching in a high velocity gas stream; and (4) ignition potential of atmospheric electrical phenomena.

For the purposes of the present investigation, fuel tank vents are considered to be configured as one of the following: (1) masts which extend across stream lines and which discharge vapors into the free stream; (2) masts which discharge rearward into a generated wake such as by a wing; and (3) flush vents which discharge into a surface boundary layer. 50 pages.

426. INVESTIGATION OF MECHANISM OF POTENTIAL AIRCRAFT FUEL TANK VENT FIRES AND EXPLOSIONS CAUSED BY ATMOSPHERIC ELECTRICITY
1962

Lockheed-California Company, Burbank, Calif.
LAC-384183, Progress Report 2 for December 5, 1961–March 5, 1962
N62-11,272
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The setup and calibration of experimental equipment for an investigation of the mechanism of potential aircraft fuel tank vent fires and explosions caused by atmospheric electricity are discussed. In the experimental determination of concentration of profiles near a fuel vent exit, the first configuration to be studied is a flush-mounted vent with the flow entering the boundary layer on the surface containing the vent. The first test specimen has been constructed and is in the final stages of calibration.

A study has been started to determine the characteristics of a discharge originating at a vent exit as a result of charge buildup on the aircraft. The object is to determine whether changes in vent exit geometry can reduce the probability of streamers. Experiments have begun on high energy discharges and over-driven flames. Preliminary results indicate that energies ten times greater than minimum ignition are capable of affecting the velocity of propagation and can, under some conditions, force propagation through a tube which would normally quench a given flame. Analytical studies on the effects of discharge type and discharge volume have been initiated.

A study of methods suitable for measuring pressures associated with lightning strikes has been made. It has been decided to use an optical technique to measure shock wave velocities from which shock pressure can be deduced. This method has been successful in shock tubes and hot-shock tunnels. 10 pages.

DISCHARGERS AND OTHER PROTECTIVE MEASURES

427. DANGER OF LIGHTNING TO GLIDERS
Bader, J., Jakubowski, J. L., Zielinski, J.
Rozprawy Elektrotechniczne, v. 6, no. 1–2, pp. 45–76, 1960

The danger of lightning to gliders is discussed, and conditions under which very strong electric fields occur are described. The parts of a glider which are most liable to be struck by lightning are noted. The design of a lightning protection installation for a Bocian-type glider is presented. (*EI*, 1960)

428. AN INVESTIGATION OF ELECTRICAL CHARGING AND DISCHARGING OF AIRCRAFT IN FLIGHT
Born, G. J., Durbin, E. J.
December 1961
Princeton University, Department of Aeronautical Engineering, Instrumentation and Control Laboratory, Princeton, N.J.
Report 593, DA 44-177-tc-524
AD-273,976
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A brief theoretical investigation was made of the factors involved in the charging and discharging of an airborne helicopter. The dominant factor is keeping this charge small is a short discharge time constant compared with the charging time constant. Practically, the only means of controlling the discharge time constant is by controlling the resistivity of the air. Possible methods are discussed and evaluated. It is concluded that only corona discharge systems seem feasible at this time. Three possible corona discharge methods are discussed: (1) active DC corona point, including a measurement device and sensing element mounted on the ship; (2) active corona system with two DC corona points of opposite polarity mounted on the rotor blades, requiring no measuring or

sensing elements; and (3) active corona system with AC corona point having a low frequency (400 cps) AC voltage, mounted on the rotor blades, and requiring no measuring or sensing elements. 41 pages; 24 references.

429. DISCHARGE OF CORONA POINT CURRENT FROM AIRCRAFT
Chapman, S.
December 1, 1954
Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y.
Technical Report, RM-824-P-5, Nonr-90400
AD-118,584

In a system for maintaining zero electrostatic charge on aircraft, where electric field meters on the surfaces of the wings control a high-voltage corona discharge point behind the tail of the aircraft, the primary factors influencing the magnitude of blowaway discharge current are the point potential, aircraft speed, point geometry, and space charge from the already discharged current. The point potential must be large enough to create an electric field vector toward the rear to drive the discharge current into the space charge behind the point, but since the same point potential creates a field vector forward toward the aircraft skin, the point must be disposed so that the wind past the point prevents return current to the aircraft. The problem is approached mathematically from several points of view. For an aircraft speed of 100 m/sec and a point potential of 100 kV, the current should lie in the range 200–250 μA, although calculations based on different approximations vary from 175–395 μA. Experiments in the laboratory with wind simulated by an electric field yield 225 μA. Limited experimental and in-flight data imply that the current is about 200 μA. 56 pages.

430. HELICOPTER STATIC ELECTRICITY DISCHARGING DEVICE
de la Cierva, J.
December 1962
Army Transportation Research Command, Fort Eustis, Va.
TCREC-TR-62-33, DA 44-177-tc-728
AD-406,212
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Results are presented of a program for the alleviation of static electricity problems associated with helicopters. During the program, a static electricity discharging device for helicopters was designed, built, and tested. Flight tests were performed with an H-37 helicopter under a number of different flight conditions. During these flights, which were conducted in a natural charging current of 2 μA, the discharging device maintained the electrostatic energy level at below 1 mJ. It has been established that this energy level satisfactorily alleviates the existing problems caused by the presence of electrostatic charge. Factors affecting the performance of the device are listed, and recommendations are made to optimize future discharger research. Also, a test program was conducted to determine the performance of high voltage corona point probes under varying conditions of vehicle charge and polarity, corona point potential, and corona point geometry. The capacitance-to-ground of H-21 and H-37 aircraft was determined experimentally, as was the effect of the air velocity on the current output of high voltage corona points. 56 pages.

431. EVALUATION OF A HELICOPTER-FUSELAGE-MOUNTED DYNAMIC-NEUTRALIZER STATIC ELECTRICITY DISCHARGING SYSTEM
de la Cierva, J.
December 1962
Army Transportation Research Command, Fort Eustis, Va.
TCREC-TR-62-93, Technical Report for January–July 1962, DA 44-177-tc-843
N63-17,102

A static electricity discharging system known as the dynamic neutralizer has been designed, built, and flight tested, and the results are presented. The dynamic neutralizer had been previously tested in a rotor-blade-mounted version. The program discussed in the present report was concerned with the evaluation of this discharger when installed in the fuselage of an Army H-37 helicopter. The test data confirm that the principle of operation of the dynamic neutralizer is not affected by locating the entire device in the fuselage. 61 pages; 4 references.

432. A HIGH-PERFORMANCE ELECTROSTATIC DISCHARGER FOR HELICOPTERS
de la Cierva, J., Egea, L., Fraser, D. B., Perlmutter, A. A.
December 1963
Army Transportation Research Command, Fort Eustis, Va.
TRECOM-TR-63-43, Final Report for December 1962–June 1963, DCR-113, DA-44-177-AMC-3(T)
AD-600,451, N64-21,237

This report contains the results of a program concerned with the design, construction, and flight testing of a high-performance static electricity discharging system for helicopters. Flight test data showed that the discharging system kept the electrostatic energy of a CH-37 helicopter below 1 mJ for natural charging currents of up to 50 μA. Data were also obtained on the radio interference characteristics of the system and on the performance of corona points located in the engine exhaust stream. 97 pages.

433. INVESTIGATION OF AN ELECTROMAGNETIC INTERFERENCE-FREE ACTIVE STATIC DISCHARGING TECHNIQUE FOR FIXED AND ROTARY WIND AIRCRAFT
de la Cierva, J., Heller, D. L., Wilson, P. B., Jr.
August 1964
Dynasciences Corporation, Fort Washington, Pa.
DCR-131, Final Report for May–December 1963, AL-TDR-64-35, AF 33(657)-11597
AD-605,947, N64-31,931

An active electrostatic discharger was designed and constructed for the elimination of electrostatic charges from air-

craft. This discharger maintains the charge potential of any type of aircraft at a very low level. The RF interference generated by the corona discharge through the active discharger is very much lower than the interference generated by discharge from an aircraft equipped with passive dischargers. A study was made of the current and RF interference characteristics of corona discharge probes for use with active electrostatic dischargers. Characteristics of numerous probe designs were evaluated by wind-tunnel tests. A reduction of 40 to 60 dB, dependent upon the frequency and conditions in the RF interference noise due to static charge buildup in helicopters, can be anticipated by using discharging techniques. 99 pages.

434. A SHORT DISCUSSION OF THE FEASIBILITY OF THE USE OF RADIOACTIVE AND OTHER COATINGS IN ELIMINATING AIRCRAFT ELECTRICAL CHARGE
Durbin, E. J., Born, G. J.
September 1961
Princeton University, Department of Aeronautical Engineering, Instrumentation and Control Laboratory, Princeton, N.J.
Report 570, DA 44-177-tc-524
AD-267,823
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Different types of active discharging methods for aircraft were investigated, with special attention given to the AC corona systems and combined AC-DC corona systems. The necessary source strength of radioactive coatings and the dangers involved are discussed. The use of coatings is considered and it is concluded that no practical solution involving the use of passive coatings is readily discernible. 4 pages.

435. LIGHTNING PROTECTION OF AIRCRAFT INSULATED SECTIONS AND ANTENNA SYSTEMS (AND RELATED PRECIPITATION STATIC PROBLEMS)
July 1951
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 187, Final Engineering Report (Phase I), AF 33(038)-11373
AD-69,242

Research was undertaken to investigate methods of lightning protection and related precipitation static interference reduction for plastic aircraft sections, external and internal aircraft antennas, and aircraft structures (electrically insulated from the main body of the aircraft) used as antennas.

For sections of sufficient dielectric strength, the most promising of the lightning protection systems considered appeared to be a guiding system in which a small conductor on the inside canopy surface guides the discharge along preferred paths across the outside of the canopy to the aircraft frame. For insulating sections of insufficient dielectric strength to withstand puncture, the following systems were considered promising: (1) an external, gapped-conductor diverting system with a resistance coating over the balance of the section to prevent corona; (2) a combination insulated-antenna diverter wire which functions normally as an antenna, but will also puncture and provide a path to the aircraft frame in event of a stroke; and (3) an external, nonlinear graded-resistance system to form a diverting path for strokes, with a high-resistance coating over the balance of the section to prevent streamering and radio noise.

In some cases, such as with insulated metallic sections used as antennas, electronic circuitry provided the best possibilities for precipitation static interference reduction. The electronic circuitry approaches were studied separately as Phase II, and are presented in a separate report. 30 pages; 7 references.

436. ATMOSPHERIC STATIC INVESTIGATION (PHASE 5, SFERICS TRIANGULATION MEASUREMENTS)
March 1953
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 250 (AD-20,139a–AD-20,139c), Interim Report 14 for December 1952–February 1953 (Report 5 on Part 2) AF 18(600)-74
AD-20,139

A series of papers is presented in which discharge-information mechanisms, channel propagation factors, and methods of sferics recording and timing coordination are discussed. 3 pages.

437. DEVELOPMENT OF LIGHTNING PROTECTIVE METHODS AND RELATED RADIO-INTERFERENCE REDUCTION FOR AIRCRAFT
June 1954
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 279, Final Report (Part 1) for November 1951–October 1953, AF 18(600)-74
AD-79,552

Laboratory artificial lightning generation facilities, successfully expanded to more accurately duplicate natural lightning effects, produced damages to aircraft components which correlated well with lightning-damaged components obtained under cooperative flight research programs. Charge transfers in excess of 200 C were indicated in natural lightning strokes to aircraft by comparison with laboratory discharges. Nonmetallic canopy expansion joints constitute a serious lightning hazard which may be reduced by use of gapped, metallic conductors. Attachment of insulated antennas to acrylic canopy interiors induces dielectric breakdown for a high voltage rate of rise discharges.

This serious problem can be remedied by antenna insulation removal, reorientation, or proper spacing; however, the best system for canopy protection is an external diverter strip.

Specifications were determined for a single aircraft lightning arrester suitable for most wing or fin cap MHF antennas. Use of conducting coatings on insulated aircraft sections will reduce the severe radio interference due to charge streamering but will not remove all residual interference. Precipitation-static radio interference on external metal protection strips for aircraft canopies may be reduced by use of conducting coatings properly located. 85 pages.

438. AEROSPACE VEHICLE PROTECTION FROM ATMOSPHERIC ELECTRICAL HAZARDS
April 1961
Lightning and Transients Research Institute, Minneapolis, Minn.
Quarterly Report 1 for January–March 1961, ASD TN 61-74, AF 33(616)-7828
AD-259,726
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Initial work was done on lightning protection of airships. High current, artificial lightning discharge tests were carried out on four samples of lightning protection braid attachment systems. The braid was intended for use in providing an external protection conductor network on the outside of the airship to prevent lightning discharges from entering the interior. Tests of the four samples disclosed that in each case excessive temperatures and burns occurred which could damage the airship envelope. On the basis of the results, the sections were modified with locally available materials, and additional tests were run. The tests on the additional sections in which thick insulation was provided between the braid and the envelope showed that the thicker insulation was effective in preventing excessive temperature rise in the envelope material; however, the more effective systems were also excessively rigid for airship use. It is proposed that the results of both series of tests be incorporated in a final test on an additional section having suitable flexibility as well as good thermal insulation to prevent excessive temperatures in the envelope material. 18 pages.

439. LIGHTNING PROTECTION FOR RCAF ARGUS AIRCRAFT
November 1963
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 418, Report for May–July 1963
AD-440,603

A protection system, based on preliminary laboratory tests, was installed on an *Argus* aircraft for full-scale tests at the U.S. Naval Air Station at Mayport, Florida, using the artificial lightning generation facilities installed on the LTRI research ship *Thunderbolt*. Protection efforts were concentrated on areas of the aircraft where lightning strikes would be most often expected and where the strike damage would be most serious. These areas were the nose radome, nose observer area, fin cap, and MAD boom. For protection of the vertical fin, graded resistance diverter rods were installed to minimize damage to the fin structure by diverting the strikes through the diverter rod base and through conductors designed to carry the lightning currents. Solid conductors were installed on the acrylic nose observer dome for protection of the occupants. Foil strips similar to those used on the radomes of U.S. civil jet transports were installed on the radome, and a single graded-resistance diverter rod, along with dual grounding conductors, was installed on the MAD boom to reduce the magnetic flux inside the MAD boom during a strike. 30 pages; 6 references.

440. DEVELOPMENT OF HF NOTCH ANTENNA FOR THE ARGUS AIRCRAFT
Fulton, G. W., Compiler
September 1963
Royal Canadian Air Force, Central Experimental and Proving Establishment, Rockcliffe, Ontario, Canada
CEPE 1697
AD-428,155

Numerous damaging lightning strikes to the *Argus* aircraft have been attributed to failure of the lightning arrester. A notch antenna, to replace the existing fin cap antenna, has been designed and evaluated for lightning protection and HF radiation capability. Flight tests were made to compare the radiation patterns of the fin cap antenna, the notch antenna, and the fixed wire antenna. The radiation patterns for the notch antenna were found favorable, and it was concluded that the use of a notch antenna on the *Argus* was feasible. 41 pages.

441. DEVELOPMENT OF AIRCRAFT DISCHARGE METHODS
Harlor, T. L., Jordan, A. R., Murcray, D. G.
April 15, 1956
Denver, University of, Denver Research Institute, Colo.
Final Report for May 1952–April 15, 1956, AF 33(616)-157
AD-103,904

Methods were sought for reducing precipitation static on high-speed aircraft. The feasibility of the following methods was considered: (1) using the exhaust gases and flames as dischargers; (2) using an electron-gun tube capable of beaming free electrons from a hot filament out through a thin titanium anode into the free air; and (3) using an iridium wire as a hot-filament emitter operating directly in the atmosphere. The experimental and theoretical values for ion densities of exhaust gases at the pipe exit were about 10^7 and $1.6 \times 10^6/cm^3$ of gas, respectively. Microwave measurements on afterburner flames without additives showed ion densities of 10^8 to $10^9/cm^3$ at 1933°K, as compared with a value of 2×10^7 predicted by theory. Both experiment and theory give values of about 5×10^{10} with additives. Parallel-plate measurements showed that additives in the fuel caused a tenfold increase in the conductivity of gases from the Dynajet, but no significant increase in that from the F-94A. The aircraft field was quickly reduced from 400 to 100 V/cm for a

charging current of 422 μA in flight tests with the F-94A afterburner. Large volumes of highly ionized exhaust gases facilitate quiet discharges with reduced voltage gradient compared to point dischargers. Analysis indicated that the aft edge of the tail pipe collects most of the discharge current from a ½-in. cylindrical sheath. Dimensional analysis showed that the discharge current from an aircraft depends principally on a relationship between a term which is a linear function of the speed of transport of the gases and a term which varies linearly with ion density, field intensity, volume of gases, and mobility. A hot wire emitter of a noble metal (Ir) showed promise as a means of providing a quiet discharge for 40-μA currents from a wire 10 cm in length in a high field. 25 references.

442. DEVELOPMENT OF AIRCRAFT DISCHARGE METHODS
Murcray, D. G., Jordan, A. R.
June 1, 1953
Denver, University of, Denver Research Institute, Colo.
Quarterly Report 4 for February 1–May 1, 1953,
AF 33(616)-157
AD-15,557

This is the fourth in a series of reports on investigations of the electrical properties of the exhaust stream as a means for discharging precipitation static. A Dynajet model (pulsejet) engine was operated in a high-intensity electrostatic field to simulate a full-size jet airplane under precipitation static conditions. An estimated overall accuracy of 10% was obtained in discharge measurements. Positive and negative potential gradients were established around the engine by means of suitable power supplies connected to an insulated metal cylindrical can (6 in. in radius and 20 in. long) which was mounted concentric with the axis of the tailpipe. An electric probe (⅛ in. in diameter and 20 in. long) was installed in the exhaust stream and connected directly to the tail pipe. Tests were made both with and without the probe and a fuel additive (cesium hydroxide in ethyl alcohol). Results showed that the discharge currents were noticeably increased by the probe and additive separately, but the highest discharge currents were obtained when both were used together. A strong transverse electric field was established across the gas stream by means of two plane-plate electrodes with six needle points mounted on one of the plates. Discharge currents as high as 500 μA were obtained. 13 pages.

443. FIELD MAPPING TECHNIQUES FOR LIGHTNING PROTECTION
Murray, W. E.
***IEEE Transactions on Aerospace*, v. AS-1, pp. 982–998,**
August 1963
(Paper presented at the IEEE International Conference and Exhibit on Aerospace Support, Washington, D.C., August 4–9, 1963)

Basic lightning phenomena, field mapping methods for determining the pre-strike field conditions, and a field equation analysis of the transition from the static to the dynamic state are briefly discussed. This analysis is provided for the pre-strike period, the lightning stroke, and follow-through period, and is continued until static field conditions are restored. 19 references. (*IAA*, A63-23,315)

444. DEVELOPMENT AND TESTING OF TECHNIQUES FOR PRECIPITATION STATIC INTERFERENCE REDUCTION
Nanevicz, J. E., Vance, E. F., Tanner, R. L., Hilbers, G. R.
January 1962
Stanford Research Institute, Menlo Park, Calif.
Final Report for April 1959–December 1961 on Electromagnetic Compatibility Techniques,
ASD-TDR-62-38, AF 33(616)-6561
AD-272,807

The theory of noise produced in aircraft antennas by corona discharges from the aircraft extremities is discussed. Some possible methods of reducing or eliminating corona interference are investigated, including passive and active dischargers, decoupled antennas, biased engine exhausts, and interference blankers. Laboratory techniques useful in determining aircraft threshold potentials, discharger currents, and discharger noise reduction are described. The coupling theory and laboratory techniques are applied to the design of active and passive ortho-decoupled dischargers which provide a noise reduction of the order of 60 dB. Tests were conducted on civil jet transports and on military jet, turboprop, and piston engine aircraft to demonstrate the effectiveness and durability of the passive ortho-decoupled discharger. A test jig was designed to measure the RF noise produced by passive static dischargers. 187 pages; 18 references.

445. SOME TECHNIQUES FOR THE ELIMINATION OF CORONA DISCHARGE NOISE IN AIRCRAFT ANTENNAS
Nanevicz, J. E., Tanner, R. L.
***IEEE, Proceedings of the*, v. 52, no. 1, pp. 53–64,**
January 1964

The theories of noise generation and coupling are applied to the development of techniques for the elimination of precipitation static interference in aircraft. The logical consequences of the theories are employed in devising several versions of a decoupled discharger capable of providing precipitation static noise reduction of 60 dB. Optimum discharge locations are determined and successful flight tests of dischargers are described. Various proposed discharger designs are considered in the light of the coupling theory, and their performance when tested in the laboratory is discussed. Several antenna designs capable of providing precipitation static reduction on vehicles which do not permit discharger installation were proposed and tested in the laboratory. Electronic techniques are considered for reducing precipitation static interference by operating on the signal at the receiver. It is indicated that, although many of the proposed

precipitation static elimination techniques are not entirely satisfactory, the satisfactory performance of the decoupled dischargers and decoupled antennas eliminates the problem of precipitation static under normal flight conditions. 17 references. (*IAA*, A64-13,665)

446. CORRELATION BETWEEN CLEAR-AIR TURBULENCE AND ELECTRIC FIELDS
Nanevicz, J. E., Vance, E. F., Serebreny, S.
February 1965
Stanford Research Institute, Menlo Park, Calif.
Scientific Report 1, AFCRL-65-112, AF 19(628)-3308
AD-613,035
(Also available through Clearinghouse, U.S. Dept. of Commerce, Springfield, Va.)

The results of a cooperative effort by Standard Research Institute, United Air Lines, and Air Force Systems Command to determine the correlation between regions of clear-air turbulence and aircraft electrical activity are described. Corona discharges from precipitation static dischargers on DC-8 aircraft were monitored and correlated with clear-air turblence encounters. A significant correlation was found to exist between clear-air turbulence encounters and periods of electrical discharge. It is suggested that these electrical discharges may be caused by electric fields in the region of clear-air turbulence, particulate matter in the region that charges the aircraft, or a combination of both. 33 pages.

447. DEVELOPMENT OF LIGHTNING PROTECTIVE METHODS AND RELATED RADIO-INTERFERENCE REDUCTION FOR AIRCRAFT
Newman, M. M., Robb, J. D.
August 1952
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 222, Interim Report 7 for May–July 1952 (Report 3 on Part 1), AF 18(600)-74
AD-1757

An artificial multiple-lightning current generator is described. Tests on the F-89 aircraft canopy showed the need for lightning protection on canopies with nonmetallic expansion joints. A canopy with an open metal-strip protection system withstood an artificial lightning discharge of 100,000 A followed by a 30-C discharge, although some pitting was observed. Three-inch sections of a 1-MΩ wick discharger, which was attached to the ends of an ARN-30 "Ramshorn" omnirange antenna mounted on top of a vertical fin, reduced precipitation static interference at 115 Mc from several hundred microvolts to a negligible amount at fields corresponding to 250 kV on a moderate size aircraft. Results of tests on proposed aircraft lightning arrestor designs for MHF fin or wing cap antennas are discussed. Reduction of VHF precipitation static from an ARN-30 omnirange antenna to a negligible value was accomplished by resistive decoupling in the form of 1-MΩ wick dischargers attached to the extremities. Investigations of the precipitation static coupling from an ARN-30 Ramshorn antenna, located on a simulated aircraft fin, to an insulated wire antenna running from the fin to an aircraft fuselage section disclosed a coupling of 0.0153 V from the corona pulse voltage of 0.354 V. Application of resistive decoupling to an experimental whip compass sense antenna reduced precipitation static interference at 1 Mc from 10,000 to 100 μV residual. 21 pages.

448. AIRCRAFT CORONA INTERFERENCE VARIATION WITH ALTITUDE
Newman, M. M., Robb, J. D.
September 1952
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 232, Appendix III (Part A-III of Final Engineering Report, AD-13,326–AD-13,329), NOa(s) 12017
AD-13,329

Earlier flight measurements at various altitudes up to 25,000 ft showed that spark gap air dielectric breakdown variations were identical with results obtained in ground tests using an altitude chamber. Tests were conducted with an altitude chamber modified to permit voltages up to about 100 kV. Oscillograms of corona produced with various types of electrodes and various test arrangements are given. Tests of a resistive fabric-wick discharger and a fine wire-type discharger showed that, if the wire is connected close to an antenna, less noise will be coupled into the receiving equipment with the fabric wick. The data showed that the rise times of the corona wave shapes are of the order of, or less than, 0.01 μsec. The pulse duration is about 0.1 μsec, and the pulse rate frequencies vary from 0 to 5 million/sec. Although the rise times do not vary much with altitude, the amplitudes vary from a few millivolts to several volts. The altitude effect is similar to that of increasing the electric field.

449. DEVELOPMENT OF LIGHTNING PROTECTIVE METHODS
Newman, M. M., Robb, J. D.
November 1952
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 242, Interim Report 10 for August–October 1952, AF 18(600)-74
AD-10,241

Precipitation static tests of the Ramshorn omnirange-ILS antenna indicated that corona discharge could be quieted by (1) a solid resistance on the glideslope studs, and (2) sections of standard AN/ASA-3 wick discharger on the rear omnirange sections. Similar tests of the whip-type compass-sense antenna showed that the discharge could be quieted by a solid resistance discharger in an insulated tube. Preliminary tests of a blade-type compass-sense antenna showed a noise threshold corresponding to an aircraft-belly electric field of 600 to 800 V/cm. 16 pages.

450. LIGHTNING PROTECTION FOR AIRCRAFT AND RELATED RADIO-INTERFERENCE REDUCTION
Newman, M. M., Robb, J. D.
July 1954
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 309, Interim Report 1 for April–June 1954, AF 33(616)-2459, (continuation of AF 18(600)-74)
AD-39,119

An electrically shielded enclosure was constructed under the top corona shield of the high-voltage DC generator. This will permit precipitation static measurements of aircraft antennas fastened to the HV generator corona shield. The electric field about an antenna fastened to the generator corona shield simulates the free-space electric field about an antenna attached to a charged aircraft in flight. Study of the voltage wave-front attenuation along a long artificial discharge path is being conducted for a better evaluation of the voltage rates of rise to be expected on aircraft canopies subjected to natural lightning discharges. Stroke guiding system resistances in the long artificial lightning discharge experiments proved to be critical as to relative lengths, and are being made longer to prevent surface flashovers from diverting current from the intended channel path to the test airplane canopy. 5 pages.

451. LIGHTNING PROTECTION FOR AIRCRAFT AND RELATED RADIO-INTERFERENCE REDUCTION
Newman, M. M., Robb, J. D., Stahmann, J. R., Magladry, R. E., Merriman, J. H.
April 1955
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 320, Interim Report 4 for January–March 1955, AF 33(616)-2459
AD-80,968

Study was continued on the problem of lightning protection of large radomes and, in particular, the radome on the nose of a large transport aircraft. Consideration was given to the following methods previously developed for protecting plastic sections from lightning damage: (1) stroke guiding systems, (2) external conductors (gapped or solid), (3) exposed metal buttons, (4) diverting rods, and (5) graded resistance methods. The stroke guiding systems and graded resistance methods were considered inapplicable to the radome problem. Studies indicated that external conductor systems are optimum for large radomes, while exposed grounded buttons or lightning diverter rods may be effectively used for small radomes or plastic enclosures. An evaluation of an all-metal aircraft wick discharger showed that, although the lightning damage to the aircraft frame may be reduced, the poor precipitation static characteristics of the metal wick probably cancel any such gains. A combination lightning diverter rod and fabric wick discharger was recommended for providing both lightning protection and quiet static discharging of the aircraft. Studies of lightning hazards to jet aircraft wingtip fuel tanks were concentrated on electrolytic tank investigations and windstream effects on pitting of fuel tanks in order to obtain interim protection pending more comprehensive studies. 28 pages.

452. AIRCRAFT PROTECTION FROM ATMOSPHERIC ELECTRICAL HAZARDS
Newman, M. M., Stahmann, J. R., Robb, J. D.
April 1960
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 366, Quarterly Report 12 for January–March 1960, WADD TN 60-248, AF 33(616)-3991
AD-243,925

Measurements on a lightweight, sensitive capacitance bridge circuit for detecting punctures in aircraft insulated antennas showed that punctures of the order of 0.08 in. in diameter could be detected. Smaller punctures were difficult to detect because of small capacitance variations on even the unpunctured portion of the antenna, which tended to mask the capacitance change at a puncture, and because of surface charge pickup. Aircraft discharger currents, as measured in still air in the laboratory, are increased in flight where some of the space charge which accumulates about the discharger is carried off in the windstream. Initial laboratory wind tunnel measurements (at air velocities up to 420 mph) showed a roughly linear relationship between discharger current and velocity at higher air velocities — above a certain threshold air velocity. The threshold air velocity increased with increased potential on the discharger. In laboratory studies, a sample braided aluminum diverter cable for airship interim lightning protection could be partly severed and pulled out of its end lugs under moderate simulated lightning current conditions. Under the worst laboratory conditions, the cable could be completely severed and a minor rip produced in the airship fabric. A 12-ft empennage diverter located above the ruddervator tab, at an angle of 35 deg with respect to the outside edge of the ruddervator and in its plane, appears optimum. 21 pages.

453. MEASUREMENT OF RESISTANCE COATINGS ON AIRCRAFT INSULATED SECTIONS
Newman, M. M., Robb, J. D., Chen, Ta.
November 1961
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 388, ASD TN 61-142, AF 33(616)-7828
AD-268,440

Resistance coatings are frequently used on aircraft insulated surfaces to dissipate precipitation charge which could produce electrical streamering, radio interference, and possible puncture of the surface. The measurement of resistive surfaces is generally made by using two probes. To correlate this point-to-point resistance measurement with the resistance per square given in specifications, the theoretical relationships were derived. Results show that the point-to-point resistances and the resistances per square are approximately equal

over a considerable range of practical measurement values. An investigation was carried out to study the possibility that ionization produced by a high-power radar beam could act as a lightning diverter to draw lightning discharges into aircraft or airships. The results show that a power of several hundred megawatts per square meter would be required. 23 pages.

454. AIRCRAFT PROTECTION FROM ATMOSPHERIC ELECTRICAL HAZARDS
Newman, M. M., Robb, J. D.
December 1961
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 374, Final Report, ASD TR 61-493, AF 33(616)-3991
AD-274,741

Thunderstorm atmospheric electric gradients can induce intense corona streamers and severe radio interference, although usually of short duration. Since direct lightning strokes to faster aircraft can involve structural hazards, protection has been developed for areas with plastic sections, as in the case of fin-cap antenna systems and radomes. Potential problems of as yet statistically undetermined degree of hazard, such as possible fuel system lightning ignition, are discussed, and related continuing research is briefly outlined. Laboratory lightning tests for production versions of new lightning protective design prototypes are considered essential. Artificial lightning checks are also desirable for the overall aircraft system. Proper relationships should exist to ensure a lower desired operating voltage within an arrester to prevent external flashovers at the highest aircraft operating altitudes. 109 pages; 22 references.

455. EQUIVALENT FIELD METHOD FOR TESTING AIRCRAFT STATIC DISCHARGERS
Newman, M. M., Robb, J. D., Nestvold, E. O., Chen, Ta.
January 1962
Lightning and Transients Research Institute, Minneapolis, Minn.
L&T Report 396, ASD-TN-61-163, AF 33(616)-7828
AD-271,432
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A new test system was devised to permit comparison of standard-type dischargers with new dischargers which require specific orientation with RF fields about aircraft. The system consists of a simulated aircraft section surrounded by an octagonal screen chamber, shaped to reproduce approximately an equipotential as measured about a model aircraft in an electrolytic tank. The new system preserves the electric field relationships which would be found at a discharger extremity in flight and permits correlation of the field magnitudes by the use of electrolytic tank plots. A theoretical study was made of radio interference fields produced by corona discharges on metal and resistive needles. Studies indicate that, for the assumed geometry, an orientation parallel to the supporting aircraft surface reduces the interference field magnitudes by approximately a factor of 200 over an orientation perpendicular to the aircraft mounting surface. Corona discharges from resistive points show an additional reduction in interference magnitudes of about 200 over the corresponding metal point discharges in either orientation. 26 pages; 4 references.

456. INVESTIGATION OF MEANS TO MAINTAIN ZERO ELECTRICAL CHARGE ON AIRCRAFT
Pelton, F. M.
1953
Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y.
Report RA-766-P-7, Interim Report for November 1, 1952–February 1, 1953, AF 19(122)-475
AD-28,623

A modified system was developed for maintaining zero electrical charge on an aircraft. The system consisted of the following: an electric field measuring instrument to detect the charge; a discharging point to release electric charge from the tail of the aircraft; a variable high voltage supply to activate the discharge point; and a set of electronic circuits to complete a feedback control of the high voltage supply based on the signals obtained from the field measuring instruments. Although the summarized system remained essentially in its original form as proposed for this contract (as described in Reports RA-766-P-1 through P-6), control circuit modifications under development during this report period will lead to a simplified and more reliable system. 15 pages.

457. INVESTIGATION OF MEANS TO MAINTAIN ZERO ELECTRICAL CHARGE ON AIRCRAFT
Pelton, F. M.
1953
Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y.
Report RA-766-P-8, Interim Report for February 1–June 30, 1953, AF 19(122)-475
AD-17,500

Flight tests were conducted to determine whether an aircraft could be zero-charged by the use of a controlled high-voltage corona discharge point, and to obtain performance data on the high-voltage discharge system and on the B-29 aircraft to determine appropriate parameters for the closed-loop control system. Four types of tests were made: (1) the natural time constants of the aircraft, (2) constant voltage runs, (3) manual control of the charge in the aircraft, and (4) automatic control of the charge on the aircraft. Three sets of time constants of the aircraft in flight were obtained with the high-voltage system inactivated. Two were taken at altitudes of 7500 and 12,000 ft during climbing conditions, and the third was taken under level flight conditions at a 20,000-ft altitude. The ability of the equipment to zero the electrostatic charge on the aircraft automatically was demonstrated by the coherence of the recorder traces. 23 pages.

458. INVESTIGATION OF MEANS TO MAINTAIN ZERO ELECTRICAL CHARGE ON AIRCRAFT
Pelton, F. M.
1953
Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y.
Report RA-766-P-9, Interim Report for July 1–October 31, 1953, AF 19(122)-475
AD-28,398

In the preceding reports under this contract, the design, fabrication, installation, and preliminary flight tests of a system for maintaining zero electric charge on an aircraft are described. During the period covered by this report, the major emphasis was on flight study and analysis. 3 pages.

459. INVESTIGATION OF MEANS TO MAINTAIN ZERO ELECTRICAL CHARGE ON AIRCRAFT
Pelton, F. M.
October 31, 1953
Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y.
Report RA-766-P-10, Final Engineering Report, AF 19(122)-475
AD-35,098

Electrostatic field detectors were installed to measure the field due to electrostatic charges on the aircraft while remaining insensitive to external fields. Electrostatic field detection was accomplished by means of rotary-vane generating voltmeters and all-electronic servomechanisms which produced DC output voltages proportional to the impressed electrostatic fields. The maximum output value was 100 V. A corona discharge point, located at the tail of the aircraft, was driven by a DC voltage supply capable of producing positive and negative voltages from 0 to 100 kV. A minor feedback loop provided suitable linearization of the control voltage vs. corona characteristic and yielded satisfactory transient response. The overall control loop had the characteristic of a single integration which provided sufficient gain to limit steady-state errors in aircraft potential to less than that which would cause 1.0 V/cm wing field. Bench tests provided information regarding linearity and transient response of the system. An altitude chamber test was made to demonstrate satisfactory operation of the high voltage equipment when operated at pressures corresponding to altitudes up to at least 40,000 ft. Flight tests revealed the satisfactory operation of the system and indicated that the system provided rapid control of the aircraft potential. 62 pages; 34 references.

460. ACCUMULATION AND DISSIPATION OF STATIC ELECTRICITY IN HELICOPTERS
Poteate, S. B., Jr.
***American Helicopter Society, Journal of the*, v. 7, pp. 3–9, April 1962**

The factors involved in the accumulation of static electricity by helicopters in flight are discussed, as well as methods by which these voltages may be reduced to acceptable levels. Preliminary data gathered in a helicopter survey are presented, the phenomenon of corona discharge is discussed, and the high-voltage corona discharge system is shown to be the most suitable technique for voltage reduction. (*IAA*, 62-7718)

461. HIGH-ALTITUDE FLASHOVER AND CORONA PROBLEMS. I — DESIGN TECHNIQUES
Starr, W. T.
***Electro-Technology*, v. 69, no. 5, pp. 124–127, May 1962**

Practical techniques used to increase corona and flashover voltages at high altitudes are summarized. Design problems connected with transformers, radar antennas, and various other components are discussed. 19 references. (*IAA*, 62-5756)

462. HIGH-ALTITUDE FLASHOVER AND CORONA PROBLEMS. II — EXPERIMENTAL DATA
Starr, W. T.
***Electro-Technology*, v. 69, no. 6, pp. 128–134, June 1962**

This article is a summary and analysis of experimental data on corona and flashover problems gathered from published and unpublished literature. 16 references. (*IAA*, 62-6769)

463. STUDY AND INVESTIGATION OF METHODS OF DISSIPATION OF STATIC ELECTRICITY ON HELICOPTERS
Tona, C. J.
September 1960
Army Transportation Research Command, Fort Eustis, Va.
TREC-TR-60-55, Report BB-1368-H, DA 44-177-tc-544
AD-252,149

Various methods for eliminating the static charge on helicopters are considered and evaluated on the basis of test data derived from an intensive field test program. Both active and passive corona systems, along with a radioactive device, were installed in an H-37 aircraft for test evaluation. Passive discharge wicks were found to be limited in operating characteristics, and the radioactive system presented problems relative to handling characteristics. The active corona discharge system provided adequate control of the aircraft charge potential and is concluded to be the most feasible approach to this problem area. 75 pages; 11 references.

464. AUTOMATIC CONTROL OF STATIC ELECTRICITY FOR ARMY HELICOPTERS
Tona, C. J.
October 1962
Army Transportation Research Command, Fort Eustis, Va.
TCREC-TR-62-22, DA 44-177-tc-652
AD-299,123, N63-13,506

A corona discharge system was designed to automatically maintain a net charge of approximately zero on a helicopter. Extensive operational tests were conducted following completion of the system. An electrostatic field sensor was used to measure the incident field due to the electrostatic charge on the aircraft. An error signal, proportional to the difference between the charge existing on the aircraft and a chosen

reference level, was used to control operational sequence of a high-voltage power supply connected to a corona discharge point. The removal of charge from the aircraft in the form of a discharge current is done in such a manner as to minimize the error within a closed-loop system. System equipment was installed in an H-37 helicopter and operational tests were conducted in a hot-day environment. The aircraft charge was maintained automatically within predetermined limits, corresponding to a net remaining charge voltage of approximately 300 V with respect to ground. 90 pages; 10 references.

465. HIGH VOLTAGE FLASHOVER OF INSULATING BARRIERS
Uhlrich, P.
December 26, 1951
The Boeing Company, Seattle, Wash.
D-12534

Information is presented concerning the use of insulating barriers between adjacent live terminals or between a live terminal and ground. Curves are included showing the effect of various barriers upon DC flashover voltages for altitudes up to 80,000 ft. The comparative effectiveness of various barriers is determined. No attempt is made to study the properties of insulating materials.

466. AIRCRAFT PROPELLER CORONA THRESHOLD AND ITS EFFECT ON PRECIPITATION STATIC NOISE REDUCTION
Vance, E. F., Nanevicz, J. E.
November 1963
Stanford Research Institute, Menlo Park, Calif.
TR-77, AFCRL-63-511, AF 19(628)-325
AD-423,414, N64-11,443

The aircraft potential at which the propellers go into corona is determined as a function of aircraft size, propeller size, and engine location. The propeller threshold potentials are used with data from earlier precipitation static studies to calculate the number of passive dischargers required to handle a given charging rate without interference from propeller corona. In general, it is found that unless the propellers are modified to prevent or decouple noise produced by propeller corona, a very large number of dischargers is required to provide noise reduction on a propeller aircraft comparable to the noise reduction obtained with 21 dischargers on a jet transport. Some possible methods of preventing propeller corona noise are discussed. The problems of discharging helicopters and other hovering aircraft are also discussed. 90 pages.

467. LIGHTNING PROTECTION METHODS. A CUSTOM ABSTRACT SEARCH
Willey, G., Henery, R. B., Compilers
June 1963
Defense Documentation Center, Cameron Station, Alexandria, Va.
DDC-ARB-17510, Report for January 1953–May 1963
AD-406,847

A bibliography was compiled on the use of lightning arresters for aircraft safety and static elimination.

468. PROTECTION D'UN PLANEUR CONTRE LES EFFETS DU COUP DE FOUDRE ET DE L'ELECTRICITÉ ATMOSPHÉRIQUE (PROTECTION OF SAILPLANES AGAINST THE EFFECTS OF THUNDERBOLTS AND ATMOSPHERIC ELECTRICITY)
Zielinski, J.
***Schweizer Aero-Revue*, v. 34, no. 9, pp. 509–602, September 1959**

Research is described which was undertaken by the Laboratory of High Voltage of the Polytechnic School at Warsaw in order to choose safety devices suitable for the protection of sailplanes against the effects of atmospheric electricity and of thunderbolts. A study of the increase of voltage in the cockpit of the sailplane shows that installation of discharge conductors on some salient spots of the sailplane will provide sufficient protection for other parts. This safety device eliminates muscular contraction during flight in thunderclouds, and the loss, owing to physical causes, of the ability to steer the sailplane during a thunderbolt. Efficacy of screening the sailplane against electromagnetic surges is greatly dependent on the number of discharge conductors, and the danger threatening the pilot is directly influenced by his bodily resistance. (*MGA*, 1960, 11.2-92)

SMALL PROJECTILES

469. CHARGE DRAG ON PROJECT WEST FORD NEEDLES
Beard, D. B.
Journal of Geophysical Research, v. 67, no. 9, pp. 3293–3297, August 1962

A detailed analysis of the estimated charge drag on the West Ford orbiting needles is presented. The electrical potential surrounding pieces of wire in the ionosphere is computed assuming photoemission is negligible, and is shown to vary logarithmically with distance at small distances from the needle and to vary exponentially with distance at distances of the order of the Debye length for the medium. The resulting drag due to Coulombic deflection of hydrogen ions is probably an order of magnitude greater than the neutral drag at the proposed altitude of 3700 km.

470. THE PLASMA-SHEATH-INDUCED RADAR ABSORPTION EFFECT IN HYPERSONIC BALLISTIC RANGES
Blore, W. E., Musal, H. M., Jr.
January 1965
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
CTN 65-03, DA-01-021-AMC-11359(Z)

An explanation has recently been proposed for the anomalously large decrease in radar cross section that occurs when spheres ½ in. in diameter are observed by 4- or 8-mm-wavelength radars at velocities near 13,000 ft/sec and pressures of 10 mm Hg. The new explanation hinges on the diffractive effect of sharp angular gradients in the plasma sheath surrounding the sphere. Some comparisons between this new theory and experiment are presented for two different bodies and range conditions.

471. RESEARCHES ON THE PHENOMENA OBSERVED WHEN A BODY IS MOVING IN AN IONIZED ATMOSPHERE BY THE METHOD OF THE REVOLVING ARM
Devienne, F. M., Roustan, A.
July 1960
Mediterranean Laboratory of Thermodynamic Research, Nice, France
Technical Note, AFOSR TN-60-907, AF 61(052)-124
AD-242,183

The revolving arm method is used to study the phenomena occurring at the surface of a body moving in an ionized atmosphere and the phenomena arising in the vicinity of the trajectory of the body. A high frequency field generated by an oscillator with a frequency range of up to 100 Mc is used to produce ionization. A pulse generator is used to study the equilibrium phenomena in rarefied gas. Ionization is measured by Langmuir probes.

The variations in the ionic current obtained from a metallic surface as a function of the velocity were shown to be smaller than predicted by theory. This is attributed to the influence of impurities on the plates, which become electrically charged during the motion and produce an electric potential tending to repulse the ions. In addition, the rise in temperature of an ionized gas is compared with the temperature rise obtained for a nonionized gas at the same pressure. The electrical phenomena arising near the trajectory of a moving body are examined. 70 pages.

472. STUDY OF THE DISTURBANCE CAUSED BY A MOVING BODY IN A PARTIALLY IONIZED GAS
Devienne, F. M., Roustan, A.
January 1961
Mediterranean Laboratory of Thermodynamic Research, Nice, France
Technical Note, AFOSR 566

An experimental investigation was made of electrical phenomena liable to occur in the vicinity of the trajectory of a body moving through a partially ionized gas, at pressures of 0.5–5.0μ. The vacuum tank and ionization apparatus are described and illustrated in detail. The ionization rate was studied by means of Langmuir probes, and special attention was given to the state of equilibrium of the medium and to the effect of the surface condition of the probes. A detailed study was made of electrical phenomena near the trajectory of a moving metal arm, and the numerous factors affecting the duration and intensity of these disturbances are discussed. The results indicate that the duration of the disturbance is, to a considerable extent, proportional to the duration of the passage of the moving body, and inversely proportional to its speed. It is concluded that variations in electronic as well as ionic density occur. 106 pages. (*IAA*, 61-8916)

473. SCALING EXPERIMENTS ON WAKE IONIZATION BEHIND NONABLATING HYPERSONIC SPHERES
Eschenroeder, A. Q., Hayami, R. A.
November 1964
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
TR 64-02L, DA-01-021-AMC-11359(Z)
AD-452,260, N65-14,063

Binary scaling is demonstrated for the ionization in the near wake of nonablating blunt objects flying at hypersonic speeds. The experiments employ transverse microwave probe instrumentation used in conjunction with a free-flight ballistic range. An accelerated-reservoir light-gas gun is used to launch copper-plastic spheres varying in diameter from 5 to 15 mm. The results indicate the validity of the scaling hypothesis, but demonstrate its limitations at high ambient densities. 18 pages.

474. IONIZATION ASSOCIATED WITH HYPERVELOCITY IMPACT
Friichtenicht, J. F., Slattery, J. C.
March 14, 1963
Space Technology Laboratories, Physical Electronics Laboratory, Redondo Beach, Calif.
Report 8699-6002-RU-000, NASw-561
N63-15,412
(Paper presented at the Sixth Hypervelocity Impact Symposium, Cleveland, Ohio, April 30–May 2, 1963; also available as TN D-2091, National Aeronautics and Space Administration, Washington, D.C., August 1963, and through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Interest in the development of micrometeoroid detection systems has led to a program of research in which efforts have been concentrated on phenomena associated with hypervelocity impact which might be applicable to such systems. It has been found that electrically charged particles are emitted from the site of a hypervelocity impact. The quantity of charge emitted from semi-infinite targets was measured as a function of target material, projectile material, particle velocity, and mass. The experiments were conducted with micron-sized iron and carbon black (graphite) particles from the electrostatic hypervelocity accelerator. Data were collected for velocities up to 16 km/sec. Qualitative observations of ionization produced from the thin-foil impacts were also made. 21 pages; 3 references.

475. MEASUREMENTS OF IONIZATION PRODUCED BY HYPERVELOCITY PROJECTILES IN AIR
Kluck, J. H., Siperly, B.
June 30, 1960
General Dynamics Corporation, Convair Division, San Diego, Calif.
Report ZPh-062, pp. IV-13, IV-14

A résumé is given of preliminary microwave measurements of the electron density in the trails of hypervelocity projectiles. (*IAA*, 61-6918)

476. A TECHNIQUE FOR MEASURING THE ELECTRICAL CONDUCTIVITY OF WAKES OF PROJECTILES AT HYPERSONIC SPEEDS
Koritz, H. E., Keck, J. C.
September 1963
Avco-Everett Research Laboratory, Everett, Mass.
RR 167, BSD-TDR-63-201, AF 04(694)-33, DA-19-020-AMC-0210
AD-425,619, N64-12,250
(See also *Review of Scientific Instruments*, v. 35, no. 2, pp. 201–208, February 1964)

A technique is described for measuring the electrical conductivity of hypersonic wakes and any conducting medium by measurement of the Joule losses produced by the oscillating magnetic field of a circular coil surrounding it. The apparatus consists of a symmetrical RF bridge with two arms which contain identical coils. A conducting medium inserted into one of the coils unbalances the bridge, changing the apparent impedance of the coil. Although the apparatus was designed specifically to investigate the conductivity of hypersonic wakes, it has also been used to measure the conductivity of electrolytic solutions, electrical discharges, flames, and plasmas produced in shock tubes. The measurements on electrolytic solutions gave results in satisfactory agreement with their known conductivities and provided a convenient check on the calibration of the apparatus. The shock-tube measurements were made in air and agreed well with the results of Lamb and Lin. Results of the measurements of the conductivity of electrolytic solutions, shock-tube heated plasmas, and hypersonic wakes of 0.22-in. (diameter) nylon spheres in argon are presented. 20 pages.

477. RADIAL ELECTRON DISTRIBUTION IN WAKES OF HYPERVELOCITY PROJECTILES
Kritz, A. H.
April 1963
General Dynamics/Astronautics, Space Science Laboratory, San Diego, Calif.
BBE63-001, DA-04-495-ORD-3383(Z)
AD-403,296, N63-16,313

The problem of utilizing microwave diagnostics to study the wakes of hypervelocity projectiles is reviewed. The utilization of back-scatter microwave data is discussed. It is shown that if the wake ionization radius is considered to grow in proportion to either the square root or cube root of distance behind the projectile, the microwave data are inconsistent with the assumption that the radial electron distribution is uniform, parabolic, J_0-type, Gaussian, or exponential. In order that the linear charge density, inferred from the forward-scatter data, be consistent with that derived from the back-scatter data, the effective ionization radius is determined as a function of distance behind the projectile for Gaussian, uniform, and parabolic radial distributions. By utilizing the data obtained from a series of shots at the NASA Ames Hypervelocity Ballistic Range, the effective radius for ionization is shown to decrease in the region of 50 to 200 body diameters behind the projectile. 31 pages; 27 references.

478. MEASUREMENT OF THE DIAMETER OF THE ELECTRONIC WAKE OF HYPERSONIC PELLETS
Labitt, M.
January 20, 1964
Massachusetts Institute of Technology, Lincoln Laboratory, Lexington
TR-342, ESD-TDR-64-20, AF 19(628)-500
AD-438,816, N64-25,992

The complex dipole moment generated by the presence of an electronic wake in a transverse alternating field is measured and used to calculate the average volume electron density and the diameter of the cylinder model (assuming a uniformly dense cylinder model). Diameters and densities are plotted as a function of time and distance behind the pellet over a pressure range of 5 to 40 torrs, encompassing both the laminar and turbulent regimes. 14 pages.

479. SONDAGE DES PLASMAS PAR DES MESURES D'IMPEDANCE (PROBING OF PLASMAS BY IMPEDANCE MEASUREMENTS)
Laug, M., Clavelin, P.
In "Proceedings of the First International Congress on Instrumentation in Aerospace Simulation Facilities, Paris, France, September 28–29, 1964," pp. 6-1–6-8
INTERCON, 1964 (Proceedings available through P. L. Clemens, Arnold Air Force Station, Tenn.)

The ionized wakes of hypervelocity pellets are investigated by the resonant-cavity method. The input admittance of the cavity is measured with a four-probe admittance meter, and displayed as an *XY*-trace with a Smith chart on an oscilloscope cathode-ray tube. Two methods are suggested to make the measurement time-resolved. From the two measured parameters (real and imaginary parts of the admittance), the plasma parameters (total number of electrons within the cavity, and electron collision frequency) are deduced. The applicable energy–perturbation theory is described. Accuracy, calibration methods, and limitations are discussed. The same apparatus is used to probe shock-ionized air in a coaxial shock tube. The propagation of 250-Mc waves is studied by this method. 11 references. (*IAA*, A64-28,110)

480. A SURVEY OF HYPERVELOCITY RANGE DATA ON WAKES
Leong, S. H.
July 1964
Brown Engineering Company, Inc., Huntsville, Ala.
Technical Note, BrownEng-R-107, DA-01-021-AMC-85(Z)
AD-607,166
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A compilation of wake data obtained from hypervelocity range experiments by various investigators is presented. Quantities of interest are wake velocity decay, electron density distribution, wake growth, and transition distance. 68 pages.

481. DYNAMICAL CONSIDERATIONS RELATING TO THE WEST FORD EXPERIMENT
Lyttleton, R. A., Singer, S. F.
In "Torques and Attitude Sensing in Earth Satellites," pp. 107–115
Singer, S. F., Editor
Academic Press, Inc., New York, N.Y., 1964
(See Entry 16)

This paper is motivated by the failure to detect the West Ford needles and the fact that as yet no explanation seems to have been found. Three effects are suggested that may have operated to prevent the system from functioning in the manner intended. These effects are: (1) a change in the axis of rotation of the needle dispenser, due to the dissipation of dynamical energy of rotation through internal imperfections of elasticity; (2) a subsequent greatly decreased dispensing rate of the needles, due to the reduced angular velocity and to possible interference effects associated with the package design; and (3) a rapid dispersion, due to the action of Coulomb electrical drag, of needles which might have been released. The consequences of these effects for the experiment are examined. (*IAA*, A64-25,297)

482. AEROPHYSICAL STUDIES AT HYPERSONIC VELOCITIES IN FREE-FLIGHT RANGES
Maiden, C. J., St. Pierre, C., Friend, W. H.
October 1960
Canadian Armament Research and Development Establishment, Valcartier, Quebec
CARDE-TM-AB-65
AD-263,750
(Paper presented at the Second International Congress of the Aeronautical Sciences, Zurich, Switzerland, September 1960)

Aerophysical studies that were conducted in the CARDE hypersonic facility are described. Results show that optical measurements and microwave interaction techniques are most valuable in studying the plasma surrounding a hypersonic body. 22 pages.

483. SOME MEASUREMENTS OF THE PHYSICAL PROPERTIES OF THE PLASMA SHEATH AROUND HYPERSONIC PROJECTILES
Maiden, C. J., St. Pierre, C.
Planetary and Space Science, v. 6, pp. 196–206, June 1961
(Paper presented at the Symposium on the Plasma Sheath: Its Effects on Communication and Detection, Boston, Mass., December 7–9, 1959—Entry 22)

A brief description of the CARDE hypersonic range facility is presented, as well as experimental results obtained on ½-in.-caliber models of various shapes which were launched into a controlled atmosphere at velocities up to 16,000 ft/sec. The stagnation point conditions relevant to the velocities and range pressures used in these tests are estimated theoretically. Physical properties of the plasma, such as temperature, density, gas composition, and electron density, are given. It is found that stagnation point temperatures as high as 7,000°K can be obtained. The ablative effect of such temperatures is discussed, and the results, showing meteor-like trails behind the models, are presented. Also described are systems developed for the measurement of the intensity of radiation emitted by the plasma surrounding a hypervelocity projectile. The equipment used in the tests, comprising photomultipliers, infrared detectors, spectrographs, and multichannel monochromators, is briefly discussed. 10 references. (*IAA*, 62-52)

484. ELECTROMAGNETIC STUDIES OF IONIZED WAKES
Murphy, E. L., Edelberg, S., Pippert, G. F.
April 20, 1962
Massachusetts Institute of Technology, Lincoln Laboratory, Lexington
Technical Report 266, AF 19(604)-7400
N62-14,782

During the hypervelocity ballistic range experiments, data on ionized trails behind hypersonic pellets were obtained using (1) microwave horns to measure the electromagnetic

complex reflection and transmission coefficients for the region of trail illuminated by the horn, (2) microwave cavities designed to measure the complex admittance of the portion of the trail within the cavity, and (3) double Langmuir probes to measure local plasma density. The three methods of measurement and the corresponding analyses for reduction of data are described. A model is adopted for the ionized region which makes it possible to relate the electromagnetic parameters to quantities such as electron density, collision frequency, and their space and time distributions. These quantities are related to flow and thermodynamic variables. Cylindrical trails with uniform and radially varying dielectric properties have been treated theoretically; both are described. However, only the uniform case was used when reducing the microwave horn data. The UHF cavity data were reduced on the basis of a complex dielectric post, axially uniform within the cavity. The double Langmuir probe data were reduced conventionally to obtain ion densities from probe current; this requires knowledge of the local ion temperature, or an assumption for its value. 27 pages; 14 references.

485. MILLIMETER RADAR INSTRUMENTATION FOR STUDYING PLASMA EFFECTS ASSOCIATED WITH HYPERSONIC FLIGHT
Musal, H. M., Jr., Primich, R. I., Blore, W. E., Robillard, P. E.
August 1964
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
TR-64-02J, DA-04-495-ORD-3567(Z)
AD-449,823, N65-12,750
(Also available in "Proceedings of the First International Congress on Instrumentation in Aerospace Simulation Facilities, Paris, France, September 28–29, 1964," pp. 7-1–7-13, INTERCON, 1964)

Millimeter wavelength radars are being used to study the plasma effects associated with the ionized flow fields of projectiles launched at hypersonic speeds into a free-flight ballistic range. Two CW Doppler radars, which operate at frequencies of 35 and 70 Gc, are used to measure the nose-on backscattering radar cross sections of projectiles during their flight. The design and performance of the two radars, which operate simultaneously through a wire-grid beam splitter, are described in detail. A Doppler signal simulator provides absolute calibration of each radar so that the dynamic radar cross section of the projectile in flight can be measured to within ± 1 dB. The purpose of this millimeter radar instrumentation is to measure the changes that occur in the radar cross sections of hypersonic projectiles caused by their highly ionized flow fields. 18 pages.

486. CW OBLIQUE RADAR FOR STUDYING THE SCATTERING CHARACTERISTICS OF IONIZED WAKES, I: 35-GC RADAR WITHOUT SEPARATE PHASE- AND AMPLITUDE-MEASURING CAPABILITIES
Robillard, P.
October 1964
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
CTN-64-11, DA-01-021-AMC-11359(Z)
AD-450,192, N65-12,757

Initial observations made with the 35-Gc oblique radar show that strong signals can be detected from wakes produced by hypersonic projectiles fired on a free-flight range. Firings of spheres and cones have been observed with both low- and high-resolution antennas, and wake transition has been detected with the high-resolution antenna. Data previously obtained with a simple CW doppler radar are being used as a guide in improving the oblique radar. 24 pages.

487. TWO-DIMENSIONAL WAKE MEASUREMENTS, PART II. ELECTRON DENSITY
Sandborn, V. A., Todisco, A.
October 25, 1963
Avco Corporation Research and Advanced Development Division, Wilmington, Mass.
TM 63-19 (Pt. II), AF 04(694)-264
AD-423,246

Exploratory measurements of the electron density in the wake of two-dimensional wedges are reported. Two shock tubes having diameters of 1.5 and 6.5 in., respectively, were used to produce a high temperature real-gas flow. A 10-deg wedge was the wake generator in the former, and a 20-deg wedge was the wake in the latter. Electron collector probes were used to explore the near wake behind the wedges. 50 pages.

488. EXPERIMENTAL STUDY OF CHARGE DRAG ON ORBITING DIPOLES
Shapiro, I. I., Maron, I., Kraft, L., Jr.
***Journal of Geophysical Research*, v. 68, no. 7, pp. 1845–1850, April 1, 1963**

The influence of charge drag on the orbital lifetime of very thin dipoles is studied. Six tin dipoles were placed in a near-polar, near-circular orbit at a mean altitude of about 3100 km. Radar observations made over a period of about two months, while the dipoles were continuously in sunlight, indicate that charge drag has not produced a decrease in mean altitude at an average rate greater than 0.3 km/yr. If an approximate scaling law is used, it is found that the corresponding upper bound on the decrease in mean altitude of microwave dipoles (1 mil in diameter) is about 90 km/yr. Additional assumptions about the plasma lead to the establishment of an upper limit of 0.6 V for the average magnitude of the electrostatic potential of the dipoles during this experiment. 12 references.

489. EXPERIMENTAL BOUND ON THE ORBITAL EFFECTS OF CHARGE DRAG
Shapiro, I. I.
***Journal of Geophysical Research*, v. 69, no. 21, pp. 4693–4695, November 1, 1964**

Radar observations of transits of the peak density of the Project West Ford dipoles are compared with theoretical calculations based on an equivalent sphere model. It is concluded that charge drag could have caused a decrease in dipole mean altitude at a rate no greater than 10 km/yr and perhaps considerably less than 3 km/yr. The calculations indicate that the average magnitude of the electrostatic potential on a typical West Ford dipole during its first 80 days in orbit probably did not exceed 0.16 V. This upper bound on the potential is four times lower than that determined from the 1962 UHF dipole experiment. 6 references.

490. MICROMETEORITE IMPACT STUDIES
Slattery, J. C.
June 30, 1964
Space Technology Laboratories, Physical Research Laboratory, Redondo Beach, Calif.
Final Report, STL-8447-6010-SU-000, NASA-CR-54057
N64-24,989
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The burst of free charge produced by a hypervelocity particle impact was investigated. The hypervelocity particles were iron spheres with diameters ranging from 0.1 to 1.0 μ. The amount of charge produced per unit impacting particle mass was measured for several target materials at velocities from 3 to 25 km/sec. The effect was found to be independent of (1) target temperature to 600°C, (2) electric field to 10^6 V/m, and (3) small amounts of cesium contamination. Self-sustaining electrical discharges have been initiated in simulated ion engines by hypervelocity particle impacts. 37 pages.

491. TECHNIQUES FOR RADIATION MEASUREMENTS AND FLOW VISUALIZATION OF SELF-LUMINOUS HYPERSONIC WAKES
Taylor, R. L., Keck, J. C., Washburn, W. K., Leonard, D. A., Melcher, B. W., II, Carbone, R. M.
In "Transactions of the Seventh Symposium on Ballistic Missile and Space Technology, Colorado Springs, Colo., August 13–16, 1962—Volume I," pp. 211–236
Air Force Systems Command, and Aerospace Corporation, Los Angeles, Calif., 1962

Techniques for investigating the wake generated by hypervelocity projectiles in a ballistic range are described. These techniques fall into two categories: (1) photoelectric instruments for measuring the radiation intensity and its distribution in the wake, and (2) instruments for visualizing or photographing the flow field. In the first category, a photoelectric recorder is discussed which measures the radiation intensity as a function of distance downstream in the wake. A wake scanner is described by which it is possible to scan the wake every few microseconds, and to obtain profiles of the radiation distribution in a plane nearly perpendicular to the flight direction. In the second category, drum-camera techniques, including a "race-track" adaptation, are described which photograph the self-luminous flow field. Data available from these drum-camera techniques include gas-particle velocity in the wake, shedding frequency of turbulent eddies, and width and rate of growth of the luminous wake. A schlieren technique is discussed in which the refractivity of the test gas is increased by using a small particle pressure of sodium vapor in the gas and taking the schlieren photograph with light of wavelength close to the sodium resonance line at 5,896 Å. Good quality schlieren photographs have been obtained at densities less than 1% of atmospheric. The use of an image converter to take snapshot photographs of the self-luminous wake is discussed. Pictures showing the details of the luminous flow field in the base region are presented. 13 references.

492. INVESTIGATION OF PRECURSOR IONIZATION IN FRONT OF THE SHOCK WAVES OF HYPERSONIC PROJECTILES
Zivanovic, S.
September 1963
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
TR-63-217E, DA-04-495-ORD-3567(Z)
AD-423,930, N64-22,288
(Paper 63-458, presented at the AIAA Conference on Physics of Entry Into Planetary Atmospheres, Cambridge, Mass., August 26–28, 1963)

An experimental attempt was made to measure the ionization level as a function of distance ahead of the shock front of hypersonic projectiles in a ballistic range. The maximum electron density just preceding the shock front was measured as a function of velocity and ambient pressure. For velocities up to 6,700 m/sec and pressures up to 30 mm Hg, the measured density of electrons in the vicinity of the shock front is of the order of 10^9 electrons/cm^3. The maximum electron density of the precursor ionization increases almost exponentially with velocity. At a fixed pressure, the maximum electron density increases about 30 times for an increase of velocity from 5,300 to 6,700 m/sec (18,000–22,000 ft/sec). The electron density also increases with pressure, but this variation is not so explicit. An additional experiment shows that, at least in the considered region of velocities (5,300 to 6,700 m/sec), the photo-ionization is the dominant mechanism and electron diffusion plays only a secondary role. 32 pages; 12 references.

493. PRELIMINARY INVESTIGATIONS OF THE IONIZATION AHEAD OF THE SHOCK WAVES OF HYPERSONIC PROJECTILES
Zivanovic, S.
January 1964
General Motors Corporation, Defense Research Laboratories, Santa Barbara, Calif.
TR-64-02A, DA-04-495-ORD-3567(Z)

Several experiments were conducted to provide a better understanding of the ionization region in front of a shock wave. It was found that the signals caused by electrons in this region can be detected several body diameters ahead of the hypersonic models, and that these signals can be altered if the model passes through a region with a strong electric field.

CELESTIAL BODIES

GENERAL REFERENCES

494. COSMICAL ELECTRODYNAMICS
Alfvén, H., Fälthammar, C.-G.
Oxford University Press, Clarendon Press, London, England, 1963 (Second Edition)

The fundamental principles of plasma physics and magnetohydrodynamics are considered in detail with regard to both cosmic and laboratory phenomena. The emphasis is on the physical (rather than the mathematical) aspects in order to strengthen the relationship between theory and experiments or observations. 228 pages.

495. FUNDAMENTALS OF COSMIC ELECTRODYNAMICS
Pikel'ner, S. B.
February 1964
National Aeronautics and Space Administration, Washington, D.C.
TT F-175
N64-17,162
(Translation of "Osnovy Kosmicheskoy Elektrodinamiki," State Publishing House for Physico-Mathematical Literature, Moscow, 1961; also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The present work systematically presents the basic idea of cosmic electrodynamics and shows how these ideas relate to astrophysics and geophysics. The subject matter presented includes the following: (1) plasma with no magnetic field; (2) plasma in a magnetic field; (3) the interaction of a magnetic field and a moving conducting medium; (4) plasma waves; (5) stability; (6) increase in field strength resulting from motion of a medium; and (7) applications to astrophysics. 273 pages; 254 references.

496. SPACE RESEARCH III
Priester, W., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1963
(Proceedings of the Third International Space Science Symposium, Washington, D.C., May 2–8, 1962)

The Third International Space Science Symposium, held from May 2 through May 8, 1962 in Washington, D.C., was organized jointly by the International Committee on Space Research (COSPAR) and the Space Science Board of the U.S. National Academy of Sciences.

More than 500 participants from 30 countries attended the symposium and 141 papers were presented by scientists from 14 countries. The symposium consisted of six sessions on the following topics:

1. Upper Atmosphere and Exosphere of the Earth and Relationship to Solar Disturbances
2. The Sun and the Interplanetary Medium
3. The Moon and the Planets
4. Galactic and Extragalactic Astronomy
5. Life Sciences
6. Technologies of Space Research

This volume contains many of the papers presented at the symposium. However, the proceedings of the fifth session (Life Sciences) have been published separately, and papers from the first session have been rearranged to include only those concerned with the Earth's atmosphere above 85 km. (See Entries 27 and 636)

EARTH

497. THE DISTRIBUTION OF IONS AND ELECTRONS IN THE EARTH'S EXOSPHERE
Angerami, J. J., Thomas, J. O.
December 1963
Stanford University, Electronics Laboratory, Stanford, Calif.
Technical Report 4, SEL-63-110, SEL TR-3412-3,
AFOSR-64-1370
AD-604,040
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.; see also *Journal of Geophysical Research*, v. 69, no. 21, pp. 4537–4560, November 1, 1964)

The factors which govern the distribution of electrons and ions in the Earth's exosphere are discussed. The theory takes into account the effect of the electric field which arises from charge separation, the centrifugal force arising from the rotation of the Earth, and the effect of the Earth's gravitational field. It is assumed that the charged particles are constrained to move only along the direction of the Earth's magnetic lines of force. Also considered are the modifications that result in the electron and ion distributions when a temperature variation is assumed along a line of force. The results predicted by the theory are compared with actual experimental observa-

tions of the exospheric plasma which have been obtained in recent years using whistlers and using topside ionograms made by the *Alouette* satellite. 134 pages. 37 references.

498. STUDY OF THE MAGNETIC FIELD IN COSMIC SPACE

Dolginov, Sh. Sh., Pushkov, N. V.
***Kosmicheskie Issledovaniya*, v. 1, no. 1, pp. 55–97, July–August 1963**
(Translated from the Russian in *Cosmic Research*, v. 1, no. 1, pp. 45–77, July–August 1963)

The experimental data on the magnetic field of the Earth, the Moon, and interplanetary space which were obtained by means of U.S. and USSR Earth satellites and space rockets are reviewed. A comparison is made of results of measurements conducted in the immediate vicinity of the Earth, in the outer radiation belt, and at the boundary of the geomagnetic field in magnetically quiet and magnetically disturbed days on the day and night sides of the Earth. Proceeding from these results, the following problems are discussed: (1) the degree of agreement between the various analytical representations of the geomagnetic field and the actual field distribution in cosmic space; (2) the existence of external sources of the permanent geomagnetic field; (3) the existence and location of the ring current responsible for the field of magnetic storms; (4) the topology of the lines of force at great distances and the physical boundary of the geomagnetic field. Also discussed are results of measurements in interplanetary space and measurements of the magnetic field in the vicinity of the Moon and Venus.

499. STRUCTURE OF THE ELECTROSTATIC FIELD IN THE FREE ATMOSPHERE FROM THE RESULTS OF INVESTIGATIONS MADE DURING THE INTERNATIONAL GEOPHYSICAL YEAR

Imyanitov, I. M., Chubarina, E. V.
***Akademiya Nauk SSSR, Doklady*, v. 132, no. 1, pp. 104–107, May 1, 1960**

The theory of a spherical capacitor is summarized as a means of explaining the origin of the electrical field of the atmosphere. The results of soundings of the electrical field of the atmosphere carried out during the IGY at Leningrad, Kiev, and Tashkent are examined in the light of the above theory. The experimental data which were obtained do not confirm the hypothesis of the spherical capacitor. However, the data can be interpreted if the hypothesis of a charged field surrounded by a total charge is assumed. The Earth is surrounded by a total charge with a field superimposed upon the field of its surface charge and fluctuations which "lubricate" the fluctuations of unitary variations since the fluctuations of potential aloft are produced by variations in the distribution and magnitude of the total atmospheric charge. If the field potential produced by the actual charge of the Earth is subtracted from the measured field, then it becomes possible to determine in the first approximation the field produced by the total atmospheric charge. The terrestrial sphere can be classified into three regions: (1) regions of generation of the total charge; (2) regions where the monotonicity of variations of potential of the electric field with height are destroyed by the total charges brought in from the first region; and (3) regions where the total charge of an entire atmosphere column is small and does not perceptibly affect the field of the surface charge of the Earth. 9 references. (*MGA*, 1961, 12.11-396)

500. ELECTRONS OF THE EARTH

Nienaltowski, W.
In "Proceedings of the 20th National Electronics Conference, Chicago, Ill., October 18–21, 1964, Volume 20," pp. 814–819
National Electronics Conference, Inc., Chicago, Ill., 1964

A structure of the Earth is postulated which assumes that at one time the Earth was in a completely molten state. The implications are discussed, and it is concluded that internal processes of a thermoelectric nature are manifested by variations in the electric charge on the Earth's surface.

It is also deduced that a circular flow of free charges generated by thermoemissivity of metallic deposits can be expected in the Earth's interior. The direction and spatial distribution of this flow are in agreement with the Earth's magnetic flux. The effects of the surface charge on the Earth's electric field are discussed. Variations of local pressure, stratification of the atmosphere, reflectivity of ionized layers, and other processes, as the charge is carried further through the atmosphere, are also considered. 6 references.

501. THE POSITIVELY CHARGED EARTH

Pietenpol, W. B.
***Planetary and Space Science*, v. 12, no. 6, pp. 652–656, June 1964**

Apparatus and experiments designed to determine the surface charge of the Earth by a direct method, independent of electrostatic induction effects, are described. Conclusive evidence was obtained that the normal fair-weather surface charge of the Earth is positive, although for about two hundred years the concept that the Earth has a normal negative surface charge has been universally maintained.

The new concept that the Earth has a positive surface charge is in good agreement with the fact that cosmic rays bring predominantly positively charged particles to the Earth and lower atmosphere. This constitutes the primary source of the positive charge of the Earth and atmosphere. A quasi-equilibrium status is reached when the rate of entry of cosmic ray positive particles equals the rate at which they are released from the upper fringe regions of the atmosphere. Thus, there is a combined Earth and lower atmosphere positive charge to provide an electric field in effect radially outward from the Earth's surface. This new concept offers a new approach to the explanation of atmospheric electrical effects.

502. ON THE HORIZONTAL COMPONENTS OF THE ATMOSPHERIC ELECTRIC FIELD NEAR A PLANE UNDERLYING SURFACE
Tammet, Kh. F., Saluvere, T. A.
***Akademiya Nauk SSSR, Izvestia, Seriya Geofizicheskaya,* v. 1963, no. 4, pp. 654–656, April 1963**
(Translated from the Russian in *Bulletin of the Academy of Sciences of the USSR, Geophysical Series*, v. 1963, no. 4, pp. 406–407, April 1963)

The electric field strength vector intersects an ideal conducting surface perpendicularly. However, the field near the ground cannot be assumed to be vertical. The relationship between the horizontal and vertical components of the electric field near the ground is studied, and the distribution of space charges is considered. An improved experimental method for determining the horizontal components is described.

503. ENVIRONMENTAL ELECTRICITY
Tilson, S.
***International Science and Technology*, no. 25, pp. 24–34, January 1964**

The flow of electricity across boundaries in space and time is surveyed. Variable fluxes of electromagnetic radiation and plasma reaching the Earth from the Sun interact with the Earth's magnetic field and atmosphere to generate electric currents that pervade every terrestrial environment. The externally induced currents are quite feeble in contrast to an internal current of 10^9 A which is generated in the Earth's liquid core by the same self-inducing dynamo action that supports the magnetic field. External current systems are not closed circuits. Various mechanisms, such as the aurora in the ionosphere and lightning in the lower atmosphere, transfer electrons from one "component" circuit to another. It is noted that such electron-transfer mechanisms are not only important in the planet's overall electrical budget, but may have also been critical in the origin and evolution of life. (*IAA*, A64-13,636)

504. ROLE OF CORONA CURRENTS IN THE MAINTENANCE OF THE NEGATIVE CHARGE OF THE EARTH
Zykova, V. V.
***Trudy Glavnoi Geofizicheskoi Observatorii*, Leningrad, no. 110, pp. 3–6, 1960**

Measurements of corona currents carried out at southern Sakhalin during 1951–1953 are described. In this region the corona currents result in a positive charge on the Earth, although in other known cases the opposite is true. The annual inflow of the positive charge was 2.6 times that of the negative. The total annual charge was 0.073 C. Analyses of meteorological conditions suggest that positive charges due to corona currents should be observable in a number of regions of the globe. The results of the measurements and the relative distribution of various forms of clouds and of meteorological phenomena are tabulated. It was found that during snow storms the inflow is 13.7 times that of the outflow. During snow (calm) it is 2.2 that of the outflow. During rains the outflow is 5.2 times the inflow, while during thunderstorms it is 3.5 times the inflow. Therefore the factors determining the preponderance of inflow may possibly have a deciding influence on the balance of corona currents. This phenomenon must be investigated further in various parts of the globe before the role of these currents in maintaining the negative charge of the Earth can be determined. 3 references. (*MGA*, 1962, 13.12-597)

MOON

505. A LUNAR EFFECT ON THE INCOMING METEOR RATE
Bowen, E. G.
***Journal of Geophysical Research*, v. 68, no. 5, pp. 1401–1403, March 1963**

Evidence was recently found for a lunar influence on rainfall and on the freezing nucleus count. Radar observations now show that the meteor rate varies in a similar way with lunar phase. The physical mechanism is uncertain, but an electrostatic charge on the Moon could produce an effect on micrometeorites of the right order of magnitude.

506. MEASUREMENT OF INTERPLANETARY ELECTRON DENSITY FROM THE EARTH
Buckingham, M. J.
***Nature*, v. 193, no. 4815, pp. 538–539, February 10, 1964**

The possibility of measuring the interplanetary electron density by radio-astronomical methods is discussed. Recent developments in radio astronomy which make such measurements possible are noted. The measurement of a lunar electron atmosphere is of considerable interest and is particularly suitable for the method discussed. 10 references.

507. CHARGING GRAINS OF DUST
Coffman, M. L.
***Journal of Geophysical Research*, v. 68, no. 5, pp. 1565–1566, March 1, 1963**

An independent calculation is presented for the maximum possible charge of dust grains and the relationship of the calculated charge to the mechanism of erosion of the surface of the Moon. 4 references.

508. ORIGIN OF THE LUNAR CRATERS
Ford, B. J.
***Spaceflight*, v. 7, no. 1, pp. 13–17, January 1965**

Various theories concerning the origin of the lunar craters are reviewed. A new theory is proposed which is based on

the assumption that a large electrostatic imbalance exists between the Earth and the Moon. It is suggested that some of the lunar craters were formed as a result of a large electrostatic discharge between the two bodies, similar to an inconceivably large lightning storm.

Laboratory experiments are described which were undertaken to verify the formation of similar craters by energetic discharges of electricity. If the lunar craters are of electrostatic origin, and if current theories of the common origin of the micrometeorites and the Moon are valid, then it can be concluded that: (1) the lunar surface is relatively free of dust, and (2) the Moon is surrounded by concentric belts of dust at a considerable distance from its surface. The possible effects of the lunar electrostatic charge on instrumentation, as well as on the operation and safety of manned lunar craft, are noted.

509. WAVELENGTH DEPENDENCE OF POLARIZATION. III. THE LUNAR SURFACE
Gehrels, T., Coffeen, T., Owings, D.
***Astronomical Journal*, v. 69, no. 10, pp. 826–852, December 1964**

Photoelectric measurements of brightness and polarization were made on various lunar regions, using diaphragms about 10 sec of arc in diameter. The lunar surface appears to be covered with a thin (about 0.06 mm) cloud of particles that have radius $a \cong 0.8\ \mu$ and separation of about 8 μ, and presumably are accreted interplanetary particles. The particles are ionized and their charges, of the order of 10^{-8} esu, keep them separated and suspended, while partial recombination causes the observed luminescense. It appears that this surface cloud explains all photometric and polarimetric observations on the Moon and asteroids. 39 references.

510. THE MOON
Gold, T.
In "Space Astrophysics," pp. 171–178
Liller, W. S., Editor
McGraw-Hill Book Company, Inc., New York, N.Y., 1961

Lunar features are surveyed in connection with current plans for landings on the Moon. Thermal measurements of the lunar surface in the near infrared indicated a low heat conduction such as that of finely divided or porous material. The large-scale features which can be resolved with telescopes are dominated by circular craters of various sizes. Some erosion is detected in the observations of the crater and is reflected in the coloration effect of the surface. It may also be inferred from the coloration effects that the Moon is not covered by a general dust blanket, but that a transportation mechanism is at work. Electrostatic forces are discussed with respect to this mechanism. Any irradiation which is capable of knocking electrons out of dust particles may leave them in a charged state. Calculations show that the existing ionizing flux can produce electric fields capable of stirring up the surface dust. The actual surface conditions are important, because an instrument landing should not dig too deeply into the ground, while for a manned landing "digging-in" may provide a shield from hazardous radiation.

511. ELECTROSTATIC EROSION MECHANISMS ON THE MOON
Grannis, P. D.
***Journal of Geophysical Research*, v. 66, no. 12, pp. 4293–4299, December 1961**

An evaluation is made of the electrostatic processes which have been suggested by Gold (Entry #510) as being responsible for erosion of the lunar features. The statistics of the charge buildup on the grains of lunar dust due to the solar gas streams are considered. On the basis of the derived probability distribution for grain charge, the electrostatic hopping effect is shown to result in an erosion rate which is lower by a factor of at least 10^2 than the rate indicated by observations of the Moon. It is found that, owing to the supporting action of the electronic space charge, positively charged dust grains may be levitated above the surface. The mass transport resulting from the "downhill" gliding of such levitated grains may be sufficient to explain observed lunar erosion. 13 references.

512. DOES THE MOON POSSESS A MAGNETIC FIELD?
Kopal, Z.
***Space Journal*, v. 2, no. 1, pp. 3–8, September 1959**

Direct information on lunar magnetism is still lacking. However, several recent astronomical investigations carried out in terrestrial observatories have thrown considerable light on the question of a possible lunar magnetic field and, in fact, may have gone a long way toward answering it—in the negative. The method employed was based on studies of lunar luminescence. The present article first explains lunar luminescence, and then presents several arguments which negate the possibility of a magnetic field on the Moon. Several photographs illustrate various probes and the lunar surface. (*MGA*, 1960, 11.7-120)

513. THE MAGNETOHYDRODYNAMIC WAKE OF THE MOON
Ness, N. F.
***Journal of Geophysical Research*, v. 70, no. 3, pp. 517–534, February 1, 1965**

The possible detection of the lee wake of the MHD interaction of the solar wind with the Moon, as observed by the *Imp I* satellite, is discussed. The interplanetary magnetic field was found to fluctuate very rapidly and reach anomalously large values when the satellite was approximately eclipsed by the Moon in December 1963. Later data on the interplanetary field in February 1964 suggest that a detached lunar shock wave analogous to that observed by *Imp I* and associated with the Earth may not be a permanent feature of the lunar environment. The approximate length of the wake

region behind the Moon is 150 lunar radii; at this distance the diameter of the region is about 70 lunar radii. Related studies on 29.5-day periodicities of K_p are reviewed. It is noted that solar wind interaction with the geomagnetic field extends the magnetosphere far behind the Earth. Hence, lunar synodic periodicities in K_p may reflect the interaction of the Moon with the Earth's magnetic tail, rather than the Moon's wake with the Earth. 71 references. (*IAA*, A65-16,725)

514. ELECTROSTATIC SCREENING OF BODIES IN SPACE
Singer, S. F., Walker, E. H.
September 1961
Maryland, University of, College Park
Technical Report 226, AFOSR-1399
(See also *Icarus*, v. 1, pp. 7–12, May 1962)

Bodies in space which are subject to the solar ultraviolet flux will emit photoelectrons. A certain number of these escape and are balanced by the accretion of thermal electrons from the surrounding plasma. However, for a positively charged body, a much larger number of photoelectrons will be released from the surface but will not escape, because their energy is insufficient to do so. Their effect will be to produce an inner screening of the body's electric charge. This screening is calculated for spherical bodies as a function of size. For large bodies the space-charge density of photoelectrons becomes quite large; in the case of the Moon it reaches a value of the order of 10^3 to 10^4 electrons/cm^3 just above the lunar surface. For small dust particles, however, the photoelectric cloud becomes negligible. 19 pages. (*AI/A*, 1961, #4509)

515. ELECTROSTATIC DUST TRANSPORT ON THE LUNAR SURFACE
Singer, S. F., Walker, E. H.
***Icarus*, v. 1, no. 2, pp. 112–120, September 1962**

It has been postulated that rapid erosion processes occur on the lunar surface. It is shown that the most favored process, electrostatic erosion, is not valid. Meteor impact produces a much smaller erosion due to mechanical crushing; its effectiveness is calculated. The velocity distribution of the dust particles ejected from the impact is also calculated.

The charging of these dust particles is considered in detail, and it is shown that a fraction of these particles will be reflected elastically by the strong electric field in the lunar electronosphere. This process leads to a limited amount of fluidity of the dust. It is concluded that the mass of dust which is "floated" and eventually redistributed forms between 1 and 10% of the incident meteoric mass. Over 5 billion years the total amount transported is of the order of 0.4 to 2.0 g/cm^2 and produces an average layer thickness of 20 to 100 cm in shadow areas.

The surface density of hopping dust particles is between 10 and 100/m^2 on the sunlit hemisphere. Dust is deposited preferentially in shadow areas. 12 references.

516. ATMOSPHERE NEAR THE MOON
Singer, S. F.
In "Advances in the Astronautical Sciences—Volume 8," pp. 531–536
Plenum Press, Inc., New York, N.Y., 1963
(Paper presented at the AAS Seventh Annual Meeting, Dallas, Tex., January 16–18, 1961)

Any reasonably anticipated steady evolution of gas from the Moon is insufficient for the formation of an atmosphere. Contrary to expectations from the classical theory of an exosphere, it is found that even the heaviest gases (e.g., the noble gases krypton and xenon) cannot be retained by the Moon. Because of the ionizing effects of solar ultraviolet radiation, electric forces now become more important than gravitational forces. The lifetime of an atmosphere containing all the krypton and xenon believed to have evolved since the origin of the Moon is of the order of 800 years and 50 years, respectively. After the atmosphere has thinned to less than one mean free path, i.e., an exosphere, still another mechanism of escape of heavy gases exists. It seems likely that the Moon as a whole is positively charged to a potential of about +20 V, owing to the great intensity of solar ultraviolet radiation. Hence, a strong electrostatic field will exist in the vicinity of the Moon. Whenever a krypton or xenon atom is ionized while it is in flight within the screening length near the Moon, the ion will be expelled by the electrostatic field. The lifetime turns out to be ~1000 years and is somewhat increased by the effect of solar corpuscular streams. Hence, it is concluded that light or heavy gases evolving from the Moon are not likely to be retained by the Moon. The only gas in the vicinity of the Moon comes from interplanetary space itself. Accreted, accommodated, and re-emitted solar coronal gas yields an average permanent density of about 80 hydrogen atoms/cm^3; this density may rise to about 10^5/cm^3 following solar eruptions. It is predicted that a peculiar type of "ionosphere" exists near the Moon, which is made up of photoelectrons that have insufficient energy to escape and are held back by the Moon's electrostatic field. However, in describing orbits, these photoelectrons produce a density that reaches a value of perhaps 10^3/cm^3 near the lunar surface. The electrostatic field is strong enough to support small electrically charged dust particles.

517. THE INFLUENCE OF A CHARGE ON A CHARGED PARTICLE FLUX
Telford, J.
***Australian Journal of Physics*, v. 16, no. 4, pp. 464–474, December 1963**

An investigation was made of the disturbance to a uniformly directed flux of charged particles which occurs when the observation point moves in a plane circular path parallel to the flux and centered on the charge. The study was undertaken as a result of a suggestion that an electrically charged Moon may influence solar particles. In this treatment, the scattering of a monoenergetic particle flux is first considered; then the case of a distribution of energies is taken up. In the

case involving repulsion, a shadow region of variable width develops; the width, at a particular radius, is dependent on the particle energy, the radial distance, and the magnitude of the scattering charge. Evidence concerning the existence of a lunar charge is considered incomplete.

518. COMMENTS ON A PAPER BY P. D. GRANNIS, "ELECTROSTATIC EROSION MECHANISMS ON THE MOON"
Walker, E. H.
***Journal of Geophysical Research*, v. 67, no. 6, pp. 2586–2587, June 1962**

A paper by Grannis (Entry 511) is discussed in which a calculation was made of the electrostatic hopping of dust grains. The author suggests that the results obtained are incorrect, since the calculations did not take into account the effect of the potential of the dust grain on the statistical process. The corrected probability function is derived.

In an independent investigation (Entry 515), it was found that electrostatic forces are insufficient to tear dust particles loose, or even to raise them. Only meteoritic impacts are able to stir up dust, and electrostatic effects on those particles produce only a minor degree of fluidity of dust on the lunar surface.

519. COMMENTS ON A PAPER BY M. L. COFFMAN, "CHARGING GRAINS OF DUST"
Walker, E. H.
***Journal of Geophysical Research*, v. 69, no. 3, pp. 566–567, February 1, 1964**

Coffman (Entry 507) has proposed a new method for calculating the equilibrium charge on a body that is embedded in a plasma and subjected to a high flux of energetic photons. It is suggested that the equilibrium charge can be calculated without consideration of the nature of the charging currents, i.e., without including such factors as the temperature of the plasma, the flux of photons to the body, the energy of the photons, reflection coefficients for the ions and electrons, and secondary production processes. The method Coffman uses to calculate the charge on dust grains is contrary to that originally used by Singer (Entry 567) and other investigators in this area. It is the purpose of this letter to show that Coffman's method is invalid and leads to an unreasonable equilibrium value for the lunar surface charge. 8 references.

(For related entries, see Interplanetary Matter—Cosmic Dust)

SUN AND OTHER STARS

520. THE EXISTENCE OF NET ELECTRIC CHARGES ON STARS
Bailey, V. A.
***Nature*, v. 186, no. 4724, pp. 508–510, May 14, 1960**

The orders of magnitude of five different astronomical phenomena are accounted for by assuming that stars like the Sun carry a net negative charge proportional to the mass multiplied by the square root of the gravitational constant. This hypothesis also explains 13 other phenomena. (*EI*, 1960)

521. MEASUREMENT OF THE NET ELECTRIC CHARGE ON THE SUN BY MEANS OF THE ARTIFICIAL PLANET "PIONEER V"
Bailey, V. A.
***Planetary and Space Science*, v. 5, pp. 70–78, 1961**

It is noted that an opportunity to determine the value of the net charge on the Sun is now provided by the magnetometric measurements made by the artificial planet *Pioneer V*. The feasibility of making such measurements is discussed. Using the hypothesis that a body (such as the Sun) of mass M carries a negative charge $-Q$ esu, where $Q = \beta G^{1/2} M$, $\beta \sim 0.03$, and G is the constant of gravitation, it is calculated that the charge on the Sun is approximately -1.5×10^{28} esu.

522. THE INTERPLANETARY MAGNETIC FIELD
Bailey, V. A.
***Nature*, v. 199, no. 4849, pp. 1029–1031, September 14, 1963**

A review of observational results derived from data obtained on the flights of the space probes *Pioneer V* (1960), *Explorer X* (1961), and *Mariner II* (1962) confirms that the observed quiet-Sun field vector $\vec{F}_1$ is the resultant of at least two vectors, $\vec{A}$ and $\vec{B}$, where $\vec{A}$ has all three space components variable, and $\vec{B}$ acts in a plane perpendicular to the ecliptic, and always in the N–S direction. This latter property apparently was not considered in previously published accounts of the space probe results. Although this observation cannot be explained on the basis of any orthodox theory, it would follow from the author's conception of the Sun as a highly negatively charged body. (*PA*, 1964, #4882)

523. NEW EVIDENCE THAT THE SUN CARRIES A LARGE NET NEGATIVE ELECTRIC CHARGE
Bailey, V. A.
***Planetary and Space Science*, v. 11, no. 12, pp. 1501–1502, December 1963**

Using the magnetometric measurements obtained from the space probe *Pioneer V*, the author finds that the Sun's charge

is at least 6.6×10^{25} esu. This is consistent with the estimate $Q = 3 \times 10^{27}$ esu required to account simultaneously for the Sun's north polar field, the maximum energy of cosmic ray particles, and the existence and position of the outer Van Allen belt. Further evidence has been supplied from the data received from *Explorer X* ($Q > 1.1 \times 10^{26}$ esu), from *Mariner II* ($Q > 4.4 \times 10^{25}$ esu), and from *Explorer XII*. (*PA*, 1964, #15,937)

524. THE SUN'S ELECTRICAL CHARGE
Bailey, V. A.
***Nature*, v. 201, no. 4925, pp. 1202–1203, March 21, 1964**

In a recent communication (Entry 522), the author has shown that the interplanetary magnetic fields measured by means of space probes all verify the prediction that the Sun carries a large net negative electrical charge. A crucial experiment is described which can supply a clear and definite answer to the question of the Sun's charge. (*PA*, 1964, #23,905)

525. COSMIC ELECTRICAL DISCHARGES OR "GOBS OF ANTI-MATTER"
Bruce, C. E. R.
***The Engineer*, v. 212, pp. 946–950, December 8, 1961**

Several new developments in electrical discharge theory are discussed, including the theoretical calculation of the energy radiated by radio-galaxies. The calculated value obtained is in accord with estimates based on observations of the amount of energy radiated by Virgo "A." (*IAA*, 62-1788)

526. BALL LIGHTNING, "STELLAR ROTATION" AND RADIO GALAXIES
Bruce, C. E. R.
***The Engineer*, v. 216, pp. 1047–1048, December 27, 1963**

The application of an electric field and discharge theory of atmospheric astrophysics to various terrestrial and stellar phenomena is considered. A theory is briefly discussed which explicates the fact that some of the emission lines in the spectrum of the star P Cygni have widths indicating gas velocities in the line of sight of about ± 250 km/sec. The theory postulates huge vortices developed in the outflowing gas, and it is shown to underlie the basic energy processes occurring in the ball lightning and in stellar rotation. An explanation of radio halos of galaxies which derives from the above theory is also considered. 10 references. (*IAA*, A64-13,300)

527. POSSIBLE MAGNETOSPHERIC PHENOMENA ASSOCIATED WITH NEUTRON STARS
Cameron, A. G. W.
***Nature*, v. 205, no. 4973, p. 787, February 20, 1965**

It is suggested that the discrete X-ray sources in Scorpius and the Crab Nebula are neutron stars with associated magnetospheres. The X-ray spectrum would thus consist of a thermal component emitted from the photosphere and a nonthermal synchrotron component emitted by trapped electrons accelerated in the magnetosphere. The neutron star is capable of storing gravitational potential energy in the form of radial oscillations having a period in the millisecond range. The gravitational binding energy may typically amount to several percent of the rest mass energy. Hence, it may be possible to store $\sim 10^{52}$ ergs as vibrational energy in such a star. The radial oscillations would generate hydromagnetic waves which could traverse the magnetosphere and accelerate the electrons there. Initially these electrons would emit X rays by the synchrotron process, with an emission lifetime of about a year. 10 references. (*IAA*, A65-18,814)

528. STELLAR ELECTROMAGNETIC FIELDS
Davis, L., Jr.
***Physical Review*, v. 72, no. 7, pp. 632–633, October 1, 1947**

Calculations show that a magnetized rotating star will be surrounded by electrostatic fields in which the potential differences are of the order of 4×10^9 V for the Sun and may be 10^{14} V for some stars. The presence of the electromagnetic field will produce an ion distribution in space that will considerably modify the electric and magnetic fields. A determination of the space charge and the resulting fields should have a bearing on problems in cosmic rays and astrophysics. Polar potentials and polar field strengths are calculated and tabulated for the Earth, Sun, and two stars. A mechanism is described by which a positive space charge may be built up in the equatorial plane of a star as the star acquires a negative surface charge. The complexity of the problem and need for further study are indicated.

INTERPLANETARY MATTER

METEORS

529. POSSIBLE EFFECTS OF MAGNETIC FIELD ALIGNMENT ON METEORIC IONIZATION
Bain, W. F.
Journal of Geophysical Research, v. 66, no. 9, p. 3065, September 1961

Consideration is given to the effect of field alignment on ionization initially produced in the form of a thin, dense column parallel to the lines of magnetic force, such as a meteor trail. The tendency of the magnetic field to maintain this initial alignment could offset normal diffusion processes to some extent and result in unusually long trail durations. Such durations have been observed on overdense meteors. The effect on underdense meteors would also be to increase duration. It is possible that the peak echo amplitude could also be increased. This would result from a similar magnetic control of the mean free path, which has been shown to be a determining factor in the initial trial radius and hence in initial density. These effects could modify radiant survey results in a manner dependent on the magnetic dip angle at the measuring site. 3 references. (*MGA*, 1963, 14.3-754)

530. RESONANCE PHENOMENA IN RADIO WAVE SCATTERING ON METEOR TRAILS AND THEIR MODELS
Bairachenko, I. V.
Geomagnetizm i Aeronomiia, v. 4, no. 2, pp. 313–320, 1964
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 4, no. 2, pp. 244–249, 1964)

Experimental data on the resonance scattering of radio waves by a meteor trail were obtained using a gas discharge tube model. The phenomenon of plasma resonance is found to occur in the case of linear electron densities of $\alpha < 10^{12}$ electrons/cm, in which the value of the averaged dielectric permeability of the plasma must be negative. Observations of resonances of higher types in real meteor trails are limited by the diffusion and initial trail radius. 22 references. (*IAA*, A64-20,724)

531. SOME STATISTICAL PROBLEMS OF METEOR ASTRONOMY
Bel'kovich, O. I., Beskin, L. N.
Geomagnetizm i Aeronomiia, v. 4, no. 4, pp. 706–716, 1964
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 4, no. 4, pp. 612–615, 1964)

A mathematical method is described for solving a series of statistical problems in meteor radio astronomy. This method is based on the consideration of codistributions of the random parameters of meteor trails. Laws governing the distribution of maximum electron densities, electron densities in mirror points of the meteor trails, and altitudes of the mirror points are obtained. 10 references. (*IAA*, A64-28,394)

532. KINETIC EQUATIONS FOR IONIZATION IN A METEORIC BODIES IN THE ATMOSPHERE
Bronshten, V. A.
Geomagnetizm i Aeronomiia, v. 3, no. 3, pp. 455–462, 1963
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 3, no. 3, pp. 374–379, 1963)

Kinetic equations for ionization and changes of electron and ion temperatures in a strong shock wave in the air are derived; such a shock wave arises during the motion of large meteor bodies through the atmosphere. The following processes are taken into account: energy transfer from ions to electrons, ionization energy due to electron collision, recombination with radiation, and triple collisions. Ionization energy is computed in accordance with two models: (1) excitation and ionization from the excited levels occur by electron collision in the presence of luminescence; and (2) a Boltzmann distribution is maintained in each level and luminescence is absent. The first model can occur in the case of low gas densities, and the second in the case of high gas densities. The ratio of ionization energies in these two models is determined. Certain refinements are introduced into the definition of the Coulomb logarithm, L, which enters into the formula for energy exchange of electron and ion gas. The results of computation for an initial temperature of 5000°C and a density of $10^{20}/cm^3$ are presented. 14 references.

533. PROBLEMS OF THE MOVEMENT OF LARGE METEORIC BODIES IN THE ATMOSPHERE
Bronshten, V. A.
November 1964
National Aeronautics and Space Administration, Washington, D.C.
TT F-247
(Translation of "Problemy Dvizheniya v Atmosfere Krupnykh Meteoritnykh Tel," Izdatel'stvo Akademii Nauk SSSR, Moscow, 1963)

The objective of this paper is to systematize and bring into focus the basic elementary processes originating in the shock wave and in the course of its interaction with the meteorite. Particular attention is given to the kinetics of ionization and to the influence of ionization on the temperature distribution within the shock wave. 124 references.

534. ELECTRICAL DISCHARGE DURING THE FLIGHT OF METEORS IN THE EARTH'S ATMOSPHERE
Dokuchaev, V. P.
Akademiya Nauk SSSR, Doklady, v. 131, no. 1, pp. 78–81, 1960

The observed electromagnetic phenomena accompanying the flight of meteors in the Earth's atmosphere, such as long

and medium radio wave emission from ionized meteor trails, the luminescent aureola around flying particles, etc., can be explained by an electric discharge in the gas arising during the flight of meteors in the upper atmosphere. For the existence of the charge, a mechanism is necessary to explain the origin of sufficiently strong electric fields and a potential E exceeding the penetrating value E_{pen}. The gas discharge in the ionosphere as applied to the aurora is considered as arising in induced electric fields, and it is shown that electrical induction fields in the meteor region have a potential of $E_0 = 10^8$ V/cm. The passage of a meteor in the upper atmosphere is accompanied by the formation of an entirely ionized trail of electrons and ions of meteoric matter so that the meteoric particles form a cloud of highly conductive gas surrounded by gas with considerably less conductivity. In order to compute the effect of intensification of the electric field near the end of a meteoric trail, the latter is approximated by a very extended ellipsoid of rotation. The intensification of the electric field near the flying meteor is shown to lead to the formation of one form of gas discharge. It is concluded that the luminous aureola adjacent to the moving meteor is a product of the corona of the anterior part of the ionized trail. During the spark discharge the electric current along the trail increases so that the Earth's magnetic field may be caused to pulsate. An equation for computing the entire current I_0 through the cross section of the trail is also developed. 14 references. (*MGA*, 1960, 11L-168)

535. FORMATION OF AN IONIZED METEOR TRAIL

Dokuchaev, V. P.
***Astronomicheskii Zhurnal*, v. 37, no. 1, pp. 111–114, January–February 1960**
(Translated from the Russian in *Soviet Astronomy—AJ*, v. 4, no. 1, pp. 106–109, July–August 1960)

The distribution of ionized gas in the wake of a meteor trail through the upper layers of the atmosphere is discussed. A solution is found for the diffusion equation for the case of an ion source traveling at constant velocity at a small angle to the horizon. It is shown that the plasma concentration in the vicinity of the moving meteor is appreciably greater than in the remainder of the meteor wake. A determination is made of the conditions under which the trail may be approximated by a cylinder, with a Gaussian distribution for the plasma concentration as a function of the radius. 9 references.

536. ON THE CORRELATION OF METEORS WITH MICROPULSATIONS

Ellyett, C. D., Fraser, B. J.
***Journal of Geophysical Research*, v. 68, no. 21, pp. 5937–5945, November 1, 1963**

Nighttime geomagnetic micropulsations are described which were observed in the 1.5-cps frequency band down to a limiting sensitivity of 0.05 mγ. In order to investigate the magnetic effects produced by meteors, the results are compared with all-sky and localized radar meteor rates obtained at the same site. Individual meteor occurrence has been examined by recording on the same chart as the micropulsation activity. Most individual meteors have no associated micropulsation activity, but the number of coincidences is greater than random, and it is possible that some of the larger meteors do produce magnetic effects. 20 references. (*IAA*, A63-25,186)

537. AN APPROXIMATE ESTIMATION OF THE PROBABILITY OF METEORIC IONIZATION

Fialko, E. I.
***Astronomicheskii Zhurnal*, v. 36, no. 3, pp. 491–496, May–June 1959**
(Translated from the Russian in *Soviet Astronomy—AJ*, v. 3, no. 3, pp. 479–483, December 1959)

An approximate estimation is made of the exponent n, which characterizes the relation of the probability of ionization to meteor velocity. 15 references. (*MGA*, 1960, 11L-170)

538. THE PROBABILITY OF METEOR IONIZATION

Fialko, E. I.
***Radiotekhnika i Elektronika*, v. 4, no. 7, pp. 1206–1208, July 1959**
(Translated from the Russian in *Radio Engineering and Electronics*, v. 4, no. 7, pp. 213–217, 1959)

The probability of ionization, β, is defined as "the probability of the production of a free electron as a result of the evaporation of one meteoric atom and its collision with atmospheric particles." The dependence of this probability upon meteoric velocity, v, may be expressed as $\beta(v) = av^n$, where a and n are constants. (Different values for n between 0 and 5.6 have been obtained empirically.) A study of the relationships between meteor velocity, the n coefficient, intensity of initial radar signal, and radar wavelength is reported and shown graphically. The largest number of meteors was found to register at meteoric velocities of 55 km (8.13-m wavelength; $n = 1.5$). Visual meteor observations were used to determine the selectivity of radar detection. 12 references.

539. RADAR METHOD OF DETERMINING THE RATE OF ATTACHMENT OF ELECTRONS TO NEUTRAL MOLECULES IN A METEOR TRAIL

Fialko, E. I.
***Geomagnetizm i Aeronomiia*, v. 1, no. 2, pp. 209–212, 1961**
(Translated from the Russian in *Geomagnetism and Aeronomy*, v. 1, no. 2, pp. 184–186, 1961)

A method is described for determining the rate of bonding between electrons and neutral molecules in a meteor trail. The method is based on the distribution of radio echoes from meteors, with respect to their duration. The experiment shows that the rate of bonding is approximately 4×10^{-15} cm^3/sec.

540. AMBIPOLAR DIFFUSION IN METEOR TRAILS

Francey, J. L. A.
***Australian Journal of Physics*, v. 16, pp. 500–506, December 1963**

Ambipolar diffusion is examined with reference to equality of electron and ion concentrations. The diffusion equations are established, based on a diffusion current under the action of a concentration gradient and a drift current due to a local electrostatic field. In the development of a numerical solution, the ion diffusion coefficient was obtained from studies of the decay rate of meteor trails, of the mobility (from Huxley's 1952 study), and of the system length (from the duration of the radio echo from a meteor trail). It is pointed out that choice of the ζ step-length is fairly critical to the process, and should be large. The results indicate that at densities above $10^7/m^3$, electrons and ions diffuse together at the ambipolar diffusion rate, and below this figure the charges tend to separate, owing to weakening of the effect of the electrostatic forces. (*IAA*, A64-14,758)

541. RADIO REFLECTIONS FROM METEOR TRAILS
Franklin, R. N.
***IEEE Transactions on Antennas and Propogation*, v. AP-12, no. 1, p. 132, January 1964**

It is suggested that the multiplicity of resonances at frequencies near the plasma frequency, which have been observed in laboratory discharges, may not be discernible in radio reflections from meteor trails. This is due to the more significant electric field in the meteor trail imposing a restriction on the wavelength of the plasma waves. (*PA*, 1964, #20,938)

542. A THEORY OF IONIZATION IN METEOR TRAILS. I. KINETICS OF THE VARIATION OF IONIZATION PARAMETERS FOR METEOROIDS HEATED BY MOTION IN THE EARTH'S ATMOSPHERE
Furman, A. M.
***Astronomicheskii Zhurnal*, v. 37, no. 3, pp. 517–525, May–June 1960**
(Translated from the Russian in *Soviet Astronomy—AJ*, v. 4, no. 3, pp. 489–497, November–December 1960)

As a meteoroid is heated during its motion in the Earth's atmosphere and its fractions of lowest boiling point evaporate, the ionization parameters of the body change, i.e., the work function of the electron and positive ion, the ionization potential of the atom, and the probability of evaporation of a neutral atom. Since oxides of the alkali and alkaline-earth metals are contained in stony and stony-iron meteors, the work functions of the electron and positive ion are low.

As a result of a continuous "blowing off" of particles from the surface of the meteoroid by the stream of gas molecules encountered, which prevents formation of a space charge, and because of the emission of positively and negatively charged particles, dynamic equilibrium is established between the emission intensities of electrons and of positive ions. Factors to be considered in the calculation of equilibrium values of the work function of the electron and positive ion are discussed. 18 references.

543. A THEORY OF IONIZATION OF METEOR TRAILS. II. THE ROLE OF IONIZATION PHENOMENA AT THE SURFACE OF A METEOROID IN THE IONIZATION OF THE METEOR TRAIL
Furman, A. M.
***Astronomicheskii Zhurnal*, v. 37, no. 4, pp. 746–752, July–August 1960**
(Translated from the Russian in *Soviet Astronomy—AJ*, v. 4, no. 4, pp. 705–710, January–February 1961)

It is shown that ionization processes at the surface of a meteoroid provide line densities of electrically charged particles which agree with the densities determined from radar measurements. The processes considered are (1) kinetic and potential ejection of electrons for all types of meteors, and (2) thermal emission of electrons and ions for stony and stony-iron meteors. 17 references.

544. A THEORY OF IONIZATION OF METEOR TRAILS. III. IONIZATION DUE TO AIR MOLECULES AND ATOMS REFLECTED FROM A METEOROID
Furman, A. M.
***Astronomicheskii Zhurnal*, v. 40, no. 4, pp. 733–741, July–August 1963**
(Translated from the Russian in *Soviet Astronomy—AJ*, v. 7, no. 4, pp. 559–565, January–February 1964)

The process of completely elastic reflection of neutral particles in the air is discussed with particular reference to nitrogen molecules and atoms. It is shown that such molecules and atoms reflected from a fast meteor acquire velocities capable of ionizing other atmospheric molecules along the meteorite trajectory. An expression is derived for the linear density of the ionization caused by reflected molecules. 31 references.

545. A SEARCH FOR MAGNETIC EFFECTS FROM METEORS
Hawkins, G. S.
***Journal of Geophysical Research*, v. 63, no. 3, pp. 467–473, September 1958**

A magnetometer was operated in conjunction with the Super-Schmidt cameras of the Harvard Meteor Project. No magnetic pulses were detected from meteors with visual magnitudes between +5 and −3. The minimum signal detectable with the equipment was $5 \times 10^{-2}\gamma$ in the first series of measurements, and was subsequently reduced to $3 \times 10^{-3}\gamma$. Since this result is in direct contradiction with previous findings, reasons for the discrepancy are discussed. 4 references. (*MGA*, 1960, 11.7-161)

546. THE MAGNETIC EFFECT AND THE SHOCK WAVE OF A METEOR
Ivanov, V. V., Medvedev, Yu. A.
***Astronomicheskii Zhurnal*, v. 41, no. 6, pp. 1118–1127, November–December 1964**

It is shown that the shock wave of a meteor in the upper atmosphere reveals itself by an isothermic discontinuity. The

width of the latter is computed. It is shown that the ionization per unit length of the train is determined by the dimensions of the meteor. Calculations are made of the magnitude of the meteoric magnetic effect and of the electromotive force which generates the electrical currents responsible for the effect. The results are in good agreement with available experimental data. 13 references. (*PA*, 1965, #7647)

547. A POSSIBLE MECHANISM FOR MAGNETIC EFFECTS FROM METEORS
Jenkins, A. W., Jr., DuVall, B. W.
***Journal of Geophysical Research*, v. 68, no. 2, pp. 599–600, January 1963**

The magnetic effect due to the enhanced conductivity in a meteor trail is estimated. It is expected to be of the same order (10^{-9} G) as the noise on magnetic records. 6 references. (*PA*, 1963, #13,844)

548. NEGATIVE IONS AND LUMINOSITY IN METEOR TRAINS
Kaiser, T. R.
***Geophysical Research Papers*, no. 75, pp. 175–180, May 1962**

A theoretical study has been made of the decay of meteoric ionization due to the combined effects of diffusion, electron attachment and detachment, and mutual neutralization of positive and negative ions. It is proposed that the excited neutral atoms resulting from mutual neutralization produce meteor train luminosity. Interpretation of experimental data, in the light of the theory, leads to values for the electron attachment coefficient which are in agreement with those obtained from radio observations, and suggests that attachment occurs through a three-body process. 10 references. (*MGA*, 1964, 15.8-103)

549. THE SCATTERING CROSS SECTION OF A METEOR TRAIL MODELED BY AN IONIZATION POINT SOURCE
Kalinin, Yu. K.
***Geomagnetizm i Aeronomiia*, v. 3, no. 4, pp. 779–780, 1963 (Translated from the Russian in *Geomagnetism and Aeronomy*, v. 3, no. 4, pp. 632–633, 1963)**

Considering a meteor as an ionization point source, expressions are derived for the distribution of concentration of the electrons and for the scattering cross section of the meteor trail. The results obtained indicate that the representation of a meteor in the form of an ionization point source, with the dissipation of charge in conformity to the law of ambipolar diffusion, leads to results in agreement with experimental findings, and is both simple and graphic. 8 references.

550. TIME DEPENDENCE OF A SIGNAL REFLECTED FROM A METEOR TRAIL
Kalinin, Yu. K.
***Geomagnetizm i Aeronomiia*, v. 4, no. 1, pp. 124–130, 1964 (Translated from the Russian in *Geomagnetism and Aeronomy*, v. 4, no. 1, pp. 93–97, 1964)**

Expressions are derived for the distribution of electron concentration in a meteor trail, using ambipolar diffusion equations. The time dependence of a signal reflected from a meteor is determined by means of the perturbation method, taking into account the finite distance to the meteor. The time dependence of the signal is expressed in the form of a Fresnel integral of a complex argument. 12 references.

551. ON THE USE OF AN ASYMMETRIC MODEL IN THE THEORY OF RADIO ECHO FROM METEOR TRAILS
Kaliszewski, T.
***Journal of Atmospheric and Terrestrial Physics*, v. 25, no. 3, pp. 151–161, March 1963**

The scattering of short radio waves from an underdense meteor trail is considered in the context of the first-order theory. The essentially asymmetric nature of the trail formed in the Earth's atmosphere is recognized, and an attempt is made to assess its effects on observables such as the echo power, energy, and duration. Tentative but specific results are derived for the case of specular scattering. These results permit the evaluation of the echo as a function of time. The dependence on the separation of the trail's terminus from the specular point and on the axial density distribution is discussed.

552. SCATTERING OF ELECTROMAGNETIC WAVES BY METEOR TRAILS
Khaskind, M. D.
***Radiotekhnika i Elektronika*, v. 7, no. 2, pp. 206–222, February 1962 (Translated from the Russian in *Radio Engineering and Electronic Physics*, v. 7, no. 2, pp. 189–205, February 1962)**

The reflection of normally incident electromagnetic waves from meteor trails is analyzed by approximation methods developed for the scattering of waves. Thus, electron concentration in the ionized meteor trail may be represented by a function that decays with distance from the axis throughout the whole volume. Also, some other possible models will be considered in which the meteor trails are approximated by plasma cylinders having finite radii.

553. THEORETICAL HEIGHTS AND DURATIONS OF ECHOES FROM LARGE METEORS
Manning, A.
***Journal of Research of the National Bureau of Standards, Section D—Radio Science*, v. 68D, no. 10, pp. 1067–1078, October 1964**

Recent studies have shown that attachment as well as diffusion is important in determining the electron-density distribution about the path of a meteor. In this paper, a mathematical theory of the durations of radio echoes from overdense trails is developed in detail. It is shown that well-defined attachment-

free and attachment-controlled duration regions exist with different line-density and wavelength dependences. The transition zone is broad, and its location depends strongly on meteor velocity. Normalized duration and line-density parameters are defined, and a single computer-calculated duration-versus-density relationship is plotted which is good for all parameter values. Bridging formulas approximating the duration relation are derived from asymptotic expressions, and the relation between echoing height and duration or line density is presented. Equations are given relating the exponent of the wavelength to echo duration. In the following paper, the theory is applied to experimental data and the values of the physical parameters and constants are derived. 6 references.

554. EXPERIMENTAL DETERMINATION OF METEORIC LINE DENSITIES AND ATTACHMENT RATES

Manning, L. A.

***Journal of Research of the National Bureau of Standards, Section D—Radio Science*, v. 68D, no. 10, pp. 1079–1093, October 1964**

A theory developed in the previous paper is used to interpret experimental meteor data of a variety of types. It is shown that the data set forms a more consistent whole, if a three-body, rather than a two-body, attachment process is assumed. No velocity dependence is found for the ratio of line density to luminosity. An attachment time constant of about 100 sec is deduced for a reference height of 95 km, and a zero-magnitude meteor is found to produce a maximum line density of about 100×10^{14} electrons/m. The combination of the theoretical and experimental results makes it possible to calculate the heights and durations of meteor echoes under a full range of conditions. 9 references.

555. ON THE MAGNETIC EFFECT OF METEORS

Marochnik, L. S.

***Geomagnetizm i Aeronomiia*, v. 4, no. 1, p. 193, 1964 (Translated from the Russian in *Geomagnetism and Aeronomy*, v. 4, no. 1, p. 149, 1964)**

A brief discussion is presented concerning the magnetic effect of meteors which is manifested during the flight of a meteoritic body through the atmosphere of the Earth when a slight local disturbance of the geomagnetic field occurs. A simple method is proposed for the treatment of this phenomenon. As an example, the magnitude of such a disturbance is established at $\Delta H \approx 5 \times 10^{-7}$ to 5×10^{-9} Oe. 6 references. (*IAA*, A64-17,020)

556. SURVEY OF OBSERVATIONS OF METEOR TRAILS

Millman, P. M.

***AIAA Journal*, v. 1, no. 5, pp. 1028–1033, May 1963 (Paper 2659-62, presented at the ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., November 13–18, 1962)**

The general nature of the luminosity and ionization appearing along the trajectories of bright meteors is discussed on the basis of observations made with optical cameras and radar equipment. Six distinct categories of phenomena are described: (1) a sharp luminosity peak that moves with the meteoroid and consists chiefly of the low excitation radiation of atoms in the neutral and first ionization stages; (2) a moving-ball type of radar target that also travels at the velocity of the meteoroid and appears along the highest portion of the trajectory; (3) a trailing wake with duration measured in small fractions of a second, and with a faint luminosity arising from the lowest excitation levels in a number of common atoms; (4) a metastable train lasting a second or two along the upper part of the trajectory, the luminosity arising from a forbidden green line of neutral oxygen; (5) a persistent train which may remain visible for several minutes and which probably includes the lines of neutral sodium and magnesium in its luminosity; and (6) an enduring radar echo which lasts for a considerably longer period than the optical persistent train and which, like it, is modified continually by the wind structure of the upper atmosphere. 36 references. (*IAA*, A63-16,981)

557. ÉTUDE DES CISAILLEMENTS DE VENT DANS LA BASSE IONOSPHÈRE PAR L'OBSERVATION RADIOÉLECTRIQUE DES TRAINÉES METÉORIQUES. I. ÉTUDE THÉORIQUE. APPENDIX — CALCUL DE L'EFFET DE DIVERSITÉ (INVESTIGATION OF THE WIND SHEARS IN THE LOWER IONOSPHERE BY RADIOELECTRIC OBSERVATION OF METEOR TRAILS. I. THEORETICAL INVESTIGATION. APPENDIX — CALCULATION OF THE EFFECT OF DIVERSITY)

Revah, I., Spizzichino, A., Taieb, C.

***Annales de Geophysique*, v. 19, pp. 43–50, January–March, 1963**

A theoretical investigation was made of the fluctuation of the electromagnetic field reflected by a meteor trail distorted by a variable horizontal wind. The classical hypothesis of a random distribution of winds following a Gaussian law, which leads to meteoric echoes having a very broad Fourier spectrum, disagrees with many experiments which show narrow echo spectra, often reduced to a single sinusoidal component of constant period. An attempt is made to explain the experimental results by introducing a hypothesis concerning the existence of a single wind shear in the lower ionosphere where meteor trails appear. The main characteristics of the echo fluctuations are deduced by assuming such a wind shear. The following are considered: (1) formation of several points of reflection in a trail; (2) comparison of the theoretical and experimental order of magnitude of the fluctuation; (3) frequency of the sinusoidal fluctuations; (4) effects of the diversity of space; and (5) effects of the diversity of frequency. (*IAA*, A63-18,244)

558. THE DISTRIBUTION OF IONIZATION ALONG UNDERDENSE METEOR TRAILS
Rice, D. W., Forsyth, P. A.
***Canadian Journal of Physics*, v. 42, no. 11, pp. 2035–2047, November 1964**

Attempts to use the decay of radio signals reflected from individual meteor trails to study the upper atmosphere have revealed a puzzling inconsistency in the signal behavior. Earlier work pointed out that this inconsistency remained even when the previously postulated sources of error were eliminated. As a result, an irregularly ionized trail model was proposed. By calculation of signal characteristics, the proposed model was shown to be capable of accounting for the observations. This paper presents results of a new experiment which permitted the determination of the ionization profiles as the meteor trails were formed. The predicted irregularities were found, even for trails which exhibited apparently "ideal" underdense signal characteristics. 9 references.

559. ELECTROMAGNETIC DISTURBANCES DURING THE HYPERVELOCITY ENTRY OF LARGE BODIES INTO THE EARTH'S ATMOSPHERE
Romig, M. F.
American Institute of Aeronautics and Astronautics, New York, N.Y.
Paper 63-456, presented at the AIAA Conference on Physics of Entry Into Planetary Atmospheres, Cambridge, Mass., August 26–28, 1963

An outline is presented of an investigation which was undertaken to determine the sensory effects and electromagnetic events occurring during fireball entry. When combined with an earlier catalog of Astapovich, data collected from various sources in the Soviet Union, the U.S., and Germany permit a delineation of the differences between sound-producing fireballs and silent meteors, as well as a summary of the phenomena surrounding a "typical" sound-producing fireball. In an attempt to shed light on the mechanism producing the hissing sounds, information on the noises and electromagnetic disturbances associated with lightning, aurora, and ordinary meteors is discussed. Previous theories for fireball sounds are briefly reviewed. 10 pages; 38 references. (*IAA*, A63-21,575)

560. ANOMALOUS SOUNDS AND ELECTROMAGNETIC EFFECTS ASSOCIATED WITH FIREBALL ENTRY
Romig, M. F., Lamar, D. L.
July 1963
Rand Corporation, Santa Monica, Calif.
RM-3724-ARPA, ARPA-SD-79
AD-412,816, N64-12,681

Observers who were located as much as 300 km from the ground trace of bright fireballs have reported hearing swishing sounds simultaneously with the fireball passage. These sounds are anomalous because the geometry of fireball path and observer locations requires that the effect producing the sound sensation be propagated at the speed of light. Sound-producing fireballs are extinguished at lower altitudes and are brighter than ordinary meteors. These fireballs deposit kinetic energy at altitudes below 30 km at rates on the order of at least 10^{16} ergs/sec. The description of the anomalous sounds as a hissing or crackling, as well as rare reports of odors which may be ozone, suggests that the sound is associated with electric discharges. The most plausible explanation of the anomalous sounds is that they are caused by electric discharges near the observer. These discharges may be the result of perturbation of the geopotential gradient by the fireball. It is also suggested that the anomalous sounds may be due to strong electromagnetic radiations from the fireball which are transduced by natural objects, perhaps even by the human ear. 66 pages.

561. ATMOSPHERIC CURRENTS AT ALTITUDES OF 80–100 KM BY OBSERVING THE DRIFTS OF METEORIC TRACES
Savrukhin, A. P.
***Meteorologiya i Gidrologiya*, no. 10, pp. 34–36, 1962**
(Translation available as FTD-TT-63-845, Air Force Systems Command, Foreign Technology Division, Wright-Patterson AFB, Ohio, October 9, 1963, AD-424,480)

Observation of the drift of meteoric ionization is one of the direct methods of studying winds in the upper stratosphere. Tracks consisting of electrons and ionized atmospheric atoms as well as meteoric material are formed at altitudes of 70–110 km along the trajectories of meteors penetrating the atmosphere from interplanetary space. It is possible to determine the reflection of radio waves from the ionized meteor trail. As a result of recombination processes, the tracks become visible. High-altitude winds shift the meteoric track, changing its form and dimensions, and make it possible to determine the direction and velocity of atmospheric currents.

562. ON THE IONIZING EFFICIENCY OF METEORS
Verniani, F., Hawkins, G. S.
February 1964
Harvard University, Harvard College Observatory, Cambridge, Mass.
Research Report 5, NASA-CR-57004
(See also *Astrophysical Journal*, v. 140, no. 4, pp. 1590–1600, November 15, 1960)

Present knowledge concerning the ionizing efficiency of meteors is reviewed. There is considerable disagreement in the literature on both the order of magnitude and the velocity-dependence of meteor ionization. Since the luminous efficiency, τ_p, is known with a fair degree of accuracy, it is possible to evaluate the ionizing efficiency from τ_p and from Millman and McKinley's data relating durations of radio echoes and visual magnitudes. 36 pages; 23 references.

COSMIC DUST

563. ANALYTIC AND EXPERIMENTAL ELECTRICAL CONDUCTIVITY BETWEEN THE STRATOSPHERE AND THE IONOSPHERE
Bourdeau, R. E., Whipple, E. C., Jr., Clark, J. F.
Journal of Geophysical Research, v. 64, no. 10, pp. 1363–1370, October 1959

Data are presented on atmospheric conductivity obtained experimentally in the altitude region between 35 and 80 km by use of rocket-borne Gerdien condensers. Analytic expressions based on ion equilibrium and ionization by cosmic rays only are derived for comparison. The experimental technique is described, and several factors that might influence the measurements are evaluated.

There is good agreement between the measured and predicted values of negative conductivity at altitudes up to 50 km. Low conductivity values observed between 50 and 80 km are attributed to ionic diffusion to particulate matter, the reduction agreeing quantitatively with that calculated from present estimates of the radius and concentration of noctilucent cloud particles. It is suggested that meteoritic dust may be an important agent for electron destruction in the ionosphere.

564. A TECHNIQUE FOR THE DETECTION AND DETERMINATION OF THE VELOCITY, MASS, RADIANT, CHARGE AND FLUX OF MICROMETEORITE PARTICLES IN SPACE
Jennison, R. C., McDonnell, J. A. M.
Planetary and Space Science, v. 12, pp. 627–635, June 1964

The potential attained by micrometeorite particles in space is considered, and it is shown that it is sufficient for the particles to be detected by an electronic technique. The preliminary design of a suitable sensor is discussed, and it is shown that the system may be extended to measure the velocity and mass of the particles. 8 references.

565. THE PERTURBATION OF INTERPLANETARY DUST GRAINS BY THE SOLAR WIND
Parker, E. N.
Astrophysical Journal, v. 139, pp. 951–958, April 1, 1964

It is expected that photoelectric emission from the interplanetary dust grains leads to a positive charge of the order of 10 V on each grain. The Lorentz forces exerted on this charge by the magnetic fields carried in the solar wind produce large perturbations in the Kepler orbits of the grains. On the assumption that the sign of the interplanetary magnetic field reverses every few days, it is shown that the orbital inclination of particles with radii equal to or smaller than about 1×10^{-4} cm at the orbit of Earth is greatly increased by the Lorentz forces. The importance of the Lorentz perturbation increases with the distance from the Sun. 15 references. (*IAA*, A64-18,726)

566. THEORETICAL INVESTIGATIONS ON MICROMETEORIC DUST PARTICLES
Rhee, J. W.
1963
Temple University, Philadelphia, Pa.
Thesis

Numerous measurements and investigations have been made to study the nature of micrometeoric dust particles in the vicinity of the Earth. Of the various methods used, direct measurement with satellites, rockets, and space probes are the most reliable for investigating the distribution and physical properties of micrometeoric dust particles. Dozens of major spacecraft with trajectories extending above the Earth's atmosphere have carried instruments for this purpose. A large amount of data has been accumulated. In order to analyze these data more correctly, theoretical investigations on micrometeoric dust particles are necessary. The effects of solar radiation pressure on micrometeoric dust particles are discussed, and a relationship between the minimum size of micrometeoric dust particles and the particle densities is obtained. A distribution of the dust particles as a function of incident particle energy and mass is derived theoretically by assuming that most of the micrometeoric dust particles have been generated by collision processes near the place where they were detected. Available experimental data are compared with the theoretically derived formula, and it is shown that the linear portion of the real unknown distribution curve can be explained by the collision theory. Interactions of dust particles with the atmosphere, the mean free path, and the electric charge of micrometeoric dust particles are discussed theoretically. 53 pages. (*DA*, 63-6817)

567. MEASUREMENTS OF INTERPLANETARY DUST
Singer, S. F.
In "Scientific Uses of Earth Satellites," pp. 301–316
Van Allen, J. A., Editor
University of Michigan Press, Ann Arbor, Mich., 1958
(Second Revised Edition)

A simple theory is developed for the motion of charged interplanetary dust particles in the vicinity of the Earth. Taken into consideration are the following: (1) the average charge of dust particles; (2) day–night effect; (3) solar-flare effects; (4) the resultant rigidity spectrum; (5) motion in the geomagnetic and gravitational field, and Liouville's theorem; (6) trapped orbits and storage of particles; (7) streams and impact zones; and (8) magnetic-storm effects.

These considerations are then applied to possible experimental tests in rockets or satellites, such as (1) dependence of dust-particle flux on geomagnetic latitude; (2) geophysical implications of latitude dependence; (3) diurnal variation of intensity; and (4) electromagnetic conditions in the vicinity of the Earth, and variation of particle flux and anisotropy.

Some suggestions are made for resolving the discrepancy between meteor data and optical measurements of interplanetary dust particle densities. The problem of dust particle accretion is briefly considered. 16 references.

568. DISTRIBUTION OF DUST IN CISLUNAR SPACE — POSSIBLE EXISTENCE OF A TERRESTRIAL DUST SHELL
Singer, S. F.
In "Lunar Exploration and Spacecraft Systems," pp. 11–24
Fleisig, R., Hine, E. A., Clark, G. J., Editors
Plenum Press, New York, N.Y., 1962
(Paper presented at the AAS Lunar Flight Symposium, New York, N.Y., December 27, 1960)

The density of zodiacal dust in the plane of the ecliptic near the Earth has the value of about 10^{-22} g/cm^3. It is shown that the gravitational action of the Earth can lead to substantial increases in densities in the vicinity of the Earth. With the orbits of the particles in the solar system similar to that of the Earth (i.e., small geocentric velocities), enhancement factors of the order of 10 to 100 are possible; a peak in the concentration is reached at an altitude of about 1,000 km above sea level. The rate of accretion of interplanetary dust into the Earth's atmosphere is also increased by this gravitational action.

For small dust particles (smoke), additional forces become important and determine their orbits. These are the forces of radiation pressure, magnetic forces and, above all, the electric drag of a charged dust particle moving through the ionized outer atmosphere of the Earth. A peculiar effect occurs which leads to a reversal of the electric charge of the dust particle in the vicinity of two Earth radii, or about 4,000 miles above sea level. Because of this effect, the concentration of dust particles would begin to be very pronounced at an altitude of about 4,000 miles and would increase toward the Earth, reaching a maximum at some distance above sea level, and may be characterized as a "dust shell." 21 references.

569. THE EARTH'S DUST BELT
Whipple, F. L.
In "Advances in the Astronautical Sciences—Volume 8," pp. 103–110
Plenum Press, Inc., New York, N.Y., 1963
(Paper presented at the AAS Seventh Annual Meeting, Dallas, Tex., January 16–18, 1961)

Rockets, satellites, and space-probe experiments suggest a high concentration of interplanetary dust near the Earth. The author continues an earlier discussion of possible physical processes leading to this concentration, which falls to approximately the interplanetary zodiacal-cloud level at a few hundred thousand kilometers from the Earth. Considered likely is the possibility that this dust is contributed by the Moon from high-velocity ejection in the formation of craters by meteoroids striking the Moon. If the mass ejected into short-lived circumterrestrial orbits is comparable to 0.1% of the total meteoritic material striking the Moon, the observed Earth's dust belt can be tentatively explained. However, other processes must be active and may make minor or major contributions to the Earth's dust belt. High variability in impact rates apparently observed on space vehicles near the Earth imposes important restrictions on theories of the origins of the belt. Various processes for modulating the impact rates are discussed, including (1) direct lunar explosion showers, (2) electrostatic explosion of particles near the Earth by the radiation belt, (3) high-drag effects induced momentarily by electrostatic processes in the radiation belt, and (4) collisional breakup of larger meteoric particles in space. The validity of the measured impact rates is questioned, especially for rockets and the early portions of satellite or space-probe travels. The validity of the lunar dust hypothesis depends heavily upon the high-velocity component of material ejected in impact crater formation, and is related to the question of whether the Moon loses mass or whether it gains mass by meteoritic accretion. (*PA*, 1964, #15,882)

570. ELECTRICITY IN THE TERRESTRIAL ATMOSPHERE ABOVE THE EXCHANGE LAYER
Whipple, E. C., Jr.
In "Problems of Atmospheric and Space Electricity," pp. 123–139
Coroniti, S. C., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, and New York, N.Y., 1965
(Paper presented at the Third International Conference on Atmospheric and Space Electricity, Montreux, Switzerland, May 5–10, 1963—Entry 590; also available as TN D-2092, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md., January 1964, N64-12,960)

Some of the reactions involving ions and electrons that might occur between the troposphere and the bottom of the ionospheric D region (20 to 60 km) are discussed. Electrons are produced by cosmic-ray ionization and by detachment from negative ions, and are lost by attachment to O_2. Photodetachment predominates during the day, but at night only collisional detachment is effective. Ion–ion recombination accounts for the removal of ions, the Thomson three-body process predominating below 45 km and the two-body mutual neutralization reaction predominating above that altitude. Probable ion and electron densities in this region during quiet solar conditions are presented. The mechanism of charge collection by bodies in the atmosphere is discussed with respect to two important applications: the effect of dust in providing a recombination surface for ions, and the problem of interpreting current–voltage curves obtained with ion probes. A perturbation solution of the Boltzmann equation to describe ion collection implies two assumptions, each of which becomes questionable at certain altitudes in this region of the atmosphere. 24 pages.

(For related entries, see Celestial Bodies—Moon)

INTERPLANETARY PLASMA

571. THE EXTENSION OF ATMOSPHERIC TO SPACE ELECTRICITY
Bruce, C. E. R.
In "Problems of Atmospheric and Space Electricity," pp. 577–586
Coroniti, S. C., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, and New York, N.Y., 1965
(Paper presented at the Third International Conference on Atmospheric and Space Electricity, Montreux, Switzerland, May 5–10, 1963—Entry 590)

It is suggested that the introduction of a new major variable (atmospheric electric fields) leads to a correlation of astrophysical phenomena and a consistent theory of universal evolution, without any additional *ad hoc* hypotheses (which are so necessary in astrophysics at present). The process of electric field building and the evidence for cosmic electrical discharges, including the whole new area of radio astronomy, are noted, and the writer's two cosmic gas thermometers discussed. It is shown that the theory offers an explanation of radio galaxies and accounts for certain characteristics of these galaxies. 34 references.

572. MAGNETIC FIELDS IN INTERPLANETARY SPACE
Cahill, L. J., Jr.
***Science*, v. 147, no. 3661, pp. 991–1000, February 26, 1965**

The theoretical developments and experimental verification of the concept of the interplanetary magnetic field are discussed. Various lines of evidence are described which clearly show that an interplanetary magnetic field is always present which is drawn out from the Sun by the radially streaming solar wind. The field is stretched into a spiral pattern by the Sun's rotation, and appears to consist of relatively narrow filaments, the fields of adjacent filaments having opposite directions. At the Earth's orbit, the field points slightly below the ecliptic plane. The magnitude of the field is steady and near 5 γ in quiet times, but it may rise to higher values at times of higher solar activity. A collision-free shock front is formed in the plasma flow around the Earth. In the transition region between the shock front and the magnetopause, the magnitude of the field is somewhat higher than it is in the interplanetary region, and large fluctuations in magnitude and direction are common. A shock front has also been observed in space between a slowly moving body of plasma and a faster overtaking plasma stream. Since the weak interplanetary field exerts considerable influence on the cosmic-ray protons, the study of these particles has been a particularly valuable tool in determining the large-scale properties of the interplanetary field. Precise measurement of the magnitude and direction of the field at a point in space and the study of small-scale fluctuations can be accomplished only by means of a spacecraft magnetometer, since the two methods are complementary. 37 references. (*IAA*, A65-18,221)

573. PLASMA OSCILLATIONS IN A STATIC MAGNETIC FIELD
Chang, H. H. C.
American Physical Society, New York, N.Y.
Paper presented at the APS Summer Meeting in the West, Honolulu, Hawaii, August 27–29, 1959

The small amplitude oscillations of a plasma in a static magnetic field, $\vec{H}_0$, are discussed. The plasma is assumed to be a perfectly conducting, nonviscous fluid composed of two perfect gases, electronic and ionic. The linearized hydrodynamic equation of motion, the equation of continuity, and Maxwell's equations are written for each component. The dispersion relation is solved for both the high-frequency and low-frequency cases. The physical significance of all cases is discussed, with emphasis on the motion of the particles and the propagation of waves in the plasma. Alfvén's transverse hydromagnetic waves and the magnetoacoustic waves are treated again as special cases.

574. THE STUDY OF INTERPLANETARY IONIZED GAS, HIGH-ENERGY ELECTRONS AND CORPUSCULAR RADIATION OF THE SUN, EMPLOYING THREE-ELECTRODE CHARGED-PARTICLE TRAPS ON THE SECOND SOVIET SPACE ROCKET
Gringauz, K. I., Bezrukikh, V. V., Ozerov, V. D., Rybchinskii, R. E.
***Iskusstvennye Sputniki Zemli*, no. 6, pp. 101–107, 1961**
(Translated from the Russian in *Planetary and Space Science*, v. 9, pp. 103–107, 1962)

At distances up to four Earth radii from the surface of the Earth, plasma with a temperature of the order of 10,000°C is observed. The existence of plasma at such distances confirms results obtained from the first space rocket. In the range 55,000 to 75,000 km, electron fluxes of approximately 10^8/cm^2/sec, with energies in excess of 200 eV, were obtained, confirming the results from the first space rocket. From 9:30 a.m. Moscow time on September 13, 1959, up to impact with the Moon, positive ions were recorded with energies in excess of 15 eV at a concentration around 2×10^8/cm^2/sec. At various distances from the Earth, e.g., at 125,000 km, a proton flux with energies in excess of 25 eV was observed in telemetering data from the October 1959 flight of the automatic interplanetary station.

575. IONIZED GAS AND FAST ELECTRONS IN THE VICINITY OF THE EARTH AND IN INTERPLANETARY SPACE
Gringauz, K. I., Kurt, V. G., Moroz, V. I., Shklovskii, I. S.
***Iskusstvennye Sputniki Zemli*, no. 6, pp. 108–112, 1961**
(Translated from the Russian in *Planetary and Space Science*, v. 9, pp. 21–25, 1962, and in *Artificial Earth Satellites*, v. 6, pp. 130–136, 1961)

The experimental data from the second Soviet space rocket has been analyzed in four ranges: (1) up to 22,000 km from

the Earth's surface, (2) from 22,000 km to 50,000 km, (3) 50,000 km to 70,000 km, and (4) greater than 70,000 km. In assessing the ion concentration from collector current measurements, it is important to know the electrical potential of the container relative to the medium, which depends on several factors. These factors include the fast electron flux in the second radiation belt, which has its maximum value in the first of the four ranges. Therefore special attention is paid to the current variations in the +15 V trap. A study of the relationship between the current and the electron concentration for different plasma densities leads to the conclusion that the electron fluxes corresponding to energies greater than 200 eV in the region of the upper radiation belt do not exceed $2 \times 10^7/cm^2/sec$, thus contradicting the concept of high electron fluxes with energies 20–30 keV in the maximum of the upper radiation belt. An assessment of plasma ion concentration in conjunction with the ion concentration as a function of distance from the Earth's surface indicates that the plasma in question is not interplanetary ionized gas, but forms an extensive cloud, which is an ionized component of the outermost section of the Earth's atmosphere. This ionized component is termed geocorona, and displays a marked increase in plasma density starting at 15,000 km, while at lower altitudes the density variation is negligible. It is proposed that the polarized component of zodiacal light is governed by the diffraction of sunlight on dust particles, and not by free electrons as proposed by Behr and Siedentopf. 12 references.

576. ATMOSPHERIC ELECTRICAL STUDIES OF OTHER PLANETS
Holzer, R. E.
In "Problems of Atmospheric and Space Electricity," pp. 573–576
Coroniti, S. C., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, and New York, N.Y., 1965
(Paper presented at the Third International Conference on Atmospheric and Space Electricity, Montreux, Switzerland, May 5–10, 1963—Entry 590)

Electrical measurements in the atmospheres of other planets are an important extension of the science of terrestrial atmospheric electricity, but these are not likely to be made for a number of years. It is suggested that, in preparation for studies of other planets, workers in the field of atmospheric electricity may gain valuable experience from rocket and satellite observations of the Earth's atmosphere. Studies of electromagnetic radiation from other planets—by means of spacecraft outside the ionosphere—may provide advance information about the electrical problems of other planets for future landings.

577. INTERPLANETARY PLASMA
Lüst, R.
***Space Science Reviews*, v. 1, pp. 522–552, 1962**

Present knowledge of the gaseous component of the interplanetary medium is reviewed. The theoretical picture which has been developed is also discussed.

The following observations provide some information about the interplanetary plasma: (1) scattering of visible sunlight; (2) the zodiacal light; (3) scattering of radio waves during occultations of radio sources; (4) ionized comet tails; (5) boundary of the geomagnetic field; (6) measurements from space vehicles; (7) influence on galactic and solar cosmic rays; (8) geophysical effects and their correlations with solar activity. With the exception of the first preliminary observations by space probes or satellites, in most cases some additional and serious assumptions must be made to obtain quantitative data concerning relevant parameters of the interplanetary medium. Various theoretical models which have been considered during recent years are outlined.

578. PLASMASTRÖMUNGEN IM INTERPLANETAREN RAUM (PLASMA FLUXES IN INTERPLANETARY SPACE)
Lüst, R.
Paper presented at the Wissenschaftliche Gesellschaft für Luft- und Raumfahrt, and Deutsche Gesellschaft für Raketentechnik und Raumfahrtforschung, Jahrestagung, Berlin, West Germany, September 14–18, 1964

A discussion is presented concerning the origin, behavior, and effects of interplanetary plasma and related phenomena such as acoustic and shock waves of the solar atmosphere and solar wind. Space probes and artificial satellites are evaluated as a means of direct interplanetary plasma investigations. It is found that artificial ionic clouds, produced (under solar UV radiation) from vaporized atoms released into space from satellites or space probes, are essential to such investigations. Laboratory experiments being conducted in Munich in preparation for such space experiments are briefly discussed. A proper selection of elements for artificial ionic clouds is discussed as one of the major problems involved. 9 pages. (*IAA*, A65-21,029)

579. THE PROBLEM OF MEASURING THE ELECTRON CONCENTRATION IN THE IONOSPHERE AND INTERPLANETARY SPACE
Mityakova, E. Ye., Mityakov, N. A., Rapoport, V. O.
***Izvestiya Vysshikh Uchebnykh Zavedeniy, Radiofizika (Bulletin of the Institutions of Higher Education, Radiophysics)*, v. 3, no. 6, 1960**
(Translations available as M-143, Morris D. Friedman, Inc., Foreign Technical Translations, West Newton, Mass., July 1961, AFCRL-568, AD-262,419)

The methods described in the literature for determining the electron concentration in the ionosphere by means of artificial Earth satellites are briefly considered. Expressions are found for the phase and group paths of a signal radiated by a satellite; these are derived in a quasi-longitudinal approximation, with the Earth's sphericity taken into account. New methods are discussed for determination of electron concentration by measurement of the angle between the polarization

planes at two frequencies, as well as by measurement of the difference of group paths at two frequencies. It is proposed that a combination of these two methods be used for the measurement of the electron concentration of interplanetary space by a space rocket.

580. THE ELECTRICAL STATE OF THE UPPER ATMOSPHERE
Obayashi, T., Maeda, K.-I.
In "Problems of Atmospheric and Space Electricity," pp. 532–547
Coroniti, S. C., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, and New York, N.Y., 1965
(Paper presented at the Third International Conference on Atmospheric and Space Electricity, Montreux, Switzerland, May 5–10, 1963—Entry 590; see also *Journal of Geomagnetism and Geoelectricity*, v. 15, no. 3, pp. 133–147, 1964)

The electrical nature of the upper atmosphere is reviewed, with emphasis on the problems related to space electricity. The physical structure and electrodynamic behavior of the ionosphere are explained in terms of an interacting ternary gas of electrons, ions, and neutral particles under the influence of the geomagnetic field. The concept of an atmospheric dynamo producing strong currents and electric polarization fields is important in the lower ionosphere. In the exosphere, the behavior of gas is essentially hydromagnetic. Possible mechanisms for generating electric fields by magnetospheric convective motions are discussed. 13 references.

581. SPACE ELECTRICITY: PHYSICAL PROBLEMS AND EXPERIMENTAL TECHNIQUES
Sagalyn, R. C.
In "Problems of Atmospheric and Space Electricity," pp. 548–565
Coroniti, S. C., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, and New York, N.Y., 1965
(Paper presented at the Third International Conference on Atmospheric and Space Electricity, Montreux, Switzerland, May 5–10, 1963—Entry 590)

Some of the important physical processes influencing the spatial and temporal variations of charged particles, ions, electrons, and protons in the upper atmosphere and interplanetary gas are outlined. Uncertainties that presently exist in the explanation of these phenomena are discussed. Techniques are described which have been used to study the properties of charged particles with instruments placed on rockets, satellites, and deep space probes. Some of the difficulties encountered in trying to make accurate measurements with instruments mounted on vehicles moving at great velocities in a highly variable plasma are discussed. 80 references.

582. ELECTROMAGNETIC RADIATION FROM ELECTRONS ROTATING IN AN IONIZED MEDIUM UNDER THE ACTION OF A UNIFORM MAGNETIC FIELD
Twiss, R. Q., Roberts, J. A.
***Australian Journal of Physics*, v. 2, no. 3, pp. 424–446, 1958**

A theory is given for the radiation from a fast electron rotating in an ionized plasma under the action of an external magnetic field. It is shown that, although the radiation is emitted predominantly in the extraordinary mode, the ordinary mode is also weakly excited, even in the limiting case in which the density of the background plasma is vanishingly small. At the harmonics of the gyrofrequency of the fast electron, the power radiated in the ordinary mode is a few percent of that radiated in the extraordinary mode. This ratio is independent of v_0, the velocity of the fast electron, as long as v_0 is sufficiently small compared with c, the velocity of light. However, at the fundamental gyrofrequency the power radiated in the ordinary mode is lower by a factor of $\simeq 10^{-2}(v_0/c)^4$ than that radiated in the extraordinary mode, and is significantly smaller than that radiated in either mode at the third harmonic.

The gyro theory of the nonthermal radiation from the Sun is discussed in the light of these results, and it is argued that this mechanism cannot explain the phenomena associated with the bursts of spectral types II and III. However, it is conceivable that the radiation on spectral type I may be of gyro origin, although even in this case there are serious objections to this explanation.

583. IONOSPHERIC RESEARCH (OCTOBER 1958–OCTOBER 1963)
November 30, 1963
Pennsylvania State University, Ionosphere Research Laboratory, University Park
Final Report, AFCRL-63-931, AF 19(604)-4563
AD-428,804, N64-14,972

The purpose of this research was to conduct theoretical and experimental investigations on the physics, dynamics, characteristics, and general properties of the conducting and absorbing regions of the Earth's atmosphere, as well as the ionized regions of other planetary atmospheres. An attempt is made to extend existing theories of the ionic layers and to supplement present knowledge regarding the characteristics and properties of the ionosphere in general.

IONOSPHERIC RESEARCH AND RELATED SUBJECTS

GENERAL REFERENCES

584. PLASMAS AND THE ELECTROMAGNETIC FIELD
Bachynski, M. P., Shkarofsky, I. P., Johnston, T. W.
January 1959
Canadian Armament Research and Development Establishment, Valcartier, Quebec
CARDE-TM-AB-26, Research Report 7-801,2 [Enclosure 16 to Air Attaché, Ottawa, Report TL-78-59]
AD-217,987

A fundamental review of plasma physics is presented, with special emphasis on the interaction of electromagnetic waves with plasmas. The basic ideas of the motion of charged particles comprising a plasma gas are presented, followed by more rigorous formulations. The interactions of the atomic gas constituents are considered and their effects assessed under various conditions. Electromagnetic wave interaction is introduced through Maxwell's equations for both uniform and nonuniform plasmas. The utility and limitations of microwave measurements and techniques for determining plasma properties are discussed. 66 references.

585. PLASMA PHYSICS — AN ELEMENTARY REVIEW
Bachynski, M. P.
IRE, Proceedings of the, v. 49, no. 12, pp. 1751–1766, December 1961

This survey of the significance of plasma physics in current research covers (1) plasma phenomena in nature; (2) the role of plasma physics in the creation, control, and diagnosis of thermonuclear fusion reactions; (3) the effect of plasmas on communication and telemetry from space and reentry vehicles; (4) plasma propulsion techniques; and (5) the use of plasmas in practical microwave, power generating, and other devices. Some future prospects of plasma physics are outlined. 134 references. (*IAA*, 62-2276)

586. ANNOTATED BIBLIOGRAPHY ON THE PHYSICS OF THE LIGHTNING FLASH
Baker, R., Kiss, E.
Meteorological and Geoastrophysical Abstracts, v. 14, no. 9, pp. 2923–2988, September 1963

There is a tremendous bulk of literature devoted to the subject of lightning and its related effects. This bibliography references selected papers concerned with the physics of the lightning flash itself, considered as a naturally occurring example of the long electric spark.

References on related subjects, such as lightning protection, atmospherics, lightning effects on transmission lines, etc., have been included only when directly related to knowledge of lightning physics. In general, references on ball lightning, bead lightning, and other unusual forms of lightning have been omitted. Since there is a wide literature on the related subject of the electrical breakdown of air, articles on this subject have only been included if a specific reference to lightning has been made. In this selection preference has been given to more recent material.

587. MONOGRAPH ON IONOSPHERIC RADIO
Beynon, W. J. G., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, 1962 (distributed through D. Van Nostrand Co., Inc., New York, N.Y.)
(Proceedings of the 13th General Assembly of the International Scientific Radio Union, London, England, September 1960)

This volume contains a collection of 16 papers dealing with various ionospheric radio phenomena. The following are considered: (1) the vertical distribution of electrons in the ionosphere ($N(h)$ profiles), (2) F-region ionization, (3) sporadic-E ionization, (4) rocket and satellite data for the ionosphere, (5) hydromagnetic and VLF emissions, (6) radio studies of the aurora, (7) ionospheric scattering of radio waves, and (8) ionospheric drifts. 264 pages. (See Entry 740)

588. GEOPHYSICAL RESEARCH WITH THE AID OF ROCKETS AND ARTIFICIAL SATELLITES
Blagonravon, A. A., Kroshkin, M. G.
Akademiya Nauk SSSR, Vestnik, no. 7, pp. 7–20, 1960
(Translation available as TT F-57, National Aeronautics and Space Administration, Washington, D.C., February 1961, and through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The accomplishments in geophysical research realized in recent years by use of rockets and artificial satellites are summarized. The primary unsolved geophysical problems relating to space are reviewed.

589. PROGRESS IN RADIO SCIENCE, 1960–1963. VOLUME III: THE IONOSPHERE
Brown, G. M., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, and New York, N.Y., 1965
(Review papers presented at Commission III on Ionospheric Radio during the 14th General Assembly of URSI, Tokyo, Japan, September 9–20, 1963)

The 14th General Assembly of the International Scientific Radio Union (URSI) met in Tokyo from September 9 to 20, 1963. Nine scientific sessions were held by Commission III on the Ionosphere (some in collaboration with Commission IV on the Magnetosphere).

The subjects discussed included the following: (1) the distribution of electrons throughout the entire ionosphere, from the D region through the topside ionosphere, to the magnetosphere and interplanetary space; (2) interrelations between the ionosphere and geomagnetism; (3) ionospheric studies during the IQSY; (4) ionizing radiation and the production of the ionosphere; and (5) the constitution of the atmosphere, including a consideration of the history of the Earth's atmosphere from its primordial state.

The introductory survey papers presented at the nine sessions are given in this volume, together with a summary of progress in ionospheric physics over the period 1960–1963. Some of the main advances which have been published over the triennium since the last General Assembly are outlined, and the chief points which emerged from the discussions at this Assembly are summarized.

The following papers are presented in this volume:

"Advances in Ionospheric Physics, 1960–1963," by J. A. Ratcliffe, pp. 1–13 (36 references)

"The Distribution of Electrons in the Lower and Middle Ionosphere," by R. W. Knecht, pp. 14–45 (111 references)

"A Survey of Topside Sounding of the Ionosphere," by J. H. Chapman, pp. 46–64 (26 references)

"Some Results of USSR Experiments in the Ionosphere and Interplanetary Space," by K. I. Gringauz, pp. 65–75 (32 references)

"Whistler Measurements of the Equatorial Profile of Magnetospheric Electron Density," by D. L. Carpenter, pp. 76–91 (32 references)

"Geomagnetism and the Ionosphere," by C. O. Hines, pp. 92–120 (163 references)

"Some Comments on the Ionosphere and Geomagnetism," by E. H. Vestine, pp. 121–148 (85 references)

"Ionospheric Studies During the IQSY 1964–65," by W. J. G. Beynon, pp. 149–166 (14 references)

"Ionizing Radiation and Constitution of the Atmosphere," by H. Friedman, pp. 167–173

"The History of Growth of Oxygen in the Earth's Atmosphere," by L. V. Berkner and L. C. Marshall, pp. 174–196 (53 references).

590. PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY
Coroniti, S. C., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, and New York, N.Y., 1965
(Proceedings of the Third International Conference on Atmospheric and Space Electricity, Montreux, Switzerland, May 5–10, 1963)

The Third International Conference on Atmospheric and Space Electricity was held in Montreux, Switzerland from May 5–10, 1963, under the joint sponsorship of The International Association of Meteorology and Atmospheric Physics, and The International Association of Geomagnetism and Aeronomy of The International Union of Geodesy and Geophysics.

This book contains all the papers and the extensive discussions presented at the conference. Since the discussions were of primary importance, prior to the conference each participant had the opportunity to read the papers and to exchange comments with the other participants. The general theme "Problems of Atmospheric and Space Electricity" was covered in seven sessions.

The following papers were presented at the session on space electricity:

"The Role of Rockets, Satellites and Space Probes in Atmospheric Electricity Research," by J. F. Clark, pp. 507–513

"Whistlers as a Phenomenon to Study Space Electricity," by N. D. Clarence, pp. 514–527

"Relations Between Lightning Discharges and Different Types of Musical Atmospherics," by H. Norinder, pp. 528–531

"The Electrical State of the Upper Atmosphere," by T. Obayashi and K. Maeda, pp. 532–547 (Entry 580)

"Space Electricity: Physical Problems and Experimental Techniques," by R. C. Sagalyn, pp. 548–565 (Entry 581)

"Rocket Experiments Aimed at Detecting an Electric Field in the Ionosphere," by G. L. Gdalevich, pp. 566–572 (Entry 58)

"Atmospheric Electrical Studies of Other Planets," by R. E. Holzer, pp. 573–575 (Entry 576)

"The Extension of Atmospheric to Space Electricity," by C. E. R. Bruce, pp. 577–586 (Entry 571)

"Discussion About Space Electricity," p. 587

The other six sessions covered the following: (1) survey of the present status of atmospheric and space electricity; (2) general problems in atmospheric electricity (fair weather); (3) general problems in atmospheric electricity (disturbed weather); (4) theorems of charge generation in thunderstorms; (5) the physics of lightning; and (6) the relation of lightning to other physical and geophysical phenomena. 616 pages. (See also Entry 570)

591. AN INTRODUCTION TO ATMOSPHERIC PHYSICS
Fleagle, R. G., Businger, J. A.
Academic Press, Inc., New York, N.Y., and London, England, 1963

This book is intended as a source of information for graduate students in the atmospheric sciences, although much work is included on other aspects of geophysics. Among the topics covered are the following: cloud formation and electrical charge, lightning discharges, the static geo-electric field, geomagnetic phenomena, ions and the ionospheric current, aurora,

and atmospheric signal phenomena. Particular mathematical and physical topics are covered in the appendices. Each chapter includes a list of references and symbols and a set of problems; however, no solutions are given. References to the latest work are given, and the discussion includes descriptions of work hitherto published only in scientific journals. 346 pages. (*PA*, 1964, #10,695)

592. COMPTES RENDUS DE LA VI^e CONFÉRENCE INTERNATIONALE SUR LES PHÉNOMÈNES D'IONISATION DANS LES GAZ (PROCEEDINGS OF THE SIXTH INTERNATIONAL CONFERENCE ON IONIZATION PHENOMENA IN GASES)
Hubert, P., Crémieu-Alcan, E., Editors
SERMA, Paris, France, 1963

This conference was held in Paris from July 8–13, 1963. The proceedings are published in four volumes. Volume I contains 110 papers, and is divided into sections on: (1) electron-molecule collisions, (2) charge exchange, (3) photon collisions, (4) kinetic theory of ionized gases, (5) particle mobility, (6) transport coefficients, (7) diffusion, (8) volume recombination, and (9) sheaths. The text is largely in English, with some articles in French and German. The subject matter is restricted to the basic physics of plasmas, and work directly related to controlled fusion or energy converters has been excluded. The verbal discussions which followed many of the papers are printed.

Volume II consists of 124 papers in two broad categories: (1) interaction with a solid surface, and (2) gas discharges.

Volume III is comprised of 84 papers which cover two broad subjects: (1) wave propagation in ionized gases, and (2) radiation from ionized gases.

Volume IV contains 93 papers and is divided into sections on (1) methods of measuring the properties of ionized gases, (2) ion sources and plasma or neutralized-beam generators, (3) shock waves, (4) magnetohydrodynamic flow of ionized gases, and (5) thermionic conversion. 2104 pages. (See Entries 236, 682, 701, 725, 758)

593. PRESENT STATE OF RESEARCH ON ATMOSPHERIC ELECTRICITY
Imyanitov, I. M., Shifrin, K. S.
***Uspekhi Fizicheskikh Nauk*, v. 76, no. 4, pp. 593–642, April 1962**
(Translated from the Russian in *Soviet Physics—Uspekhi*, v. 5, no. 2, pp. 292–322, September–October 1963)

The present state of knowledge of atmospheric electricity is reviewed with particular attention to electricity in a free atmosphere. The following are covered: (1) the vertical structure of the electric field, the conductivity, and the current in fine weather; (2) the distribution of charges in the atmosphere; (3) daily variations in the field voltage and potential with respect to altitude; (4) electricity in layer clouds, cumulus, and cumulus congestus; and (5) the formation of thunder- and rainclouds and the accumulation of charges in thunderclouds. 157 references. (*IAA*, 62-10,049)

594. SPACE RESEARCH V
King-Hele, D. G., Muller, P., Righini, G., Editors
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1965
(Proceedings of the Fifth International Space Science Symposium, Florence, Italy, May 12–16, 1964)

The Fifth International Space Science Symposium, held from May 12 through May 16, 1964 in Florence, Italy, was organized jointly by the Committee on Space Research (COSPAR) and the Italian Space Research Committee.

The symposium was originally divided into three parts:

1. Interaction of Energetic Particles With the Atmosphere
2. Life Sciences and Space Research
3. Latest Results in Space Research by Means of Rockets or Satellites

This published volume consists only of the papers relating to the first and third topics. Included are 26 papers concerning satellite and rocket measurements of ionospheric properties, processes, and anomalies. 1248 pages. (See Entry 120)

595. ANNOTATED BIBLIOGRAPHY ON ROCKET METEOROLOGY
Kiss, E., Compiler
***Meteorological and Geoastrophysical Abstracts*, v. 11, no. 9, pp. 148–1535, September 1960**

During the past 15 years rocketry has developed enormously, and this development has created a new method for scientific research. Rocket research was further emphasized during the International Geophysical Year (1957–1958). The general fields of application of rockets include meteorology, astronomy, astrophysics, astronautics, radio astronomy, cosmic rays, meteorites, geodesy, geomagnetism, ionospheric and upper atmospheric physics and chemistry, etc. This bibliography is limited to articles, monographs, and collected works dealing with meteorology and the upper atmosphere. To satisfy the wide interest in this rapidly developing field, an attempt has been made to include all significant literature on the meteorological use of rockets. The bulk of the literature was published during the period 1950–1960; however, a few items dated earlier than 1950 have been included. Meteorological research articles giving results of work using satellites have been omitted from this publication.

596. BIBLIOGRAPHY ON THE USE OF SATELLITES IN METEOROLOGY
Kiss, E., Compiler
***Meteorological and Geoastrophysical Abstracts*, v. 11, no. 10, pp. 1683–1729, October 1960**

This bibliography is limited to papers dealing with the use of satellites in upper atmospheric and meteorological research, and

particularly with those concerned with observations of atmospheric density, pressure, temperature, and cloud formations.

597. ANNOTATED BIBLIOGRAPHY ON UPPER ATMOSPHERE STRUCTURE ABOVE 300 KM
Kiss, E., Compiler
***Meteorological and Geoastrophysical Abstracts*, v. 12, no. 6, pp. 1211–1237, June 1961**

This is the third and last in a series of compilations on upper atmospheric structure. The first bibliography, published in the April 1961 issue of *Meteorological and Geoastrophysical Abstracts*, contained 210 references covering the altitude range from 30–80 km; the second publication, in the May 1961 issue, was concerned with atmospheric structure from 80–300 km (180 entries). This issue presents about 100 references treating the atmospheric regions beyond 300 km. Observations carried out with satellites are emphasized.

A few items published in April and May 1961, which are supplementary to the previous compilations, have been included at the end of this bibliography.

598. ADVANCES IN UPPER ATMOSPHERE RESEARCH
Landmark, B., Editor
The Macmillan Company, New York, N.Y., 1963

This volume is published for the Advisory Group for Aeronautical Research and Development of the North Atlantic Treaty Organization, and contains a number of papers presented July 1960 at the NATO Advanced Study Institute that was organized by the National University of Athens at Corfu.

New experimental methods and important new features in research of the upper atmosphere are discussed, and some problems which are still unresolved are noted.

599. RAREFIED GAS DYNAMICS, VOLUME II
Laurmann, J. A., Editor
Academic Press, Inc., New York, N.Y., 1963
(Proceedings of the Third International Symposium on Rarefied Gas Dynamics, Paris, France, June 1962)

The Third International Rarefied Gas Dynamics Symposium convened in June 1962, at the Palais de l'UNESCO, Paris, under the aegis of the Air Force Office of Scientific Research, the Office of Naval Research, the International Union of Theoretical and Applied Mechanics, the National Aeronautics and Space Administration, the Délégation Générale à la Recherche Scientifique et Technique (France), and the Université de Paris. Most of the papers delivered at the conference are included in this two-volume second supplement to the Advances in Applied Mechanics Series; the first supplement contains the Proceedings of the Second Symposium held at Berkeley in 1960. The subject areas covered in this volume are (1) ionized gas flows, and (2) transition flow, including both theory and experiment. 529 pages. (See Entries 75, 102, 118, 643, 661)

600. PROCEEDINGS OF THE FIFTH INTERNATIONAL CONFERENCE ON IONIZATION PHENOMENA IN GASES
Maecker, H., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, 1962

The conference was organized by the Verband Deutscher Physikalischer Gesellschaften "Fachausschuss für Gasentladungen und Plasmaphysik," and was held in Munich from August 28 to September 1, 1961. It was attended by 764 physicists from many countries and 240 papers were read. The program was restricted to the basic elements of gas discharge and plasma physics. The papers presented are published in two volumes and are printed in English, French, and German. Volumes I and II contain 1139 pages and 1198 pages, respectively. (See Entries 40 and 719)

601. PHYSICS OF LIGHTNING
Malan, D. J.
English Universities Press, Ltd., London, England, 1963

Various types of thundercloud and lightning discharge are briefly summarized. A description of lightning cameras is followed by a detailed examination of the mechanism and characteristics of an Earth discharge and the methods of measurement and the amplitudes and wave shapes of electric field changes. A description of the generation and distribution of cloud charges leads to a presentation of modern theories of the mechanism of charge generation. Factual data are given on the magnitudes and wave shapes of lightning currents. The electromagnetic radiation from Earth discharges, "sferics," and whistlers is discussed. Brief reference is made to the protective effect of lightning conductors, flash counters, and direction finding. An account is given of the different effects of the lightning discharge, its optical spectrum, and frictional static charges. The book covers theoretical and experimental aspects and is well illustrated, but the bibliography is largely confined to references to textbooks and codes of practice on lightning. 176 pages. (PA, 1964, #17,900)

602. BIBLIOGRAPHY ON THE IONOSPHERE AND UPPER ATMOSPHERE 1961–1963
Palluconi, B. B., Compiler
June 1964
HRB-Singer, Inc., State College, Pa.
Report B4
AD-441,450

This bibliography consists of over 1700 references compiled from *Physics Abstracts* over the period 1961 through 1963. Numerous references to satellite and rocket ionospheric studies are included, as well as many references to satellite and rocket effects on the ionosphere. The references are arranged alphabetically by author, and a subject index is provided.

603. THE UPPER ATMOSPHERE ABOVE F2-MAXIMUM
Poeverlein, H., Editor
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Paris, France, 1959 (available as AGARDograph 42, through the National Aeronautics and Space Administration, Washington, D.C.)

The papers presented at the Symposium of the Ionospheric Research Committee AGARD Avionics Panel, held May 1959 in Paris, are contained in this volume.

The first section covers papers on the physics of the exosphere. The second section deals with the radiation trapped in the radiation belts. The subjects of the third section are natural disturbances of the outer atmosphere and of the geomagnetic field, high-altitude auroras, and the effects of high-altitude nuclear detonations. In the fourth section, which is concerned with electron densities, observational results and methods of measurements are discussed in a number of papers. The final section covers whistlers and natural noise emissions of the higher atmosphere.

A listing of the papers and subject categories follows.

I. Physics of the Exosphere
- "Information About the Gas Density in Space Derived From Radiation Measurements," by H. Friedman, pp. 3–9
- "Ionization Above the F2-Peak, as Affected by the Interplanetary Gas," by S. Chapman, pp. 11–18
- "The Structure of the Outer Atmosphere Including the Ion Distribution Above the F2-Maximum," by F. S. Johnson, pp. 19–35
- "Motions in the Magnetosphere of the Earth," by T. Gold, pp. 37–45

II. Trapped Radiation
- "Summary of Results on the Trapped Particle Zone," by R. Jastrow, pp. 47–54
- "Properties of the Upper Atmosphere and Their Relation to the Radiation Belts of the Earth," by S. F. Singer, pp. 55–65
- "Measurement of Geomagnetically Trapped Particles of Natural and Artificial Origin," by L. Allen, Jr., pp. 67–82
- "Atmospheric and Magnetic Losses Mechanisms for Geomagnetically Trapped Particles," by J. A. Welch, Jr., pp. 83–94
- "The Determination of the Directional Distribution of Charged Particles Trapped in the Magnetic Field of the Earth," by R. D. Shelton, pp. 95–111

III. Disturbances and Auroras
- "Solar Flare Protons and Electrons and Their Interaction With the Geomagnetic Field," by J. R. Winckler, pp. 113–138
- "Hydromagnetic Theory of Geomagnetic Storms," by A. J. Dessler and E. N. Parker, pp. 139–149
- "VHF Radio Wave Absorption in Northern Latitudes and Solar Particle Emissions," by H. Leinbach and G. C. Reid, pp. 151–163
- "Traveling Disturbances Originating in the Outer Ionosphere," by K. Bibl and K. Rawer, pp. 165–174
- "On the Interpretation of Very High Aurorae," by A. Omholt, pp. 175–181
- "Optical, Electromagnetic and Satellite Observations of High-Altitude Nuclear Detonations – Part I," by P. Newman, pp. 183–200
- "Optical Electromagnetic and Satellite Observations of High-Altitude Nuclear Detonations – Part II," by A. M. Peterson, pp. 201–209

IV. Electron Densities
- "A Model of the F-Region Above $H_{max}F2$," by J. W. Wright, pp. 211–221
- "Incoherent Scattering by Free Electrons as a Technique for Studying the Ionosphere and Exosphere: Some Observations and Theoretical Considerations," by K. L. Bowles, pp. 223–241
- "The Faraday Effect and Satellite Radio Signals Propagated Through the Ionosphere," by W. T. Blackband, B. Burgess, I. L. Jones, and G. J. Lawson, pp. 243–262 (Entry 628)
- "Densitè Électronique Au-Dessus de F-Maximum, Déduite de l'Émission des Satellites," by E. J. Vassy, pp. 263–270 (Entry 750)
- "High-Latitude Studies of F-Layer and Outer Atmosphere Ionization," by L. Owren, H. Bates, and J. Pope, pp. 271–284
- "Ionospheric Electron Content From Refraction Measurements on Cosmic Radio Sources," by M. M. Komesaroff and C. A. Shain, pp. 285–289
- "Radar Studies of the Cislunar Medium – Part I: Theoretical," by V. R. Eshleman, R. C. Barthle, and P. B. Gallagher, pp. 291–300
- "Radar Studies of the Cislunar Medium – Part II: Experimental," by P. B. Gallagher, R. C. Barthle, and V. R. Eshleman, pp. 301–312
- "Measurements of Ionospheric Electron Content by the Lunar Radio Technique," by S. J. Bauer and F. B. Daniels, pp. 313–319
- "Remark Concerning the Charge of a Satellite," by K. Rawer, pp. 321–322 (Entry 114)

V. Natural Electromagnetic Signals
- "Hybrid Whistlers and the Problem of the Whistler Paths," by R. A. Helliwell, pp. 323–332
- "Low-Frequency Electromagnetic Radiation Associated With Magnetic Disturbances," by G. R. A. Ellis, pp. 333–344
- "Transparency of the Ionosphere and Possible Noise Signals From High Altitudes at Extremely Low Frequencies," by H. Poeverlein, pp. 345–354.

604. ANNOTATED BIBLIOGRAPHY ON THE IONOSPHERE
Samuel, P., Compiler
***Meteorological and Geoastrophysical Abstracts*, v. 15, no. 12, pp. 2479–2580, December 1964**

This special bibliography consists of 379 references to theoretical and experimental works published since 1960, and is one of a series published irregularly in *Meteorological and Geoastrophysical Abstracts*. Other bibliographies included in this series during the past five years are:

"Recent Literature in Physics of the Ionosphere," compiled by G. Thuronyi, *Meteorological and Geoastrophysical Abstracts*, v. 11, no. 4, pp. 584–620, April 1960 (162 references)

"Recent Literature on Ionospheric Radio Propagation," compiled by G. Thuronyi, *Meteorological and Geoastrophysical Abstracts*, v. 11, no. 5, pp. 743–782, May 1960 (172 references)

"Recent Literature on the Ionosphere," compiled by G. Thuronyi, *Meteorological and Geoastrophysical Abstracts*, v. 11, no. 6, pp. 928–967, June 1960 (160 references)

"Recent Literature on the Ionosphere," compiled by A. J. Meglis, *Meteorological and Geoastrophysical Abstracts*, v. 13, no. 6, pp. 1691–1748, June 1962 (236 references)

"Recent Literature on the Ionosphere," compiled by G. Thuronyi, *Meteorological and Geoastrophysical Abstracts*, v. 13, no. 10, pp. 3003–3062, October 1962 (231 references)

"Recent Literature on the Ionosphere," compiled by A. J. Meglis, *Meteorological and Geoastrophysical Abstracts*, v. 15, no. 1, pp. 149–212, January 1964 (252 references).

605. INTERNATIONAL CONFERENCE ON THE IONOSPHERE
Stickland, A. C., Editor
The Institute of Physics, and The Physical Society, London, England, 1963 (distributed by Chapman & Hall, Ltd., London, England)

The 1962 International Conference on the Ionosphere was held at Imperial College, London, from July 2–6, under the auspices of The Institute of Physics and The Physical Society. The conference was divided into four sections: (1) ionospheric constitution and ionizing radiations; (2) geomagnetism and the ionosphere; (3) irregularities and drifts in the ionosphere; and (4) mathematics of wave propagation through the ionosphere. Papers giving preliminary results from the first Anglo-American satellite, *Ariel* (*UKI*), are also included. (See Entries 269, 700, 722)

606. RAREFIED GAS DYNAMICS
Talbot, L., Editor
Academic Press, Inc., New York, N.Y., and London, England, 1961
(Proceedings of the Second International Symposium on Rarefied Gas Dynamics, Berkeley, Calif., August 3–6, 1960)

The text of 41 papers presented at the Second International Symposium on Rarefied Gas Dynamics held at the University of California in Berkeley from August 3 through August 6, 1960, is contained in this first supplement to the Advances in Applied Mechanics Series. The book is arranged in sections as follows: Molecular Beams and Surface Interactions; Free-Molecule Flow; Fundamentals of Kinetic Theory and Fluid Mechanics; Application of Kinetic Theory; Low-Density Gas Dynamics and Ionized Gases. 748 pages. (See Entries 32, 51, and 100)

607. ELECTRON DENSITY DISTRIBUTION IN IONOSPHERE AND EXOSPHERE
Thrane, E., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1964
(Proceedings of the NATO Advanced Study Institute, Skeikampen, Norway, April 17–26, 1963, sponsored by NATO Science Committee, Norwegian Defense Research Establishment)

The papers presented at the NATO Advanced Study Institute, Skeikampen, Norway, on April 17–26, 1963, comprise this volume. Significant changes in the observational techniques used for deriving the electron density profiles in the ionosphere are noted, and new techniques, some of which are more efficient, more accurate, and more simple than the older methods, are discussed. The following broad areas are covered: electron densities in the undisturbed E and D region; electron density distributions during polar blackouts; electron densities in the F region; seasonal and diurnal variation of the electron densities in the F region; measurements of the total electron content of the ionosphere; electron densities deduced from measurements of incoherent backscatter; and electron densities in the upper F region and exosphere. 395 pages. (See Entry 730)

608. CONFERENCE ON PLASMA PHYSICS, CULHAM LABORATORY, ABINGDON, SEPTEMBER 1963
Ware, A. A.
***British Journal of Applied Physics*, v. 15, no. 1, pp. 3–11, January 1964**

This conference, held by the Institute of Physics and the Physical Society, was the first full-scale conference on plasma physics in the United Kingdom, and covered the subjects of controlled nuclear fusion research, direct conversion, plasma propulsion, and the natural plasmas of the ionosphere and outer space. (*PA*, 1964, #5589)

609. INTERNATIONAL SYMPOSIUM ON PLASMA PHENOMENA AND MEASUREMENT
***IEEE Transactions on Nuclear Science*, v. NS-11, no. 1, pp. 1–388, January 1964**

Most of the papers read at the meeting of the IEEE Professional Technical Group on Nuclear Science held in San

Diego, California in October 1963 are included. Plasma phenomena and measurements constituted the general theme, and the 49 papers published are classified under the following subjects: (1) plasma measurements; (2) electromagnetic interactions with plasma; (3) plasma generation; (4) plasma diagnostics; (5) radiation effects; (6) nuclear instrumentation; and (7) general instrumentation. (*PA*, 1964 #14,624) (See Entries 191 and 249)

610. ION CLOUDS AND PLASMA PHENOMENA
May 19, 1961
Library of Congress, Air Information Division, Washington, D.C.
AID 61-68, Background Report for January 1958–January 1960
AD-257,912
(Also available through U. S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This background report is a bibliography based on source materials received at the Air Information Division. Information which is indirectly related to the subject has also been included because of its broad implications for study in the field of ion clouds and plasma phenomena. 10 pages; 16 references.

611. TRACKING OF MISSILES AND SPACE VEHICLES: COMPILATION OF ABSTRACTS
May 22, 1964
Library of Congress, Aerospace Information Division, Washington, D.C.
AID P-64-36 (Report 21), TT 6411680
AD-600,656
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is the twenty-first report in a series reviewing Soviet developments in tracking missiles and space vehicles, and covers materials contained in Soviet open literature published during the first half of 1963. Information not directly related to the assigned subject has been included because of its broad implications for study in this field. Topics covered in this series are (1) electromagnetic problems, (2) ion clouds and ionosphere perturbations, and (3) radio astronomy (radio emission, antennas, and quantum molecular oscillators). 40 pages.

612. PHENOMENA IN THE UPPER ATMOSPHERE. COMPILATION OF ABSTRACTS
September 2, 1964
Library of Congress, Aerospace Technology Division, Washington, D.C.
ATD P-51
AD-605,327
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is one of a series of monthly reports reviewing Soviet developments in selected problems in astrophysics and geophysics. Topics covered in this series are (1) ionospheric electron concentrations, (2) solar radiation and the ionosphere, (3) Van Allen belts and cosmic rays, (4) telluric currents, (5) atmospheric electricity, (6) nuclear bursts in the atmosphere, (7) satellite and missile data, (8) arctic and antarctic communications, and (9) meteorology of the upper atmosphere. This particular compilation is based on materials received at the Aerospace Technology Division in May 1964. 32 pages.

613. ROCKETS AND SATELLITES. WORLD DATA CENTER A
January 1964
National Academy of Sciences, National Research Council, World Data Center A, Washington, D.C.
Catalogue of data received by WDC-A during the period January 1, 1962–December 31, 1963 (second compilation submitted to COSPAR)
N64-19,319

Listed are data on sounding rockets launched by Australia, Japan, Sweden, the Soviet Union, the United Kingdom, and the United States, and data on artificial Earth satellites and space probes launched and/or observed over the two-year period. A bibliography of reports and reprints, listed by author and by subject, is included. 90 pages.

INSTRUMENTATION AND DATA

614. MODERN PROBE TECHNIQUES FOR PLASMA DIAGNOSIS
Aisenberg, S.
In "Engineering Aspects of Magnetohydrodynamics," pp. 89–126
Mather, N. W., Sutton, G. W., Editors
Gordon and Breach Science Publishers, Inc., New York, N.Y., 1964
(Paper presented at the Third Symposium on Engineering Aspects of Magnetohydrodynamics, Rochester, N.Y., March 28–29, 1962)

The plasma diagnostic probe theory, techniques, and data interpretation methods are discussed. Basic probe theory is reviewed, and double probe and rapid measurement techniques are discussed. Examples of information that can be deduced from probe data are given, and methods for reducing errors in measurement and interpretation are described. The theory of the Druyvesteyn probe method for determining the electron energy distribution function is presented, along with some experimental results on its application. An improved theory for the collection of positive ions by a negative probe

in a plasma is given, together with experimental data. Measurement techniques for probes in magnetoactive plasmas are also considered. 44 references.

615. METHOD OF IONOSPHERIC INVESTIGATION BY MEANS OF ARTIFICIAL EARTH SATELLITES

Al'pert, Ya. L.
***Uspekhi Fizicheskikh Nauk*, v. 64, no. 1, pp. 3–14, January 1958**

Rockets and artificial Earth satellites can contribute to the solution of various problems. Among the subjects considered by the author are the following: (1) investigation of the relationship between the electronic concentration, N, the effective number of collisions, r, and the height, z; (2) the nature and causes of the statistical instability of the ionosphere; (3) the attempt to obtain a true understanding of the processes of ionization and deionization; and (4) the construction of a theory accounting for the formation of different ionospheric layers. An examination is made of the method of investigating the ionosphere with the aid of an artificial Earth satellite situated above the regions where the electron concentration of the F_2 layer is a maximum and having an elliptical orbit whose closest approach to the Earth is in the F_2 layer (250–300 km) and an apogee up to ~800–900 km. The entire number of electrons in a column of 1-cm^2 cross section extending from the lower level of the ionosphere to height z_0 of the satellite during the period of passage above the observer is given by

$$N_p(z_0) = \int_0^{z_0} N dz.$$

Under certain conditions (in an undisturbed ionosphere) the electron concentration is given by $N_0 = N(z_0)$. The magnitudes, m_0, and the characteristics of the fluctuations of electron density and the linear dimensions of inhomogeneous formations along the course of the satellite can be determined in some instances. The method of measurement is described with the aid of the relevant equations. The results of measurement are analyzed for the case when $N = N(z)$ and when $N(x, z) = N(z)\,[1 + m \cos(2\pi/\Lambda)\,x]$. The expected values of measured magnitudes and their precision for given ionospheric parameters are examined. 7 references. (*MGA*, 1960, 11F-4)

616. RADIO INVESTIGATIONS OF THE STRUCTURE OF THE IONOSPHERE BY MEANS OF THE "COSMOS" SATELLITES USING COHERENT FREQUENCIES (PRELIMINARY RESULTS)

Al'pert, Ya. L., Belyanskiy, V. B., Mityakov, N. A.
***Geomagnetizm i Aeronomiia*, v. 3, no. 1, pp. 10–24, 1963 (Translated from the Russian in *Geomagnetism and Aeronomy*, v. 3, no. 1, pp. 6–17, 1963)**

The results are reported of a preliminary analysis of measurements of the difference in Doppler shift of the frequencies of coherent radio waves emitted from *Cosmos I* (1962θ) and *Cosmos II* (1962_t) at frequencies of 20.005 and 90.0225 Mc. New data are obtained on the gradient of the large-scale inhomogeneity in electron concentration along the orbit of the satellites. In an experiment using a single method, spatial (i.e., three dimensional) modulation of the coherent radio-wave frequencies made it possible to determine the total spectrum of linear dimensions of inhomogeneous ionospheric formations in the range from 1–300 km and more. A new maximum was discovered in the spectrum of inhomogeneities at approximately 100–130 km. The earlier known maximum at about 2–6 km is verified. The refraction angle of radio waves in the ionosphere changes markedly from point to point and has a maximum of approximately 3–4 deg at a frequency of 20 Mc. In contrast, when the electron concentration increases or decreases along the orbit, the frequency decreases or increases correspondingly. On sections of the orbit where the electron concentration is almost constant, the refraction angle also changes little.

617. A HIGH-SENSITIVITY ELECTROSTATIC RELAY

Antonova, I. A., Pisarenko, N. F., Savenko, I. A., Shumshurov, V. I.
***Geomagnetizm i Aeronomiia*, v. 4, no. 4, pp. 781–784, 1964 (Translated from the Russian in *Geomagnetism and Aeronomy*, v. 4, no. 4, pp. 607–609, 1964)**

A compact, high-sensitivity, electrostatic relay is described which was developed for recording weak currents as low as 10^{-15} A in automatic ionizing chambers. A drawing of the device and its electric circuit is included. 6 references. (*IAA*, A64-28,402)

618. MEASUREMENT OF FLUXES OF SOFT ELECTRONS IN THE UPPER ATMOSPHERE WITH A SECONDARY ELECTRON MULTIPLIER

Antonova, L. A., Ivanov-Kholodny, G. S., Masanova, N. D., Medvedev, V. S.
***Kosmicheskiye Issledovaniya*, v. 3, no. 1, pp. 82–88, 1965 (Translation available as FTD-TT-65-170, Air Force System Command, Foreign Technology Division, Wright-Patterson AFB, Ohio, April 1, 1965)**

A description is given of an instrument with a secondary electron multiplier designed for recording fluxes of soft electrons in the upper atmosphere. Also given are the preliminary results of a rocket experiment in October 1962. The apparatus was used to measure the total intensity of the electron flux at heights of 200–500 km. This experiment was the first attempt to record fluxes of extremely soft electrons with a secondary electron multiplier.

619. ELECTRON DENSITIES OF THE IONOSPHERE UTILIZING HIGH-ALTITUDE ROCKETS

Baker, K. J.
December 1956
Utah, University of, Upper Air Research Laboratories, Salt Lake City
Report 2, AF 19(604)-384

Aerobee rocket data are used to test the author's theory regarding electron densities in the ionosphere (E layer). The equations for ionospheric propagation are derived under the

assumption that free electrons are inductive, and no allowance is made for the negative capacitance usually postulated. Curves and data are included as well as photographs of the equipment.

620. ELECTRON COLLISION FREQUENCY IN THE IONOSPHERIC D REGION
Benson, R. F.
Journal of Research of the National Bureau of Standards, Section D—Radio Science, v. 68D, no. 10, pp. 1123–1126, October 1964

Ionospheric D-region electron collision frequency information that is available from rocket observations and laboratory investigations is briefly reviewed. It is indicated that the equation $\nu_m = 8.40 \times 10^7$ p(mm Hg) is accurate within about ± 10% in the portion of the D region above 40 km. The results of the cross-modulation experiment at College, Alaska, agree with this equation. 10 references. (*IAA*, A65-10,131)

621. THE TESTING OF APPARATUS FOR GROUND FAIR-WEATHER SPACE-CHARGE MEASUREMENTS
Bent, R. B.
Journal of Atmospheric and Terrestrial Physics, v. 26, no. 2, pp. 313–318, February 1964

Test results are presented to verify the efficiency of a glass-asbestos filter medium for fair-weather space-charge measurements. Negative small ions were produced artificially to a density of 12,000/cm^3 with a polonium ion generator. Experiments were made using the collectors in tandem, then using an Ebert ion counter, and finally in a conductivity test. The results show that the filter retained 99.8% of the negative small ions with an air flow of 3 liters/sec. 5 references. (*IAA*, A64-16,140)

622. THEORY OF ELECTROSTATIC PROBES IN A LOW DENSITY PLASMA
Bernstein, I. B., Rabinowitz, I. N.
October 17, 1958
Princeton University, Plasma Physics Laboratory, Princeton, N. J.
PM-S-38, NYO-8052

The theory of spherical and cylindrical probes immersed in plasmas of such low density that collisions can be neglected is formulated. The appropriate Boltzmann equation is solved, yielding the particle density and flux as functions of the electrostatic potential, the situation in the body of the plasma, and the properties of the probe. This information when applied to Poisson's equation serves to determine the potential, and hence the probe characteristic. No *a priori* separation into sheath and plasma regions is required.

The method is applied in detail and numerical results are presented for the collection of monoenergetic ions, for the case of negligible electron current. These results indicate that the potential is not so insensitive to ion energy as has been believed, and that if the probe radius is sufficiently small, it is possible that a class of ions may exist which are trapped near the probe in troughs of the effective radial potential energy. The population of these trapped ions is determined by collisions, however infrequent, is difficult to calculate, and conceivably can have a marked effect on the local potential. 36 pages; 5 references.

623. MEASUREMENTS OF CONDUCTIVITY DURING REENTRY
Betchov, R., Fuhs, A. E.
In "Proceedings of the National Aerospace Electronics Conference, Dayton, Ohio, May 8–10, 1961," pp. 176–177
NAECON, Dayton, Ohio, 1961

An instrument capable of measuring the conductivity of a moving fluid is described, which operates through a single wall, without electrodes. The instrument meets the requirements of missile practice and has been operated successfully during the reentry portion of an ICBM flight.

624. MEASUREMENT OF ELECTRICAL CONDUCTIVITY OF IONIZED AIR DURING REENTRY
Betchov, R., Fuhs, A. E., Meyer, R. X., Schaffer, A. B.
January 16, 1962
Aerospace Corporation, El Segundo, Calif.
TDR-930(2230-03)TR-1, DCAS TDR-62-3, AF 04(647)-930
AD-273,478
(Also available through U. S. Dept. of Commerce, Office of Technical Services, Washington, D. C.; see also *Aerospace Engineering*, v. 21, pp. 54–54+, November 1962)

An instrument has been developed for measuring the electrical conductivity of ionized air during reentry. The operation and design of the meter are discussed. Data from a 5000-mile flight of the meter aboard a reentry vehicle are presented and interpreted. The meter output is found to be correlated with vehicle dynamics during reentry. The estimated peak value of observed conductivity is 160 mhos/m. 26 pages.

625. A SURVEY OF DIAGNOSTIC METHODS FOR IONIZED GASES USING MAGNETIC FIELDS
Betchov, R., Fuhs, A. E.
September 21, 1962
Aerospace Corporation, El Segundo, Calif.
TDR-169(3153)TR-1, BSD-TDR-62-237, AF 04(695)-169
N63-12,104

This report describes a number of instruments designed to probe the plasma sheath during reentry or any other plasma flow. The instruments produce magnetic fields and respond to the currents induced in the plasma as it cuts through the magnetic field. The set of instruments can measure an averaged value of the product of conductivity times velocity, a profile of the same product, the local flow direction, an averaged flow velocity, and certain turbulent fluctuations. Another instrument, now being developed, will measure an

average value of the electron–neutral collision frequency. Flight instruments and laboratory instruments are briefly described. Calibration procedures are outlined. 27 pages; 7 references.

626. A RELATIONSHIP FOR PLASMA SHEATHS ABOUT LANGMUIR PROBES
Bettinger, R. T., Walker, E. H.
January 1964
Maryland, University of, Center for Atmospheric and Space Physics, College Park
Scientific Report 1, AFCRL-64-429, AF 19(628)-2792
AD-603,008, N64-20,587, N64-26,907
(Also available through U. S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

An analytical expression for the sheath about a spherical Langmuir probe was empirically derived from calculated data; this relation reproduced the data with a mean error of less than 10%. A semiquantitative analysis verifies the functional dependence of this relation, and a similar analysis develops the corresponding relationship for cylindrical geometry. In the absence of sophisticated calculations for the cylindrical case, a detailed evaluation of coefficients is not possible. The expressions derived, even in their present relatively crude form, should aid considerably in the analysis of experimental Langmuir probe results, particularly those involving spherical geometry. 14 pages; 3 references.

627. OFFSET VOLTAGES OF LANGMUIR PROBES IN THE IONOSPHERE
Bettinger, R. T.
October 1964
Maryland, University of, Center of Atmospheric and Space Physics, College Park
Scientific Report 3 for January–October 1964, Technical Report 414, AFCRL-65-54, AF 19(728)-2792
AD-613,065
(Also available through Clearinghouse, U.S. Dept. of Commerce, Washington, D.C.)

Bipolar Langmuir probes display a voltage offset in their volt-ampere characteristics when immersed in the ionospheric plasma. The dependence of the equilibrium potential as a function of probe scale, ambient charge density, and high energy "tail" in the electron energy distribution is examined. It is concluded that the offset arises from geometric considerations and is strongly influenced by all of the above factors. The observed altitude dependence is qualitatively explained in terms of vehicle velocity and precessional motion. 21 pages.

628. THE FARADAY EFFECT AND SATELLITE RADIO SIGNALS PROPAGATED THROUGH IONOSPHERES
Blackband, W. T., Burgess, B., Jones, I. L., Lawson, G. J.
In "The Upper Atmosphere Above F_2-Maximum," pp. 243–262
Poeverlein, H., Editor
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Paris, France, 1959 (available as AGARDograph 42)
(Paper presented at the Symposium of the Ionospheric Research Committee AGARD Avionics Panel, Paris, France, May 22–28, 1959—Entry 603)

The total ionospheric electron content between the ground and a radio transmitter on an artificial Earth satellite can, in certain circumstances, be determined from the Faraday fading effects. Methods of deducing and evaluating electron content are presented, and the interpretation of fading records is discussed. Experimental data are given and compared with those obtained by other methods. 8 references.

629. LANGMUIR PROBE MEASUREMENTS IN THE IONOSPHERE
Boggess, R. L., Brace, L. H., Spencer, N. W.
***Journal of Geophysical Research*, v. 64, no. 10, pp. 1627–1630, October 1959**

A description is given of the measurement of electron temperature and positive ion number density which was made by a rocket-borne adaption of a Langmuir probe over Manitoba. The probe was ejected from the rocket in order to permit complete isolation in the ionosphere. The bipolar probe yields the volt-ampere characteristic as a function of electron temperature, ion number density, ion temperature, electron number density, particle energy distribution, probe geometry, etc. A typical experimental curve obtained by data reduction is diagrammed along with the determined electron temperature. Also shown is the electron temperature vs. the altitude for a small altitude interval of 111 to 177 km. Interesting ionospheric features, although not firmly established, are suggested. The positive ion density vs. altitude diagram was obtained by two methods, both dependent on electron-temperature data. The applicability of the Langmuir probe technique to various properties of the ionosphere is indicated. High electron temperatures in reasonable agreement with higher gas temperatures in the auroral zone over Fort Churchill indicate entirely different properties of the auroral zone atmosphere vs. those of lower latitudes. One of three other probes similarly flown permitted a sampling of a greater percentage of available electrons. 6 references. (*MGA*, 1960, 11.12-356)

630. ELECTROSTATIC PROBE MEASUREMENTS OF THE IONOSPHERE
Boggess, R. L.
November 1959
Michigan, University of, Engineering Research Institute, Ann Arbor
Scientific Report GS-1, AF 19(604)-1843

A Langmuir probe that measured the properties of the E layer of the ionosphere shows that the electron temperature and temperature gradient are greater than expected. Typical values such as 1980°K at 153 km were observed. The first measurement of electron temperatures in this high altitude

ranged between 112 and 177 km. The history of the investigation, dating back to 1901, is outlined, as well as the subsequent progress in the theoretical and instrumental development. Discussions cover transmitted data, directly measured data, direct-channel high-sensitivity calibration, experimental probe volt–ampere characteristics, electron temperature data, and the accuracy of the data reduction. The electrostatic ionosphere probe experiments and the instrumentation are detailed. 135 pages; 27 references. (*MGA*, 1960, 11.12-355)

631. **IONOSPHERIC RESULTS WITH SOUNDING ROCKETS AND THE EXPLORER VIII SATELLITE (1960ξ)**
Bourdeau, R. E.
August 1961
National Aeronautics and Space Administration, Washington, D.C.
TN D-1079
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is a review of data reported since the IGY from rocket and satellite-borne ionospheric experiments, including (1) electron density (RF impedance probe); (2) D-region conductivity (Gerdien condenser); and (3) electron temperature (Langmuir probe). Also included are data obtained from the *Explorer VIII* satellite for ion concentration (ion current monitor) and electron temperature in the 1000-km region. 24 pages; 24 references. (*IAA*, 61-8507)

632. **IONOSPHERIC RESEARCH FROM SPACE VEHICLES**
Bourdeau, R. E.
***Space Science Reviews*, v. 1, pp. 683–718, 1962–1963**

The available interdisciplinary experimental data are compared with theoretical models of the D, E, and F regions as well as the upper ionosphere, and eventually models which best fit the space flight observations are selected. Because a significant amount of low-energy charged particle data was obtained by direct sampling techniques and because this methodology is relatively new to ionospheric research, the validity of some of the results presented is briefly discussed. Although the theoretical models of all ionospheric regions have been enhanced significantly by increased space flights, refinement and changes in these models await the next two major steps — the launching of satellites and rocket probes which are truly geophysical in nature, and the correlation of such interdisciplinary measurements with data resulting from recent breakthroughs in ground-based observational methods.

Much of the data discussed was obtained by direct measurement techniques (plasma probes). The success of experiments of this type is dependent upon an evaluation of the effects of the interaction between the spacecraft and the ionized atmosphere immediately surrounding it. In the appendix (Entry 36), this interaction is discussed.

633. **ROCKET STUDIES OF SPORADIC-E IONIZATION AND IONOSPHERIC WINDS**
Bowen, P. J., Norman, K., Willmore, A. P., Baguette, J.-M., Murtin, F., Storey, L. R. O.
***Planetary and Space Science*, v. 12, pp. 1173–1177, December 1964**

Simultaneous investigations of positive ion density and high-altitude winds were made in three rocket firings in Algeria in order to study the correlation of sporadic-E layers and high-altitude wind shears. Positive ion density was measured by means of Langmuir probes, and wind velocity was measured by optical tracking of a sodium-potassium vapor trail released from the rocket. On one occasion a sporadic-E layer was found to occur at 95 km, where the E–W component of the wind was zero and the wind shear was in the sense predicted by the theory of Whitehead. However, on two occasions, layers were also observed near 115 km, where the E–W component was zero but the wind shear was in the opposite sense. This suggests that some modification of the theory is required.

634. **OPERATION OF LANGMUIR PROBES IN ELECTRONEGATIVE PLASMAS**
Boyd, R. L. F., Thompson, J. B.
***Royal Society of London, Proceedings of the, Series A—Mathematical and Physical Sciences*, v. 252, no. 1268, pp. 102–119, August 25, 1959**

The criterion that must be satisfied by the positive-ion energy distribution at the edge of the sheath surrounding the negative probe is derived for the case when negative ions are present. This criterion is then used to derive the potential outside the sheath region surrounding a spherical probe immersed in an electronegative plasma. It is found that the potential falls to low values when the ratio of negative ions to electrons exceeds two. 11 references. (*EI*, 1960)

635. **THE USE OF PROBING ELECTRODES IN THE STUDY OF THE IONOSPHERE**
Boyd, R. L. F.
***British Institution of Radio Engineers, Journal of the*, v. 22, pp. 405–408, November 1961**
(Paper presented at the Convention on Radio Techniques and Space Research, Oxford, England, July 5–8, 1961)

The problems involved in using Langmuir probes for the measurement of ionospheric parameters are discussed. Attention is given to the magnitude of the probe currents and the problem of carrier-vehicle motion, and the instrumentation planned for the first Anglo–U.S. satellite is described. (*IAA*, 62-956)

636. **A METHOD OF STUDYING THE ENERGY DISTRIBUTIONS OF IONOSPHERIC IONS AND ELECTRONS**
Boyd, R. L. F., Willmore, A. P.
In "Space Research III," pp. 1168–1173
Priester, W., Editor

North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1963
(Paper presented at the Third International Space Science Symposium, Washington, D.C., May 2–8, 1962—Entry 496)

The *Ariel* satellite, launched on April 26, 1962, carried three plasma probe experiments which were designed to study the energy distribution functions of the ionospheric charged particles using the Druyvestyn method of analyzing the probe characteristic. Two of the plasma probes, identical in design but located differently on the satellite, were used to obtain the electron energy distribution function, while the third operated on the positive ions. In this way, electron and positive ion densities and temperature and the positive ion mass spectrum were obtained. The satisfactory operation of these experiments is reported, and some typical probe characteristics are shown.

637. FIRST ELECTROSTATIC PROBE RESULTS FROM EXPLORER XVII

Brace, L. H., Spencer, N. W.
Journal of Geophysical Research, v. 69, no. 21, pp. 4686–4689, November 1, 1964

In addition to the neutral particle instruments carried by the *Explorer XVII* satellite, two cylindrical electrostatic probes were used, one for the measurement of electron temperature, T_e, and the other for determining the positive ion density, N_i.

Explorer XVII measurements of T_e and N_i in the F_2 region above Blossom Point, Md., have shown that thermal nonequilibrium is the normal condition both day and night and, further, that the degree of nonequilibrium is strongly latitude-dependent in the daytime and moderately variable at night. The data also reveal a strong inverse relationship between the local values of T_e and N_i (or N_e). There is no evidence that the observed latitude dependence of T_e, seen in previous rocket flight data and apparent in *Ariel* satellite measurements, is related in an important way to particle fluxes at higher latitudes. Rather, the data suggest that the latitude dependence of T_e primarily reflects the global distribution of electron density and its controlling mechanism. 15 references.

638. A MULTIPLE-BEAM DEVICE FOR PLASMA DIAGNOSTICS

Brodskii, V. B., Belitskii, B. M., Zagik, S. E., Liutomskii, V. A., Spiridonov, A. V.
Pribory i Tekhnika Eksperimenta, v. 9, pp. 116–119, July–August 1964
(Translated from the Russian in *Instruments and Experimental Techniques*, no. 4, pp. 835–837, July–August 1964)

A five-beam radiosonde is described which uses focused radio emission in the centimeter and the millimeter ranges to analyze the interaction of a plasma with UHF radio waves. The dimensions of the cross section of a focused beam of radio waves are determined for the case where the focal length is of the order of one wavelength. The schematic diagram and radiation pattern of the device are presented. (*IAA*, A64-27,190)

639. *IN SITU* DETECTION OF AN IONOSPHERIC ELECTRIC CURRENT

Burrows, K., Hall, S. H.
Nature, v. 204, pp. 721–722, November 21, 1964

Ionospheric electric currents were investigated experimentally using *Skylark* rockets in conjunction with ground equipment. The results of two flights are plotted in the form of differences between measured values of F and values computed by approximating the geomagnetic field to that of a geocentric dipole and neglecting the horizontal component of the rockets' trajectories. The data from the rocket-borne magnetometer show an unmistakable change in slope at a height of about 104 km, followed by a return to the original slope at about 112 km. The displacement of the upper section of the curve relative to the lower section is approximately 20γ. This indicates that the rocket passed through an electric current sheet flowing in a direction having a westerly component, and of a nature similar to that which has been postulated to account for the daily magnetic variations recorded at ground level. 10 references. (*IAA*, A65-11,639)

640. STUDIES OF THE DYNAMIC PROPERTIES OF LANGMUIR PROBES. I: MEASURING METHODS

Carlson, R. W., Okuda, T., Oskam, H. J.
Physica, v. 30, no. 1, pp. 182–192, January 1964

Three different measuring techniques are presented for use in the study of the transient behavior of Langmuir probes in a gaseous plasma. These techniques make it possible to study the dynamic behavior of positive and negative space-charge sheaths. A special type of Langmuir probe was developed for these studies. A description is given of the plasma phenomena resulting from a sudden change in the probe potential with respect to the plasma. 15 references. (For Parts II and III, see Entries 726 and 728)

641. MEASUREMENT OF LOW ELECTRIC FIELDS UNDER UPPER ATMOSPHERE CONDITIONS

Chalmers, J. A., Hutchinson, W. C. A., Wildman, P. J. L., Edwards, M. G.
November 1962
Durham University, Durham City, England
Final Technical Report for October 1, 1959–September 30, 1962, AFCRL-63-236, AF 61(052)-278
AD-418,211
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A field mill has been devised to measure the electric field strength at the surface of a vehicle, in the presence of charged particles. The calibration of the field mill is described. Probe techniques for the purpose of measurement of electric potentials under ionospheric conditions are discussed. 23 pages.

642. WEAKLY IONIZED NONEQUILIBRIUM VISCOUS SHOCK LAYER AND ELECTROSTATIC PROBE CHARACTERISTICS
Chung, P. M.
July 1964
Aerospace Corporation, San Bernardino, Calif.
TDR-269(S4230) 40-1, BSD-TDR-64-103, AF 04(695)-269
AD-603,168
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The electrochemical interactions between the hypersonic stream of weakly ionized gases and the stagnation region of electrically biased blunt bodies are analyzed. The analysis is based on a continuum description. From the study, typical current–potential relationships for electrostatic stagnation probes are obtained. The effects on the electrical characteristics of the finite rate collisional energy exchange between electrons and neutrals, and the nonequilibrium electron–ion recombination are studied. Particular attention is given to the electron temperature variations in the free stream and to the effects of shock and the shock layer. Among other things, it was found that the classical electron saturation current is not usually attained. 71 pages.

643. LANGMUIR PROBE MEASUREMENTS IN THE R.A.R.D.E. PLASMA JET
Clayden, W. A.
In "Rarefied Gas Dynamics, Volume II," pp. 435–470
Laurmann, J. A., Editor
Academic Press, Inc., New York, N. Y., 1963
(Paper presented at the Third International Symposium on Rarefied Gas Dynamics, Paris, France, June 1962—Entry 599)

A method of interpreting results from a spherical Langmuir probe is given for conditions when the probe is in free molecule flow with respect to the neutral particles, and the diameter of the probe is large compared with the Debye length. Measurements are made with a spherical probe in the working section of an arc-heated low density wind tunnel, and the results are compared with results from cylindrical and disk-shaped probes. Spherical probes are used to study the distribution of electron density and temperature and the flow of a partially ionized gas over simple bodies. 14 references.

644. ROCKET-BORNE INSTRUMENTATION EQUIPMENT FOR IONIC CONDUCTIVITY STUDIES IN THE UPPER ATMOSPHERE
Cooper, O. L.
Oklahoma Academy of Science, Proceedings of the, Section C: Physical Sciences, v. 42, pp. 164–171, 1962
N63-13,044
(Paper presented at the Fiftieth Annual Meeting of the American Association for the Advancement of Science, Stillwater, Okla., December 15–16, 1961)

The payload instrumentation for ionic conductivity studies of the upper atmosphere, which was provided for the two Aerobee-100 rockets launched in November 1960 in Manitoba, Canada, is described. Each payload consisted of a nose cone instrumentation rack accommodating the electronic equipment and control circuits, and two cylindrical Gerdien condensers mounted on the forward tips of the nose skins. Each condenser housed a polarized conductivity-measuring electrode. Both rockets performed well, and all of the instrumentation appeared to function satisfactorily. However, reduction of the telemetry data is incomplete.

645. THE RESONANCE PROBE—A TOOL FOR IONOSPHERE AND SPACE RESEARCH
Crawford, F. W., Harp, R. S.
October 1964
Aerospace Research Laboratories, Wright-Patterson AFB, Ohio
ARL-64-137, AF 33(616)-8121
AD-608,440, N65-12,126

Experiments on the RF impedance between two probes immersed in a plasma, and on the incremental DC characteristics of an RF-modulated probe, have suggested that resonance effects occur at the local electron plasma frequency, ω_p, and can be interpreted to obtain a direct measurement of electron density, free from many of the errors to which conventional Langmuir probe techniques are prone. Diagnostic techniques based on these experiments have already been applied in ionospheric research. It is shown here that the two resonance effects are strongly related, but that the resonant frequency occurs below ω_p. The extremely complicated theory that describes the resonance probe behavior accurately can be simplified to obtain a model that gives predictions which agree well with experiment. This model is developed and applied to several different probe geometries of interest in ionospheric and space studies. 36 pages.

646. METHODS FOR OBTAINING ELECTRON DENSITY PROFILES FROM CAPACITIVE IONOSPHERIC ROCKET PROBES
Crouse, P. E.
May 15, 1964
Pennsylvania State University, Ionosphere Research Laboratory, University Park
Scientific Report, IRL-208, AFCRL-64-529,
AF 19(628)-4050
AD-603,625
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Two rockets were fired in July 1963 at Fort Churchill Canada, in which the nose cone was insulated and the resistive and capacitive components of the admittance of two frequencies were measured between this insulated portion of the rocket and the main rocket body. In a previous report (Entry 686), a description is given of the theory on which the reduction of these measurements to electron density and collision frequency profiles can be accomplished. This procedure has since been modified, and has been applied to the analysis of the two experiments. The first firing took place during the solar eclipse of July 20, 1963, when the percentage

of totality was approximately 93%, and the second firing took place on July 26, 1963, at approximately the same local time. Electron density and collision frequency profiles for the two experiments are presented. 86 pages.

647. MEASURING ATMOSPHERIC POTENTIAL WITH PASSIVE ANTENNAS
Crozier, W. D.
***Journal of Geophysical Research*, v. 68, no. 18, pp. 5173–5179, September 15, 1963**

Equipment is described which was developed for measuring atmospheric potentials, using antennas with no special means for coupling to the atmosphere, such as radioactive collectors or water droppers. The antennas are well-insulated horizontal wires about 20 m long, but the method is not limited to this type of antenna. After any initial net charge on the antenna has leaked off, the antenna is at atmospheric potential and subsequently closely follows variations in the atmospheric potential. Antenna potential is sensed with an electrometer tube coupled to an amplifier, providing feedback for neutralizing input capacitance and for guarding. Examples are given of potential recordings made with antennas at heights ranging from 25 cm to 3 m. (*IAA*, A63-22,371)

648. A MICROWAVE METHOD OF MEASURING PLASMA VELOCITY
Cunningham, J. W., Dicks, J. B.
In "Third Hypervelocity Techniques Symposium, Denver, Colo., March 17–18, 1964," pp. 364–394
Denver, University of, Denver Research Institute, Colo., 1964

A method of measuring plasma velocity is described which depends on observing the rate at which electron density fluctuations travel downstream. Two variations of the method are possible. First, it is possible to time the passage of naturally occurring electron density fluctuations between two stations at which microwave energy is transmitted through the plasma. Second, it is possible to produce an artificial disturbance in electron density and to time its passage to a single microwave transmission path a short distance downstream. Correlation plots are shown for several spacings between microwave channels using natural fluctuations. Waveforms obtained at varying distances downstream from a spark discharge are shown, and the velocity measured is compared to an aerodynamically measured velocity. 5 references.

649. ELECTROSTATIC PLASMA PROBES
de Leeuw, J. H.
In "Physico-Chemical Diagnostics of Plasma," pp. 65–95
Anderson, T. P., Springer, R. W., Warder, R. C., Jr., Editors
Northwestern University Press, Evanston, Ill., 1964
(Paper 63-370, presented at the AIAA Fifth Biennial Gas Dynamics Symposium on Physico-Chemical Diagnostics of Plasmas, Evanston, Ill., August 14–16, 1963)

The use of electrostatic probes for the measurement of plasma properties is reviewed. The measured probe characteristics are theoretically interpreted, and the available treatments for the variety of plasma conditions are discussed. In addition, the sources of error and the practical form of arrangement of probes are considered. 44 pages; 33 references. (*IAA*, A63-24,325)

650. PASSIVE ANTENNA AND COLLECTOR ANTENNA FOR THE MEASUREMENT OF THE ATMOSPHERIC ELECTRIC POTENTIAL
Dolezalek, H.
***Journal of Geophysical Research*, v. 68, no. 18, p. 5181, September 15, 1963**

Crozier's proposal (Entry 647) to use a passive antenna to measure the atmospheric electric potential is criticized. The disadvantage of the passive antenna, in comparison with the radioactive collector, is its great susceptibility to disturbance from convection currents hitting the antenna. The passive antenna has its greatest advantages at locations with little air movement. These locations, in general, will also show small disturbing convection currents. The disadvantages of the radioactive collector can be avoided by proper circuitry and careful installation, as long as a minimum amount of air movement is present. (*IAA*, A63-22,372)

651. STUDY OF ATMOSPHERIC ELECTRIC TRACING OF HIGH-ALTITUDE IRREGULARITIES
Dolezalek, H.
October 5, 1964
Avco Corporation, Research and Advanced Development Division, Wilmington, Mass.
Final Report, AFCRL-64-678, AF 19(628)-3289
AD-606,874, N64-33,309

Atmospheric electric parameters measured at the ground or in the troposphere are frequently correlated with auroras or other cosmic or ionospheric events. Such correlations cannot be explained on the basis of present knowledge of atmospheric electricity and auroral physics. Several qualitative hypotheses are presented. A new experimental approach is proposed that utilizes a high-flying aircraft suitably equipped with ionospheric instrumentation. The aircraft would tow a float containing atmospheric electric equipment. A general survey of measuring methods for small electric fields in the stratosphere is included. 63 pages.

652. ANALYSIS OF PROBE CHARACTERISTICS IN DRIFTING PLASMA
Dote, T., Takayama, K., Ichimiya, T.
***Physical Society of Japan, Journal of the*, v. 17, no. 1, pp. 174–183, January 1962**

A new method is suggested for calculating the altitude profiles of positive ion density in the ionosphere from the ion current obtained by a rocket-borne Langmuir probe. For a spherical probe moving relative to a plasma, the ion sheath is deformed, losing its spherical shape. It is assumed that the radius of the ion sheath perpendicular to the direction of motion is equal to that of the probe at rest. For the forward

sheath a rotating ellipsoid is applied; for the backward sheath the ordinary relation between the total current and the current density at the surface of sheath is used. Positive ion densities of the ionosphere are determined, using the above relations and observed total current. The positive ion density values thus obtained have been compared with electron density values calculated from an h'-f curve of vertical incidence sounding. The two independent observations are in close agreement, which suggests the validity of the method described.

653. SOME EXPERIMENTS ON PROBE CHARACTERISTICS IN DRIFTING PLASMA
Dote, T., Ichimiya, T., Tamaki, F.
In "Proceedings of the Fourth International Symposium on Space Technology and Science, Tokyo, Japan, August 27–31, 1962," pp. 476–481
Nomura, J., Editor
Japan Publications Trading Company, Ltd., Tokyo, Japan, and Rutland, Vt., 1963
(See also *Proceedings of the IEEE*, v. 51, pp. 480–481, March 1963)

An experimental investigation of the probe characteristics in drifting plasma was undertaken in order to evaluate a previously proposed method of calculating altitude profiles of positive ion density in the ionosphere from the ion current obtained by a rocket-borne Langmuir probe. The plasma was formed in a low-pressure supersonic wind tunnel, where the probe characteristics were measured. It is noted that, since air was used in the experiments and since the environment influences the experimental conditions, some scatter in data was inevitable. However, the experimental check of the previous analysis is considered satisfactory for the present. In addition, in this case, the type of discharge region belongs to the high-pressure, or "many-collision," region, and the drift of plasma corresponds to Mach number 3. The ionospheric plasma, however, extends over various kinds of regions, and the relative velocity between the probe and plasma often corresponds to Mach number values greater than 3. It is found that the experiment verifies the previous analysis.

654. EFFECT OF THE GEOMAGNETIC FIELD ON AN IONOSPHERIC SOUNDING PROBE
Dote, T., Amemiya, H., Ichimiya, T.
Journal of Geophysical Research, v. 70, no. 9, pp. 2258–2261, May 1, 1965

The effect of the geomagnetic field has been ignored by many researchers who have used an electrostatic probe to measure the density of the ionosphere. Later researchers considered this effect and warned that erroneous results would be obtained if the field were ignored; however, quantitative treatments have not yet been made. In this letter, it is concluded that the effect must be taken into consideration when the dimensions of the probe are large. Specifically, it is found that, although the effects of including the geomagnetic field can be neglected for positive ion measurements, they are significant for electron temperature and density measurements under certain conditions.

655. COSMIC NOISE AND IONOSPHERE STUDIES—PROJECT VELA. PART I
Dyce, R. B., Winkelman, R. E., Hodges, J. C., Johnson, G. L., Fair, B. C.
December 1963
Stanford Research Institute, Menlo Park, Calif.
Final Report, AF 49(638)-989
AD-444,659, N64-33,365

Results are described of an experimental and theoretical study of the riometer and phase sounder for the detection of a nuclear burst in deep space. Particular attention is given to experimental studies of the natural ionospheric variations. 130 pages.

656. INVESTIGATING INHOMOGENEITIES OF THE ELECTRON DENSITY IN THE IONOSPHERE USING RADIOASTRONOMY METHODS AND ARTIFICIAL EARTH SATELLITES
Erukhimov, L. M.
Izvestiya Vysshikh Uchebnykh Zavedenii, Radiofizika (Bulletin of the Institutions of Higher Education, Radiophysics), v. 5, no. 5, pp. 839–865, September–October 1962

This paper is a survey of experimental papers on the investigation of ionospheric inhomogeneities by radioastronomy methods and by means of artificial Earth satellites. The data are systematized as much as possible and compared with the results obtained from different methods of investigation of the upper layers of the Earth's atmosphere. Special attention is devoted to problems involving the altitude distribution of the inhomogeneities that cause the fluctuations both in cosmic radio emission and in the signals from artificial Earth satellites. The qualitative and quantitative features of the inhomogeneities at various latitudes are considered. The following are covered: (1) methods for investigating the ionospheric inhomogeneities using the radio emission from discrete sources and the signals from artificial Earth satellites; (2) analysis of the diffraction pattern; (3) diurnal and seasonal graph of the fluctuations, dependence of the fluctuations on latitude, and relationship to solar activity; (4) the relationship between the fluctuations and the ionospheric parameters; (5) the altitude, dimensions, and shape of the inhomogeneities, and fluctuation of the electron density in the ionosphere; (6) drifts of the ionosphere inhomogeneities; (7) relationship to magnetic activity, and the inhomogeneities in the ionosphere in the polar and equatorial regions; and (8) large-scale inhomogeneities in the ionosphere. The results obtained are discussed.

657. INTERACTION OF AN ANTENNA WITH A HOT PLASMA AND THE THEORY OF RESONANCE PROBES
Fejer, J. A.
Journal of Research of the National Bureau of Standards, Section D—Radio Propagation, v. 68D, no. 11, pp. 1171–1176, November 1964

The impedance and the radiation field in the surrounding hot plasma are calculated for an electrically short antenna that consists of two spherical conductors excited through thin wires in phase opposition. The pressure tensor is replaced by a scalar pressure, and a discontinuous model of the ion sheath is used. The losses due to the radiation of electromagnetic waves are calculated and are expressed in terms of equivalent series resistances. The operation of resonance probes is discussed; it is shown that the resonant frequency is well below the electron plasma frequency if the probe radius is much larger than the Debye length. This is significant in the interpretation of both past and future ionospheric rocket probe experiments. The limitations of the present treatment are discussed. (*PA*, 1965, #6008)

658. THE DEVELOPMENT OF THE ELECTRIC FIELD METER FOR THE EXPLORER VIII SATELLITE. APPENDIX A—MOTOR TEST DATA. APPENDIX B—PROTOTYPE TEST DETAILS. APPENDIX C—BRUSH WEAR IN A VACUUM. APPENDIX D—BEARING WEAR IN A VACUUM
Flatley, T. W., Evans, H. E.
April 1962
National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md.
TN D-1044
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The electric field meter (EFM) which was one of the sensors flown in the *Explorer VIII* satellite is described. The EFM, located on the spin axis of the payload, was designed to measure the strength of the electrostatic field caused by the ion sheath surrounding the satellite. Since the sensor required DC motor elements to operate in an ionospheric vacuum, methods were sought to avoid the catastrophic wear rate of standard commercial commutator brushes and ball bearings in a vacuum environment. After an extensive test program, gold-plated stainless-steel ball bearings and carbon brushes with a molybdenum disulphide core lubricant were used in the EFM flight units. By using these special components, an EFM was developed with a life expectancy exceeding that of the battery power available. 37 pages. (*IAA*, 62-6312)

659. AN INSTRUMENT FOR MEASURING ION COMPOSITION OF THE UPPER ATMOSPHERE
Flowerday, T. W.
***IEEE Transactions on Instrumentation and Measurement*, v. IM-13, no. 1, pp. 14–17, March 1964**

An instrument is described which is well suited for use in rocket and satellite work and is capable of measuring the ion composition of the upper atmosphere. The theory of operation of a Paul-type mass spectrometer is given, and a system consisting of a Paul mass spectrometer and an electron-multiplier-type detector, capable of measuring ion composition, is then described. The electronic system, which produces the RF and DC potentials required by the Paul mass spectrometer and measures the current output of the electron multiplier, is discussed.

660. FALLING PROBE ELECTRON DENSITY MEASUREMENTS
Forsyth, P. A., Kavadas, A.
***Canadian Aeronautical Journal*, v. 7, pp. 105–108, March 1961**
(Paper presented at the Symposium on Canadian High Altitude Research, Ottawa, Canada, October 21, 1960)

A planned electron density experiment is discussed which uses a modified RF probe to investigate the structure of the ionization in an auroral display. Previous electron density measuring methods and the problems associated with them are discussed. Unlike a previous effort, the planned experiment uses an RF source which is not fixed in frequency. The frequency is made variable and caused to track the critical frequency of the surrounding medium continuously. It is expected that this approach will overcome the difficulties introduced by sheath formation.

661. THE USE OF LANGMUIR PROBES IN LOW DENSITY PLASMA FLOWS
French, J. B., Sonin, A. A., de Leeuw, J. H.
In "Rarefied Gas Dynamics, Volume II," pp. 471–494
Laurmann, J. A., Editor
Academic Press, Inc., New York, N.Y., 1963
(Paper presented at the Third International Symposium on Rarefied Gas Dynamics, Paris, France, June 1962—Entry 599)

An experimental study of Langmuir probes which are small in relation to neutral-particle mean free paths is presented. The probes were studied in a moderately supersonic plasma stream at high and low ion concentrations. Probe theory is reviewed and extended, and by comparison with experiment it is indicated that these small probes can be used for the determination of plasma properties when care is exercised in ascertaining the conditions to which the probe is subjected. In particular, the charged-particle mean free paths in terms of the probe size and the ratio of electron-to-ion temperatures are of importance. The probes were used in the study of the stagnation region in front of a blunt body. 20 references.

662. DEVELOPMENT OF A DEVICE FOR MEASURING ELECTRICAL CONDUCTIVITY OF IONIZED AIR DURING REENTRY
Fuhs, A. E.
September 20, 1960
Space Technology Laboratories, Inc., Los Angeles, Calif.
STL-TR 60-0000-09256, AF 04(647)-309
AD-252,222

Interaction of a magnetic field and the flow of ionized air during reentry develops forces and moments on the reentry vehicle. In order to proceed with the design of a control system based on this interaction, it is necessary to know the

electrical properties of the conducting gas. An electrical conductivity meter was developed for measuring σuB integrated over space. 48 pages.

663. AN INSTRUMENT TO MEASURE THE ELECTRICAL CONDUCTIVITY OF ARC PLASMA JET
Fuhs, A. E.
American Rocket Society, New York, N.Y.
Paper 2635-62, presented at the ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., November 13–18, 1962
(See also *AIAA Journal*, v. 2, no. 4, pp. 667–673, April 1964)

A transducer is described which measures the product of the electrical conductivity and velocity, σu, of the conducting gases that flow along its axis. The instrument is calibrated by moving aluminum or graphite rods through the transducer. It is shown that by using thin-walled, stainless-steel tubing, the influence function of the transducer can be determined. Tests performed at two different arc-plasma-jet facilities, yielded σu values ranging from 0.02 to 9.0 megamhos/sec. 7 pages; 12 references. (*IAA*, A63-12,580)

664. A VELOCITY–ELECTRICAL CONDUCTIVITY TRANSDUCER FOR AXISYMMETRIC REENTRY VEHICLES
Fuhs, A. E., Gibb, O. L.
October 10, 1963
Aerospace Corporation, Los Angeles, Calif.
TDR-269-4810-20-I, BSD-TDR-63-206, AF 04(695)-269
AD-424,550
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A transducer for measuring the product of electrical conductivity and velocity is described which has a geometry particularly suitable for axisymmetric vehicles. The relation of the plasma sheath properties to the signal is investigated theoretically. It is the current within a narrow ring of the plasma sheath concentric with the sensing coil that causes the signal. An experiment was performed using an arc plasma jet. The purpose of the experiment was to confirm the operation of the instrument. 25 pages.

665. PLASMA SHEATH TRANSDUCER FOR AXISYMMETRIC REENTRY VEHICLES
Fuhs, A. E., Gibb, O. L.
AIAA Journal, v. 2, no. 4, pp. 773–775, April 1964

A transducer is described which serves two functions: it provides useful information concerning the plasma sheath, and serves as ballast if located at the forward tip of the reentry vehicle. The transducer consists of three circular coils with a common axis. The two outer coils are driven at audio frequencies and are connected so that the magnetic fields are in opposition. A sensing coil is located between the primary coils. The voltage appearing at the terminals of the sensing coil can be related to the electrical conductivity–velocity (σu). A plot of the measured normal component of magnetic field and calculated tangential component of velocity is given, as well as a plot of temperature ratio and electrical conductivity ratio. Testing of the transducer by immersing a Teflon cone and coil assembly in a plasma arc jet demonstrated that signals could be obtained. Most of the signal originated from a narrow region of flow near the sensing coil. 5 references.

666. AN ELECTRICAL CONDUCTIVITY–VELOCITY INSTRUMENT USING STEADY APPLIED MAGNETIC FIELD
Fuhs, A. E., Betchov, R., Gibb, O. L., Abshear, J. R.
August 21, 1964
Aerospace Corporation, Plasma Research Laboratory, El Segundo, Calif.
SSD-TDR-64-158, TDR-269(4280-50)-3, AF 04(695)-269
AD-449,824, N64-33,348

A flight instrument using a permanent primary magnetic field has been developed. The flight instrument can measure plasma flows with σu equal to 10^4(mho/m)(m/sec). In order to reduce the data, it is necessary to determine the no-flow reference level, $eE(\theta,\phi)$, which requires knowledge of the vehicle's motion. The instrument could be adapted for use with plasma flows, such as MHD generators. Since the transducer has a fixed orientation relative to external magnetic fields, the sensitivity could be increased so that σu equal to 10^3, and possibly 10^2(mho/sec), could be measured. 28 pages.

667. FLIGHT INSTRUMENTATION FOR THE REENTRY PLASMA SHEATH
Fuhs, A. E.
In "Physico-Chemical Diagnostics of Plasma," pp. 383–401
Anderson, T. P., Springer, R. W., Warder, R. C., Jr., Editors
Northwestern University Press, Evanston, Ill., 1964
(Paper 63-379, presented at the AIAA Fifth Biennial Gas Dynamics Symposium on Physico-Chemical Diagnostics of Plasmas, Evanston, Ill., August 14–16, 1963)

Instruments for probing the plasma sheath during reentry are described. The instruments respond to the induced magnetic field produced by the interaction of the ionized gas flowing through an applied magnetic field. Flight models to measure the product of electrical conductivity and velocity, σu, and the σu profile are discussed, and laboratory transducers for determining velocity, σu fluctuations, and average electron-collision frequency are analyzed and described. 36 pages; 20 references. (*IAA*, A63-24,267)

668. EFFECT OF THE IONOSPHERE ON THE DETERMINATION OF THE POSITION OF A SPACE ROCKET
Gdalevich, G. L., Gringauz, K. I., Rudakov, V. A., Rytov, S. M.
Radiotekhnika i Elektronika, v. 8, no. 6, pp. 942–949, June 1963

(Paper presented at the Thirteenth International Astronautics Congress, Varna, East Bulgaria, September 1962; translated from the Russian in *Radio Engineering and Electronic Physics*, v. 8, no. 6, pp. 951–958, June 1963)

Errors are introduced by the ionosphere when determining the coordinates and velocity of a rocket by radio methods. The possibility of computing these errors is discussed. Expressions are derived for the error as a function of the ionosphere parameters, and the possibility of approximating the real altitude distribution of electrons is evaluated for purposes of computing the error. 25 references.

669. AN ELECTROSTATIC FLUXMETER DESIGNED FOR MEASUREMENTS IN THE HIGH LAYERS OF THE ATMOSPHERE

Gdalevich, G. L., Imyanitov, I. M., Shvarts, Ya. M.

Kosmicheskiye Issledovaniya, v. 3, no. 1, pp. 102–110, 1965

An electrostatic fluxmeter for measurement of the strength of the electrostatic field is described which is designed for measurement in the high layers of the atmosphere. A block diagram and a circuit diagram of the instrument are included. The sensor is described in detail. The measurement range of the instrument is ±2–3 V/cm; the measurement error is ±0.25 V/cm ±0.25 E_{meas}.

670. ON THE INFLUENCE OF ION SHEATHS UPON THE RESONANCE BEHAVIOR OF AN RF PLASMA PROBE

Gierke, G., Muller, G., Peter, G., Rabben, H. H.

Zeitschrift für Naturforschung, v. 19A, no. 9, pp. 1107–1111, September 1964 (in English)

The applicability of the RF resonance probe method to the measurement of the electron density in a plasma is investigated in a thermal plasma of low density. The experiments show that, in contrast with the earlier published investigations, the resonance frequency determined by the RF probe does not agree with the plasma frequency but is always found to be lower than this. The difference between resonance frequency and plasma frequency is caused by the ion sheath in front of the probe; the thickness of the sheath determines the amount of the frequency shift. Therefore, the RF resonance probe determination of the electron density is valid only if the geometrical dimensions of the probe environment are taken into account. By means of the RF probe, information on the plasma ion sheath (i.e., in front of the probe) can be obtained. 9 references.

671. RESULTS OF OBSERVATIONS OF CHARGED PARTICLES OBSERVED OUT TO R = 100,000 KM, WITH THE AID OF CHARGED-PARTICLE TRAPS ON SOVIET SPACE ROCKETS

Gringauz, K. I., Kurt, V. G., Moroz, V. I., Shlovskii, I. S.

Astronomicheskii, Zhurnal, v. 37, no. 4, pp. 716–735, July–August 1960
(Translated from the Russian in *Soviet Astronomy—AJ*, v. 4, no. 4, pp. 680–695, January–February 1961)

Results of the deductions of measurements made with the aid of trielectrode ion traps mounted in the Soviet space ships launched on January 2 and September 12, 1959, are presented. Rocket trajectories out to $R < 100{,}000$ km were studied. The potential of the container, which was immersed in a hydrogen plasma and was subject to the action of electrons present in the radiation belts and to short-wavelength radiation of solar origin, is discussed. Values for the container potential, computed with different values assigned to temperature, plasma concentration, and density of photocurrent at the container surface, are tabulated. The plasma density was estimated with the ion-trap outer grid at zero potential. The motion of the container was calculated as was the effect of radiation-belt electrons on collector currents. Since all of the ion traps were insensitive to the radiation-belt environment (as shown by the absence of sizeable negative currents in all of the traps), it is concluded that the flux of radiation-belt electrons over the region $R < 50{,}000$ km does not exceed 3×10^7/cm²/sec for electrons of energy $E > 200$ eV. In the region 50,000 km $< R <$ 75,000 km, negative currents were recorded in all the traps, corresponding to an electron flux at energy $E > 200$ eV of about 2×10^8/cm²/sec, which suggests the existence of a new, more remote radiation belt. An ion density of the order of several hundred ions per cubic centimeter was found out to 15,000 km. The density falls off farther out, and only an estimate can be offered for the upper limit of density at $R < 20{,}000$–22,000 km, $n_i < 30$–60/cm³. This supports the view that polarization of the zodiacal light is entirely due to the dust component, while the high electron density found from studies of atmospheric whistlers relates to the geocorona. (*PA*, 1962, #918)

672. INSTRUMENTATION FOR ROCKET MEASUREMENTS OF THE FREE-ELECTRON DENSITY IN THE IONOSPHERE

Gringauz, K. I., Rudakov, V. A., Kaporskii, A. V.

Iskusstvennye Sputniki Zemli, no. 6, pp. 33–47, 1961
(Translated from the Russian in *Planetary and Space Science*, v. 9, pp. 247–257, 1962; see also *ARS Journal*, v. 32, no. 7, pp. 1152–1159, July 1962)

A brief description is given of the radio equipment for studying changes in the electron concentration in the atmosphere with changing altitude, which was employed on vertically launched geophysical rockets. The equipment includes the radio-transmitter unit with transmitting antennas, the ground receiving antennas, the receiving phase-metering instruments, and the recording and auxiliary equipment. The rocket transmitter generates coherent oscillations on three frequencies, and the rocket antennas take the form of symmetrical linear vibrators. Reception occurred at a number of sites near the projection of the trajectory peak on the Earth. Two methods are employed for recording the measurements on 35-mm film: the first employs a loop oscillograph for recording the interference frequency and current; the second measures the phase difference, recording the characteristic

currents of the Lissajous figure on the moving film. Measurement discrepancies, as indicated by the dispersion of results from variously sited receiving stations, amount to 5%.

673. MEASUREMENTS OF ELECTRON CONCENTRATION IN THE IONOSPHERE UP TO ALTITUDES OF 420–470 KM, CARRIED OUT DURING THE INTERNATIONAL GEOPHYSICAL YEAR BY MEANS OF RADIO-WAVE TRANSMISSIONS FROM THE GEOPHYSICAL ROCKETS OF THE ACADEMY OF SCIENCES U. S. S. R.
Gringauz, K. I., Rudakov, V. A.
Iskusstvennye Sputniki Zemli, no. 6, pp. 48–62, 1961
(Translated from the Russian in *Planetary and Space Science*, v. 8, pp. 183–193, 1961)

Measurement results are discussed which afforded some material conclusions regarding the structure of the ionosphere. A comparison of the sections of the electron concentration versus altitude curves for altitudes above the principal ionization maximum (above 300 km) during the time of the three rocket launchings described shows that the rate of electron concentration decay with altitude over one and the same geographical point can vary over a wide range (apparently as a function of time of year and day). This conclusion contradicts an earlier concept of an ionization model only slightly dependent on time of day, season, latitude, etc.

The variation with time of the rate of decay with altitude of charged particle concentration in the upper ionosphere is confirmed by results obtained with ion traps installed on the third Soviet Earth satellite.

Measurement results at the time of all three launchings fully confirm that the ionosphere has one principal electron concentration maximum at an altitude of approximately 300 km, and that the concept of a sharply defined so-called E layer of the ionosphere arose only as the result of the limited possibility of establishing a pure altitude–electron concentration distribution on the basis of altitude–frequency characteristics obtained from ionosphere stations. An assessment is made of the possibility of using the dispersion interferometer on rockets ascending to an altitude on the order of thousands of kilometers and on artificial Earth rockets. The method is shown to be unreliable for these altitudes, and impossible at distances greater than 20,000 km. 18 references.

674. RESULTS OF MEASUREMENTS OF POSITIVE-ION CONCENTRATIONS IN THE IONOSPHERE EMPLOYING ION TRAPS ON THE THIRD SOVIET EARTH SATELLITE
Gringauz, K. I., Bezrukikh, V. V., Ozerov, V. D.
Iskusstvennye Sputniki Zemli, no. 6, pp. 63–100, 1961
(Translated from the Russian in *Artificial Earth Satellites*, v. 6, pp. 77–121, 1961)

If negative ions exist in the F region of the ionosphere, they are present only in negligible quantities, since the measured electron concentrations are roughly equal to the positive ion concentrations. The ionization of neutral particles of air as the result of the satellite motion does not appreciably affect the ion trap measurements. The absence of appreciable quantities of negative ions in the upper ionosphere indicates that the values obtained for the positive ion concentrations can also apply to the electron concentration values. At altitudes above 400 km, the positive ion concentration decreases slowly; the rate of decrease is in good agreement with measurements obtained with the aid of the geophysical rockets of the USSR which were launched vertically and reached altitudes of 470 km. At 1000 km a positive ion concentration of approximately $5.7 \times 10^4/cm^3$ of ions of a given mass is appreciably greater than the concentration of all ions with other masses. This confirms mass spectrum measurements which indicate that atomic oxygen ions are the main constituent of the ionosphere at this altitude. 18 references.

675. THE STRUCTURE OF THE IONIZED GAS ENVELOPE OF EARTH FROM DIRECT MEASUREMENTS IN THE USSR OF LOCAL CHARGED PARTICLE CONCENTRATIONS
Gringauz, K. I.
Iskusstvennye Sputniki Zemli, no. 12, pp. 105–118, 1962
(Translated from the Russian in *Planetary and Space Science*, v. 11, pp. 281–296, March 1963)

Ionosphere electron and ion concentration measurements were obtained using radio waves radiated from geophysical rockets. The overall results made it possible to plot the approximate altitude distribution of the charged particles in the ionized gas envelope of Earth, to determine the boundary of this envelope, and to draw certain conclusions regarding its variability at different altitudes. It is noted that a new theory is needed to explain satisfactorily some of the facts revealed by recent discoveries in this field. In particular, it is necessary to explain the substantial increase in the negative gradients of the concentration detected at altitudes between 15,000 and 20,000 km near the boundary of the gas envelope. 11 references.

676. ANALYSIS OF RESULTS OF SIMULTANEOUS MEASUREMENTS OF ELECTRON CONCENTRATION IN THE IONOSPHERE BY IONOSPHERE STATIONS AND ROCKETS
Gringauz, K. I., Gdalevich, G. L.
Iskusstvennye Sputniki Zemli, no. 13, pp. 89–96, 1962
(Translated from the Russian in *Planetary and Space Science*, v. 11, pp. 321–326, March 1963)

It is shown that up to the maximum of the F_2 layer, the altitude distribution of the electron concentration can be estimated accurately from high frequency characteristics by using Shinn-Kelso coefficients. Calculations are made of height frequency characteristic curves on the basis of height distribution of the electron concentration obtained with rockets. The distributions calculated on the basis of height frequency curves are compared with those obtained with a dispersion interferometer. The desirability is noted of having some of

the results of observations by the ionosphere stations published in the form of profiles of the height distribution of the electron concentration. Such publications would allow the accumulation of data on the variations with the time of day and year, and would facilitate the clarification of a number of questions in ionosphere physics. 10 references.

677. RESONANCE DISTURBANCES OF THE IONOSPHERE NEAR THE SURFACE OF AN ANTENNA LOCATED ON AN ARTIFICIAL EARTH SATELLITE
Gurevich, A. V., Pitaevskii, L. P.
International Astronautical Federation, Paris, France
Paper presented at the 15th International Astronautical Congress, Warsaw, Poland, September 7–12, 1964
(in Russian)

A new method is discussed for studying the ionosphere by means of satellite-borne resonance probes (antennas). The role of nonlinear effects is investigated and time-averaged distributions of electrons near a satellite antenna are determined, using the Miller equation for mean forces acting on electrons in the high-frequency field. The relationship between the field amplitude in the ionospheric plasma and the frequency is determined in formulating the theory of resonance probes. The field within the plasma is determined by the dielectric constant, taking into account the nonlinear effects and three-dimensional dispersion. 12 pages; 9 references. (*IAA*, 65-11,581)

678. A PROBE ASSEMBLY FOR THE DIRECT MEASUREMENT OF IONOSPHERIC PARAMETERS
Hale, L. C.
October 1964
Pennsylvania State University, Ionospheric Research Laboratory, University Park
Scientific Report 223(E), NASA-CR-59136
N64-33,223
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A detailed description is given of a direct probe for measurement of ionospheric parameters, such as positive ion density, composition, and temperature, as well as electron temperature and vehicle potential. A rugged, reliable, lightweight electronics assembly was constructed incorporating the following features: (1) simple automatic range switching of the electrometer sensitivity to both positive and negative current ranges, (2) circuitry for extracting the time derivative of the probe current waveform, (3) in-flight calibration of system sensitivity, and (4) automatic switching from an ion mode to an electron mode of operation. 33 pages.

679. A ROCKET-BORNE LOW-FREQUENCY PROPAGATION EXPERIMENT TO DETERMINE D-REGION ELECTRON DENSITIES
Hall, J. E., Bullough, K.
***Nature*, v. 200, pp. 642–644, November 16, 1963**

The preliminary results are presented of ionosphere experiments with *Skylark* rockets, launched at Woomera, Australia. A continuous wave of 202 kc was transmitted from the ground, and was subject to refraction, absorption, reflection, and changes in polarization in the lower ionosphere. The rocket was sent through the resulting wave pattern to measure the variations in field strength, and hence to deduce the ionospheric parameters. From the plot of the scalar field quantity, F, as a function of height, it can be seen that (1) ionospheric absorption causes the wave amplitude to decrease by a factor of ten between 70 and 80 km; (2) above 80 km the reflected wave was strong enough to produce a well-defined standing wave; (3) the wavelength of the standing wave increased with the height as the refractive index of the ionosphere decreased; and (4) total reflection occurred at a height of about 89 km. An interpretation of these results is proposed. (*PA*, 1964, #20,869)

680. SINGLE-FREQUENCY RADIO TRANSMISSIONS FROM SATELLITES
Hame, T. G., Potts, B. C.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 429–435
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17)

A method is discussed for determining the electron density at the height of a satellite by an analysis of single-frequency radio transmission from the satellite.

681. A POTENTIAL METHOD FOR DETERMINING NET ION DENSITY IN AIR
Hammond, S. B.
1958
Purdue University, Lafayette, Ind.
Thesis

The potential method for determining the net space charge or net ion density in air requires (1) a means for measuring the electrostatic potential attributed to the ion space charge, and (2) the calculation of net space charge or ion density from the potential measurements and the boundary conditions of the ionized region. An electronic electrometer and the rotary electrostatic generator with radioactive probe for the potential-measuring problem are discussed. Also treated is the solution of Poisson's equation relating electrostatic potential to space charge or net ion density by finite differences and by an electric circuit analog. A set of curves is presented which can be used to convert electrostatic potential to net ion density for a large number of geometric configurations of boundaries, from which other solutions can be extrapolated. (*DA*, 59-6275)

682. MEASUREMENT OF FIELDS IN THE PLASMA SHEATH BY AN ELECTRON BEAM PROBING TECHNIQUE
Harp, R. S., Kino, G. S.
In "Comptes Rendus de la VI^e Conférence Internationale sur les Phénomènes d'Ionisation dans les Gaz, Volume III," pp. 45–50
Hubert, P., Crémieu-Alcan, E., Editors
SERMA, Paris, France, 1963
(Paper presented at the Sixth International Conference on Ionization Phenomena in Gases, Paris, France, July 8–13, 1963—Entry 592; for abstract, see Entry 683)

683. MEASUREMENT OF FIELDS IN THE PLASMA SHEATH BY AN ELECTRON BEAM PROBING TECHNIQUE
Harp, R. S., Kino, G. S.
January 1964
Aerospace Research Laboratories, Wright-Patterson AFB, Ohio
ARL-64-14, AF 33(616)-8121
AD-431,861, N64-16,776
(See also Entry 682)

An experiment to measure both the RF and the DC fields in the sheath is described. The fields are determined by finding the deflection of an electron beam passed parallel to the sheath–plasma interface. The sheath in which these experiments were performed was formed in a low-density plasma on a metal plate inserted into the plasma. Both the DC field variation and the RF field variation through the sheath were measured when an RF potential was applied to the plate. The observed DC field variation is in good agreement with a theory by Self; the measured RF field variations are in good agreement with a theory given by Pavkovich. The fact that no self-oscillations of any kind were measured in the sheath is thought to be due to a good Maxwellian distribution of electron velocities obtained by careful design of the discharge electrodes. 23 references.

684. A STUDY OF THE PLASMA BOUNDARY
Harp, R. S.
October 1964
Aerospace Research Laboratories, Wright-Patterson AFB, Ohio
ARL-64-138, AF 33(616)-8121
AD-609,567, N65-15,123

This study is concerned with an experimental investigation of the static and dynamic properties of the plasma sheath. The basic experimental technique used was the passage of an electron beam through the sheath parallel to the wall; by measuring the deflection of the beam, transverse DC and RF electric fields in the sheath were measured. Measurements of the DC fields are compared with a theory based on a solution of the complete plasma sheath equation. By means of this comparison, it is possible to accurately evaluate the plasma parameters n_e and T_e. It is concluded that the static and dynamic properties of the sheath are adequately described by theory, and that the resonance probe can be a useful and accurate device for plasma diagnostic measurements. 131 pages.

685. CHARACTERISTICS OF THE PLASMA RESONANCE PROBE
Harp, R. S., Crawford, F. W.
October 1964
Aerospace Research Laboratories, Wright-Patterson AFB, Ohio
ARL-64-139, AF 33(616)-8121
AD-608,613, N65-12,127

Detailed experiments have been carried out to confirm the predictions that (1) the resonance frequency lies below the local electron plasma frequency, (2) the resonance frequency is dependent on probe potential and probe size, and (3) the resonance should be highly damped when probe dimensions are smaller than a few electronic Debye lengths. If the resonance probe is to be of great practical importance, a simplified theoretical model describing its behavior is desirable. The theory of such a model is presented and compared with experimental results. Improved methods of applying the resonance probe are discussed. 46 pages; 38 references.

686. THEORETICAL DETERMINATION OF THE IMPEDANCE CHARACTERISTICS OF A CAPACITIVE IONOSPHERE ROCKET PROBE
Herman, J. R.
March 1, 1963
Pennsylvania State University, Ionosphere Research Laboratory, University Park
Scientific Report 180, AFCRL-63-285, AF 19(604)-8012
N63-15,724

The impedance characteristics of a capacitive ionospheric rocket probe were determined as a function of the electron density, collision frequency, and temperature. The physical model used in developing the theory incorporated both the effect of the ion sheath which forms about the rocket body and the effect of the anisotropic nature of the surrounding magneto-ionic medium. The results obtained are numerically evaluated to show that the sheath makes a very significant contribution to the impedance characteristics. 76 pages; 14 references.

687. A METHOD FOR DETERMINING D-REGION ELECTRON-DENSITY PROFILES UTILIZING A CAPACITIVE IMPEDANCE ROCKET PROBE
Herman, J. R.
Journal of Geophysical Research, v. 69, no. 11, pp. 2329–2336, June 1, 1964

An analysis of a capacitive impedance probe for measuring electron density in the lower ionosphere is presented. The method employed accounts for the effects of the ion sheath surrounding the rocket probe and the collisions of oscillating

electrons with neutral particles. The applicability of the method and theory developed is illustrated by utilizing indicated ionospheric models to determine typical impedance characteristics of the probe. 9 references.

688. THE IMPEDANCE OF A ROCKET-BORNE CAPACITIVE IONOSPHERIC PROBE

Herman, J. R.
***Journal of Geophysical Research*, v. 69, no. 15, pp. 3299–3300, August 1, 1964**

An expression is derived for the expected impedance of a capacitive ionospheric probe as a function of electron density, collision frequency, temperature, magnetic field, and rocket attitude with respect to the magnetic field. This expression permits an analysis of capacitive rocket probes for any attitude. The expression contains no information about possible ion sheath effects. (*EI*, 1964)

689. MEASUREMENT OF POSITIVE ION DENSITY IN THE IONOSPHERE

Ichimiya, T., Takayama, K.
***Report of Ionosphere and Space Research in Japan*, v. 13, no. 3, pp. 155–176, 1959**

In order to measure the positive ion densities in the ionosphere directly using a double probe method by rocket-borne instrument, several points must be clarified. Effects of photoelectric emission from the probe, existence of negative ions in the plasma, and other disturbances are discussed. The predominant effect of photoemission on the probe current can be reduced by adoption of a small-sized probe, especially a meshed spherical probe. When the motion of ions in the sheath is assumed, the plasma potential is easily determined from a recorded characteristic curve of the positive ion collections. The corrections due to the existence of the negative ions are calculated from Boyd's equation, and this value is nearly equal to unity in the lower parts of the E layer and the D layer. The positive ion density in the lower parts of the ionosphere can be measured with the double probe method using the meshed spherical probe. To examine the characteristics of a meshed spherical probe, an ultra-low, uniform-density plasma ($10^{5\text{-}6}$/cm^3) is obtained in a mercury discharge tube which is constructed with a Pyrex sphere 30 cm in diameter and with two plasma sources near the tube wall. Two movable probes are inserted in the plasma. One is a cross-ring spherical probe having two equal tungsten wire rings 4 mm in diameter; the other is a cylindrical probe 15 mm in length and 0.38 mm in diameter. The electron density of the plasma is determined from the current at the plasma potential of the cylindrical probe. The ion density is determined from the characteristic curves of the ion collection obtained from the cross-ring spherical probe. A plot of the saturated positive ion-probe current vs. voltage is in good agreement with the theory of one collision in the sheath, when a correction of voltage is made. The good agreement between the ion density and the electron density is shown in the region of 1.8×10^5 to 3×10^6/cm^3.

It is concluded that the cross-ring spherical probe is applicable to the measurement of the low ion-density region of the ionosphere under the influence of the intense solar radiation. To measure the positive ion density of the ionosphere by the double probe method, a simple cathode-follower circuit amplifier is constructed. The potential difference between the probe and the other electrode (i.e., the rocket body) is varied widely, using a potentiometer which is driven by a micromotor and gear system. The probe current of 10^{-6} to 10^{-9} A is measured as a potential drop across the input of the cathode follower circuit. The grid leak is changed in three steps, one for each rotation of the potentiometer, in order to vary the range of probe current. The total weight of the amplifier (including dry cells and without the probe) is 1.4 kg, and continuous operation for two hours is possible. A shock test, up to 100 g, gives no effect. Experiments with a discharge tube in the laboratory indicate an ion density of 10^5 to 10^7/cm^3. 20 references. (*MGA*, 1960, 11.12-358)

690. MEASUREMENT OF POSITIVE ION DENSITY IN THE IONOSPHERE BY SOUNDING ROCKET

Ichimiya, T., Takayama, K., Dote, T., Aono, Y., Hirao, K., Miyazaki, S., Sugiyama, T., Muraoka, T.
***Nature*, v. 190, no. 4771, pp. 156–158, April 8, 1961**

Profiles of positive ion density, calculated from Langmuir probe results obtained by rocket sounding of the ionosphere, are presented. The probes used in the experiment are described, ion density is plotted as a function of altitude, and the results are discussed briefly. (*IAA*, 61-5499)

691. INVESTIGATION OF COSMIC PLASMA BY MEANS OF THREE-ELECTRODE PROBES

Ionov, N. I.
***Zhurnal Tekhnicheskoi Fiziki*, v. 33, no. 3, pp. 366–368, March 1963**
(Translated from the Russian in *Soviet Physics—Technical Physics*, v. 8, no. 3, pp. 269–272, September 1963)

A plane, three-electrode probe is used to measure positive ion concentrations. The probe can also be applied to the measurement of plasma parameters, such as the electron concentration and distribution of electrons and ions with respect to the energy of their motion relative to the vehicle, as well as to the potential of the vehicle relative to the plasma. The current–voltage characteristics of the collector ion current are presented. It is shown that the secondary and photoelectron emission from the collector of the probe can be suppressed by using a fourth dynatron circuit. 4 references. (*IAA*, A63-16,812)

692. STUDY OF GAS-DISCHARGE AND COSMIC PLASMAS BY MEANS OF MULTI-ELECTRODE PROBES (A REVIEW)

Ionov, N. I.
***Zhurnal Tekhnicheskoi Fiziki*, v. 34, no. 5, pp. 769–787, May 1964**

(Translated from the Russian in *Soviet Physics—Technical Physics*, v. 9, no. 5, pp. 591–604, November 1964)

A survey is made of probe methods for studying characteristics of gas-discharge and cosmic plasmas having a relatively small particle concentration. The use of various combinations of single- and multi-electrode probes is considered for measuring stationary and cosmic plasmas. Probe characteristics can be utilized to yield information such as concentration and kinetic energy of the charged particles, potential of the unperturbed plasma, and potential acquired by an insulated probe in the plasma.

693. **INVESTIGATION OF THE IONIC COMPOSITION OF THE EARTH'S ATMOSPHERE USING GEOPHYSICAL ROCKETS IN THE PERIOD 1957–1959**
Istomin, V. G.
***Iskisstvennye Sputniki Zemli*, no. 7, pp. 64–77, 1961**
(Translated from the Russian in *Planetary and Space Science*, v. 9, pp. 179–193, 1962)

The positive ion composition (mass spectrum) of the ionosphere was measured at altitudes of 100 to 200 km, and data on the variation of composition with altitude were obtained. At altitudes of 100 to 200 km, hydrogen or helium ions were not detected. Certain preliminary data were obtained concerning the variation in the ionospheric composition as a function of solar altitude or time of day. Additional verification of the "validity" of the composition measurements performed by the equipment on board the third artificial Earth satellite was obtained, as well as verification of certain conclusions made on the basis of these measurements. A large number of impurity ions were recorded in addition to the ionospheric ions; these ions could easily be distinguished by the method of measurement employed. It is demonstrated that the ionization of the gas evolved by the rocket occurs as a result of charge exchange with atmospheric ions. Subsequent work should take into account the danger of a distortion of the atmospheric composition by interaction with gases evolved by the rocket when a transition is made to higher altitudes.

694. **MEASUREMENT OF IONOSPHERIC ELECTRON DENSITIES USING AN RF PROBE TECHNIQUE**
Jackson, J. E., Kane, J. A.
***Journal of Geophysical Research*, v. 64, no. 8, pp. 1074–1075, August 1959**

Measurements of the capacitive reactance of a rocket-borne transmitting antenna at 7.75 Mc were obtained as a by-product of ionosphere radio propagation experiments. The results obtained indicate that at altitudes greater than 110 km the variations in the impedance are directly related to the electron density. The electron density profile obtained from the propagation data agrees well with the probe data when a constant correction factor is applied to compensate for the effects of the positive ion sheath which develops around the rocket.

695. **PERFORMANCE OF AN RF IMPEDANCE PROBE IN THE IONOSPHERE**
Jackson, J. E., Kane, J. A.
***Journal of Geophysical Research*, v. 65, no. 7, pp. 2209–2210, July 1960**

The authors reported in a previous letter (Entry 694) that an RF impedance technique of measuring ionospheric electron densities yielded results that were too small by a factor of three. The purpose of this note is to report the improvement obtained in a later rocket flight. When the RF field distortion of the probe environment was reduced by performing the impedance measurement at lower RF levels, the results were quite different. With RF amplitudes of 2 and 0.2 V on the probe, the capacitive detuning by the ionosphere was determined by measuring the amount of compensating capacitance required to restore the probe circuitry to its free-space condition. This procedure yielded a response curve from which the resistive loading by the ionosphere can also be determined. The electron density profiles are shown. It is possible, in principle, to calculate the proper sheath correction to be applied to the electron density profile.

696. **USE OF GUARD RING SHIELDS ON NEGATIVELY BIASED LANGMUIR ION COLLECTION CURRENT PROBES**
Janes, G. S., Dotson, J. P.
April 1964
Avco-Everett Research Laboratory, Everett, Mass.
AMP137, AF 49(638)-659
AD-600,473
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D. C.)

This note describes a shielded ion-collection probe that provides a constant effective ion-collection area. It is particularly useful when the plasma properties vary in time or space. 6 pages.

697. **SHIELDED LANGMUIR ION COLLECTION PROBES**
Janes, G. S., Dotson, J. P.
***Review of Scientific Instruments*, v. 35, pp. 1617–1618, November 1964**

A shielded ion-collection probe that provides a constant effective ion-collection area is described. When investigating an annular electrostatic plasma accelerator, floating biased double probes are used to measure ion fluxes. A second probe, used with the shield probe, provides a reference voltage and also yields information on voltage gradients and electron temperatures. When the shield is maintained at the ion probe potential, the ion current remains constant with decreasing bias potential. With the shield connected, the difference between the effective and actual probe areas is found to be less than 5%, and hence is neglected. This arrangement permits the choice of a fixed-bias potential and allows the direct, accurate measurement of ion fluxes for a wide variety of plasma conditions.

698. A ROCKET-BORNE ELECTRIC FIELD PROBE
Johnson, D. W., Kavadas, A.
Canadian Journal of Physics, v. 41, no. 12, pp. 1980–1990, December 1963

An instrument is described which was developed to measure electric fields in and near auroral displays. The sensing element is a voltage-variable capacitor connecting two insulated portions of the container. The instrument is carried aloft in a rocket and is ejected once the rocket is above the region where air drag is appreciable. During the free-fall portion of the flight, the instrument continuously measures the ambient electric field and telemeters this information to ground. (*IAA*, A64-11,888)

699. THEORY OF ION CURRENT IN A PROBE
Kagan, Yu. M., Perel, V. I.
Zhurnal Teknicheskoi Fiziki, v. 32, no. 12, pp. 1479–1482, December 1962
(Translated from the Russian in *Soviet Physics—Technical Physics*, v. 7, no. 12, pp. 1093–1095, June 1963)

Expressions for the probe current are derived which take into account the electron density in the space-charge sheath surrounding the probe. 9 references. (*PA*, 1964, #18931)

700. THE BEHAVIOR OF AN ELECTRIC DIPOLE IN A MAGNETO-IONIC ENVIRONMENT
Kaiser, T. R.
In "Proceedings of the International Conference of the Ionosphere Held at Imperial College, London, July 2–6, 1962," pp. 478–483
Stickland, A. C., Editor
The Institute of Physics, and The Physical Society, London, England, 1963 (distributed by Chapman & Hall, Ltd., London, England)
(See Entry 605)

The problem of the behavior of dipole aerials in an ionized medium, rendered birefringent by an imposed steady magnetic field, has assumed practical significance in connection with investigations employing rocket and satellite vehicles. The present study is relevant to short dipoles used as receiving aerials or as impedance probes for determining the electrical properties of the immediate environment of the vehicle. Thus, as a first approximation, radiation resistance is ignored and the input admittance is evaluated by treating the dipole as a capacitance with a lossy anisotropic dielectric (quasi-electrostatic approximation). The problem is further simplified by assuming that the medium is homogeneous and can be described by macroscopic parameters (the components of the dielectric tensor), although inhomogeneity due to ion-sheath formation near the dipole surfaces may limit the validity of the results. A further limitation arises when the magnitude of the dipole electric field varies appreciably over an electron mean free path; in this case the loss term is no longer simply related to the collision frequency. In spite of these qualifications, the homogeneous solution is valuable in understanding the nature and magnitude of the effects on the dipole admittance due to the medium.

701. THE INTERACTOMETER: A FREE-SPACE MICROWAVE SYSTEM FOR PLASMA DIAGNOSTICS
Kaliszewski, T.
In "Comptes Rendus de la VI^{e} Conférence Internationale sur les Phénomènes d'Ionisation dans les Gaz, Volume III," pp. 87–92
Hubert, P., Crémieu-Alcan, E., Editors
SERMA, Paris, France, 1963
(Paper presented at the Sixth International Conference on Ionization Phenomena in Gases, Paris, France, July 8–13, 1963—Entry 592)

The construction and operation of a free-space microwave system, operating on the principle of the so-called Luxemburg effect, are discussed. This system, referred to as an interactometer, represents a laboratory adaptation and extension of techniques used recently for probing the D layer in the Earth's ionosphere. The Luxemburg effect is induced in a small, laboratory sample of plasma by illumination with a strong microwave pulse. The resulting alterations in the electron temperature and, consequently, in the complex index of refraction are then studied with a weak microwave signal operated in a dual (pulse and CW) mode. In the pulse mode, measurements are made of the change in amplitude and phase of the weak wave due to interaction; in the CW mode, the energy relaxation constant is measured. The interpretation of these measurements appears to be especially simple for thin, tenuous, homogeneous plasma samples, and leads directly to estimates of the electron collision frequency, the fractional energy-loss factor, and the ratio of electron density to electron temperature. An example of data generated by an interactometer, operating in the *X*-band, is used to illustrate the feasibility, as well as the potential, of the system. 9 references.

702. THEORY OF CURRENT COLLECTION OF MOVING SPHERICAL PROBES
Kanal, M.
April 1962
Michigan, University of, Space Physics Research Laboratory, Ann Arbor
Scientific Report JS-5, AF 19(604)-6124
N62-11,523
(Also available through U. S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Ion and electron current functions are derived for a spherical Langmuir probe moving in a plasma which is assumed to be Maxwellian. It is assumed that the ion sheath about the probe is spherical (a good approximation for relatively low collector velocity), and only the effects of the electric field in the sheath are considered.

Three distinct current functions are derived: (1) the general ion current to a moving spherical probe; (2) the general electron current to a moving spherical probe; and (3) the ion current to a sheath-area-limited moving hemispherical probe, including the random electron current. Various special cases are deduced from (1) and (2). The limiting cases of the stationary probe and a probe having large velocity agree with

results previously obtained by Langmuir. Two asymptotic forms of the general ion current function are also considered: the first, the sheath-area-limited case, which occurs for very large electrode radius, r, and the second, the orbital-motion-limited case, which occurs for very small electrode radius. Mathematically, the first asymptotic form is obtained by letting a/r approach unity (where a is the radius of the sheath), and the second asymptotic form is obtained by letting a/r approach infinity. An interesting result occurs in conjunction with the general ion current and its second asymptotic case. The ion current for certain values of the probe voltage, velocity, and a/r decreases with increasing velocity, W. As expected, for sufficiently large W, the ion current increases linearly with velocity. The behavior of the current functions against probe potential and probe velocity is illustrated in graphs. 90 pages; 12 references.

703. THEORY OF CURRENT COLLECTION OF MOVING CYLINDRICAL PROBES

Kanal, M.
***Journal of Applied Physics*, v. 35, no. 6, pp. 1697–1703, June 1964**

The theory of current collection of a moving cylindrical probe with a nonvanishing collector-to-ion-sheath-diameter ratio is investigated. Volt-ampere relations are derived for two distinct cases: (1) the general ion current for accelerating collector potential and its special cases, including general ion current to the stationary probe, orbital-motion-limited current to the moving and the stationary probe, and sheath-area-limited current to the moving and stationary probes; and (2) the general electron current for the retarding collector potential and its special cases, including general electron current to the stationary probe and random electron current to the moving and the stationary probes. Orientation of the cylinder with respect to the drift velocity vector is taken into account. Volt-ampere characteristics which illustrate the functional behavior of the current relations are presented. A theory is presented which would permit the volt-ampere relation to be predicted as a function of probe velocity. 8 references. (*IAA*, A64-20,921)

704. ELECTRON DENSITIES IN THE E REGION DEDUCED FROM ROCKET OBSERVATIONS

Kane, J. A.
In "Electron Density Profiles in the Ionosphere and Exosphere," pp. 67–79
Maehlum, B., Editor
The Macmillan Company, New York, N.Y., 1962

The results of earlier experiments using the CW propagation method are explained and reviewed. The studies of Jackson and Kane (Entry 694) are compared with a NASA rocket experiment. It was found that under the ideal conditions of a stable ionosphere, electron densities can be obtained to an accuracy of the order of 5%. Under conditions of a disturbed ionosphere, such as with aurora and spread-F conditions, the CW propagation experiment breaks down. To measure electron densities under disturbed ionospheric conditions, an environmental probe technique should be used. An RF impedance probe was used in the NASA experiment considered. The circuit of the probe is shown in outline. Results obtained using RF and CW propagation methods are considered, and effects of irregularities in the ionosphere and of the ion sheath are discussed. It was found that the RF probe technique in its present form can measure electron densities to an accuracy of the order of 20%. 8 references.

705. RF IMPEDANCE PROBE MEASUREMENTS OF IONOSPHERIC ELECTRON DENSITIES

Kane, J. A., Jackson, J. E., Whale, H. A.
***Journal of Research of the National Bureau of Standards, Section D—Radio Propagation*, v. 66, no. 6, pp. 641–648, November–December 1962**

The *Aerobee-Hi* rocket obtained vertical electron density profiles in the ionosphere simultaneously by the Seddon CW propagation technique and by an RF impedance probe technique. The experimental goal was to assess the performance of the RF probe against the accurate values from the CW method. In the RF probe method, the electron density, N, was derived from the dielectric constant, K, of the medium at a frequency $f = 7.75$ Mc. If the Earth's magnetic field is neglected, the relation between these quantities may be given as $K = 1 - (81\,N/f^2)$. An expression for the dielectric constant, including the effects of the Earth's magnetic field, is derived. The fractional error introduced by neglecting the Earth's field is of the order of $(f_H/f)^4$ where f_H is the electron gyrofrequency. It is concluded that, with allowance for the positive ion sheath around the rocket, the RF impedance probe can yield reliable values of electron density. These values were obtained from changes in the capacitive part of the probe's impedance. Small, apparently anomalous, changes in the resistive part were also observed. (*PA*, 1963, #6972)

706. A LOCAL VERTICAL REFERENCE FOR AIRCRAFT AND SATELLITES

Kaplan, M. N.
In "Proceedings of the Seventh National Convention on Military Electronics, Washington, D.C., September 9–11, 1963," pp. 101–103
Goldfarb, B. J., Editor
Institute of Electrical and Electronics Engineers, Inc., New York, N.Y., 1963

Accurate means for sensing the Earth's atmospheric potential gradient are discussed. At low altitudes, unshielded MDM transducers could be used only as fair weather cursory local vertical references. At higher altitudes, where variations in charge density are remote and negligible, but where the electric field, F, is very large relative to the motion vector field $[\gamma \times \beta]$, the direction of the potential gradient, F, can be accurately determined by two orthogonal unshielded MDM transducers. At very high altitudes, where F and $[\gamma \times \beta]$ are comparable in magnitude, the direction of the potential gradient can be accurately determined using two orthogonal sets comprised of one shielded and one unshielded

MDM transducer. When the roll axis of the vehicle can be oriented so as to lie in the $[\gamma \times \beta]$ plane, the shielded transducer in that plane can be omitted. (*IAA*, A64-22,495)

707. ELECTRON DENSITIES AND ELECTRIC FIELDS IN THE AURORA
Kavadas, A., Johnson, D. W.
In "Space Research IV," pp. 365–370
Muller, P., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1964
(Paper presented at the Fourth International Space Science Symposium, Warsaw, Poland, June 4–10, 1963—Entry 10)

Two devices designed to probe ionospheric microstructure are described: an electron density tracking probe, and an electric field measuring device. Both devices are small-size packages which can be ejected from the rocket. The sampling takes place away from the rocket in order to reduce the effects produced by the large body of the rocket. Electric fields within an auroral display, as measured with this device, are briefly discussed.

708. ELECTRICALLY SHORT ANTENNA AS A PROBE FOR MEASURING FREE ELECTRON DENSITIES AND COLLISION FREQUENCIES IN AN IONIZED REGION
King, R., Harrison, C. W., Jr., Denton, D. H., Jr.
***Journal of Research of the National Bureau of Standards, Section D—Radio Propagation*, v. 65, no. 4, pp. 371–384, July–August 1961**

If the admittance of a missile, satellite, or drone-aircraft antenna is monitored as the vehicle traverses an ionized region, it is possible to determine the free electron density and the collision frequency of the region if theoretical relations between these quantities are available. Formulas are developed for antenna immersion in a conducting dielectric which relate the antenna admittance to the effective dielectric constant and conductivity of the medium. The relationships are obtained for an electrically short center-driven dipole or a base-driven monopole. Using well-known formulas relating these quantities to the free electron density and the collision frequency of an ionized region, the latter may be determined directly from measured admittances. The results obtained when the antenna is treated as a lumped capacitor are considered. It is shown that when the conductivity of the medium is increased to a value that is still quite small, the effect of radiation on the input admittance becomes negligible. The case of an electrically short antenna immersed in sea water is discussed briefly. 18 references. (*MGA*, 1962, 13.8-245)

709. SATELLITES AND THE EARTH'S OUTER ATMOSPHERE
King-Hele, D. G.
***Royal Meteorological Society, Quarterly Journal of the*, v. 87, pp. 265–281, July 1961**

Advances made possible through the use and observation of satellites are comprehensively reviewed. (*PA*, 1962, #4683)

710. THEORY OF AN ELECTRON-EMITTING PROBE IN A LOW DENSITY PLASMA
Koren, M.
American Astronautical Society, Inc., New York, N.Y.
Preprint 61-66, presented at the AAS Symposium on Interactions of Space Vehicles With an Ionized Atmosphere, Washington, D.C., March 17, 1961

A metallic object which emits photoelectrons produces an electric field in the surrounding region. If the region contains an ionized gas which is neutral in the absence of the object, the gas undergoes a separation of plus and minus charge. It is this effect which is considered.

A preliminary study is made of the electron-emitting probe in vacuum. The problem is formulated for a steady state (no net electric current), and the Boltzmann and Poisson equations are written for an object (probe) of arbitrary shape and for an arbitrary photoelectron emission spectrum. A characteristic unit of length, λ, is introduced, in terms of which all distances are measured.

The problem is then formulated for three probes of very simple geometry, namely, infinite plane, infinite circular cylinder, and sphere. The Poisson equation is solved for these three cases using assumed simplified charge distributions. It is shown in this study that for radii of the order of λ or greater, the potential for cylindrical and spherical probes very closely approximates that for an infinite plane. The infinite plane probe is then studied. Approximate values of the potential, electric field and charge density around the probe are obtained using an experimentally determined photoelectron emission spectrum. The spectrum is that of tungsten irradiated by the Sun.

The second half of the study concerns the probe in a fully ionized gas (plasma). It is assumed that the gas is neutral infinitely far from the probe. The simplest case, that of a probe bombarded by a beam of protons and electrons (each component having the same speed at infinity), is considered. (*AI/A*, 1961, 4294)

711. SOVIET INVESTIGATIONS OF THE IONOSPHERE WITH THE AID OF ROCKETS AND ARTIFICIAL EARTH SATELLITES
Krasovskii, V. I.
***Iskusstvennye Sputniki Zemli*, no. 2, pp. 36–49, 1958**
(Translated from the Russian in *Planetary and Space Science*, v. 5, no. 3, pp. 223–232, July 1961, *Artificial Earth Satellites*, v. 2, pp. 45–62, 1960, and *Annals of the International Geophysical Year*, v. 12, pt. 2, pp. 529–546, 1960)

This paper, which was presented at the Fifth Assembly of the Special IGY Committee in Moscow, August 1958, reviews Soviet ionospheric research that has been carried out by

means of rockets and satellites. Several methods of investigation are discussed; these include radio-sounding from ground stations, studies of reception from extraterrestrial sources (Sun, radio stars, etc.) and from rockets and satellites, and direct measurements from instruments on rockets and satellites. Some results of the investigations are presented. 16 references.

712. A GENERAL THEORY FOR THE FLOW OF WEAKLY IONIZED GASES

Lam, S. H.
American Institute of Aeronautics and Astronautics, New York, N.Y.
Paper 64-459, presented at the AIAA Conference on Physics of Entry Into Planetary Atmospheres, Cambridge, Mass., August 26–28, 1963

A theory is developed for the flow of a weakly ionized gas about an arbitrary solid body with absorbing surfaces, in order to predict the electrical responses of the body as a function of the pertinent properties of the flow. The theory is based on continuum formulation, and is valid when (1) the mean free path of the charged particles is much smaller than the thickness of the sheath, and (2) the Debye length is much smaller than the thickness of the boundary layer adjacent to the body surface. The entire range of flow velocity in terms of an electric Reynolds number R is investigated, but the detailed analysis is devoted to the case where $\sqrt{R} \gg 1$. It is found that the electrical disturbances can be divided into three physically distinct and mathematically uncoupled regions (the outer, the ambipolar diffusion, and the sheath regions). Closed-form analytical results are obtained for the floating potential and the current–voltage characteristic. These are useful in the interpretations of Langmuir probe data. Detailed structures of the solutions are given in terms of explicit universal functions. 11 pages. (*IAA*, A63-21,577)

713. THE LANGMUIR PROBE IN A COLLISIONLESS PLASMA

Lam, S. H.
March 1964
Princeton University, Gas Dynamics Laboratory, N.J.
Report 581, AF AFOSR-112-63, AFOSR-64-0353
AD-434,842, N64-18,901
(See also *Physics of Fluids*, v. 8, no. 1, pp. 73–87, January 1965)

This paper presents an asymptotic analysis of the Langmuir probe problem in a quiescent, collisionless plasma in the limit of large body dimension to Debye length ratio. The structures of the electric potential distribution about spheres and cylinders are analyzed and discussed in detail. It is shown that when the probe potential is smaller than approximately $\frac{1}{2} KT$, where T is the undisturbed temperature of the repelled particles, there exists no sheath adjacent to the solid surface. At large body potentials for which a sheath is present, the electric potential distribution is given in terms of several universal functions. Master current–voltage characteristic diagrams are given that exhibit clearly the effects of all the pertinent parameters in the problem. An explicit trapped-ion criterion is presented. The general problem with an arbitrary body dimension to Debye length ratio is qualitatively discussed. 71 pages.

714. DESIGN, CONSTRUCTION AND TESTING OF INSTRUMENTATION FOR THE INVESTIGATION OF THE ELECTRICAL STRUCTURE OF THE UPPER ATMOSPHERE

Mardone, L. J., Stuart, R. D.
December 31, 1963
Northeastern University, Boston, Mass.
Final Report, AFCRL-64-50, AF 19(604)-7225
AD-436,588, N64-19,640

Research was conducted on the design, construction, and testing of instrumentation for the investigation of the electrical structure of the upper atmosphere. A description is given of a spherical sensor which can be used on rockets and satellites to measure the positive and negative charged-particle densities. Complications which may arise because of the charge on the vehicle are described, and measures for correcting such complications are discussed. The data reduction procedures employed are presented, and typical results from some of the flights are given. 17 pages.

715. RADIO-FREQUENCY PROBES FOR IONIZED WAKE STUDIES

Marshall, T., Hill, L. L., Crapo, B. J.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 354–364
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass., April 10–12, 1962—Entry 12)

During the past few years, ionized wake studies have been made using a hypersonic shock tunnel. The procedure, ideally, was to make a point measurement of the electrical conductivity in the wake region of a model which is undergoing high-speed environmental flight conditions.

The technique considered in this paper was that of electronically monitoring the interaction between the moving ionized gas and a high-frequency perturbing magnetic field. Preliminary experiments were performed using coils wrapped on the outside of a glass, T-type, electromatic shocktube. Instrumentation was developed and the qualitative results confirmed theoretical estimates.

The final probes consist of small coils mounted in ferrite supports which have a lower limit of sensitivity for the probes of about 5×10^{11} electrons/cm^3. A description is given of a direct calibration procedure that was necessary in order to make the conductivity measurements independent of inaccuracies encountered by theoretical assumptions. 7 references.

716. ANGULAR DISTRIBUTIONS AND ENERGY SPECTRA OF ELECTRONS ASSOCIATED WITH AURORAL EVENTS
McDiarmid, I. B., Budzinski, E. E.
Canadian Journal of Physics, v. 42, pp. 2048–2062, November 1964

Rocket measurements were made of the intensities, angular distributions, and energy spectra of particles associated with auroral radio absorption and visible aurora. The firings of *Black Brant II* probes took place at Fort Churchill, Manitoba, in 1963 and 1964. Pitch-angle distributions were observed for electrons with energies greater than 40 keV, with varying degrees of isotropy in the range 0 to 90 deg. In no case was a distribution observed in which the intensity increased toward small angles. In some cases electron-intensity changes appeared to be correlated with changes in spectrum and angular distribution, while in other cases changes in these quantities appeared to be unrelated. The particle-intensity measurements, together with radio-frequency probe measurements of electron density, are used to infer values for the nighttime recombination coefficient in the D region of the ionosphere. 8 references. (*IAA*, A65-10,962)

717. A DIRECT MEASUREMENT OF CHARGE DENSITY IN THE F_2 REGION
McKibbin, D. D.
IRE Transactions on Instrumentation, v. I-11, pp. 96–99, December 1962
(Paper 1.3, presented at the International Conference on Precision Electromagnetic Measurements, Boulder, Colo., August 14–17, 1962)

A measurement of the charge density in the F_2 region was made in 1962 with an ion trap mounted on an oriented satellite. Orbital monitoring of ionospheric characteristics continued for about four days. Current from collected ions (grid-modulated by a triangular sweep voltage) indicated charge density, temperature, vehicle potential, and some information on ion mass ratios. The current-measuring circuitry consisted of a hybrid electrometer followed by two amplifiers of similar circuit design. The ion kinetic temperatures were determined and found to be 1500°K and higher; ion concentrations varied from 5×10^3 to 10^6 ions/cm^3 over latitudes of 73°N to 73°S.

718. INSTRUMENTATION FOR ROCKET MEASUREMENTS OF ELECTRON DENSITY IN THE IONOSPHERE
Mechtly, E. A., Hamaker, R. W., Nisbet, J. S., Quinn, T. P.
January 1, 1960
Pennsylvania State University, Ionospherics Research Laboratory, University Park
Scientific Report 127
NASA TPA-61-1967

The Army development and testing of instrumentation for electronic density measurement in the ionosphere by means of rockets are discussed. Circuit diagrams, performance characteristics, and test procedures are given. Several observations which were made by this instrumentation and were telemetered in flight are shown. 96 pages.

719. THEORY OF PROBES WITH NONUNIFORM WORK FUNCTION
Medicus, G.
In "Proceedings of the Fifth International Conference on Ionization Phenomena in Gases, Munich, Germany, August 28–September 1, 1961, Volume II," pp. 1397–1405
Maecker, H., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, 1962
(See Entry 600)

Langmuir's theory for the plane probe and for the infinitely small spherical probe is extended to "microscopic patchiness" of the work function of the probe. The case of a Maxwellian electron energy distribution and a Gaussian work function distribution is treated. The normalized probe currents and their second derivatives are plotted, with the width of the Gaussian as a parameter. Breaks in the curves, such as the "knee" in the probe curve for the plane probe, are "smeared out." However, the exponential character in the electron retarding region is maintained for sufficiently high probe voltages. The exact location of space potential results. (*PA*, 1963, #7572)

720. THÉORIE DE LA SONDE À RÉSONANCE (THEORY OF RESONANCE PROBE)
Messiaen, A.
Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences, v. 259, no. 10, pp. 1710–1713, September 7, 1964

A general method of treatment is described which is applicable to all probe configurations, and is based on near-static approximations and equivalent permittivity. This method makes it possible to associate the characteristics of the probe with those of the plasma. 11 references. (*IAA*, A64-27,701)

721. AURORAL MEASUREMENTS AND UPPER ATMOSPHERIC PHYSICS
Meyerott, R. E., Evans, J. E.
AIAA Journal, v. 2, no. 7, pp. 1169–1174, July 1964
(Paper 62-145, presented at the IAS National Meeting, Los Angeles, Calif., June 19–22, 1962)

Many of the most spectacular features of the space environment can be described in terms of basic physical processes that have been studied theoretically or measured extensively in the laboratory. In most large-scale space phenomena, however, the physics required to describe the observations involves many fields of basic research. One of the principal problems of the space physicist is to reduce the geophysical data to familiar concepts. A major difficulty is that in many large-scale phenomena several events occur simultaneously, so that it is not clear if cause-and-effect relations exist among the observed phenomena. An example of a space physics

subject in which many basic physics fields are represented and in which cause and effect are not easily distinguished, is the polar aurora. A survey experiment is discussed in which measurements of the particle flux and spectrum above the atmosphere were made almost simultaneously with measurements of the luminosity and of the electron densities in the atmosphere. The experiment consisted of measurements carried out in satellites, using the techniques of nuclear physics, optical spectroscopy, and radio propagation. This and similar experiments should increase understanding of the role of energetic charged particles in producing auroras.

722. THE VLF ADMITTANCE OF A DIPOLE IN THE LOWER IONOSPHERE
Mlodnosky, R. F., Garriott, O. K.
In "Proceedings of the International Conference on the Ionosphere Held at Imperial College, London, July 2–6, 1962," pp. 484–491
Stickland, A. C., Editor
The Institute of Physics, and The Physical Society, London, England, 1963 (distributed by Chapman & Hall, Ltd., London, England)
(See Entry 605)

The admittance of a dipole in the lower ionosphere has been calculated for very low frequencies. Both the real and active parts of the admittance are found to be related to the ion sheath which forms about the dipole, and are functions of electron density and temperature of the ionosphere. An electron density profile is estimated on the basis of measurements reported in an earlier rocket flight.

723. ON THE THEORY OF ARTIFICIAL SATELLITE PROBES
Moskalenko, A. M.
International Astronautical Federation, Paris, France
Paper presented at the 15th International Astronautical Congress, Warsaw, Poland, September 7–12, 1964

The particle distribution in a low-density collisionless plasma in the vicinity of a moving charged body which is much smaller than the Debye radius is discussed. The influence of the trapped particles is not taken into account. This limits the ϕ_o value of the body potential; ϕ_o, however, can be much greater than kT/e. The expressions of the total particle current and the particle concentration when the body velocity $v_o \ll v_{i,e}$ and $v_o \gg v_{i,e}$ are calculated (where $v_{i,e}$ are the thermal velocities). The particle absorption on the body surface is taken into account. The formulas can be used to analyze the results of ionosphere and interplanetary investigation by means of satellites. 24 pages; 7 references. (*IAA*, A65-10,947)

724. THEORETICAL INVESTIGATION OF SOUNDING-ROCKET- AND SATELLITE-BORNE ION TRAPS
Nagy, A. F.
1963
Michigan, University of, Ann Arbor
Thesis

A systematic review is made of the different ion trap configurations which are used to measure the density and temperature of the charged particles in the atmosphere. The advantages of measuring the number of particles reaching only a small surface area, especially if that area is in the direction of the spacecraft velocity vector, are emphasized. Two ion trap configurations suitable for performing such measurements are proposed.

It is pointed out that charged particle traps are necessary when ionization gages are used for neutral particle measurements. A number of traps suitable for such gages are investigated, and the relative advantages of the cylindrical configuration are demonstrated. It is also pointed out that such a trap can serve as an important measuring device in certain cases as well as being necessary for the neutral particle experiment.

The equations describing the number of charged particles reaching a small area on both planar and spherical collectors are derived. Although certain simplifying assumptions are necessary for the spherical case, the results give a reasonably good approximation, especially for small angles of attack. The resulting computer solutions are given in graphical form for a large number of typical parameters. 127 pages. (*DA*, 63-6930)

725. A PROBE FOR THE INTERPLANETARY PLASMA
Ogilvie, K. W., McIlwraith, N., Zwally, H. J., Wilkerson, T. D.
In "Comptes Rendus de la VI^e Conférence Internationale sur les Phénomènes d'Ionisation dans les Gaz, Volume IV." pp. 91–96
Hubert, P., Crémieu-Alcan, E., Editors
SERMA, Paris, France, 1963
(Paper presented at the Sixth International Conference on Ionization Phenomena in Gases, Paris, France, July 8–13, 1963—Entry 592)

Previous studies of the "solar wind" suggest many important measurements of its state, its interactions with planets, and its wave phenomena. A new detection technique is used to study the energy distributions of protons and other species of ions in interplanetary space as well as at satellite altitudes. A satellite instrument which is being developed will permit observations to be made as a function of time, direction, and position over an energy range of at least 10 eV to 10 keV, with a maximum sensitivity of 10^{-18} A, and will be capable of detecting single ions. The instrument, which is $10 \times 30 \times 20$ cm^3 in size, contains an electrostatic energy analyzer, a secondary-electron scintillation detector, high voltage supplies, and signal conditioning circuits. Laboratory work demonstates constant response for protons having energies from 30 eV to 3 keV and a minimum detectable current corresponding to $\sim$ 10 particles/sec. Progress is reported on the development of a velocity selector for separating ionic species, which, it is hoped, may lead to the

solution of an important problem in solar wind studies: the determination of the relative abundance of protons and alpha particles. 18 references.

726. STUDIES OF THE DYNAMIC PROPERTIES OF LANGMUIR PROBES. II: EXPERIMENTAL RESULTS
Okuda, T., Carlson, R. W., Oskam, H. J.
Physica, v. 30, no. 1, pp. 193–205, January 1964

The dynamic properties of Langmuir probes were studied and the results obtained are presented for the pulsed probe, the high-frequency probe, and the static probe time varying plasma methods. The studies showed that for the highly negative probe the influence of the displacement current spike due to the probe–plasma sheath capacitance is dominant. The magnitude of this capacitance was found to increase with increasing plasma density, as expected. Large delays in the collection of electrons by the probe were observed for final probe potentials close to plasma potential. The magnitude of the delay effect decreases for increasing plasma density and/or increasing value of the mobility of the charged particles in the gas. The results obtained with the pulsed probe and the high-frequency probe were consistent, while the phenomena observed during the static probe-time varying plasma method could easily be explained. (For Part I, see Entry 640; for Part III, see Entry 728)

727. ELECTRODELESS PLASMA CONDUCTIVITY PROBE APPARATUS
Olson, R. A., Lary, E. C.
Review of Scientific Instruments, v. 33, no. 12, pp. 1350–1353, December 1962

A probe is described which can be used to measure the electrical conductivity of a fluid without the use of electrodes. The device, consisting of a cylindrical single-layer solenoid enclosed within an insulating tube, is used in conjunction with an RF oscillator-detector to measure the ohmic dissipation of a small amount of RF power in the fluid. Since the probe samples the conductivity of the fluid in its immediate vicinity, it may be used, for example, to resolve conductivity profiles in an operating magnetohydrodynamic device. Because the surface of the probe is an insulator, under certain conditions the influence of the Hall effect and the electrostatic sheaths may be effectively eliminated. Electrolytic solutions are used in the calibration of the instrument. The instrumentation, developed for the application of the measuring technique to plasmas, is described. Successful operation of the probe in the positive column of a hydrogen glow discharge, as well as in a 4500°F rocket-nozzle flow, is reported. (*IAA*, A63-11,407)

728. STUDIES OF THE DYNAMIC PROPERTIES OF LANGMUIR PROBES. III: DISCUSSION OF THE RESULTS
Oskam, H. J., Carlson, R. W., Okuda, T.
Physica, v. 30, no. 2, pp. 375–386, February 1964

In the two earlier papers (Entries 640 and 726) the methods used for the study of the dynamic properties of a Langmuir probe are described and the results which were obtained are presented. It was found that the phenomena observed during the studies with the high-frequency probe method are consistent with those observed during the pulsed-probe method.

This paper deals with the discussion of phenomena inside the plasma and plasma-probe sheath which may occur when the potential of this probe with respect to the plasma is suddenly changed. The relative influence on the resulting transient probe-current curve is estimated. A qualitative theory explaining all phenomena observed is presented. This theory is based on the relatively slow motion of positive ions with respect to that of the electrons, as well as on the transient distortion of the plasma region adjacent to the probe plasma sheath. It is found that the plasma distortion may have a large influence on the probe current collection when the final probe potential is close to plasma potential. In the same region there is a possibility that transient space-charge barriers, which temporarily prevent charged particles from being collected by the probe, are produced by a sudden change in probe potential.

729. MEASUREMENT OF THE ELECTROSTATIC FIELD IN THE STRATOSPHERE
Paltridge, G. W.
Journal of Geophysical Research, v. 69, pp. 1947–1954, May 15, 1964

The electrostatic field is measured in the altitude range of 10–30 km. In a field radiosonde, which is based on the collector principle, large disks were used in place of the usual radioactive probes, and many of the disadvantages of probes were eliminated. Results of three balloon releases made from Melbourne, Australia, show that the potential gradient decreased from about 4 V/m at an altitude of 10 km to about 0.5 V/m at 25 km. The transient behavior of the apparatus also provides a means of measuring the conductivity of the air, though no results on conductivity have been obtained thus far. 9 references. (*IAA*, A64-18,718)

730. PARAMETERS IN THE D-REGION ATTAINABLE WITH A GERDIEN CONDENSER ROCKET PROBE
Pedersen, A.
In "Electron Density Distribution in Ionosphere and Exosphere," pp. 60–64
Thrane, E., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1964
(Paper presented at the NATO Advanced Study Institute, Skeikampen, Norway, April 17–26, 1963—Entry 607)

A Gerdien-condenser rocket probe for measuring the ion conductivity and the ion and electron concentrations in the D region is described. In contrast to earlier tests, the probe is

not permanently fixed on the rocket carrier but separates at a height of about 90 km to make measurements during descent, with the instrumentation attached to a parachute made of Mylar. Two types of Gerdien-condenser electrode arrangements and typical electron densities obtained by cross-modulation are diagrammed. The possibilities of obtaining absolute values for ion and electron densities and the relative concentrations of negative ions and electrons are evaluated. 8 references. (*IAA*, A64-27,648)

731. **THE UPPER ATMOSPHERE AND ITS INVESTIGATION WITH SATELLITES AND ROCKETS**
Petrov, V. P., Sochivko, A. A.
April 24, 1963
Joint Publications Research Service, Washington, D.C.
JPRS-18882 (pp. 1–35)
N64-11,849
(Also available as OTS-63-21665, U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.; see also Entry 732)

The general structure and composition of the upper atmosphere are reviewed, and satellite and rocket discoveries regarding the upper atmosphere are discussed. Two of the most important of these discoveries have led to the establishment of two major geophysical facts: (1) the Earth is surrounded by layers of intense cosmic radiation; and (2) the density of the atmosphere above 500 km is 16 to 40 times higher than was estimated prior to 1955. The first of these discoveries was made with the Cerenkov and gas-discharge counters. Observations of satellite orbits played a large part in the second discovery.

732. **METEOROLOGICAL SATELLITES**
Petrov, V. P., Sochivko, A. A.
April 24, 1963
Joint Publications Research Service, Washington, D.C.
JPRS-18882 (pp. 36–69)
N64-11,850
(Also available as OTS-63-21665, U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.; see also Entry 731)

Meteorological recording and transmitting equipment of the *Vanguard II*, *Explorer VIII*, *Tiros I*, and *Tiros II* is described and observations made by these satellites are discussed.

733. **IONOSPHERIC STUDIES USING POLARIZATION ROTATION OF SATELLITE RADIO SIGNALS**
Potts, B. C.
Ohio State University Research Foundation, Antenna Laboratory, Columbus
Report 1116-16, Scientific Report 11, AFCRL-62-155, AF 19(604)-7270
N62-11,410

The polarization rotation is studied for radio signals received from an artificial satellite in the ionosphere. A first-order analysis is used which leads to values for the integrated electron density in the ionosphere. These values are compared with those calculated by other means and with those obtained by other investigators. A new parameter, the rate-of-polarization null position, is introduced as a method for obtaining the electron density at satellite altitudes. The methods employed in the analysis are outlined, and additional means of improving the analysis are discussed. 69 pages; 43 references.

734. **THE SOUNDING ROCKET AS A TOOL FOR COLLEGE AND UNIVERSITY RESEARCH**
Pressly, E. C.
In "Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration, Chicago, Ill., November 1–3, 1962," pp. 107–114
National Aeronautics and Space Administration, Office of Scientific and Technical Information, Washington, D.C., December 1962 (available as SP-11, Volume 1)

Advantages are noted of the use of sounding rockets by colleges and universities for scientific investigations in the various disciplines of geophysics and astronomy. Examples of studies accomplished are described to represent different rocket techniques. Experiments were carried out to measure electron temperature and charge density as a function of altitude, using Langmuir probe and RF resonance probe techniques. Experiments were conducted over Wallops Island, Va., to determine the altitude and intensity of electric current systems. The electron density and electron temperature in the ionosphere were measured. (*EI*, 1964)

735. **ERFORSCHUNG DER IONOSPHÄRE MIT RADIOWELLEN VON SATELLITEN UND RAKETEN —PHASEN-VERFAHREN (INVESTIGATION OF THE IONOSPHERE BY RADIO WAVES FROM SATELLITES AND ROCKETS—PHASE METHODS)**
Rawer, K.
***Space Science Reviews*, v. 3, pp. 380–432, October 1964**

The possibilities for conducting ionospheric research by means of radio waves generated by satellite-borne transmitters are discussed. The advantages of this technique over the conventional echo-sounding technique are indicated. Various phase and frequency measurement methods are described in detail, including the use of plane waves in the ionospheric plasma, the Doppler effect, and Doppler difference measurements. Polarization measurements are also considered, with special reference to the calculation of the Faraday effect. 80 references. (*IAA*, A65-11,772)

736. **INTERPRETATION OF THE READINGS OF AN INSTRUMENT MOVING AT A GREAT VELOCITY IN THE HIGH LAYERS OF THE ATMOSPHERE**
Repnev, A. I.
October 6, 1964
Joint Publications Research Service, Washington, D.C.
JPRS-26742 (pp. 61–72), TT 64-41999
N64-32,334
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is one of 12 articles included in the JPRS report entitled "Methods and Instruments for Meteorological Observations." The report consists of the English translation of selected articles from Volume IX of "Trudy Vsesoyuznogo Nauchnogo Meteorologicheskogo Soveshchaniya, Pribory i Metody Nablyudency" (Proceedings of the All-Union Scientific Meteorological Conference: Instruments and Methods of Observations, edited by M. S. Sternzat, and published by the Hydrometeorological Publishing House, Leningrad, in 1963).

The problems associated with interpreting data obtained from rocket- or satellite-borne instruments are considered. The measured values of atmospheric parameters are affected by gas rarefaction, disassociation, and ionization in the upper layers of the atmosphere. The factors that can cause the pressure, density, and composition of the gas in the instrument to vary from their values in the atmosphere are discussed, as well as the relationships that are used in correcting for these factors. 25 references.

737. **COMBINATION COUNTER FOR ATMOSPHERIC IONS**
Reynet, Ya. Yu.
December 1959
Wright Air Development Center, Technical Information Center, Wright-Patterson AFB, Ohio,
F-TS-9891/V
(Also available as OTS: PB 61-11152, U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is the second of two articles included in this report; the articles were selected for translation from the 1956 issue of *Trudy Glavnoi Geofizicheskoi Observatorii (Transactions of the Main Geophysical Observatory)*. The first article appears in Entry 385.

738. **SOME RESULTS OF ROCKET MEASUREMENTS OF THE ELECTRON CONCENTRATION IN THE IONOSPHERE UP TO HEIGHTS OF 200 KM MADE IN 1959–1960**
Rudakov, V. A.
***Iskusstvennye Sputniki Zemli*, no. 10, p. 102, 1961**
(Translated from the Russian in *Planetary and Space Science*, v. 11, pp. 59–60, January 1963

For a number of years the USSR Academy of Sciences has been using vertical sounding rockets to study the variation in the concentration of free electrons in the ionosphere with height. The present paper gives profiles obtained in 1959 and 1960 during firings of the sounding rockets to heights of 200 km. The results of the rocket measurements can be used to develop methods of introducing corrections into the data obtained at ionosphere stations. 3 references.

739. **THE USE OF THE LANGMUIR PROBE TO DETERMINE ELECTRON DENSITIES SURROUNDING REENTRY VEHICLES**
Scharfman, W. E.
January 1964
Stanford Research Institute, Menlo Park, Calif.
Final Report, NASA-CR-56371, NAS1-2967
N64-27,909
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

An experimental investigation of the operation of electrostatic probes in a flowing plasma was carried out to determine the operation of such probes when the probe radius is comparable to, or larger than, the mean free path. The investigation was carried out in an electromagnetic shock tube capable of producing plasma flows greater than 1 cm/μsec and electron densities greater than 10^{14} electrons/cm^2. The voltage applied to the probes was sinusoidally varied at a 100-kc rate, so that electron temperature and electron density could be obtained from the current–voltage characteristics. The probe results obtained are compared to the microwave results and to each other. Good agreement is obtained between the microwaves and the probes as well as between probes, even when the mean free path is one-fifth the probe radius. All probe data are interpreted by using free molecular theory. 53 pages.

740. **SUMMARY OF ROCKET AND SATELLITE OBSERVATIONS RELATED TO THE IONOSPHERE**
Seddon, J. C.
In "Monograph on Ionospheric Radio," pp. 87–126
Beynon, W. J. G., Editor
Elsevier Publishing Company, Amsterdam, The Netherlands, 1962 (distributed through D. Van Nostrand Co., Inc., New York, N.Y.)
(Paper presented at the 13th General Assembly of the International Scientific Radio Union, London, England, September 1960—Entry 587)

This paper summarizes the more important data on the ionosphere obtained since 1957 by the use of rockets and satellites. The following subjects are included: rocket measurements of electron density, satellite measurements of electron density, ionospheric currents, atmospheric structure, ionizing particles and radiation, and solar ionizing radiation. 114 references. (*MGA*, 1964, 15A-231)

741. **A TRANSISTORIZED RADIATION-FIELD-ACTUATED LIGHTNING FLASH COUNTER**
Sonde, B. S.
***IEEE, Proceedings of the*, v. 51, no. 11, pp. 1501–1506, November 1963**

An instrument is described for recording various types of lightning, including discharges within a cloud, from cloud to air, from cloud to ground, and between clouds. The instrument is an extension of the Aiya noise meter and employs identical calibration and test procedures, but is completely transistorized to make it portable. It is triggered by the HF radiation field arising from lightning flashes. The instrument operates from a 15-volt battery supply, drawing 10 mA normally and about 35-40 mA when registering a flash. The

exact operating frequency, bandwidth, and sensitivity are capable of adjustment to desired values over a wide range. Two flashes occurring at an interval exceeding 1.5 sec can be resolved by the instrument. 20 references. (*IAA*, A64-10,402)

742. AERONOMY RESEARCH WITH ROCKETS AND SATELLITES

Spencer, N. W.
In "Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration, Chicago, Ill., November 1–3, 1962," pp. 147–151
National Aeronautics and Space Administration, Office of Scientific and Technical Information, Washington, D.C., December 1962 (available at SP-11, Volume 1)

Two new projects underway at Goddard Space Flight Center provide examples of aeronomy experiments needed for productive atmospheric explorations. The "Geoprobe" series will initially provide data to several hundred, and later to a few thousand, kilometers. The measurements will include neutral particle and ion composition, and neutral particle, ion, and electron density and temperature. These measurements will provide better insight into separation (layering) of ions and neutral particles, and will show how solar ultraviolet energy is dissipated in atmospheric heating. (*EI*, 1964)

743. CONTINUUM THEORY OF SPHERICAL ELECTROSTATIC PROBES

Su, C. H., Lam, S. H.
***Physics of Fluids*, v. 6, no. 10, pp. 1479–1491, October 1963**

A continuum theory for spherical electrostatic probes in a slightly ionized plasma is developed. The plasma is assumed to be sufficiently dense to provide numerous collisions of both ions and electrons with the neutrals before being collected by an absorbing probe. A general discussion of probes at an arbitrary potential is included. It is found that for very negative probe potentials the sheath thickness can be comparable to the probe radius. Two explicit forms of current–voltage characteristics are given: one for very negative probes, the other for probes at nearly plasma potential. Both of these are based on the assumption that the probe radius is large compared with the Debye length. A numerical computation is also given for negative probes of a wider range of probe sizes. (*PA*, 1964, #526)

744. LANGMUIR PROBE METHOD FOR A PLASMA HAVING SMALL AMPLITUDE OSCILLATIONS

Sugawara, M., Hatta, Y.
***Physical Society of Japan, Journal of the*, v. 19, no. 10, pp. 1908–1914, October 1964**

A detailed discussion is given of Langmuir probe characteristics for a plasma having oscillations of space potential, electron density, and electron temperature. A method is introduced to derive amplitudes of oscillation as well as values of the DC component in the case of the ideal plane probe.

An extension of the constant-current probe method (developed by Barnes and Eros) is used to gain information about oscillatory components. The newly developed method should be useful because of its improved accuracy.

745. RETARDING POTENTIAL ANALYZER

Sullivan, J. D., McGrath, J. F., Thorburn, W. J.
August 31, 1964
Comstock and Wescott, Inc., Cambridge, Mass.
Investigation of Ultraviolet Solar Radiation and Its Influence on the Aerospace Environment (Part 1), Final Report, AFCRL-64-773, AF 19(604)-7496
AD-608,680, N65-14,505

The need for instrumentation for the analysis of photoelectron emission, environmental ions, and environmental electrons at the surface of a space vehicle has resulted in the development of the Retarding Potential Analyzer. The design, construction, and operation of the instrument are described as well as the major modifications made to improve accuracy and reliability. Photographs, schematic diagrams, and assembly drawings are also presented. 55 pages.

746. THE USE OF ION PROBES FOR DIAGNOSING REENTRY PLASMAS

Taylor, W. C.
July 1963
Stanford Research Institute, Menlo Park, Calif.
TR 11, SD-103
AD-420,827, N64,32,138

The use of wire probes for determining electron density in plasmas formed by hypersonic shock waves in air was investigated. The simpler relations used to interpret the data in terms of plasma parameters over a wide range of pressures are discussed. The experiments are described, the results are listed, and the errors involved are discussed. Most of the measurements were made in an electromagnetic shock tube, where microwave transmission measurements were used as an independent check on electron density. Several special topics associated with the probe are discussed, such as flow velocity effects, bias levels, ion vs. electron collection, probe shapes, contamination, and thermionic emission. 35 pages.

747. ELECTRON DENSITY AT THE ALOUETTE ORBIT

Thomas, J. O., Sader, A. Y.
***Journal of Geophysical Research*, v. 69, no. 21, pp. 4561–4581, November 1, 1964**

Alouette topside soundings are analyzed to determine the diurnal, seasonal, and latitudinal variations of electron density at the orbit of the satellite (~1000 km) over a wide range

of latitudes. The electron density is found to be larger in summer than in winter by a factor of approximately 2 at the level of the satellite. The derived latitudinal distributions of electron density at the base of the exosphere are of importance to the theory of electron and positive ion distributions in the exosphere. 17 references.

748. FIRING OF AN ASTROBEE 200 ROCKET WITH A MULTIPLE IONOSPHERIC EXPERIMENT
Ulwick, J. C., Pfister, W., Vancour, R. P., Bettinger, R. J., Haycock, O. C., Baker, K. D.
***IRE, Proceedings of the*, v. 50, no. 11, pp. 2272–2286, November 1962**

The instruments are described which were used in an *Astrobee 200* rocket to measure electron density, positive ion density, electron temperature, vehicle potential, and incoming radiation in the ionosphere. Details are given of the tracking, telemetry, attitude and ejection systems, the field operation, and the data recording and reduction systems. Some of the preliminary results obtained are illustrated. (*PA*, 1963, #5213)

749. ROCKET MEASUREMENTS WITH ELECTRON AND ION PROBES IN AN AURORA
Ulwick, J. C., Pfister, W., Haycock, O. C., Baker, K. D.
September 1964
Air Force Cambridge Research Laboratories, Upper Atmosphere Laboratory, Bedford, Mass.
Environmental Research Paper 56, AFCRL-64-791
AD-609,454, N65-14,493

An *Aerobee* rocket was fired into a Class I aurora. Data were obtained from the following instruments: retarding potential probes mounted on the front and side, a standing-wave impedance probe on two frequencies, a plasma frequency probe, a plasma resonance probe, and a Langmuir probe. In addition, simultaneous measurements have been made with ionosondes, all-sky cameras, photometers, spectrometers, auroral radar, riometers, and magnetometers. The rocket went through the aurora on ascent and descent at about 105 km. Density values measured at this altitude were about $2.5 \times 10^5/cm^3$. This is about a factor of 10 more than that measured at the peak altitude of 228 km. The data are relatively smooth, with little of the irregularities expected in an aurora. 31 pages.

750. DENSITÉ ÉLECTRONIQUE AU-DESSUS DE F-MAXIMUM, DÉDUITE DE L'ÉMISSION DES SATELLITES (ELECTRON DENSITY BEYOND F-MAXIMUM, DETERMINED BY THE EMISSION FROM SATELLITES)
Vassy, E. J.
In "The Upper Atmosphere Above F2-Maximum," pp. 263–267
Poeverlein, H., Editor
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Paris, France, 1959 (available as AGARDograph 42)
(Paper presented at the Symposium on the Ionospheric Research Committee AGARD Avionics Panel, Paris, France, May 22–28, 1959—Entry 603)

The interesting method proposed by Al'pert and his associates for the determination of the electron density beyond F-maximum is discussed. This method is based on the investigation of the refraction at the moment of radio-electric "rise" or "setting" of an artificial satellite. Al'pert assumes an exponential decrease of the electron density beyond F-maximum.

As a consequence of data provided by *Pioneer III* (Van Allen), this assumption must be restricted to altitude intervals where experimental verification can be made. It is suggested in this paper, that (1) the refraction be determined by experimentation; (2) ionospheric soundings be used up to F-maximum, as proposed by Al'pert; and (3) the experimental data for various altitudes of the satellite be used, and consideration be given to a law of distribution to be determined solely for the range between the altitude of the satellite and that of F-maximum. 4 references.

751. AIRPLANE INSTRUMENT FOR MEASUREMENT AND VECTORIAL PRESENTATION OF ELECTRICAL POTENTIAL GRADIENT
Vonnegut, B., McCaig, D. A.
***Journal of Geophysical Research*, v. 65, no. 7, pp. 1959–1963, July 1960**

An apparatus is described that measures simultaneously all three components of the atmospheric potential gradient and presents the resultant vector on a cathode-ray oscilloscope. (*PA*, 1960, #16,492)

752. ADJUSTABLE POTENTIAL-GRADIENT-MEASURING APPARATUS FOR AIRPLANE USE
Vonnegut, B., Moore, C. B., Mallahan, F. J.
***Journal of Geophysical Research*, v. 66, no. 8, pp. 2393–2397, August 1961**

An apparatus for measuring the electrical potential gradient from aircraft by the use of radioactive, ionizing probes is described. An adjustable, rotating capacitor system was devised that permits compensation for asymmetry in the exposure of the probes. While this arrangement compensates for the effects of charge on the airplane, it does not compensate for the effects of space charge produced by the airplane. It is concluded that all airplane gradient measurements in cloud or intense fields, whether made with this or any previous apparatus, are not to be trusted because of errors caused by this space charge. As the result of these errors, the gradients measured in weakly electrified clouds are probably too large and the large gradients measured near thunderstorms are probably too small. Examples of gradient records obtained with this apparatus near a source of artificially produced space charge are presented. (*PA*, 1961, #20,843)

753. AGRIMETER FOR MEASUREMENT OF ATMOSPHERIC ELECTRICAL POTENTIAL GRADIENT
Vonnegut, B., Moore, C. B., Harris, C. K.
Journal of Meteorology, v. 18, pp. 813–815, December 1961

A device for the measurement of the atmospheric potential gradient is described. The operation and calibration of the instrument are covered, and a modified form of the apparatus for the measurement of weak gradients is described. (*IAA*, 62-2783)

754. THE SUDDEN IONOSPHERIC DISTURBANCE
Warwick, C. S.
In "Radio Astronomical and Satellite Studies of the Atmosphere," pp. 457–475
Aarons, J., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1963
(Paper presented at the Conference on Radio Astronomical and Satellite Studies of the Atmosphere, Corfu, Greece, June 1962)

Studies of sudden ionospheric disturbances are reviewed, emphasizing the influence of direct measurements of ionizing radiation from rockets and satellites. Individual cases of sudden ionospheric disturbance are found to show a great diversity of form of development that is only generally described by classification schemes. Different ionospheric models are noted and various observational data are presented. 73 references. (*IAA*, A63-26,000)

755. A KINETIC THEORY APPROACH TO ELECTROSTATIC PROBES
Wasserstrom, E.
1964
Brown University, Providence, R. I.
Thesis

A spherical electrostatic (Langmuir) probe in a slightly ionized plasma is studied from a kinetic theory point of view. In contrast to neutral gases, where only one length parameter (the mean free path) characterizes the gas, in a plasma it is necessary to consider another characteristic length, the Debye distance. This may lead to problems in which in one region the changes in the macroscopic variables (e.g., number density and potential) occur over distances much larger than the mean free path, while in another region these changes may occur over distances much shorter than the mean free path. To treat such a problem, even when the mean free path is much shorter than the appropriate characteristic length (e.g., the probe radius), a kinetic theory approach is required. In the present analysis the existence of a sheath region is not assumed *a priori*. Rather, the sheath appears as the natural consequence of an appropriate asymptotic analysis in which the ratio of the Debye length to the probe radius tends to zero. 84 pages. (*DA*, 65-2256)

756. KINETIC THEORY APPROACH TO ELECTROSTATIC PROBES
Wasserstrom, E., Su, C. H., Probstein, R. F.
Physics of Fluids, v. 8, no. 1, pp. 56–72, January 1965

A spherical electrostatic (Langmuir) probe in a slightly ionized plasma is studied from a kinetic theory point of view. The two-sided distribution function method of Lees, which embodies the Mott-Smith approach, is used. The velocity space is divided into two regions along the straight cone tangent to the spherical probe, and different distribution functions are defined in the two regions. On satisfying the two relevant moments of the distribution function (continuity and number density flux), three simultaneous ordinary nonlinear differential equations (which are appropriate to all values of the Debye length, collision mean free path, and probe potential) are obtained for determining the ion and electron number densities, and the potential. These equations reduce to the usual linear flux equations when the mean free path is much shorter than the probe radius and the Debye length. The equations are first linearized and solved for the case of small probe potential. Explicit solutions are given for the current–voltage characteristics and the distributions of the number densities and the potential. The general case of arbitrary probe potential is also studied. Results for the characteristics and for the potential drop in the sheath are presented for some representative cases. Many of the results which are obtained do not appear in the original simplified Langmuir model. The modifications required to take into account the curvilinear orbits of the charged particles are discussed.

757. PERTURBATION OF A PLASMA BY A PROBE
Waymouth, J. F.
December 26, 1962
Massachusetts Institute of Technology, Research Laboratory of Electronics, Cambridge
Technical Report 406, DA 36-039-sc-78108
AD-296,210
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The perturbation of the plasma by a probe is analyzed as a problem in ambipolar diffusion, subject to the assumptions that the mean free path of plasma particles is (1) comparable to or smaller than probe dimensions, and (2) much greater than the thickness of any sheaths that may be present. Sheaths must therefore be assumed to be thin in comparison with probe dimensions. Analyses are carried through for spherical probes and for plane probes oriented normal to a magnetic field. The results can be expressed in terms of a parameter, Q, which is approximately equal at zero sheath potential to the sum of the ratios of probe size to electron mean free path and probe size to ion mean free path. Since Q also depends on sheath potential, the current–voltage characteristics are distorted. 43 pages; 14 references.

758. PERTURBATION OF A PLASMA BY A PROBE
Waymouth, J. F.
In "Comptes Rendus de la VI^e Conférence Internationale sur les Phénomènes d'Ionisation dans les Gas, Volume IV," pp. 57–61
Hubert, P., Crémieu-Alcan, E., Editors
SERMA, Paris, France 1963
(Paper presented at the Sixth International Conference on Ionization Phenomena in Gases, Paris, France, July 8–13, 1963—Entry 592)

A fundamental assumption in the Langmuir derivation of the current–voltage characteristic of a probe in a gas-discharge plasma is that the probe dimensions are small compared to the mean free paths of plasma particles. It will be shown that, when this is not true, the probe behaves like a sink for ions and electrons, which must then diffuse through the plasma to the vicinity of the probe. The perturbations in plasma density and potential at the probe surface are shown to be dependent on sheath potential; therefore, the shape of the probe electron current characteristic is distorted. The problem is treated in a manner similar to that employed by Davydov and Zmanovskaja, except that the ion temperature is retained explicitly in all the expressions. The results are shown to be dependent on ion temperature, suggesting the possibility that probes may be used in this domain to measure ion temperature in a plasma. 5 references.

759. PERTURBATION OF A PLASMA BY A PROBE
Waymouth, J. F.
***Physics of Fluids*, v. 7, no. 11, pp. 1843–1854, November 1964**

The theory of the electrostatic probe immersed in a plasma is discussed under the assumption that particle mean free paths are comparable with or smaller than the probe radius. The range of validity of the results is for $\lambda_c/r_p < 10$, $r_p/100\lambda_D > 1$, $\lambda_c/\lambda_D > 10$, where r_p is the probe radius, λ_c is the particle mean free path, and λ_D is the Debye length. In the limit of λ_c/r_p approaching infinity, the results converge toward the Langmuir result for the same probe. The probe current vs. voltage characteristic obtained when mean free paths are short is distorted because the degree of perturbation of the plasma density and potential vary with the probe voltage. An unexpected result is that the shape of the probe characteristic in the vicinity of the "knee" is sensitive to ion temperature, and may possibly be used to determine the ion temperature. 15 references.

760. DIRECT MEASUREMENTS OF ION DENSITY AND CONDUCTIVITY IN D REGION
Whipple, E. C., Jr.
October 1960
National Aeronautics and Space Administration, Washington, D.C.
TN D-567

The electrical properties of the D region can be measured by the direct measurement techniques used in the lower atmosphere. Details are given of an ion collector experiment adapted for rocket determination of ion density and conductivity in the D region (up to 80 km). Results obtained when the collector was flown in the *Viking V* rocket are discussed. The importance of dust in providing the recombination surface for charged particles is considered for the D region and for interplanetary space. 7 pages. (*EI*, 1961)

761. EXPERIMENTAL INVESTIGATION OF THE CHARACTERISTICS OF A LANGMUIR PROBE IN IONIZED LOW-DENSITY FLOWS
Wilber, P. C.
In "Physico-Chemical Diagnostics of Plasmas," pp. 97–112
Anderson, T. P., Springer, R. W., Warder, R. C., Jr., Editors
Northwestern University Press, Evanston, Ill., 1964
(Paper 63-371, presented at the AIAA Fifth Biennial Gas Dynamics Symposium, Evanston, Ill., August 14–16, 1963)

An experimental investigation was made of the performance of a charged circular cylinder immersed in an essentially uniform rarefied plasma stream. Data are presented for side ranges of speed ratio, electron and neutral particle number densities, and electron temperature with the collector axis oriented both parallel and transverse to the flow. Results are discussed in terms of a recently developed theory which relates the probe measurements to local charged-particle density and temperature in the flowing plasma.

762. THEORY OF THE PLASMA RESONANCE PROBE
Wimmel, H. K.
***Zeitschrift für Naturforschung*, v. 19A, no. 9, pp. 1099–1106, September 1964 (in English)**

The DC electron current to a resonance probe, as a function of frequency and other pertinent parameters, is computed from a one-dimensional plasma-sheath model. From linearized macroscopic plasma equations with damping, the longitudinal RF field that is caused in the two-slab model by the applied RF voltage is derived. The dielectric constant in the sheath is taken to be 1; the sheath thickness is estimated from the Langmuir-Child law. In accordance with Mayer, an RF resonance occurs at a frequency $\omega'_{res} \lesssim \omega_s < \omega_p$, where ω_s/ω_p is determined by the probe-sheath plasma geometry. The DC electron current to the probe is computed numerically by means of an approximate classification of the (collisionless) electron orbits in the combined DC and RF fields. There is a DC resonance at $\omega_{res} \lesssim \omega_s$, but none at the plasma frequency, ω_p. For $\omega \ll \omega_{res}$ and $\omega \gg \omega_{res}$ the correct limiting values of the DC current are reproduced. There is good qualitative agreement with recent experimental results by Peter, Müller, and Rabben, but disagreement with a theory by Ichikawa and Ikegami. Arguments are presented which question the validity of that theory.

763. ELECTRON DISTRIBUTION IN THE IONOSPHERE
Wright, J. W.
Journal of Research of the National Bureau of Standards, Section D—Radio Science, v. 68D, no. 5, pp. 589–594, May 1964
(Paper presented at the 14th General Assembly of the International Scientific Radio Union, Tokyo, Japan, September 9–20, 1963)

This paper is a progress report concerning new measuring techniques and their significance in determining the electron distribution in the ionosphere. Topics discussed include the D region, E region, F region, and the total electron content of the ionosphere. An electron density profile obtained with the aid of rockets is presented, as well as electron distributions obtained by the incoherent scatter technique. 95 references. (*EI*, 1965)

764. DETERMINATION OF IONOSPHERE PARAMETERS BY MEANS OF A SATELLITE ANTENNA-TYPE PROBE. I
Zachary, W. W., Wolff, E. A., Katzin, M.
June 30, 1960
Electromagnetic Research Corporation, College Park, Md.
CRC-6656-1, Scientific Report 1, GRD TN 60-492

A spherical antenna-type probe for determining the parameters of the ionosphere is described. This consists of a main slot around which are disposed pairs of small orthogonal slots. By applying a driving voltage to the main slot and measuring the input impedance as well as the voltages induced in the orthogonal slots, the ionization density, collision frequency, and the Earth's magnetic field may be determined. Preliminary to the main analysis, the input admittance of a slotted plane antenna in a magneto-ionic medium is analyzed. The solution is obtained in a form suitable for numerical evaluation. Measurement systems for the determination of the quantities necessary to evaluate the parameters of the ionized medium are considered. Three systems are shown, and their relative advantages and disadvantages are outlined. 57 pages; 11 references. (*IAA*, 62-2777)

765. DETERMINATION OF IONOSPHERE PARAMETERS BY MEANS OF A SATELLITE ANTENNA-TYPE PROBE. II. ANALYSIS FOR SPHERICAL GEOMETRY
Zachary, W. W.
December 31, 1960
Electromagnetic Research Corporation, College Park, Md.
CRC-6656-2, Scientific Report 2, AFCRL 235

The field distribution and input admittance of a slotted-sphere antenna are analyzed. The change in input admittance upon immersion of the antenna in a magneto-ionic medium is evaluated by expressing the field as the sum of the free space field and a secondary field. The latter is evaluated by successive approximations, and detailed calculations are made for the first approximation. Higher order approximations can be evaluated by the same procedure. 43 pages; 12 references. (*IAA*, 62-2472)

766. DETERMINATION OF IONOSPHERE PARAMETERS BY MEANS OF A SATELLITE ANTENNA-TYPE PROBE. III. PERTURBATION ANALYSIS AND ADMITTANCE MEASUREMENT SYSTEM
Zachary, W. W., Wolff, E. A., Katzin, M.
June 30, 1961
Electromagnetic Research Corporation, College Park, Md.
CRC-6656-3, Scientific Report 3, AFCRL 849

A spherical antenna-type probe is analyzed by means of the reaction of the medium on the antenna admittance. The effect of the anisotropy of the medium which is produced by the Earth's magnetic field is evaluated by a perturbation technique. This is accomplished by separating the conductivity tensor into a scalar plus an anisotropic part, both of which depend on the terrestrial magnetic field. The integral equation which results from a Green's function solution is approximated by the isotropic Green's function, which has been obtained previously. With this approximation, it is possible to carry out all the necessary integrations to obtain the field components. The input admittance can then be evaluated in terms of known functions. A system previously proposed for the measurement of input admittance has been further refined by the application of single-sideband modulation techniques. A study of the errors which may occur in such a system shows that an overall accuracy on the order of 1% or better should be achievable without difficulty. 59 pages; 15 references. (*IAA*, 62-2778)

767. DETERMINATION OF IONOSPHERE PARAMETERS BY MEANS OF A SATELLITE ANTENNA-TYPE PROBE. IV
Zachary, W. W., Katzin, M., Yang, K. C., Wolff, E. A., Washburn, A. B., Jr.
November 30, 1961
Electromagnetic Research Corporation, College Park, Md.
CRC-6656-4, Final Report, AFCRL 1096

A probe suitable for measuring the parameters of the ionosphere is described. The probe system consists of an energized, spherical slot antenna, together with three sets of auxiliary slots which are disposed around the sphere in orthogonal orientations to the energized slot. The large slot is fed from a low-power RF source in the vehicle, and both the applied voltage and current fed to this slot are measured, so that the input admittance can be determined. The signal-frequency voltages induced across the auxiliary slots are also measured. These measured quantities are sufficient, in general, to determine the electron density, collision frequency, and the vector of the Earth's magnetic field relative to the vehicle. The measured quantities can be recorded on tape for storage until the satellite attains a suitable position relative to a ground station. The results of a complete mathematical analysis of the probe system are given. Specifications and requirements for a typical ionosphere probe are discussed, and recommendations are made for sphere size, slot lengths, cavity feeds, and the admittance measurement system. 44 pages. (*IAA*, 62-3874)

768. THE THEORY OF THE CONDUCTIVITY PROBE
Zachary, W. W.
June 15, 1963
Electromagnetic Research Corporation, College Park, Md.
Memorandum Report, NASA-CR-55101, NAS-585-8
N64-12,401
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The existing theory of the conductivity probe is summarized and the analysis which produced the existing theory is discussed. Preliminary results which have been obtained in an attempt to improve upon the theory are described. An expression is sought for the conductivity of ions scattering against neutral particles, with no restriction on the relative masses of the two particles. When particles of comparable mass are colliding, the types of particle orbits which occur must be taken into account. Since the existing theory does not contain enough detail for this purpose, it is concluded that the existing theory of the conductivity probe is not adequate for the present problem. 10 pages.

SELECTED REFERENCES ON RELATED SUBJECTS

769. INITIATION OF ELECTRICAL BREAKDOWN IN ULTRAHIGH VACUUM
Alpert, D., Lee, D. A., Lyman, E. M.
August 1964
Illinois, University of, Coordinated Science Laboratory, Urbana
R-234, DA-28-043-AMC-00073(E)

Existing theories for the initiation of electrical breakdown are reviewed, and the experimental observations on which these theories are based are discussed. In the experiments described, the available data on electrical breakdown of broad area electrodes under ultrahigh vacuum conditions are extended. The results, together with those of several other experimenters, are interpreted on the basis of a single picture which explains and relates the phenomena of predischarge currents and the initiation of breakdown.

770. ELECTROMAGNETIC INDUCTION ON AN EXPANDING CONDUCTING SPHERE
Bahiana, L. C.
May 30, 1964
Massachusetts Institute of Technology, Research Laboratory of Electronics, Cambridge
TR-421, DA-36-039-AMC-03200(E)
AD-602,435
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

One of the explanations that has been proposed for the origin of the radio signals emitted by nuclear explosions in the atmosphere is that such signals are generated by the interaction of the hot, expanding, electrically conducting gases (which result from the explosion) with the Earth's magnetic field. The model adopted for the study of this process consists of a conducting sphere expanding radially in a uniform, static magnetic field. The velocity is prescribed, as a function of space and time, for all points in the interior of the sphere. The problem consists in the determination of the electromagnetic fields and the electromagnetic force acting on the sphere as a result of its expansion. By prescribing the velocity, the hydrodynamic problem is avoided and the problem is restricted to the domain of classical electromagnetic theory.

Most of the work reported here is concerned with the case of a perfectly conducting expanding sphere. This problem is solved rigorously, with the help of an integral equation relating the current density to the magnetic vector potential. The fields are determined in integral form for any arbitrary velocity of expansion, and calculated explicitly for the particular case of constant velocity of expansion. The physical interpretation of these solutions is discussed. The electromagnetic force acting on the sphere is found, and the energy–power balance at the surface of the sphere is investigated with the help of Poynting's theorem.

The case of the expanding sphere with finite conductivity is formulated, but exact solutions are not given. A high-conductivity approximation is obtained under the assumption that the external magnetic field at the surface of the sphere is essentially the same as that found for the case of infinite conductivity. The approximate solution is found by deriving and solving the differential equation satisfied by the magnetic vector potential inside the sphere. Constant velocity of expansion is assured. The solution is reduced to a particularly simple form for points not too far from the surface.

A rough calculation of the expected electric field 1000 km from a typical nuclear explosion shows that the field is measurable, and its value is of the same order of magnitude as that predicted by another proposed theory. 78 pages.

771. ELECTROSTATIC SHIELDING OF HIGH ENERGY PROTONS. APPENDIX I—CHARGE CALCULATIONS FOR THREE ELECTROSTATIC SHIELD CONCEPTS. APPENDIX II—MECHANICAL FORCES ON CHARGED SHELLS. APPENDIX III—POWER REQUIREMENT
Bailey, T. W.
March 1962
Aeronautical Systems Division, Directorate of Materials and Processes, Wright-Patterson AFB, Ohio
ASD-TDR-62-244

The feasibility of using electrostatic shielding for the protection of manned space vehicles against solar cosmic rays was investigated experimentally. It is concluded that electrostatic shielding is feasible and has some advantages over other types of shields, but that considerable applied research will be necessary. 21 pages; 13 references. (*IAA*, 62,9365)

772. WAVES IN A PLASMA IN A MAGNETIC FIELD
Bernstein, I. B.
***Physical Review*, v. 109, no. 1, pp. 10–21, January 1, 1958**

The small oscillations of a fully ionized plasma (in which collisions are negligible) in a constant external magnetic field are treated by the Laplace transform method. The full set of Maxwell equations is employed and the ion dynamics are included. Various limiting cases are considered. It is shown that self-excitation of waves around thermal equilibrium is impossible. It is also demonstrated that for longitudinal electron oscillations propagating perpendicular to the constant magnetic field, there are gaps in the spectrum of allowed frequencies at multiples of the electron gyration frequency, but zero Landau damping. These particular waves are also associated with a nonuniformity of convergence in the limit of vanishing magnetic field. This phenomenon, however, is of

no physical consequence. When the ion dynamics are included, two classes of low frequency oscillations are found, the existence of which had been predicted by the simple hydrodynamic theory. These are longitudinal ion waves and transverse hydromagnetic waves. The well-known results for the propagation of electromagnetic waves in an ionized atmosphere are also recovered, as well as the effects on such waves in various limiting cases of the magnetic field and particle motion. These calculations indicate that in many cases the transport equations are capable of yielding correct results (apart from such things as Landau damping) for a wide class of waves in a collision-free plasma.

773. ÉTUDE DES CONDITIONS D'APPARITION DES PHÉNOMÈNES ÉLECTROSTATIQUES ET EXPOSÉ DE MÉTHODES DE DÉTECTION ET D'ÉLIMINATION DES CHARGES (CONDITIONS FOR APPEARANCE OF ELECTROSTATIC PHENOMENA—METHODS OF DETECTION AND CHARGE ELIMINATION)
Bertein, H.
***Revue Générale de l'Électricité*, v. 72, no. 7–8, pp. 401–417, July–August 1963**

Mechanisms of electrostatic charge and discharge are reviewed. Methods used for measuring static electricity and for the precipitation of charge are illustrated by applications to various insulating plastics. The hazards involved in static electricity are reviewed from a more general point of view, and methods of avoiding these hazards are discussed. (*EI*, 1964)

774. MODIFICATION OF THE ELECTRICAL PROPERTIES OF THE PLASMA SHEATH BY CONTAMINANT INJECTION
Betchov, R., Fuhs, A. E., Head, R. M.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 1–11
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Detection, Boston, Mass., April 10–12, 1962—Entry 12)

Measurements of the electrical conductivity, σ, of ionized air in the laboratory and during reentry indicate that σ is of the order of 100 to 200 mhos/m. Naturally, σ depends on altitude, velocity, shape of reentry vehicle, angle of attack, and similar variables. For magneto-aerodynamic applications larger values of σ are sought. Seeding is suggested as a means for attaining increased σ.

It would also be advantageous to know how to decrease the values of σ in the plasma sheath. The inverse of seeding with molecules having low ionization potentials is to inject electronegative species. While the number of electrical charges is not altered, the mobility of the negative ions is far less than that of the electrons. For many phenomena, the degree of ionization has effectively been decreased. Experiments were conducted using sulfur-doped epoxy, since sulfur has a high (2.05 eV) electron affinity. The experiments described were performed to determine the extent to which the electrical conductivity could be modified by using ablating materials impregnated with contaminants. 13 references.

775. RESEARCH ON PHYSICS OF THE IONOSPHERE
Borowitz, S.
November 30, 1963
New York University, Physics Department, N.Y.
Final Report, AFCRL 63-925, AF 19(604)-4555
AD-428,963, N64-15,084

The work on this contract consisted of a general investigation of the structure of many-electron systems and, in particular, scattering problems involving multichannel processes. The work falls into two main categories — structural problems and scattering problems.

776. LONG WAVES ASSOCIATED WITH DISTURBANCES PRODUCED IN PLASMAS
Bremmer, H.
***Journal of Research of the National Bureau of Standards, Section D—Radio Science*, v. 68D, no. 1, pp. 47–58, January 1964**

An analysis is made of disturbances produced in a cold, homogeneous plasma by passing charges. Field disturbances in a zero or infinite magnetic field show a spectrum containing exclusively low frequencies. The disturbances produced by a charge moving along a rectilinear path (assuming an infinite magnetic field) comprise predominantly low frequencies, although theoretically all frequencies do occur. The limitation to low frequencies is more pronounced at large distances from the path of the moving charge. The general results are expected to hold also for a finite magnetic field. (*EI*, 1964)

777. ATMOSPHERIC ELECTRICITY
Brook, M.
***American Geophysical Union Transactions*, v. 44, no. 2, pp. 369–373, June 1963**
(United States National Report, 1960–1963, Triennial Report to the International Union of Geodesy and Geophysics Thirteenth General Assembly, Berkeley, Calif., August 19–31, 1963)

The major advances which have been made in atmospheric electricity research during the past three years are briefly reviewed. Electrical precipitation relationships in thunderstorms are emphasized. Noted are studies of the possible interrelations of precipitation growth and cloud electrical phenomena, a technique for artificial initiation of lightning, a new magnetic method for measuring thunderstorm currents, and new instruments for space-charge and fair-weather field measurements. 43 references. (*IAA*, A63-19,949)

778. ON THE MOVEMENT OF POSITIVE IONS THROUGH THE POSITIVE SPACE-CHARGE SHEATH
Ciobanu, G., Popescu, I.
Journal of Electronics and Control, v. 16, pp. 59–64, January 1964

A kinetic analysis of the movement of positive ions through the positive space-charge sheath is given for the plane, cylindrical, and spherical geometries. This problem is of basic importance for (1) the theory of cathode fall of the abnormal glow discharge with the simple or hollow cathode, (2) the theory of the ionic current to the Langmuir probe, (3) the mechanism of corona discharge, and (4) the flow-to-arc transition. Expressions are derived for the positive ion relaxation time, concentration, drift velocity, mean kinetic energy, and electric field in the sheath.

779. ELECTROMAGNETIC RADIATION IN MAGNETO-IONIC MEDIA FOR VLF AND VHF SPECTRA
Cook, K. R.
1963
New Mexico, University of, Albuquerque
Thesis

A method of analysis is presented for obtaining approximate solutions to Maxwell's equations pertaining to current sources in a homogeneous magneto-ionic medium. The analysis is applied to the radiation of electromagnetic energy in the VLF and VHF spectra. 131 pages. (*DA* 63-1912)

780. GAS DISCHARGES IN INSULATING SYSTEMS AT PRESSURES BETWEEN ATMOSPHERIC AND HIGH VACUUM
Dakin, T. W., Works, C. N.
In "Collected Papers of the Dielectrics in Space Symposium, Westinghouse Research Laboratories, Pittsburgh, Pa., June 25–26, 1963," pp. 2/1–2/21
Westinghouse Electric Corporation, Pittsburgh, Pa., 1963
N63-22,688

A survey is presented of the gas discharge situation which exposed, energized electrical systems will encounter as they pass from atmospheric pressure through the low-pressure regions at high altitudes, and on to the vacuum of outer space. Part of the survey is based on a scrutiny of well-known low-pressure discharge phenomena as they apply to electrical system environments at high altitude. The discharge behavior of gaps and simple insulation systems in the low-pressure glow discharge region is illustrated by experiments made on such systems. Observations made on discharges with insulating barriers in a vacuum are discussed. Results of this survey indicate the following: (1) The complete insulation of conductors at at least one terminal voltage can lead to high DC electric strengths (and with a minimum number of discharges) corresponding to the DC insulation strength throughout the low-pressure range and at high vacuum; with high AC voltage such an insulation system would have discharges which would reduce the electric strength of the solid. (2) It will be necessary to completely enclose the electrical system in a sealed capsule or avoid high stresses across solid insulation where series gaps may occur, in order to avoid all discharges. 21 pages; 6 references.

781. THE SPACE ENVIRONMENT AS A DIELECTRIC
Denholm, A. S.
In "Collected Papers of the Dielectrics in Space Symposium, Westinghouse Research Laboratories, Pittsburgh, Pa., June 25–26, 1963," pp. 1–21
Westinghouse Electric Corporation, Pittsburgh, Pa., 1963
N63-22,687

There are many uses for high voltage in space, and in some cases it will be convenient, or necessary, to use the vacuum environment as a dielectric. The limitations of this dielectric are discussed before proceeding to the mechanisms which have been proposed to account for these limitations. Several factors are enumerated which must be considered when utilizing vacuum as a dielectric. 26 references.

782. MOTION OF A CHARGED PARTICLE THROUGH PLASMA
Devanathan, C., Bhatnagar, P. L.
Beiträge aus der Plasma Physik, v. 3, no. 3, pp. 107–121, 1963

The motion of a particle projected in an infinite stationary electron plasma is studied. The effect of the induced fields on the particle motion is considered. Apart from the field arising out of a Heaviside ellipsoidal charge distribution, there is a field propagated inside the "sound sphere" due to the coupling between plasma-acoustic and plasma-electromagnetic modes. First-order particle–plasma interaction is taken into account. The acceleration and velocity of the particles are considered and it is shown that these modes are mainly responsible for any acceleration of the particle. Contribution to any radiation that might escape is also due to the above modes. (*PA*, 1964, #505)

783. THERMAL ELECTRIFICATION OF A CONDUCTING SPHERE
Dimick, R. C., Soo, S. L.
August 1964
Virginia, University of, School of Engineering and Applied Science, Charlottesville
TR-ILL-15-P, Nonr-3623(00)

A study was made of the charging by thermionic emission, as limited by space charge, of a conducting sphere enclosed in a concentric vacuum. A method is presented which can be used to solve the integral equation of the electric field.

784. A STUDY OF ELECTRICAL DISCHARGE IN LOW-PRESSURE AIR
Ellion, M. E.
April 1, 1965

Jet Propulsion Laboratory, California Institute of Technology, Pasadena
TR 32-678

The available literature describing the mechanisms of electrical breakdown in gases was reviewed. The mechanisms suggested by various investigators were then modified or expanded to a form suitable for determining the maximum allowable voltage that can be applied, at any given air pressure, across any gap between conductors in a spacecraft. The final results, giving breakdown voltage as a function of gas pressure for typical gap spacings, are presented in graphic and tabular form. These results indicate that, at air pressures of less than 10^{-2} mm Hg, electrical discharge will not occur at any voltage. A bibliography of the literature reviewed prior to the study is included. 12 pages; 21 references.

785. A THEORETICAL STUDY OF ELECTROSTATIC FIELDS IN THE IONOSPHERE

Farley, D. T., Jr.
1960
Cornell University, Ithaca, N.Y.
Thesis

A theory is developed to describe quantitatively the behavior of electrostatic fields in the ionosphere. Particular attention is given to small-scale fields with horizontal scale sizes of the order of one to several kilometers.

The electrostatic coupling between the E and F layers of the ionosphere is investigated in some detail at all latitudes, in order to define the conditions under which the often made assumption that the geomagnetic lines of force are equipotential lines is valid. It is found that, particularly at high latitudes, the coupling to the F region may be significant even for sources situated at heights as low as 120 km with horizontal scales as small as 2 or 3 km. The coupling becomes weaker at lower latitudes, but it may still be significant for large-scale sizes, even at the equator. Decreasing the height or size of the source decreases the coupling, which is also affected by the temperature and electron density gradient.

Under the assumption that the small-scale fields are created and maintained by irregular, horizontal winds in the lower ionosphere, the actual field strengths to be expected in the F region are then computed. This strength is found to be less than 10^{-3} V/m for all latitudes and all scale sizes considered. A brief study is also made of the possibility of producing an irregularity of ionization density by means of an irregular, externally imposed, electric field. 117 pages. (*DA*, 60-1890)

786. FEASIBILITY OF ELECTROSTATIC SYSTEMS FOR SPACE VEHICLE RADIATION SHIELDING

Felten, J. E.
***Journal of the Astronautical Sciences*, v. 11, pp. 16–22, Spring 1964**

The possibility of using electrostatic shielding devices to protect interplanetary vehicles from space radiation is analyzed. Various types of charged particles in interplanetary space are considered, including solar flare particles, galactic cosmic rays, and solar wind fluxes. Three shielding schemes for an idealized spherical vehicle are studied; the first uses a positively charged vehicle skin, the second adds to this a concentric, negatively charged outer grid to suppress the electron current, and the third replaces the outer grid with a solid shell. Schemes I and II are found to be catastrophically unstable against discharge, and all three subject the vehicle occupants to unacceptable doses of bremsstrahlung X rays due to the collection of solar photoelectrons and plasma electrons by the high positive potential. It is concluded that such electrostatic shielding systems are unfeasible under interplanetary conditions. 25 references. (*IAA*, A64-20,833)

787. HYDROMAGNETIC SIGNALS IN THE IONOSPHERE

Field, E. C.
September 1963
Rand Corporation, Santa Monica, Calif.
RM-3830-PR, AF 49(638)-700
AD-421,842
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The equations which govern the propagation of hydromagnetic signals in a spatially inhomogeneous, multi-species, anisotropic ionosphere are derived and applied to several situations. Numerical results for the dependence of the ionospheric refractive indices on height and signal frequency are presented and discussed. Simplified model ionospheres, characterized by the refractive indices, are used to compute the ground-level magnetic signals produced by hydromagnetic waves at normal incidence upon the collision-dominated lower ionosphere. Magnetic disturbances, which were observed at great distances from the high-altitude *Argus* nuclear explosions, are considered and shown to have also probably been hydromagnetic in origin. It is shown that, in principle, the ionosphere is capable of supporting hydromagnetic surface waves. The relevant equations for the case of propagation across the geomagnetic field lines are derived and discussed. 44 pages.

788. THERMAL IONIZATION AND ELECTRONEGATIVE SPECIES

Fuhs, A. E.
***Pyrodynamics*, v. 1, pp. 3–25, January–February 1964**
(Paper 62-19, presented at the Fall Meeting of the Western State Section of the Combustion Institute, Sacramento, Calif., November 1962)

Free electrons that are present in the ionized gas of the reentry plasma sheath or in the exhaust of rockets cause severe attenuation and reflection of electromagnetic waves. A frequently proposed solution to the resultant communication problem is the addition of trace amounts of an electronegative species. In this study, the conditions which are favorable or unfavorable for "soaking up" electrons are described.

789. IONIZATION PHENOMENA IN A GAS-PARTICLE PLASMA
Gibson, E. G.
1964
California Institute of Technology, Pasadena
Thesis

Several interesting and important types of ionization phenomena which occur in a plasma that is composed of thermionically emitting particles and an ionized gas are investigated. Many interactions can take place between the particles and the gas which may alter the electron density of the plasma appreciably from what it would be in the absence of the particles. Several of these interactions are explored. Throughout the analysis, emphasis is placed on gaining a physical understanding of the basic phenomena involved. 189 pages. (*DA*, 64-11,396)

790. FORMATION OF AN ELECTRON-DEPLETED REGION IN THE IONOSPHERE BY CHEMICAL RELEASES
Golomb, D., Rosenberg, N. W., Wright, J. W., Barnes, R. A.
In "Space Research IV," pp. 389–398
Muller, P., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1964
(Paper presented at the Fourth International Space Science Symposium, Warsaw, Poland, June 4–10, 1963—Entry 10; also available as Environmental RP-63, AFCRL 64-846, Air Force Cambridge Research Laboratories, Bedford, Mass., October 1964)

The formation of an electron-depleted region in the ionosphere on release of a chemical with a high-attachment coefficient for free electrons is reported. About 10^{26} molecules of sulfur hexafluoride were released from a rocket-borne pressurized tank at an altitude of 220 km. Marked perturbations observed on sweeping and pulsed radio frequency sounders can be interpreted as resulting from an electron-depleted region. 16 references.

791. MAGNETOHYDRODYNAMIC FLOW PAST A SPHERE
Gotoh, K.
Physical Society of Japan, Journal of the, v. 15, no. 1, pp. 189–196, January 1960

The flow of an incompressible, viscous, electrically conducting fluid past a sphere in the presence of a uniform magnetic field parallel to the undisturbed flow is investigated using the Oseen approximation. The drag coefficient is calculated up to the second order of magnitude for the following parameters: the Reynolds number, R, the magnetic Reynolds number, R_m, and the Hartmann number, M. Numerical values are shown graphically for a few typical cases. It is found that the drag coefficient is continuous at the pressure number $S = 1$, where it changes abruptly in the two-dimensional case. The flow pattern changes remarkably with variations in the pressure number.

792. STOKES FLOW OF AN ELECTRICALLY CONDUCTING FLUID IN A UNIFORM MAGNETIC FIELD
Gotoh, K.
Physical Society of Japan, Journal of the, v. 15, no. 4, pp. 696–705, April 1960

The flow of an incompressible, viscous, electrically conducting fluid past an obstacle in a uniform magnetic field is investigated using Stokes approximation. The result applies to the general three-dimensional problems, since no particular configuration of the flow and the magnetic field is assumed.

The general theory is discussed, and it is found that the neutrality of the electric charge density does not hold exactly when the undisturbed magnetic field is not perpendicular to the vorticity vector. It is also found that the vorticity and the electric current density are confined in a paraboloidal region, thus forming a wake which extends in the direction of the undisturbed magnetic field. The distribution of the electric charge density also shows the same structure.

The flow past a sphere is investigated. The drag is obtained in the form of a power series of the Hartmann number, M. The component of the drag perpendicular to the undisturbed magnetic line of force is found to be larger than its parallel component. An interesting feature of the three-dimensional cases is noted, i.e., the velocity field includes components which express the two-dimensional irrotation flow.

793. INDUCED OSCILLATIONS IN A RAREFIED PLASMA IN A MAGNETIC FIELD
Greifinger, P. S.
Physics of Fluids, v. 4, no. 1, pp. 104–108, January 1961

Consideration is given to the excitation of collective plasma motion by a small charged object moving through a low-density unbounded plasma in an external uniform magnetic field which is static. The energy loss per unit path length due to the excitation of collective plasma motion is found as a function of magnetic field strength for an arbitrary angle between the velocity of the object and the field direction. It is assumed that the ion temperature is zero and the velocity of the charged object is small compared to the mean thermal electron speed.

794. THE PLASMA TEST PARTICLE PROBLEM
Hirt, C. W.
1963
Michigan, University of, Ann Arbor
Thesis

A charged test particle passing through an electron plasma is subject to a drag force. The calculation of the drag, when the test particle's velocity is maintained at a constant value,

is referred to as the plasma test particle problem. Several calculations of the drag have been given, but all treatments have resulted in a logarithmically diverging drag expression. The purpose of this dissertation is to give a convergent and consistent treatment of the plasma test particle problem. 158 pages. (*DA*, 64-8176)

795. STRUCTURE OF A PLASMA SHOCK WAVE
Jaffrin, M. Y.
1964
Brown University, Providence, R. I.
Thesis

The one-dimensional, steady-state structure of a shock wave in a fully ionized plasma is investigated in the absence of external applied magnetic or electric fields. The structure is assumed to be described by the appropriate Navier-Stokes equations written for the electron and ion fluids, together with Poisson's equation for the self-induced electric field effects. The shock structure is shown to be described by a system of five coupled nonlinear ordinary differential equations of which three are of first order and two of second order. The collisional broadening mechanisms considered, along with their respective length scales, are (1) electron heat conduction and ion–electron energy and momentum transfer, (2) ion heat conduction and viscosity, and (3) electron viscosity. 70 pages. (*DA*, 65-2211)

796. ACTIVE SHIELDING FOR MANNED SPACECRAFT
Kash, S. W., Tooper, R. F.
***Astronautics*, v. 7, no. 9, pp. 68–75, September 1962**

A magnetic field will deflect both positively and negatively charged particles, and when employed as a corpuscular radiation shield (if sufficiently strong) can prevent most incoming particles from impacting material components of spacecraft. Since there will be considerably fewer impacts by electrons, the problem of secondary emission will also be greatly reduced.

Electrostatic shielding against proton bombardment could be obtained with a positively charged spherical shell. Power requirements would be negligible in the absence of appreciable charge leakage. The problem of X-ray flux within the structure would be magnified since the charge on the shield would accelerate the bombarding electrons to greater energies. Solution of this problem by applying a negatively charged sphere concentric to the proton shield involves a configuration that would be dynamically unstable; a slight relative displacement between the spheres would result in large forces tending to draw them quickly together. 68 references.

797. ACTIVE SHIELDING AGAINST METEOROIDS
Klahr, C. N., Stein, N. N.
August 1963
Aeronautical Systems Division, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio
Report for April 1962–May 1963, ASD-TDR-63,537, AF 33(657)-8531

The feasibility of a number of methods of active shielding against meteoroids is investigated. The effects of meteoroid flux on space vehicles and their components are first assessed, and the requirements for passive (mass) shielding are calculated. It is found that some active shielding concepts are practicable in the near term, while others would require at least a ten-year development period. Among the methods considered are various electrostatic and magnetostatic techniques. 387 pages; 82 references.

798. MAGNETOHYDRODYNAMIC AND PLASMA TURBULENCE
Kovasznay, L. S. G.
September 1964
Johns Hopkins University, Baltimore, Md.
TR-JHU-23-P, Nonr-3623(00)
AD-606,395
(Report on Project Squid, prepared in cooperation with the University of Virginia, Charlottesville; paper presented at the XIth International Congress of Applied Mechanics, Munich, Germany, August 30–September 5, 1964; also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Developments in turbulence of electrically conducting media are reviewed. Theories of both active and passive homogeneous turbulence are summarized. The "chemical" approach in hot wakes is also reviewed, and the possibility of electrostatic turbulence is discussed. 27 pages.

799. EFFECT OF ADDITION OF IMPURITIES ON ELECTRON–ION RECOMBINATION TIMES AND ON TRANSMISSION THROUGH IONIZED LAYERS
Kuhns, P. W.
In "Electromagnetic Aspects of Hypersonic Flight," pp. 12–21
Rotman, W., Moore, H. K., Papa, R., Editors
Spartan Books, Inc., Baltimore, Md., 1964
(Paper presented at the Second Symposium on the Plasma Sheath—Its Effect Upon Reentry Communication and Deflection, Boston, Mass., April 10–12, 1962—Entry 12)

When a body enters the Earth's atmosphere it is surrounded by the plasma sheath and trailed by a wake of ionized gas. Although this gas may be at a comparatively low temperature, a high degree of ionization exists because of the finite recombination times between electrons and ionized atoms or molecules. If something could be added to this gas to shorten this recombination time sufficiently, many problems would be solved.

The addition of water in small quantities has the property of shortening the recombination times of otherwise pure gases. Some experiments with impurity addition were performed as part of a study of microwave transmission properties of ionized gases. Two types of experiments performed are of

interest here: first, the measurement of electron–ion recombination times of pure gases and gases containing water as an impurity; second, the measurement of microwave transmission from a reentry model surrounded by ionized gas with and without water vapor.

The data taken show the marked effect that the addition of water vapor can make on an ionized gas that is either stationary or moving at supersonic velocities, when the water is added before ionization. However, the results for water vapor addition after ionization are neither so promising nor so conclusive, and further experimentation will be necessary before any definite conclusion can be reached. Future work will probably be done using pulsed ionization, other additives will be tried, and an attempt will be made to add impurities to the shock after ionization. 14 references.

800. PLASMA WITH MAGNETIC FIELD
Majumdar, S. K.
September 14, 1962
Massachusetts Institute of Technology, Research Laboratory of Electronics, Cambridge
TR-401, DA-36-039-sc-78108
AD-285,384
(Also available through U.S. Dept. of Commerce, Office of Technical Service, Washington, D.C.; see also *Proceedings of the Physical Society*, London, v. 82, pt. 5, pp. 669–688, November 1963)

The motion of a charged particle through a low-density electron plasma placed in an external constant magnetic field has been investigated by using transport equations. The motion of the particle in the direction of the applied magnetic field is considered in detail; the particles moving at right angles to the magnetic field are considered briefly. The charge density developed in the medium as a result of interaction of the medium with the moving particle (through the long-range Coulomb force) is evaluated for the wavelength, λ, which is such that $R > \lambda > \lambda_D$, where R is the distance from the moving particle and λ_D is the Debye wavelength. Three types of charge-density waves are associated with the moving test particle. One is a plasma electron wave that exists only for velocities of the test particle that are greater than the average thermal speed of the plasma electron; this wave also shows a Mach cone distribution. The second is an elliptically shaped "extraordinary" electromagnetic wave that exists for all velocities of the test particle, and is coupled to the plasma electron wave. The third is an almost spherical weak wave associated with the ordinary electromagnetic wave. This third wave is not coupled to the other two waves within the range of approximation considered here, and it goes over to an exponentially decreasing charge distribution in the limit of a very small magnetic field. 36 pages; 11 references.

801. ELECTRICAL DISCHARGES IN HYPERSONIC FLOWS
Marlotte, G., Demetriades, A.
***Physics of Fluids*, v. 3, no. 6, pp. 1028–1029, November–December 1960**

Experiments are described which were conducted with low-current discharges in the 5×5 in. test section of a hypersonic tunnel for continuous uniform flows up to $M = 5.8$ and total temperatures of 150°C. The breakdown voltages of air were measured between two copper or tungsten electrodes immersed in the hypersonic stream, with the electric field either parallel or transverse to the stream. The results disagree with the Paschen similarity criterion and indicate that the criterion must be extended to include aerodynamic similarity. An attempt to confine an electrical discharge in the axisymmetric wake behind a body is described, and photographs and voltage–current characteristics indicate that the wake should be a good confinement channel for electrical current flow. (*PA*, 1961, #2958)

802. CONCENTRATION AND FLOW OF PARTICLES IN THE VICINITY OF A CYLINDRICAL BODY IN PLASMA
Moskalenko, A. M.
International Astronautical Federation, Paris, France
Paper presented at the 15th International Astronautical Congress, Warsaw, Poland, September 7–12, 1964 (in Russian)

Using the Boltzmann and Poisson equations, expressions are derived for the concentration and flow of particles in a rarefied plasma situated in a cylindrical potential field. The cases in which the radius of the cylinder is far greater and far smaller than the Debye radius are analyzed in detail. The distribution of the electrical field and electron and ion concentrations at the surface of cylindrical bodies is determined for different potentials of the electrical field. Calculations are made of the electron flow and the ion flow per unit length of cylindrical surface, and probe characteristics are developed. 30 pages; 5 references. (*IAA*, A65-11,552)

803. PARTICLE DISTRIBUTION AND MOTION IN A FIELD OF FORCE
Öpik, E. J.
In "Interactions of Space Vehicles With an Ionized Atmosphere," pp. 3–60
Singer, S. F., Editor
Pergamon Press, Inc., Oxford, England, and New York, N.Y., 1965
(See Entry 17)

The problems of particle density distribution and energy dissipation in a central field and of shielding of Coulomb charges are reviewed for the cases of local thermodynamic equilibrium and of free orbital motion. Formulas are derived for the application to electrostatic fields in plasmas, as well as to gravitational and other unipolar fields. The screening length for finite-size and moving bodies is derived; according to circumstances, it may differ greatly from the "classical" Debye length. The validity of the reciprocity between the Maxwellian velocity distribution and the barometric density formula is examined.

804. SOME POSSIBLE CHEMICAL CONTRIBUTIONS TOWARDS THE FORMATION OF THE ATMOSPHERIC ELECTRIC CHARGE
Papée, H. M., Zawidzki, T. W., Petriconi, G. L., Montefinale, A. C.
Tellus, v. 15, no. 2, pp. 194–201, May 1963

Laboratory experiments show that some solid particles which occur in the atmosphere can act as strong electron emitters when irradiated with visible light, while other substances, because of their chemical composition, can assume substantial negative electric charges. Implications resulting from these effects are discussed. (*PA*, 1963, #25,890)

805. ELECTROSTATIC FIELD ABOUT AN ION MOVING SLOWLY IN A HIGHLY IONIZED GAS
Rand, S.
In "Avionics Research: Satellites and Problems of Long Range Detection and Tracking," pp. 68–74
Glazier, E. V. D., Rechtin, E., Voge, J., Editors
Pergamon Press, Inc., New York, N.Y., 1960 (available as AGARDograph 40)
(Paper presented at the AGARD Avionics Panel Meeting, Copenhagen, Denmark, October 20–25, 1958—Entry 6; see also *Physics of Fluids*, v. 2, no. 6, pp. 649–655, November–December 1959)

A particle treatment is used to determine the potential distribution about an ion moving subsonicly through a plasma. A fore–aft asymmetry is obtained which has the effect of producing a drag on the ion. This asymmetry is the most important difference between the results of this treatment and the results obtained for the subsonic case by the linearized treatment of the electrohydrodynamic equations.

806. DYNAMIC FRICTION AND ION WAVE RADIATION REACTION IN A PLASMA
Rand, S.
Physics of Fluids, v. 6, no. 9, pp. 1268–1279, September 1963

The reaction forces on a small charged body which traverses a low density plasma are studied. The contributions to these forces are discussed with respect to individual particle and collective plasma action, and the relationships between these two contributions are demonstrated. The reaction forces are obtained for a subsonic acceleration body and, in various limiting cases, for a supersonic body undergoing a small degree of acceleration. (*IAA*, 63-23,553)

807. RADIO PROPAGATION BETWEEN A SPACE VEHICLE AND THE EARTH IN THE PRESENCE OF THE IONOSPHERE
Rawer, K.
In "Space Research," pp. 245–271
Kallmann, H. K., Editor
North-Holland Publishing Company, Amsterdam, The Netherlands, and John Wiley & Sons, Inc., Interscience Publishers Division, New York, N.Y., 1960
(Paper presented at the First International Space Science Symposium, Nice, France, January 11–16, 1960)

There is always some appreciable refraction for tangential rays as viewed from a space vehicle in the ionosphere. As seen from the Earth, a fundamental difference exists between frequencies with the limiting angle of elevation caused by refraction and those with the limiting angle of elevation caused by the Earth's shadow. Attenuation by geometrical optics is calculated for the first case. Formulas are given for the radio horizon and for the photometric attenuation. Attenuation by absorption and spread refraction is discussed.

808. THE PRODUCTION AND REMOVAL OF SMALL IONS AND CHARGED NUCLEI OVER THE ATLANTIC OCEAN
Sagalyn, R. C.
In "Recent Advances in Atmospheric Electricity," pp. 21–41
Smith, L. G., Editor
Pergamon Press, Inc., New York, N.Y., 1958
(Paper presented at the Second International Conference on Atmospheric Electricity, Portsmouth, N.H., May 1958)

The spatial distribution and time variations of electrical conductivity and charged nucleus concentration have been investigated in a series of aircraft flights carried out over the Atlantic Ocean, approximately 1000 mi from the east coast of the United States, in the altitude range 500–20,000 ft. Over the ocean, unlike the results obtained over land, no regular daily variation is observed in the vertical distribution of the electrical conductivity or charged nuclei. The results of measurements of the ratio of the negative to positive conductivity obtained on the ocean flights are presented. 19 references.

809. THE STATIC POTENTIAL ATTAINED BY AN INFINITE CYLINDER IMMERSED IN A MOVING AND LOW DENSITY PLASMA OF INFINITE EXTENT
Sengupta, D. L.
Canadian Journal of Physics, v. 41, no. 1, pp. 132–142, January 1963

The static potential acquired by an infinite cylinder immersed in a low density collisionless plasma is discussed in detail. It is assumed that the plasma is uniform at large distances from the cylinder, is of infinite extent, and has a constant drift velocity in one specific direction. Approximate expressions for the distribution functions of the electrons and ions in the presence of the conducting cylinder are derived from the collisionless Boltzmann equation. The expression for the static potential of the cylinder is derived from the condition that the electrical neutrality of the plasma is maintained at large distances from the cylinder. Simplified expressions for the static potential are given for various physical situa-

tions. The case of stationary plasma is obtained as a special case in which drift velocity equals zero. Numerical values are given for some cases. (*IAA*, A63-11,527)

810. SCATTERING BY A PERFECTLY CONDUCTING CYLINDER IN A COMPRESSIBLE PLASMA

Seshadri, S. R., Morris, I. L., Mailloux, R. J.
***Canadian Journal of Physics*, v. 42, no. 3, pp. 465–476, March 1964**

A study was made of the scattering of a plane electromagnetic (EM) or plasma wave by a perfectly conducting and rigid circular cylinder immersed in an isotropic compressible plasma. Expressions for all the physical quantities of interest are obtained in the form of infinite series. For the case of a plane EM wave incidence, numerical results for the current induced on the surface of the cylinder, the total scattering cross sections, and the backscattering cross section are obtained as functions of $k_{e0}a$ for various values of the plasma frequency, where a is the radius of the cylinder and k_{e0} is the wave number of the EM wave in free space. (*IAA*, A64-15,372)

811. RADIATION FROM ELECTROMAGNETIC SOURCES IN A PLASMA

Seshadri, S. R.
***IEEE Transactions on Antennas and Propagation*, v. AP-13, no. 1, pp. 79–88, January 1965**

The radiation from electromagnetic sources in an unbounded, isotropic plasma is treated. Using a two-fluid magnetohydrodynamic approach, the problem is formulated in terms of three orthogonal modes: (1) the electromagnetic mode, (2) the electron plasma mode, and (3) the ion plasma mode. When formulated in this manner, the radiation from simple electromagnetic sources is obtained easily. Three specific sources are treated: (1) a point source of electric current, (2) a uniformly moving charge, and (3) a short filament with prescribed current distribution. For the cases of the electric dipole and the current filament, the total power radiated in each of the three modes is obtained. A point charge moving uniformly with the velocity of sound, for example, is found to excite only the ion plasma mode. The frequency and the angular spectrum of the emitted radiation are obtained. It is found that at frequencies less than a critical frequency (which is approximately equal to $\sqrt{2}$ times the ion plasma frequency) the radiation has the character of a simple sound wave.

812. STRUCTURE OF PLASMA SHEATHS

Sestero, A.
***Physics of Fluids*, v. 7, no. 1, pp. 44–51, January 1964**

A model to provide a microscopic description of plasma sheaths is presented, using the Vlasov equation for ions and electrons coupled with Maxwell's equations for the fields. The sheaths considered connect two different constant states of a plasma in a magnetic field. In the charge–neutral approximation a solution is obtained in closed form in terms of quadrants. The solution depends essentially on three free parameters, related to the differences in density and electric potential between the two end states, and to the value of β, the ratio of the plasma pressure to the magnetic pressure, on one side of the sheath. The scaling law changes considerably from one solution to another. Solutions are obtained which scale according to some representative electron Larmor radius, or ion Larmor radius, or "piecewise" according to both. As a limiting case, when the density is allowed to go to zero on one side of the sheath, the boundary layer between a plasma and a containing vacuum magnetic field can be obtained. As a peculiar feature in this limiting situation, the curve for the electric potential in the asymptotic region where the plasma density becomes vanishingly small appears to be very sensitive to the slightest changes in the distribution functions. 6 references. (*IAA*, A64-14,276)

813. EFFECT OF GAS FLOW ON THE MICROWAVE DIELECTRIC BREAKDOWN OF OXYGEN

Skinner, J. G., Brady, J. J.
***Journal of Applied Physics*, v. 34, no. 4 (Part I), pp. 975–978, April 1963**

An experiment was undertaken to determine the effects of gas flow on the dielectric breakdown of a gas confined in a waveguide, in the attempt to gain information on the dielectric breakdown of air flowing past antennas of high-altitude missiles. "Steady-state" discharges were studied which were produced by microwave pulses of about 1-μsec duration, with gas pressures of about 15 mm Hg, and maximum flow velocities of the order of 10^4 cm/sec. The power necessary to maintain the discharge after it has been initiated increases with flow velocity up to the critical velocity because the electron density at the constriction is reduced by the flow. Beyond the critical velocity the necessary power decreases with the flow velocity. This latter phenomenon is believed to be due to "back flow" of the gas. (*IAA*, A64-10,618)

814. FAILURE MECHANISMS IN DIELECTRICS UNDER SPACE CONDITIONS AND TECHNIQUES FOR THEIR INVESTIGATION IN THE LABORATORY

Skinner, S. M., Lytle, W. J., Merck, J. W.
In "Collected Papers of the Dielectrics in Space Symposium, Westinghouse Research Laboratories, Pittsburgh, Pa., June 25–26, 1963," pp. 9/1–9/23 Westinghouse Electric Corporation, Pittsburgh, Pa., 1963 N63-22,695

Mechanisms which cause failures in dielectrics under space conditions, excluding high-energy radiation in space, are discussed. For the exterior (or the unencapsulated interior) of the spacecraft, the mechanisms include micrometeorite impact, fluctuating temperature, and magnetic fields. For the enclosed capsule, such as the living space for an astronaut, these mechanisms include temperature fluctuations, internal

frictional contact between capsule materials, and the accumulation within the enclosed environment of trace amounts (or more) of gaseous products too expensive to remove by atmospheric treatment. A number of unconventional experimental techniques which are related to electrical phenomena are also described. 18 references.

815. THERMAL ELECTRIFICATION AND IONIZATION OF SOLID PARTICLES
Soo, S. L.
April 1963
Virginia, University of, School of Engineering and Applied Science, Charlottesville
TR-ILL-10-P, Nonr3623(00)

The distribution of an electron cloud around a solid particle charged by thermal electrification is studied. It is shown that most of the electrons emitted by thermionic emission are bounded by the charge of the solid particle. Ionization of this system can be produced by an electromagnetic field or scattering by gas molecules.

816. COMPRESSIBLE PLASMA FLOW OVER A BIASED BODY
Su, C. H.
March 1964
Massachusetts Institute of Technology, Fluid Mechanics Laboratory, Cambridge
Publication 64-3, Nonr-1841(93)
AD-434,731, N64-18,313

The flow field of a compressible plasma over a biased body is discussed, with special emphasis on the electrical characteristics. The governing equations in various asymptotic regions are investigated. A stagnation point probe theory, because of its great practical interest, is given in detail. An analytic current–voltage characteristic is obtained for this case under the assumption of a very thin electrical sheath. 39 pages.

817. THE GENERATION AND EFFECT OF ELECTROSTATIC FIELDS DURING AN AURORAL DISTURBANCE
Swift, D. W.
***Journal of Geophysical Research*, v. 68, no. 8, pp. 2131–2140, April 15, 1963**

The equations of motion of electrons and ions in the presence of electric, magnetic, and neutral particle velocity fields are derived for conditions likely to exist in an auroral arc. The electric field resulting from charge separation is computed. Electron densities, charged-particle motion, and electric currents are also computed. It is shown how these computations can account for magnetic bays, electron drifts, and electric field fluctuation observed during auroral disturbances. Analytical expressions for electric field strengths and neutral plasma drift velocities are derived. 12 references.

818. THE INFLUENCE OF THE EARTH–AIR DISCONTINUITY ON THE ELECTRIC FIELD OF A POLARIZED SPHERE
Tarasov, G. A.
October 29, 1963
Joint Publications Research Service, Washington, D.C.
Soviet Research on the Earth's Magnetic Field, JPRS-21,641 (pp. 37–41)
N64-10,166
(Also available as OTS: 63-41,028, U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This is one of four articles translated from *Uchenye Zapiski Leningradskogo Gosudarstvennogo Ordena Lenina Universiteta imeni A. A. Zhdanova (Scientific Reports of the Leningrad State University named for A. A. Zhdanov), Seriya Fizicheskikh i Geologicheskikh Nauk (Series on Physical and Geological Sciences)*, no. 303, *Voprosy Geofizika (Problems in Geophysics)*, no. 13, pp. 222–225, 1962.

A method is presented for estimating the distorting influence of the Earth–air discontinuity on the electric field of a vertically polarized ideally conducting sphere. 3 references.

819. PRESENT-DAY IDEAS CONCERNING THE MECHANISM OF ELECTRICAL BREAKDOWN IN HIGH VACUUM
Tarasova, L. V.
***Uspekhi Fizicheskikh Nauk*, v. 58, pp. 321–346, February 1956**
(Translation available as TT-F-42, National Aeronautics and Space Administration, Washington, D.C. October 1960, and through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Breakdown potentials and side effects for various conditions are discussed, and theoretical explanations are considered. Cases involving breakdown across the surfaces of dielectrics are also considered. It is found that coating a dielectric with a semiconductor increases its breakdown potential. (*IAA*, 61-2362)

820. IONIZATION BEHIND SHOCK WAVES
Teare, J. D.
In "Ionization in High-Temperature Gases," pp. 217–283
Shuler, K. E., Fenn, J. B., Editors
Academic Press, Inc., New York, N.Y., 1963
(See Entry 14)

Ionization phenomena occurring behind shock waves, such as those present under reentry conditions, have been of considerable interest in recent years. The research accomplished in this field is discussed. The equilibrium ionization behind a shock wave is considered, and electrical conductivity, radiation, and corrective heat transfer are also treated. Equilibrium ionization in argon is discussed in terms of inelastic collisions, energy balance, the initial production of electrons, and recombination processes. Calculations based on a theoretical model for the chemical and ionization processes occurring in air are compared with experimental data, taking into account

ionization by atomic and molecular collisions, electron-impact ionization, photo-ionization, and charge exchange. For shock speeds < 7 km/sec, the dominant mechanism is shown to be the reaction $N + O > NO^+ + e$. Experiments which produced shock velocities of ~400 km/sec in hydrogen are briefly reviewed. 83 references.

821. ELECTROMAGNETIC SHIELDING OF SPACE VEHICLES

Tooper, R. F., Davies, W. O.
Institute of Aerospace Sciences, Inc., New York, N.Y.
Paper 62–156, presented at the IAS National Summer Meeting, Los Angeles, Calif., June 19–22, 1962

A method is evaluated for shielding space vehicles by dipole-like magnetic fields using superconducting coils. The energy distributions of charged particles in space are briefly summarized, and the shielded regions for charges moving in a dipole field are discussed. Protons of energy less than 866 MeV are completely shielded and those of energy less than 8.1 BeV are partially shielded by a dipole moment of 3×10^{11} G-cm^3 over the equator of a sphere 2 m in diameter; shielding is less effective away from the equatorial plane. Particle trajectories are calculated to determine shielding effectiveness in the partially shielded regions, and design parameters are given for two sample niobium-tin solenoids. 15 pages; 32 references. (*IAA*, 62-8329)

822. ELECTROSTATIC SHIELDING FOR SPACE VEHICLES

Vogler, F. H.
Institute of the Aerospace Sciences, Inc., New York, N.Y.
Paper 63-12, presented at the IAS 31st Annual Meeting, New York, N.Y., January 21–23, 1963
(See also *AIAA Journal*, v. 2, pp. 872–878, May 1964)

The capability of an electrostatic field as a shield against charged-particle radiation is analyzed. The radiation source used is the inner Van Allen belt, and the configuration investigated is the field between two concentric, spherical, conducting surfaces. The volume protected is the space enclosed by the inner spherical surface. Shielding is achieved through the deflection of particles away from the inner sphere by the electric field. Induced electric-field loads on the shield system are investigated. Weight of the electrode and the structure required to support the electrostatic loads are computed for a range of shield sizes. It is assumed that the shield electrode can be charged using a belt-type electrostatic generator. The power source weight is estimated by using the power-to-weight ratios of currently available turboelectric generating equipment.

Effectiveness of the electrostatic shield is evaluated in terms of the fraction of the total incident radiation removed as a function of shield weight. The electrostatic shield weight is compared to the weight of a polyethylene shield that removes the same amount of the radiation. A range of electrostatic shield weights from 443 to 1758 kg is investigated. The fraction of the proton flux removed corresponding to these shield weights varies from 0.41 to 0.57, and the fraction by which the radiation dose rate is reduced varies from 0.79 to 0.89. The static polyethylene shield is more effective than the electrostatic shield, when compared on the basis of weight required to remove the same fraction of incident proton flux. The static shield effectiveness varies from 1.4 to 1.5 times the effectiveness of the electrostatic shield. 19 pages; 15 references. (*IAA*, A63-11,363)

823. ELECTRICAL THEORY OF TORNADOES

Vonnegut, B.
***Journal of Geophysical Research*, v. 65, no. 1, pp. 203–212, January 1960**

Modern theory and observations appear to support the very old and almost forgotten idea that tornadoes are a manifestation of thunderstorm electricity. It is suggested that there is sufficient electrical energy in an intense thunderstorm to power a tornado and that the electrification could cause extraordinarily intense winds by electrically heating air or by accelerating charged air in an electric field. (*EI*, 1960)

824. TECHNIQUE FOR INTRODUCING LOW-DENSITY SPACE CHARGE INTO THE ATMOSPHERE

Vonnegut, B., Maynard, K., Sykes, W. G., Moore, C. B.
***Journal of Geophysical Research*, v. 66, no. 3, pp. 823–830, March 1961**

A technique is described for modifying the natural fair-weather electric field over large areas by the introduction of artificially produced space charge. The apparatus consists of a fine horizontal wire supported on insulators and maintained at a high voltage by a DC power supply. For a wire 0.013 cm in diameter, 4.5 km long and 4 m high, maintained at 12 kV of negative polarity, there is a corona current flow of about 1 mA, and the normal fair-weather electric field is reversed for a distance of 10 km or more downwind. The experimental observations are in fair agreement with a simple theory. 5 references.

825. ARTIFICIAL MODIFICATION OF ATMOSPHERIC SPACE CHARGE

Vonnegut, B., Moore, C. B., Stout, G. E., Staggs, D. W., Bullock, J. W., Bradley, W. E.
***Journal of Geophysical Research*, v. 67, no. 3, pp. 1073–1083, March 1962**

An experimental investigation of the behavior of artificially produced space charge is discussed. An electrified-wire space-charge generating system is described, as are experiments in which a charge of positive or negative polarity is released into the atmosphere. Airplane measurements show that the charge mixes rapidly with the lower atmosphere, causing large perturbations in the fair-weather potential gradient and space charge. It is found that, during convective activity, the charge is rapidly carried aloft by thermal updrafts. (*IAA*, 62-4985)

826. ION KINETICS IN THE LOWER IONOSPHERE
Whitten, R. C., Poppoff, I. G.
Journal of the Atmospheric Sciences, v. 21, pp. 117–133, March 1964

The positive and negative ionic processes which contribute to the control of electron density in the lower ionosphere are discussed. Particular attention is given to the recombination of free electrons with positive ions, the recombination of negative ions with positive ions, and to charge transfer and ion–atom interchange. Models of the effective dissociative recombination coefficient are constructed on the basis of laboratory and ionospheric experiments. Rate constants for charge transfer and ion–atom interchange in the region from 70 to 150 km are determined from various measurements in this region, and the results are compared with the corresponding laboratory data. An analysis of processes involving negative ions supports the concept that 0_2^- is not the dominant negative ion. A discussion of the diffusion of electrons to dust shows that this diffusion cannot constitute an important mode of electron removal. 75 references. (*IAA*, A64-17,613)

827. IONOSONDE STUDIES OF SOME CHEMICAL RELEASES IN THE IONOSPHERE
Wright, J. W.
Journal of Research of the National Bureau of Standards, Section D—Radio Science, v. 68D, no. 2, pp. 189–204, February 1964

Ionosonde observations are reported which were obtained during the release of chemicals and high-explosive detonations in the E and F regions of the ionosphere during Project *Firefly* in 1962. The experiments included several designed to reduce ambient electron density locally. The effects are discussed and compared with calculated ambient electron distributions. Chemicals which were released in the E and F regions were SF_6, and CO_2; explosives which were released in the F region were pure explosive HEX, and a cesium-salted high explosive, CsHEX. (*EI*, 1965)

828. MOTION OF THIN BODIES IN A HIGHLY RAREFIED PLASMA
Yoshihara, H.
September 22, 1959
Convair, San Diego, Calif.
Report ZPh-044, AF 19(604)-5554
AD-230,573
(See also *Physics of Fluids*, v. 4, no. 1, pp. 100–104, January 1961)

The motion of a thin body having a velocity in the range between the electron and positive-ion thermal speeds is analyzed. Magnetic effects are considered to be negligible. The self-consistent field approach is used in which the electron distribution is assumed to be Maxwellian, while the positive ion distribution function is given by the collision-free Boltzmann equation. The solution for the simple case of a dielectric body with a given surface charge is given, as well as some general properties to be expected for a conducting body. (*IAA*, 61-1489)

829. RADIATION PROCESSES OF CHARGED PARTICLES MOVING IN THE UPPER ATMOSPHERE, AND COMPOSITION AND PROPERTIES OF THE MAGNETOSPHERE
May 1963
Brooklyn, Polytechnic Institute of, N.Y.
Final Report for May 1, 1962–April 30, 1963,
NASA-CR-56721
N64,27,810
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report summarizes four problems — radiation from a rotating point charge, thermionic screening of hot objects in planetary atmospheres and interplanetary space, photoelectric screening of hot objects in interplanetary space, and modification of the geomagnetic field by the magnetic moment of the Earth's radiation belt. 4 pages.

AUTHOR INDEX