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to the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Grant No. NsG-382

LUNAR AND SOLAR SYSTEM RESEARCH

May 1, 1965 through October 31, 1965

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I. INTRODUCTION

This report covers the research which has been carried on under NASA Grant NsG-382 during the period May 1, 1965 through October 31, 1965.

Lunar surface investigations (Section IIA) were continued on the experiments described in the previous report (CRSR 197, November 1, 1964 - April 30, 1965) and include photometric studies, radiation effects, theoretical studies of the lunar surface, thermal inertia studies, dust transport and electromagnetic properties of soils. Research capabilities, formerly limited by shortage of scientific personnel, have been increased by the addition of Drs. Malcolm Campbell and Juris Ulrichs to the staff of the Lunar Surface Laboratory. Their arrival has permitted a wider variety of investigations to be initiated, especially in the areas of radar-reflective properties of materials and thermal radiation from surfaces.

Solar system research (Section IIB) includes studies on the multiple scattering of electromagnetic waves in a turbulent plasma, cosmic rays, the solar wind, magnetic storms and aurorae, interplanetary dust, the ionosphere, Venus radar echoes, short and long period comets. Dr. L. J. Gleeson joined the solar system staff during the period.

Graduate students working on thesis topics under the grant during the period of this report included H. Y. Chow, D. S. DeYoung, M. L. Dwarkin, A. B. Friedland, M. A. Keppel-Jones, H. M. Newman, T. Kan, R. C. Newman, L. A. Fisk, L. Whitehill, and D. Cunnold.

Kan and Newman had NSF Fellowships, Fisk and Whitehill NASA Traineeships, and Cunnold a Cambridge Fellowship.

Chow received a Master's degree in June 1965. Dwarkin and Friedland are expected to receive Ph.D. degrees in February 1966.

II. SUMMARY OF RESEARCH

A. LUNAR SURFACE STUDIES - B. Hapke, M. Campbell, J. Ulrichs

1. Photometric Studies

Studies of the manner in which surfaces reflect and polarize light as a function of the angles of incidence and reflection and of wavelength are continuing. It has been found that almost all of the known photometric properties of the lunar surface can be reproduced by finely ground rock powder after irradiation by hydrogen ions. Optical measurement described in previous reports and papers have provided strong evidence that the lunar surface is everywhere covered with a layer of fine dust whose size distribution peaks in the range of 1 to 10 microns. Bombardment by 2 Kev hydrogen ions equivalent to about 10^5 years of solar wind irradiation on the moon has been found to be necessary to impart the optical properties characteristic of the lunar surface to the rock dust.

The manner in which chemical composition effects the optical property of irradiated rock powder is presently being studied. Small but real differences in the photometric characteristics exist

between various species of irradiated rock powders, particularly in color. It is hoped that the present studies will allow us to restrict the range of chemical constitution of the rocks which may be thought of as composing the lunar surface. To date, the only rock which matches the moon in all optical properties studied is irradiated dunite. However, it may be that other types of rocks or combination of rocks will be found which duplicate the lunar surface.

It has been demonstrated that the metallic iron present in chondritic meteorites is incompatible with the lunar optical properties. Free iron powder present on the lunar surface in the amounts characteristic of chondrites would cause the moon to have a higher polarization, lower albedo, and less red color than it now possesses. It may be inferred that material of chondritic composition is not present in significant amount on the moon's surface.

It is presently planned to extend the photometric studies to cover a wider range of wavelengths including the near ultraviolet through the visible to the near infra-red. Preliminary measurements of the reflectivity of several irradiated and unirradiated powder samples in the wavelength range of 1 to 3 microns have been made in collaboration with R. Wattson of Princeton University. The near infra-red reflectivity of the irradiated powder samples are similar in important aspects to the lunar spectrum as recently obtained by Stratoscope II. Unirradiated samples did not match the moon. These preliminary measurements were too crude to allow

the rejection of rocks of any particular composition, with the exception of chondritic material. The chondrite powder apparently does not duplicate the lunar surface in the near IR or in the visible.

Gehrels has recently discovered that the brightness of the moon increases by 25 to 30 percent as the phase angle decreases from 5° to 1/2°. Several laboratory surfaces have been measured to see whether they possess such an "opposition effect". It has been found that all materials investigated display this effect to a certain extent but only in the scatter diagrams of very fine rock powders is the effect as strong as the moon's. The laboratory studies of the opposition effect corroborate our earlier findings that the lunar optical properties can be matched in several parameters only by an unconsolidated soil which contains an appreciable number of particles less than 10 μ in size.

2. Effects of Radiation

Hydrogen and helium ion bombardment of rock surfaces to investigate the effects of the solar wind on the lunar surface is continuing. The effects of ion irradiation on the optical properties of fine rock powders have been described in the preceding section.

Investigation of the physical and chemical changes responsible for the darkening by ion irradiation are continuing. It has been hypothesized that the solar wind sputtering induces an oxygen-depleted layer on the particles. Because of a lack of suitable analytical equipment at Cornell University most of the fundamental

investigations of the physical cause of darkening have been temporarily suspended on the Cornell campus. However, arrangements have been made with personnel at the Goddard Space Flight Center, Greenbelt, Maryland and the University of California at San Diego, La Jolla, California to look into certain aspects of this problem. Problems of interest include the determination of the oxygen content of the sputtered layer, and the amount of hydrogen gas injected into the particles by irradiation.

3. Theoretical Studies

The theoretical photometric model of the lunar surface, which previously successfully predicted the lunar photometric function between selenographic longitude of $\pm 60°$, has been modified so that is valid out to the limb. The new model predicts that on a scale which is probably on the order of centimeters the lunar surface is completely covered with crater-like depressions whose sides make steep angles with the local horizontal. The theoretical photometric function is currently being studied to ascertain whether it can be used to describe the light reflecting characteristics of other bodies in the solar system. In particular, airless bodies, such as Mercury and the asteroids, should have photometric properties similar to the moon if the hypothesis is correct that the lunar optical characteristics are due to external agents.

4. Thermal Inertia Studies

Experimental studies are continuing of the manner in which the thermal inertia of a material cooling by radiation into a vacuum is affected by various properties of the material. Properties investigated include: particle size, soil composition, compaction

and surface roughness. The studies are being carried out over a range of temperature of 200°K - 400°K. The results of these experiments are being compared with theoretical studies being carried out by computer. The thermal inertias of fine powders of the size required to give proper optical characteristics are compatible with recent observations of the moon by Low, which indicate that thermal inertias as high as 2000 may be common on the lunar surface. A strong dependence of thermal inertia on temperature has been noted, particularly for very fine particles. This is to be expected if the bulk of the heat is transported by radiation between grains of soil.

5. Dust Transport

Studies are continuing of possible electrodynamic and other processes which might transport dust over the lunar surface. Bombardment of fine insulating powders by charged particle beams has been observed to induce motion of powder grains. However, the electrostatic fields which appear to be necessary to induce such motion are far higher than those which may reasonably be expected to occur on the moon. Thus, it presently appears doubtful that dust transport induced by charged particle bombardment occurs on the lunar surface. However, other transport mechanisms may be important, such as the trajectories of secondary and tertiary ejecta from meteorite impacts being extended by electrostatic effects. This possibility is presently being investigated.

6. Electromagnetic Properties of Soils

Experiments are presently being planned to measure bulk electromagnetic characteristics of materials which might occur on the lunar surface. The dielectric constant and loss angle of a wide variety of material will be measured as a function of such parameters as porosity, composition, and radiation damage, at several wavelengths ranging from about 1 cm to several meters. Standard components and techniques, such as slotted waveguides and resonant cavities will be used for these measurements. This data will be important for the interpretation of radar and radiothermal studies of the moon and other planets.

B. SOLAR SYSTEM STUDIES

1. Theory of Multiple Scattering of Electromagnetic Waves in a Turbulent Plasma - M. Dwarkin, E. E. Salpeter

Multiple scattering of high frequency radiation by a plasma in a state of incompressible, stationary, isotropic turbulence (Kolmogoroff turbulence) is being investigated. Since no analytic method of solving the Boltzmann equation which describes the process is available, a Monte Carlo technique is being employed. To reduce the labor of the Monte Carlo procedure, an approximate analytic form of the angular distribution of radiation emerging from a thin foil of scattering centers has been found. Several slab atmospheres of different thickness will be investigated by using the foil thickness as the unit step length in the Monte Carlo

calculation and the results then compared with the corresponding results for diffusion scattering.

2. Cosmic Rays - W. I. Axford, A. Friedland, R. C. Newman

A paper on the anisotropic diffusion of solar cosmic rays has been accepted for publication in Planetary and Space Sciences, and will appear shortly (see report for November 1, 1964 to April 30, 1965).

Friedland has returned from Goddard Space Flight Center, where he worked under the supervision of E. C. Ray on cosmic ray trajectories in the geomagnetic field. He is at present completing some numerical calculations and having done so will be in a position to write a Ph.D. thesis which is expected to be submitted early in 1966.

Newman and Axford collaborated on a paper on the interaction between galactic cosmic rays and the solar wind which will be published in the Proceedings of the London Cosmic Ray Conference. The investigation concerned the manner in which the solar wind Mach number is decreased by the frictional effect of the cosmic ray pressure gradient. The latter is of course maintained by the solar wind at the expense of its own outward momentum. It has been found that the effect is probably rather small as far as limiting the extent of the solar wind as a supersonic flow is concerned. Furthermore none of the usual mechanisms seem capable of limiting the solar wind to 15 - 20 a.u. as deduced by Patterson and his colleagues on the basis of Lyman-α observations. A possible

alternative mechanism has been suggested, namely charge-exchange with neutral interstellar hydrogen, which can take up the outward momentum of the solar wind and in doing so, permit the interstellar magnetic field to stop the solar wind quite close to the sun where its ram pressure is still high.

3. Solar Wind - W. I. Axford, R. C. Newman, D. DeYoung

An investigation of viscous-transonic aspects of the solar wind flow has just been completed and this will be combined with some remarks concerning the effect of viscosity generally and the formation of shock waves for a paper to be submitted to the Astrophysical Journal. An important boundary condition in the solar wind problem is that the pressure at infinity must be prescribed, and this in turn determines the position of an inwards-facing shock which renders the flow subsonic. When the shock occurs near the critical point where the Mach number is unity, it is very weak, but because it is also thick, the usual Rankine-Hugoniot relations cannot be used. The structure of such weak shocks in the transonic regime and the manner in which they emerge from the critical point has been analyzed successfully using a singular perturbation method similar to that used by Sichel in his study of transonic flows in nozzles.

The next problem to be tackled concerns the formation of forward-reverse shock pairs of following solar flares, as described by Coburn and Sonnet.

4. Magnetic Storms and Aurora - W. I. Axford

Axford will present a review paper on the subject at an ESRO meeting on the magnetosphere. He proposed that the sporadic annihilation of magnetic field lines and associated injection of hot plasma into the inner magnetosphere which apparently occurs during magnetic bays (polar substorms) is due to a gross resistive instability of the whole configuration of plasma and magnetic field which constitutes the tail. Normally this tail is stable and the neutral sheet is thin, but when the equilibrium is disturbed by changes in interplanetary conditions, the instability manifests itself and (if a state of lower energy is available) the excess energy (residing in the form of magnetic energy in the tail) is released. This is observed on the earth as energy dissipated by ionospheric currents and aurora, and also by the formation of a ring current. The process is in many respects similar to a solar flare. A note concerning this topic will be submitted shortly to the Journal of Geophysical Research.

5. Interplanetary Dust - S. J. Peale

Peale's Ph.D. thesis was submitted and found satisfactory in February. During the summer he worked on a paper summarizing his results which has been accepted for publication in the Journal of Geophysical Research. An outline of this work was given in the report for November 1, 1964 to April 30, 1965.

6. Ionosphere - W. I. Axford, D. M. Cunnold, L. Gleeson

A paper on the effects of meteoritic ions on the formation of temperate zone sporadic E layers was presented at the COSPAR meeting held in Mar Del Plata in May 1965. During June, Axford and Cunnold attended the specialist meeting on this subject held at Estes Park, Colorado, and presented a full account of their work. This has been summarized in a recent CSUAC report which will appear shortly in "Radio Science" with the proceedings of the meeting. Whether or not slow recombining ions play a dominant role in the formation of sporadic E layers will be answered in the very near future when results are obtained by a French team which will send a rocket-borne ion mass spectrometer with fixed mass number settings through such a layer.

We have suggested that the magnetic field profile might provide a more sensitive test of the mechanism than the wind profile, since the latter does not provide information about electric polarization fields. Dr. Gleeson is at present carrying out some calculations on the magnetic field variations to be expected; preliminary results show these to be quite substantial (several tens of gammas), so that they could easily be detected with a rocket-borne magnetometer. We intend next to look into the question of the electron temperature in such a layer -- since this is not likely to be equal to the normal E region value. Later the problem of stability will be examined to see whether small scale features can be produced that would cause scattering.

Cunnold successfully submitted a Ph.D. thesis on this topic in June. A paper on the effect of negative ions on the mechanism is in preparation.

7. Venus Radar Echoes - T. Gold, S. Peale, T. Kan

The JPL preliminary radar data of 1964 surrounding inferior conjunction for the planet Venus indicates the existence of two regions, Alpha and Beta, of high reflectivity which appear to be permanent features of the planetary surface. Using the physical location for the "centers of reflection" of Alpha and Beta with respect to a Venus centered coordinate system defined at July 23, it is possible to extrapolate both forward and backwards in time to determine the range location of each region at neighboring dates. Combined with the observed doppler shifts of each region as a function of date, the expected range-doppler coordinates of each region is thus determined. This information was then applied to the AIO Venus radar date by Mr. Kan in an attempt to verify the existence of these features and to study their properties.

A radar determination of the rotation of the planet Mercury obtained by Pettengill and Dyce at AIO has shown that the planet does not rotate synchronously and maintain one face always directed toward the sun as a simple application of tidal theory would suggest. Peale and Gold have pointed out that the fact that the orbit of Mercury is not exactly circular requires that in order for the net torque on the planet due to tidal effects to vanish

when integrated around the orbit there must be a direct sidereal component of the rotation. They have also pointed out that in order to explain the difference between the expected synchronous period of 88 days and the observed 59 day period the tidal effects must be non-linear. A note on this work appeared in Nature in June 1965.

8. Comets - M. Harwit

It has long been suspected that there is a genetic relationship between short and long period comets. This idea has usually been based on the fact that Jupiter is observed to perturb comets to a sufficient extent to make transitions between long and short period orbits possible.

The present work shows that even for comets of very long period, one finds a surplus of orbits whose inclinations are unexpectedly low. This is an indication of an intermediate stage between parabolic and short period comets, and substantiates the idea that a slow transition occurs.

III. PUBLICATIONS, PAPERS AND MEETINGS

W. I. Axford, "Anistropic diffusion of solar cosmic rays," Planetary and Space Science, (in press); also CSUAC 12

W. I. Axford, "The interplanetary magnetic field," New Scientist, July 29, 1965; CSUAC 16

W. I. Axford and D. M. Cunnold, "The wind-shear theory of temperature zone sporadic E layers," Radio Science, (in press); CSUAC 14

W. I. Axford and R. C. Newman, "The interaction between galactic cosmic rays and the solar wind," Proceedings of the I.U.P.A.P. Conference on Cosmic Rays, London, September 1965

S. Peale, "The dust belt of the earth," J. Geophys. Res., (in press); CRSR 202

S. Peale and T. Gold, "The rotation of the planet Mercury," Nature, 206, 1240 (1965); CSUAC 22

M. Harwit, "On the transition between short and long period comets," Proceedings of Liege Symposium (IAU) 1965; CSUAC 18

W. I. Axford and D. M. Cunnold, "The effect of negative ions on the wind shear mechanism for sporadic E layers," in preparation

W. I. Axford and R. C. Newman, "The effect of viscosity on the flow of the solar wind," in preparation

W. I. Axford, "Resistive instability of the tail of the magnetosphere", in preparation

W. I. Axford, D. M. Cunnold and L. Gleeson, "Magnetic field variations in the vicinity of sporadic E layers formed by the wind-shear mechanism," in preparation

B. Hapke, "An improved theoretical lunar photometric function," in preparation

B. Hapke, "Some comments on Gehrels' model of the lunar surface," Icarus, in press

B. Hapke, "Effects on a simulated solar wind on the photometric properties of rocks and powders," Ann. N.Y. Acad. Sci., 123, 711 (1965)

R. Wattson and B. Hapke, "A comparison of the infrared spectra of the Moon and simulated lunar surface materials," Ap. J., April, 1966, in press

B. Hapke, "Properties of surfaces optically similar to the Moon," in preparation

B. Hapke, "Lunar Soil," in Encyclopedia of Earth Sciences, in press

B. Hapke, "Optical Properties of the Moon's Surface," in Proceedings of the Conference on the Nature of the Lunar Surface, in press

S. Peale, "The dust belt of the earth," Ph.D. thesis, February, 1965

D. M. Cunnold, "The windshear theory of temperature zone sporadic E," Ph.D. thesis, June 1965

H.Y.C. Chow, "Effects of several parameters on the optical properties of some rock powders, with applications to the Moon," M.S. thesis, June 1965

MEETINGS ATTENDED AND LECTURES GIVEN

B. Hapke, Lunar and Planetary Conference, California Institute of Technology, September, 1965

B. Hapke, Air University, Wright-Patterson Air Force Base, Dayton, Ohio, July, 1965

B. Hapke, Boeing Scientific Research Laboratories, Seattle, Washington, September 1965

B. Hapke, Cornell University, Department of Astronomy, Oct. 1965

B. Hapke, Cornell University, National Science Foundation-High School Science Teacher lecture, Oct. 1965

D. M. Cunnold, S. Peale, and B. Hapke, American Geophysical Union, Washington, D. C., April 1965

W. I. Axford, COSPAR, Mar del Plata, May 1965

W. I. Axford, and D. M. Cunnold, Sporadic E. Conference, Estes Park, Colorado, June 1965

W. I. Axford and T. Gold, IUPAP Cosmic Ray Conference, London, England, September 1965

M. Harwit, IAU Symposium, Liege, June 1965

W. I. Axford presented colloquia at National Research Council, Ottawa; NASA-ASEA Summer School, Goddard Space Flight Center; University of Texas, Austin; Southwest Graduate Center, Dallas.

IV. PERSONNEL

The following is a list of personnel associated with the grant during the period of this report.

Scientific Staff

T. Gold	Director	Part Time
*E. E. Salpeter	Professor	Part Time
W. Ian Axford	Assoc. Professor	Part Time
*M. Harwit	Assoc. Professor	Part Time
B. Hapke	Sr. Res. Assoc.	Full Time
S. Colbert	Res. Assoc.	Part Time
H. Eckelmann	Res. Assoc.	Full Time
S. Peale	Res. Assoc.	Part Time
J. Ulrichs	Res. Assoc.	Part Time
L. Gleeson	Res. Assoc.	Part Time
M. Campbell	Res. Assoc.	Part Time

Graduate Students

H. Chow	Res. Asst.	Part Time
D. DeYoung	Res. Asst.	Part Time
M. Dwarkin	Res. Asst.	Part Time
A. Friedland	Res. Asst.	Part Time
M. Keppel-Jones	Res. Asst.	Part Time
H. Newman	Res. Asst.	Part Time
*T. Kan	NSF Fellow	Part Time
*R. Newman	NSF Fellow	Part Time
*L. Fisk	NASA Trainee	Part Time
*L. Whitehill	NASA Trainee	Part Time
*D. Cunnold	Cambridge Fellow	Part Time

Support Personnel

E. Armbruster	Elec. Tech.	Full Time
M. Axton	Senior Clerk	Part Time
R. DeBell	Sr. Machinist	Full Time
J. Franklin	Adm. Sec.	Part Time
J. Payne	Exec. Officer	Part Time
R. Pipher	Sr. Elec. Tech.	Full Time
G. Barnes	Res. Aide	Part Time
L. Pollock	Jr. Draftsman	Part Time
M. Seacord	Hd. Acct. Clerk	Part Time
G. Strasser	Lab. Tech.	Full Time
A. Echandi	Typist	Part Time
D. Gezari	Lab. Asst.	Part Time

*No charge to grant

T. Gold

T. Gold, Director, CRSR