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MERCURY ATMOSPHERE AND SURFACE

by

Herbert H. Hoop

January 1967

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Research Branch
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ABSTRACT

This summary and bibliography is a selection of the more accepted literature from the sizable quantity which covers the range of hypotheses as to rotation of the planet Mercury, temperature, atmosphere, surface, and terrain. Various hypotheses and the few generally accepted facts are discussed. Included is a selected bibliography and author index.

FOREWORD

This literature survey and bibliography was made at the request of Mr. Otha H. Vaughan, Jr., Aerospace Environment Division, Aero-Astrodynamics Laboratory, Marshall Space Flight Center, Huntsville, Alabama. Emphasis was placed on literature which postulates the Mercury atmosphere, surface, and terrain.

The primary sources searched are as follows:

1) Redstone Scientific Information Center Document Card File.
2) Defense Documentation Center Abstract Bulletins and Bibliographic Service.
3) National Aeronautics and Space Administration Tape Search Which References International Aerospace Abstracts and Scientific Technical Aerospace Reports.
4) Astronomical and Scientific Publications.
5) Communications with Jet Propulsion Laboratory on Mariner IV.
6) Geophysical Abstracts.
7) Government Wide Index.
8) Late Astronomical Publications.
9) Meterological and Geoastrophysical Abstracts.

CONTENTS

Section I. INTRODUCTION

Exploration of the planet Mercury has not been seriously considered in the U. S. space program, which at present includes manned and unmanned exploration of near Earth space, the Moon, and unmanned trips to Mars and Venus. However, interest in Mercury may increase as more is learned about this planet, the Moon, Mars, and Venus.

The energy or velocity requirements are of the same order as that required for a flight to the moon or the near planets. There is a possibility of a tenuous atmosphere surrounding the planet which could decelerate a landing craft. Another interesting possibility is that the planet holds frozen light elements such as carbon, carbon dioxide, oxygen, hydrogen, and nitrogen around the poles.

The successes of Ranger, Mariner, Surveyor, and Orbiter spacecraft have added fact and confidence which may inspire those wishing to explore all the planets and may result in an early effort to send a fly-by or landing craft to Mercury.

Before reconnaissance and exploration of Mercury, all existing information on the planet must be evaluated to plan the most profitable data gathering spacecraft missions. Much useful information may be gained from ground based observations and from balloon and Earth satellite observatories.

Those interested in designing wheeled land vehicles capable of moving over most of a planet's surface will be interested in reliable information on the conditions of the surface and range of temperature along the surface. The engineer is interested in soil characteristics, size and distribution of obstacles, and the maximum slopes which the vehicle is to pass over.

The several volumes related to the solar system (edited by Kuiper and Middlehurst and written by 59 authors)[1,2,3] is a very complete review of the observations, studies, theories, and data produced by the solar system observers during the past several decades. Each chapter is written by an active astronomer who often had access to unpublished data and material and was capable of evaluating it. In the volume "Planets and Satellites,"[2] Mercury is compared with other planets and satellites. Some of the subjects discussed are as follows:

1) Albedo.
2) Polarization.

3) Daytime observations.
4) Magnitude.
5) Mass.
6) Core.
7) Phase variations.
8) Rotation period.
9) Atmosphere.
10) Surface.

Mercury is covered in more detail by Sandner in his book "The Planet Mercury."[4] He covers history, observations, motion, the question of an atmosphere, temperature, and the surface. Present knowledge of the rotations of the planet may force many of these writers and others to reevaluate Mercury data received prior to 1965. However, a study of these reviews may quickly bring a reader up-to-date and prepare him for speculation upon what the manned or unmanned spacecraft will find when it intercepts the planet.

Mercury is the smallest of the major planets and has a diameter of only about 3,000 miles (4840 km)--1.4 times that of the Moon -- and is planet number one with respect to the Sun, i.e., the innermost planet of the solar system. It is at a mean distance from the Sun of 36 million miles, .387 A.V., Earth's distance. Normally it appears as a small round dot near the Sun after sunset or before sunrise. At times it may be seen crossing the Sun. The eccentricity of its orbit, .206, is greater than any other major planet. Its perihelion and aphelion distances from the Sun are respectively 28,500,000 and 43,350,000 miles, approximately in the ratio of 2 to 3. This eccentricity and Moon-like phases varies the brilliancy of the planet as seen by the earth observer.[5]

Previous to 1965, it was believed by practically all astronomers that Mercury keeps one side toward the Sun, that the rotational period of the planet is the same as the orbital period, "Captured rotation," i.e., it turns once on its axis in the same time that it takes to complete one orbit around the Sun. However, the majority of astronomers now do not accept the captured rotation theory. The orbital period is 88 Earth days in length. The predicted surface environment has been based on this assumption. It has been stated that the greatest extremes in planetary surface temperatures are probably on the light and dark sides of Mercury.

Mercury is the most difficult major planet to observe because of its nearness to the Sun. At its most favorable elongation it recedes only 28 degrees from the Sun.[6] Its greatest distance from the Earth, 136 million miles, is reached when the planet is in its remote superior conjunction. Its closest approach to the Earth, at the most favorable inferior conjunction, is about 50 million miles. Observations which require that the planet be well above the horizon must be made by day against a bright sky. In spite of the difficulty in viewing the planet, it has been studied by astronomers for 500 years or more.[4] Under the best observation conditions, surface markings may be seen on Mercury which resemble those on the Moon as observed with the naked eye.

The apparent angular diameter of Mercury is approximately 13 seconds at its closest approach to the Earth and 4.5 seconds at its greatest distance.[5] The diameter is less than one-half that of the Earth and the mass is approximately one-eighteenth that of the Earth. Its density, according to Kiess, is about four times that of water and .76 times that of the Earth.[6] According to Kuiper, its density is about six times that of water and higher than any other planet.[7]

A precise value of the diameter (and ellipticity) is required to compute the mean density, surface gravity, and atmospheric escape velocity of a planet.[8]

New values for the masses of the inner planets, differing only slightly from the best figures previously available, were calculated by Lincoln Laboratory scientists. This effort resulted in the following reciprocal masses (that is, Sun's mass divided by the planet's mass): Mercury, 6,021,000; Venus, 408,250; Earth and Moon, 328,900; and Mars, 3,111,200. The mass of the Moon was very precisely determined at 1/81.303 that of the Earth.[9]

Section II. ROTATION

Prior to June 1965, Mercury was thought to be in synchronous rotation, i. e., always keeps the same side toward the Sun, to be constrained by powerful sunraised tides, to rotate and revolve in the same period (keeping the same face toward the Sun) and that because of the large eccentricity, the libration in longitude caused only 30 percent of the planetary surface to be in permanent darkness.[10] Shiaparelli first concluded that the period of rotation was equal to the orbital period of 88 days and that Mercury (like the Moon) has synchronous rotation with respect to its parent body. Radiometric measurements were thought to confirm the synchronous rotation, since some observers reported measuring no radiation from the dark side.[6] Most observers of Mercury agreed with these conclusions. Some still seem to believe it correct. Radar observations have resulted in new opinions.

The new determination of Mercury's rotation by Pettengill at Arecibo Ionospheric Observatory, Arecibo, Puerto Rico, is at variance with four generations of optical work and is not confirmed by Jet Propulsion Laboratory workers.[10] During the inferior conjunction of Mercury in April 1965, radar observations were obtained by the Arecibo Ionospheric Observatory (operated by Cornell University). The sensitivity was sufficient to obtain significant echoes not only from the nearest part of the planetary disk but also from more distant regions, removed by up to 0. 06 of the planet's radius. The data were used to compute a most likely value of intrinsic planetary rotation with a procedure developed by Dr. Irwin Shapiro of the Lincoln Laboratory, Massachusetts Institute of Technology. The findings of a value for the rotational period of Mercury which differs from the orbital period was unexpected.[11]

The radar observations indicated a rotational period of 59 ± 5 days, and may imply that Mercury has not much permanent rigidity.[12] The axis of rotation is thought to be nearly perpendicular to the plane of the orbit. McGovern gives a rotational period of 58. 4 ± 0. 4 days as a probable value.[13] The fact that this rotational period is different from the orbital period indicates that Mercury has not been in its present orbit through geological time or that the tidal forces acting to slow the rotation have not been treated correctly. The non-synchronous rotation may be the consequence of tidal friction as shown by Peale and Gold.[13] The final rotational rate will be between the mean orbital angular velocity and orbital angular velocity at perihelion.[13]

Section III. OBSERVATIONS AND DATA COLLECTION

Galileo made the first telescopic observations of Mercury in 1609 with a resolving power of 10 seconds of arc. In 1680, telescopes had reached a resolving power of one second of arc. Measurements of the Nineteenth Century were collected by Kaiser (1872), Ambronn(1891), and See (1901). The first successful radiation measurements were made on the whole lunar image by the Earl of Rosse (1869) with a three-foot reflector.

A critical survey of visual observations made during the past several decades, additional planetary photography, and a review of planetary spectroscopy is offered by Kuiper in "Planets and Satellites."[2] Studies on the polarization of the Moon and planets were begun in 1922.[2] Since 1948 Dollfus has added new information by the use of special equipment attached to a 24-inch refractor of Pic du Midi Observatory. The bolometer was developed in 1889 and used to study lunar radiation from 1885 through 1890.[2] In 1956, a new phase of planetary radio astronomy was introduced by the detection of thermal radiation from Venus, Mars, and Jupiter by Mayer, McCullough, and Sloanaker at the U. S. Naval Research Laboratory.[14]

The surfaces and atmospheres of the terrestrial planets can be inferred in part from their sizes and reflective characteristics - the reflection of infrared, visible, and radio waves.[8] Light striking an object may be reflected, refracted, diffracted, scattered, or absorbed.[15] Polarization is due to the optical properties of a planetary surface and atmosphere. A polarization curve may be obtained for a planet as a whole or for various parts of its disk. In this manner and with the aid of laboratory and field studies of terrestrial phenomena, much detailed information may be obtained. The power of the method is greatly increased by an extension of the observations over a wide range of wavelength bands.[15]

Photometric parameters involve the visual phase curve and albedo, the spectral reflectivity curve and integral (or radiometric) albedo, measuring the fraction of the solar-energy flux reflected back to space.[8] Measurements of the differential polarization effects as a function of phase angle and wavelength of light were made by Dollfus over the surface of Mercury.[15] He used two filters, one in green and one in red, and looked for differences between the center and limbs of the planet. There is a large polarization effect which is produced by the scattering properties of the surface of Mercury. This effect was compared to that of the Moon, and found to be quite similar, with the exception that the polarization does not depend on the inclination of the surface to the sunlight. Since in every other way the polarization for Mercury is very similar to that of the Moon, it is, therefore, suggested that any effect deviating from that may be explained by an atmosphere.[15] There is a differential polarization between the center and the limb of the planet, and the effect is greater for green than for red. There is an indication that there is a differential polarization effect over the surface of Mercury which varies with the phase angle and with the wavelength in such a way as would be expected from Rayleigh scattering in an atmosphere.

Before the landing of Surveyor I on the Moon, all data which could be used to predict the surface properties of the planetary bodies were received on Earth or from craft circling the Earth or Sun.[16] The reflective and radiating properties of planets have been used to predict their surface and atmospheric properties. The best present information on the planet Mercury is almost entirely from ground-based observatories.

Smith and Brison review remote lunar measurements which correspond to those made on the planets.[17] In the visual range, albedo, color, backscatter, and polarization have been used to gain information on atmospheres and surface layers. Infrared has been used to estimate surface material temperatures and thermal properties. In addition to these, radar and radio measurements have been used to indicate various properties of the terrain and subsurface.

Until recently the evidence for a Mercurian atmosphere has been weak and rather inconclusive. Field (1962, 1964) pointed out that the radio measurements at three-centimeter wavelength by Howard, Barrett, and Haddock (1962) indicated that perhaps the dark side is much hotter than had been supposed, and suggested that even the tenuous atmosphere suggested by Dollfus could transport heat from the bright side in sufficient amounts. Further radio measurements by Kellermann (1964) at 11-centimenter wavelength also suggest that the dark side is hot, perhaps as high as 300° K. Field pointed out that radiogenic argon[18] might be available in the required amounts, and would be retained if the exospheric temperature were below 1400° K. The excellent observing conditions at Pic du Midi Observatory have enabled Dollfus to make delicate daytime studies of the polarization of light from different parts of Mercury's disk.[19]

Dollfus (1962) pointed out that the similarity of the photometric properties of Mercury to those of the Moon could be interpreted in terms of cratering by meteors and subsequent covering of the surface by ejected dust. The atmosphere therefore cannot be too dense, or the dust would be blown back into the craters to form a surface quite different from that of the Moon. Hodge (1962)[20] also considered meteoritic erosion to be important, adducing as evidence the infrared observations by Pettit (1961) which point to a rougher surface in the forward direction of planetary motion.

In recent years, the sensitivity of radar telescopes has permitted observations of Mercury and Venus in all parts of their orbits. Dr. Irwin I. Shapiro of Lincoln Laboratory recently reported the first fruits of a major program to study the orbital motions of the four inner planets by radar techniques.[9]

The albedo gives some hint of the surface type and conditions. The geometric albedo is the ratio of the average luminance of the planet at full phase ($i = 0$) to that of a perfectly diffusing surface (Lambert surface) at the same distance from the Sun and normal to the incident radiation.[8]

Spectrographic studies of planetary atmospheres brought the chemistry of the planets within reach. The masses determined dynamically, from planetary and satellite motions, may be combined with accurate measures of diameter, and the resulting densities interpreted with the aid of the physics of compressed matter.[2]

Astronomical observations, at radio wavelengths from 100 meters to 1 millimeter, have given rise to unexpected results. The first radio emission from any planet was detected from Jupiter at 13.5-meter wavelength by Burke and Franklin (1955), and it was obvious immediately from the intensity and time dependence of the emission that the radiation process could not be ascribed to thermal mechanisms.[21] Radio emission has been detected from Mercury, Venus, Mars, Jupiter, Saturn, and (perhaps) Uranus. Radio emission was first detected from Mercury, in 1960, at 3.45-centimeter and 3.75-centimeter wavelengths by Howard, Barrett, and Haddock (1962).[22] A measurement of Mercury emission at 1.53-centimeter wavelength has been reported by Welch and Thornton (1965).[21] The wavelength dependence of the radio power received shows an advantage of short wavelengths when trying to detect thermal radiation.[21]

Barrett discusses radio observations of Mercury and other planets since 1955. He states that measurement of Mercury's radio emission is difficult for two well-known reasons: First, the planet is of small angular size, subtending approximately 11 seconds of arc at mean conjunction, and second, the planet's angular distance from the Sun is never more than 28 degrees. Reception of solar radio emission can exceed the radio emission from Mercury, particularly when the planet is separated from the Sun by a small angle, thereby making detection of Mercury a difficult observational problem.[21] He discusses the measurements made by Petit, 1961; by Howard, et al, 1960 and 1962; Kellermann, 1965; and other data.

In June 1962, the Radiotechnical and Electronics Institute Academy of Sciences USSR, in cooperation with a number of organizations, carried out a radar survey of the planet Mercury.[23] The measurements were made at Mercury's perigee, when it is closest to Earth. The distance to Mercury during the measurements was 83- to 88-million kilometers and was twice that during the radar survey of Venus in 1961. The study was carried out at a frequency of about 700 megacycles. The transmitter antenna had circular polarity. The density of radiated power was 375 megawatts per steradian. Because of the great distance and small size of the object (Mercury's surface area is one-sixth that of Venus), a total of about one watt reached the entire visible surface of the planet. The transmission occurred in sessions of about 10 minutes, during which the signal travelled the distance from the Earth to Mercury and back. The transmitted signal had the form of sequential telegraph transmissions on two frequencies differing by 62. 5 cycles. The duration of transmissions and pauses on each frequency was 1024 milliseconds. The reflected signals were received with a linearly polarized antenna. The receiver input was equipped with a paramagnetic and parametric amplifier. A coefficient of reflection close to that of the lunar surface was obtained.[23]

Section IV. TEMPERATURE

Thermoelectric measurements of radiation from Mercury were made first in 1923 and 1924 at the Mt. Wilson Observatory by Pettit and Nicholson with the 100-inch reflector. According to this result, at the subsolar point at mean distance from the Sun, the temperature is 337° C; at perihelion, 412° C; at aphelion, 282° C.[6] Mercury receives about seven times as much heat per unit area as the Earth at its mean distance from the Sun, but the amount of heat received varies considerably because of the eccentricity of the orbit.[6]

It has been generally assumed that because of a very tenuous atmosphere and its synchronous rotation, Mercury has a hot and a cold side with the hot side above 600° K and the cold or dark side near 0° K. Mercury was thought to be both the hottest and the coldest planet in the solar system. Radio and radar observations in the last two years have indicated that these assumptions are in error.[24] Pettit's infrared radiometric measurements of the subsolar point gave approximately 610° K with expected variations from 560° K at aphelion to 690° K at perihelion.[19] Fields suggests dark side temperatures between 56° K and 250° K which would be in agreement with the 370° ± 125° K observed by Howard at three-centimeter wavelengths.[25] Blackbody disc temperatures ranging from 130° to 320° K with an average value of 220° ± 35° K is reported by Epstein, based on observations made at 3.4 millimeters in April 1965. Welch and Thornton obtained a disc temperature of 465° ± 115° K from the ratio of Mercury emission to Jupiter emission in September 1964 when a series of observations of Jupiter, Saturn, and Mercury were made at 1.53 centimeter.[26] A disk temperature about three times that of Jupiter was obtained. This value is three times 155° K, the assumed temperature of Jupiter. The observed value implies a substantial contribution from the unilluminated hemisphere of Mercury. With the present antenna beam widths, there is not sufficient angular resolution to measure the brightness temperature distribution over the disk. Welch and Thornton, assuming a subsolar temperature of 620° K and a dark side temperature of 0° K, obtained a mean brightness temperature of approximately 100° K. This implies a substantial contribution from the unilluminated hemisphere since the observed value is on the order of 465° K.[25]

Radio observations of Mercury were reviewed and compared with knowledge of the planet acquired by other means by Barrett. He shows that radio observations imply a temperature of ~ 300° K for the unilluminated hemisphere, a result which appears to be in sharp disagreement with infrared measurements of Mercury.[21]

Epstein and other personnel of Aerospace Corporation made observations of Mercury and Mars in 1965, at 3.4 millimeters (88 GHz) with the 15-foot antenna of Aerospace Corporation's Space Radio Systems Facility. Atmospheric attenuation corrections for the Mercury data were made using the "average-temperature" method.[27] The dark side brightness temperature of 220° ± 35° K recorded at 3.4 millimeters (88 GHz) during the April 1965 inferior conjunction of Mercury and the brightness temperatures recorded at longer wavelengths, including the preliminary results at eight millimeters, led the observors to expect a large variation with phase in the three-millimeter emission of Mercury. This expectation was based on the assumption that Mercury's surface layers behave as do those of the Moon. If the Moon was moved to Mercury's distance from the Sun, its three-millimeter emission would show a phase variation of approximately ± 200° K about a mean temperature of ≈ 350° K.[28]

The observations produced some very unexpected results. The most significant features are the brightness temperature of only ≈ 200° K recorded when major fractions of the illuminated hemisphere were visible and the apparent absence of any variation with phase. Both features were completely unexpected. Brightness temperatures of approximately ≈ 500° K were recorded with the planet near inferior conjunction.[28] It is possible to explain the anomalous results by suggesting that the emissivity of the surface layers of Mercury varies inversely with physical temperature. There is no known material which exhibits low emissivity at three millimeters only.[28] It has been suggested that the dark side temperature could be produced by internal radioactive heat sources. This was suggested before radar observations indicated a nonsynchronous rotation.

Section V. ATMOSPHERE

Until quite recentlv Mercury was thought by most astronomers to have no atmosphere.[29] Astronomers did not see any noticeable refraction of the Sun's rays at the edge of the planet as it traversed the Sun's disk, nor could they watch the twilight on Mercury. Calculations seemed to indicate that, if any atmosphere existed on Mercury, it would quickly disperse into space.[19] The reason it was thought that the atmosphere would be tenuous, if it existed at all, was the fact that the escape velocity is small and the surface temperature is very high.[30] It should be capable of retaining a tenuous atmosphere if the maximum temperature is appreciably lower than the predicted value. Urey, in his book on the origin and development of the planets, published in 1952, ascribed half a sentence on the discussion of the atmosphere of Mercury. He said "No atmospheres have been detected on the Moon and Mercury."[31] For reasons of its small mass and proximity to the Sun, Mercury is listed as the most unlikely planet to possess an atmosphere. Any atmosphere that could be retained by the low gravity would be very difficult to detect from 50 to 100 million miles. It has been generally believed that because of the low escape velocity of Mercury (4.3 kilometers/second or 2.6 miles/second) that no atmosphere would exist. The escape velocity of such a body (with a radius 30 percent greater than that of the Moon, but with 4.2 times more mass) is small and the predicted high surface temperature (600° to 700° K) approaches the critical value for the exospheric escape of light gases.

Most attempts to find evidence of an atmosphere on Mercury have failed. Observations of Mercury, as it passed in front of the solar corona, showed no phenomena at the edge of the planet which could be attributed to an atmosphere.[6] Spectrograms showed no trace of absorption lines which could indicate carbon dioxide, oxygen, or water vapor.[6] A low albedo indicates that the light is reflected from a solid surface. This low albedo or small degree of light reflected from the surface of Mercury is comparable to that of the Moon, and it is conclusive evidence that any possible atmosphere would have to be very thin. Light white traces sometimes veil the dark areas and may indicate a volcanic dust cloud supported by a tenuous atmosphere. Local heating of the planet's crust by radioactive material could cause this veiling. Such gases would rapidly escape into space but would still create a somewhat temporary atmosphere. Observations of polarization of reflected sunlight indicate a tenuous atmosphere.[32]

Fields describes the evidence which indicates an atmosphere on Mercury and attempts to interpret it.[6]. Measurements by Dollfus over the surface of Mercury revealed differential polarization effects. Unlike observations of the Moon, the polarization depended on the inclination of the surface to sunlight -- an effect which is explainable by the presence of an atmosphere. Measurements of brightness temperature were made by a group at the University of Michigan (Howard, et al, 1962) in the three-centimeter wavelength at different phase angles.[30] It was assumed that the temperature on the dark side of Mercury is extremely low, yet the measurements lay above the theoretical curve assuming a dark-side temperature of 0° K. One possible interpretation of this result is that the dark side is not entirely cold, but has a temperature which is significantly different from zero -- perhaps as much as half that on the bright side -- that there is some mechanism for heat transport from the bright to the dark side.[30, 23]

When Venus crosses the Sun, the disk is blurred but Mercury's outline is sharp and clear. However, a very thin atmosphere might not blur the disc.[33]

Since the light gases would escape at 600° to 700° K, and it is believed that the exosphere temperature for Mercury is not much less than that, it is not likely that a Mercury atmosphere would contain any of the common atoms, such as carbon, nitrogen, oxygen, or their molecules.[30]

Photographs of Mercury's spectrum have never shown any detectable difference from the solar spectrum, that is, no bands or lines due to absorption by atmospheric atoms or molecules have been found.[30] But if there are traces of an atmosphere present, Kuiper has suggested that it could consist of the heavy element argon and possibly krypton and xenon. He believes any other elements could be expected to have either escaped into space a long time ago, or they would have been frozen out on the cold side of the planet. Radiometric measurements have given average surface temperature values of about 600° K for the subsolar point.

In postulating an atmosphere for Mercury, look for gases that are considerably more massive than carbon, nitrogen, oxygen, etc., the possibility of an atmosphere of argon[18] (which is radiogenic), also including the more massive noble gases xenon and krypton.[30]

Kuiper suggests that radiogenic argon may be retained by Mercury. The critical temperature for escape in 4. 5 billion years is 1800° K.[30]

Atmospheric polarization observed by Dollfus may be ascribed to this gas since the more abundant lighter gases have probably escaped. His results show small differences in the amount of polarization in the light from the cusps and from the center of the planet. Analysis of these data leads to the conclusion that this difference arises from the presence of a very thin atmosphere. A surface pressure of one to three millimeters is implied by Dollfus' measurement, corresponding to Earth altitudes of 130, 000 to 150, 000 feet.

Dollfus calculates that if such gas on Mercury has the optical properties of our air, it would be equivalent in amount of 0. 003 of the Earth's atmosphere. It is also interesting that Dollfus occasionally observed local deficiencies in polarization, which might be due to dust in the planet's atmosphere.[19]

Nikolai Kozyrev of Pulkovo Observatory, who is credited with the discovery of lunar volcanos, traced a hydrogen atmosphere on Mercury in April-May 1963. Using a spectrograph, he determined that the density of this atmosphere is about one-thousandth of the Earth's.[29]

Occasional veiling of dark surface features by faint, whitish clouds has been reported. As Whipple has pointed out, this is really negative observational evidence and a failure to see already rather indistinct dark markings. But the veiling could be caused by dust, and motions of dust would indicate an atmosphere.

A tenuous atmosphere was discovered by Dr. Audouin Dollfus at the Pic du Midi Observatory. He used a 24-inch refractor, and the method used was an indirect one based on polarimetric observations.[33] The composition is not likely to be at all similar to our own -- it is much more likely to be carbon dioxide, or something of the kind -- and the estimated pressure is bound to be arbitrary; but Dollfus' investigations do at least show that Mercury is not the utterly airless world so often described in textbooks.[33] Dollfus and his collaborators do not support Antoniadi and Schiaparelli with regard to the question of clouds.[33]

Kozyrev's observations in 1950 indicated a hydrogen atmosphere. A hydrogen atmosphere would be heated only by contact with the daylight surface and cooled by contact with the night surface. This would result in atmospheric circulation transferring energy to Mercury's cold side. Under thermal equilibrium,the atmosphere's temperature must be near the average of 600° and 0° K, that is, about 300° K or 86° F. According to Kozyrev, this low temperature is confirmed by spectrographic observation of the planet's vicinity. He states that the height of a homogeneous atmosphere is proportional to the temperature, but inversely proportional to the molecular weight and to the acceleration of gravity and, hence, Mercury's homogeneous atmosphere must be about 40 times as high as that of the Earth, if the temperatures are equal, that the atmosphere of Mercury must amount to not less than 0.0001 of the Earth's.[19]

This supports the Dollfus estimate of Mercury's atmosphere. If it consists of hydrogen only, instead of air like ours, the number of molecules must be about four times as great to produce the observed polarization effect. Consequently, Dollfus' data indicate that Mercury's atmosphere, if of hydrogen, would be about 0.01 of the Earth's.[19]

From a theoretical viewpoint, an atmosphere of this planet might seem hardly possible, particularly of such a light gas as hydrogen. However, the existence of a stable atmosphere, especially of hydrogen, could have been foreseen. Because a hydrogen atmosphere is cold, its dissipation proceeds comparatively slowly, and the loss of hydrogen can be compensated by the interception of solar protons.

The escape of particles takes place from the exosphere, the fringe layer where the molecular mean free path is of the order of the height of the homogeneous atmosphere. To make up losses, a long-term average influx of 100 particles per cubic centimeter is provided by the solar wind. Without this compensation, Mercury's atmosphere would dissipate in the relatively short interval of 100,000 years.[19]

These calculations make the assumption that the influx of solar corpuscles does not cause an appreciable ejection of molecules from the planet's atmosphere. To ensure this, the atmosphere has to be dense enough to prevent corpuscles from reaching the surface; instead they impart their energy to a large number of particles in the atmosphere. Thus a planet initially devoid of an atmosphere cannot accumulate one by an inflow from outside. Most probably, the present envelope of Mercury is the remainder of an extensive primitive atmosphere.[19]

Conceivably gases other than hydrogen occur in Mercury's atmosphere, for example, by escape from the interior of the planet, but they can form only a small fraction, for otherwise the atmosphere could not be cold and would have lost the properties ensuring its stability.

Mercury's nearness to the Sun can make up for the atmospheric loss to space as the Sun shoots fluxes of protons, which are hydrogen nuclei, towards Mercury at a velocity of 1000 kilometers per second. To make up for the losses in the Mercurial atmosphere, it is quite sufficient if the density of the proton fluxes is 10^2 to 10^3 per cubic centimeter. The probable actual density of the proton fluxes at Mercury's distance from the Sun is very close to this figure.[18] Allowing for rough approximation in the dispersion of the Mercurial atmosphere, it is quite possible for the planet to have a hydrogen atmosphere maintained by fluxes of solar protons. As, for the most part, the particles ejected by the Sun are protons, the Mercurial atmosphere, whatever it could have been sometime in the past, has long been replaced by the hydrogen supplied by the Sun.[19]

The value of 10^{16} particles per cubic centimeter Kozyrev obtained for the Mercurial atmosphere corresponds to an altitude of 50 to 60 kilometers on the Earth. Meteors ignite exactly at this altitude. Therefore, one may suppose that the Mercurial atmosphere has sufficient density for the elevated temperatures and high pressures developed by impinging meteors to fix atmospheric hydrogen into a mineral fallout, a rain of dust settling on the surface of Mercury.

The planet Mercury was 20 degrees of arc to the east of the Sun on 26 April 1963. Therefore, it could be watched without interference for a long time -- for about 30 minutes -- after sunset. Kozyrev describes this observation: "During the ten evening sessions that I had at the 50-inch reflector telescope at the Crimean Astrophysical Observatory between 19 April and 3 May, I took about 20 spectrograms of Mercury and its vicinity. For comparison, I made a point of taking photographs of the Sun's spectrum in exactly the same position Mercury would assume in about two hours. During these observations Mercury was 13 degrees above the horizon. Most of the spectrograms were obtained by means of a highspeed spectrograph with an exposure time of 2 to 10 minutes. During each exposure, the spectrum was extended by moving the planet's disk across the slit of the spectrograph."

"A thorough comparison of the Mercurial and solar spectrograms of absolutely the same optical density revealed an unambiguous difference in the hydrogen lines of both spectra. While the other lines coincided, one of the hydrogen lines in the Mercurial spectrogram seemed narrower and was shifted towards the red region of the spectrum, while another looked broader and was shifted towards the violet region of the spectrum. Microphotometric measurements showed that these peculiarities in the hydrogen lines were due to the superimposition of the bright hydrogen lines in the Mercurial spectrum over the solar spectrum. The Sun's ultraviolet radiation, which ionises hydrogen, is not sufficient to produce lines of such brightness. This implies that the hydrogen on Mercury is present as a genuine dense atmosphere rather than as an ionosphere. It can be calculated that the number of hydrogen atoms in the Mercurial atmosphere is 10^{34} per square centimeter of its surface area. The number of hydrogen molecules must be greater -- of the order of one-thousandth of their number in the terrestrial atmosphere, which works out to 3×10^{23} molecules per square centimeter of surface area." [19]

According to Spinrad, the spectroscopic, polarimetric, and radio observations point to the conclusion that Mercury has a tenuous atmosphere, although its amount is still uncertain.[35] He states that more observational work is needed before this conclusion can be considered final, and that refinement of the polarization measurements would be helpful. The indication in the radio observations that the dark side is not cold should be checked by infrared techniques to be sure that the radio waves originate at the surface. Further high resolution spectroscopy to find other possible volcanic gases should be attempted.[36]

Because of the low gravity of Mercury, the atmospheric density would change more gradually with altitude than for the Earth. There should be a cross-over point at some distance from the planet where the density would be higher than for a corresponding distance from the Earth.[37]

Section VI. SURFACE

Because of its small apparent size and the unfavorable conditions for its observation, it is very difficult to observe any distinct markings on the surface of Mercury. Some observors have detected dusky spots and hazy dark markings.[6] Antoniadi drew a chart which was somewhat similar to earlier observations. Antoniadi constructed his Mercury map from his extensive visual observations with the 33-inch refractor of Meudon Observatory a generation ago.[19] The names he assigned to its surface markings remain in general use. Because Mercury's axial rotation is uniform and its orbital revolution is not, the subsolar point of the planet is not fixed, but oscillates. Photographs have been made by Slipher and Carmichel which show faint detail. The agreement between drawings and photographs produced by different observors indicate there are real irregularities on the surface.[6] By comparing the reflective properties of the planet with that of known Earth materials, the Moon and Mars, some knowledge of the surface materials may be gained. Cruikshank notes the similarities between the Moon and Mercury and states that the probable luminescence phenomena on the Moon may make it possible to interpret changes on Mercury as the effects of luminescence of the surface materials.[38] The albedo and polarization effects of both bodies are similar. It has been generally assumed that Mercury has a very tenuous atmosphere -- possibly no atmosphere -- and that the temperature of the dark portions of the planet is near 0° K. The Moon does have a back side with respect to the Earth but no dark side.

Measurements of the brightness of Mercury yield an albedo of .06, while that of the Moon is .07[6] and that of Mars is .25[39] which indicate that the surface materials of Mercury is more like the Moon than that of Mars or most of the Earth's surface. Both the Moon and Mercury are poor reflectors of light. This indicates an irregular surface of basalt and dark lava rock.[6]

The polarization of the reflected light from Mercury and the Moon are very similar, as observed by Dollfus.[6] Near opposition, the polarization of the two bodies is in perfect agreement.[2] The variation of brightness with phase is almost the same.[19]

Surveyor photographs show the lunar surface to be rough and strewed with rocks of all sizes and sinkage of the vehicle into the surface of the moon showed the surface to be soft, to have lower compressive strength than earth soils, to be cohesive, and with sufficient strength to support manned landings and exploration. The Mercury surface characteristics may be very similar, but the very thin atmosphere of Mercury may have some slight smoothing effect on the surface.[35,36]

Sharonov discusses the possibilities of powdery materials on the surface of the planets. He assumes that the surface of Mercury should resemble that of the Moon -- a slag-like material produced by the impact of meteors.[40]

The appearance of dust clouds in the atmosphere and the characteristics of the reflected light are offered as evidence of a dust covered surface. A dust cover may be the result of an atmosphere which protects the surface from meteor impacts and the absence of cementation agents.[40]

Sharonov states that the surface of Mercury should resemble that of the Moon and, therefore, there is no reason to suppose that there are dust covers on it.[40] There are some differences in the surface environments of the two bodies which may have some bearing on the surface material. These are as follows:

1) The great difference in radiant energy striking the two bodies.
2) The difference in the surface temperature extremes and cycle.
3) The differences in the density of the two bodies.
4) The difference in the gravitational constant.

Mercury's radius is about 30 percent greater than that of the Moon (although Mercury has about 4.2 times more mass).

Carpenter and Goldstein, 1963, and Kotelnikov, et al, 1962, have shown that the radar reflection properties are similar to those of the Moon. In his paper, "Spectroscopic Observations of Mercury," Spinrad states "Unless these similarities are accidental (which seems unlikely), and if the erosion of the Moon is in reality caused by meteoritic bombardment, it appears that the pressure estimates of this paper are in conflict with the observations of the properties of the surface. One way to remove the conflict is to suppose that the atmospheric pressure has at times been at levels low enough to permit penetration by meteorites. For example, if the dominant constituent is radiogenic argon, it would have required about 10^8 years after the formation of the planet to build up 0.1 millibar pressure, and the similarity to the Moon could then be attributed to a particularly high rate of bombardment early in the history of the Solar System. On the other hand, an atmosphere which results from a balance between a high rate of influx from volcanos and a high rate of exospheric escape might undergo considerable fluctuations in surface pressure as a result of changes in volcanic activity. This possibility would imply that Mercury has a part-time atmosphere with periods of low pressure when meteorites can penetrate effectively."

A large portion of the Mercury surface, like the Moon, is expected to be very rough or mountainous. Present methods of observing Mercury would not detect mountains or huge craters such as are found on the Moon. It is probable that craters exist. Radar echo observations of Mercury at 23-centimeter wavelengths at Millstone Hill radar observatory indicate that Mercury is rougher than the Moon.[33]

A number of lengthy reports and bibliographies have been written on the surface materials of the Moon.[16] Also, several writers have written reports analyzing mobility problems which could apply to the lunar surface. A vehicle designed for a rough lunar surface and the high and low temperature extremes may very well fulfill the requirement for a Mercury vehicle.

The reflective properties of sands and clays have been studied to understand and compare with the reflections received from the moon and planetary surfaces.[2] Kuiper states that the difference in the curves produced from these data and from observations of the Moon, Mercury, and Mars is evidence of the absence of quartz in powdered form in the surface layers of these bodies.[2] The high density of Mercury implies a high percentage of iron, higher than the Earth.[7]

Section VII. CONCLUSIONS

From our present knowledge of the Moon, we can assume that the surface of Mercury has also been formed by endless pounding of meteorites and by volcanic activity. The effect of the tenuous atmosphere may have resulted in a surface slightly different from the Moon. The size of meteorites reaching the surface at high velocity would be limited by the atmosphere. The surface could be covered with condensed meteorite vapor and dust, condensed surface vapor produced by the impacts, ejected broken and melted crater materials, shock or volcanic-cemented breccia, and lava rock. A very rough surface may be expected. The higher density of Mercury would be expected to have resulted in different surface materials and formation of the surface. The volcanic activity may not be similar.

Mercury probably has a magnetic field which may affect the direction of small high velocity particles. The atmosphere may produce some slight smoothing effect.

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The surface slopes of Venus appear to be less steep than in the case of the Moon, while for Mars they are smoother yet. In the case of Venus, rotation has very reliably been established to be 247 ± 5 days retrograde sidereal with an axis oriented very nearly perpendicular to the orbital plane of the planet.

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This paper is a discussion of the evidence for the composition of the hazes of each of the inner planets. The Earth possesses a wide variety of chemically different atmospheric particulate materials: water and ice, biogenic hydrocarbons, free metals, nitrogen dioxide, and the products of silicate weathering. On the whole, the hazes of Mercury are likely to be fluorescent-free radicals or volcanic sulphur. For Venus, however, it is possible to construct only a hypothetical model system because of the uncertain chemical composition of the two hazes present in the atmosphere. The hazes of the Mars atmosphere are of three types, one due to dust storms, another to ice crystals, while the third one (the so-called "blue haze" or "violet layer") has an undefined chemical composition.

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THERMAL HISTORY OF THE MOON AND OF THE TERRESTRIAL PLANETS: NUMERICAL RESULTS by Z. Kopal, 9 December 1962, Report No. 32-225, MSD Document No. 79988, (Unclassified).

The equations governing the distribution of the internal temperature and thermal dilation deduced in the first report of this series, have been integrated for the cases of the Moon, Mercury, and Mars, on the assumptions that their sources of radiogenic heat (due to spontaneous disintegration of K^{40}, TH^{232}, U^{235}, and U^{238}) are distributed uniformly throughout their mass in the same concentration as exhibited by the chondritic meteorites, and that conduction represents the principal mechanism of heat flow. The major part of this report consists of the numerical tabulations of the respective particular solutions for the temperature and thermal dilation during a time span of seven billion years constructed for four different values of the coefficient of thermal diffusivity, and the variation of these functions.

27. Camichel, H., Hugon, M. and Rösch, J.,
MEASUREMENT OF THE DIAMETER OF MERCURY BY HERTZPRUNG'S METHOD ON NOVEMBER 7, 1960 (MESURE DU DIAMETRE DE MERCURE PAR LA METHODE DE HERTZSPRUNG LE 7 NOVEMBRE 1960), Icarus, Vol. 3, December 1964, pp. 410-422, A65-17763, (In French).

This paper is a description of observations of the transit of Mercury on 7 November 1960, including an account of the use of Hertzprung's photometric method and the manner in which the acquired data were reduced. A general interpretation is given of the discrepancy between double-image micrometer measurements and photometric measurements of small disks. Laboratory experiments have been conducted, affording a complete agreement with this explanation. The effect of the limited diameter of the hole used is also discussed and a correction computed. The values proposed are 6.84 ± 0.03 inches for the angular diameter at unit distance (corresponding to 4960 ± 20 kilometers), and 5.09 ±0.07 gm/cm^3 for the density.

28. Carpenter, R. L. and Goldstein, R. M.,
RADAR OBSERVATIONS OF MERCURY, Science, Vol. 142, 18 October 1963, p. 381, A63-25078, Contract No. NAS 7-100.

This paper is a review of radar observations of Mercury during its conjunction in May 1963. The planet was illuminated with 100 kilowatts at a wavelength of 12.5 centimeters. Three types of signal processing were used: (1) the receiver was used in the configuration of a Dicke radiometer, and the total power of the echo was measured; (2) the power of the echo was analyzed into its frequency components by means of an autocorrelation function approach; and (3) a spectrometer was used to analyze the signal selected by a range-rate gate. The data obtained provide a confirmation of the astronomical unit reported by Muhleman, based on radar observations of Venus during the conjunctions of 1961 and 1962.

29. Chebotarev, G. A.,
A NEW DETERMINATION OF THE MASS OF MERCURY, Problem of Cosmogony, Vol. 1, 25 May 1964, pp. 228-235, N64-21135, (N64-21126 14-05).

The corrected value for the mass of Mercury, according to E. Rabe who used the motion of the minor planet Eros in his determination, is $1:m_1 = 6,120,000 \pm 43,000$. However, only the first significant figure was reliably determined. Therefore, the problem of further determinations of the mass of Mercury, as before, remains an acute question of theoretical astronomy. Also, various methods for determining planetary mass are discussed.

30. Cole, D. M.,
MERCURY, "DEEP FREEZE" OF THE SOLAR SYSTEM, Saturday Review, 1 February 1964, pp. 54-55.

Not abstracted.

31. Cole, D. M.,
MERCURY MISSIONS SEEN MORE USEFUL THAN MARS VENUS PROBES, Missiles and Rockets, Vol. 12, No. 34, 24 June 1963, pp. 37-38.

It is shown that the problem of Mercury flights, in terms of velocity requirements, are of the same order as those involved in flights to the Moon, Mars, and Venus. The major aspects of exploration of Mercury include the possibility of finding large quantities of frozen light elements, particularly carbon, oxygen, hydrogen, and nitrogen, on dark side and possible value of tenous atmosphere in decelerating space-craft prior to landing. The table includes total velocity change requirements for various astronautical objectives in inner solar system. Four missions are considered for manned and unmanned vehicles.

32. Colombo, G., ROTATIONAL PERIOD OF THE PLANET MERCURY, Nature, Vol. 208, 6 November 1965, p. 575, A66-13265.

This paper is a comment on Peale and Gold's recent explanation of Mercury's 59 ± 5-day rotational period, determined from radar Doppler-spread measurements. The axial asymmetry of Mercury's inertia ellipsoid may result in a torque that counterbalances the tidal torque, giving a stable motion with this orientation and with a period two-thirds of the orbital period, or about 58.65 days. It would therefore be possible for Mercury to have a permanent rigidity higher than that permitted by Peale and Gold's model.

33. Cornell University, Ithaca, New York, RANGE, DECLINATION, AND DOPPLER-SHIFT CALCULATIONS FOR AN INTERPLANETARY RADAR by L. M. LaLonde, TN-60-1161, AD-250 477, Contract No. AF 19 (604)-6158 (Unclassified).

Efforts will be made to receive a radar echo from planets using the facilities of the Arecibo Radio Observatory. Calculations show that Venus, Mars, Mercury, and Jupiter are likely radar targets for this facility. The planets have a predetermined motion with respect to the radar on the Earth's surface, and to tune a narrow-band receiver to the frequency of the reflected echo, Doppler shifts must be predicted. An approximate equation for the relative velocity of a planet is given. Plots of relative velocity and Doppler shift are given as well as plots of range and declination for the likely targets (planets) for the years 1960 through 1967.

34. Cragg, T., and Heath, M. B. B., and Haas, W. H., MERCURY, Strolling Astronomer, Vol. 4, No. 1, 1950.

Not abstracted.

35. Cragg, T. and O'Toole, D. O.,
MERCURY, Strolling Astronomer, Vol. 5, No. 3, 1951.

Not abstracted.

36. Cruikshank, D. P.,
MERCURY'S LIBRATION IN LONGITUDE, Strolling Astronomer, Vol. 17, March-April 1963, pp. 72-73.

The libration in longitude of Mercury is expressed graphically as a function of days past perihelion.

37. Cruikshank, D. P.,
OBSERVATIONS OF VENUS AND MERCURY WITH LARGE APERTURES, Strolling Astronomer, Vol. 13, 1959, pp. 108-115.

Not abstracted.

38. Cruikshank, D. P.,
POSSIBLE LUMINESCENCE EFFECTS ON MERCURY, Nature, Vol. 209, 12 February 1966, p. 701, A66-23558.

Study of a series of visual observations of Mercury confirming that variations in the intensity of certain of its markings can occur in a matter of hours. Four drawings based on the observations are presented that cover a nine-day period, in which progressive darkening of the southern cusp is apparent. It is suggested that because of many similarities between Mercury and the Moon, the changes in surface contrast on Mercury may be due to luminescence effects of the surface materials, as is probable for the Moon. Observations cover the period 1958 through 1964, using a variety of telescopes up to 82 inches in aperture.

39. Cruikshank, D. P.,
SOME OBSERVATIONS OF MERCURY IN JUNE 1960 AND SOME COMMENTS ON A COMPOSITE DRAWING TECHNIQUE, Strolling Astronomer, Vol. 15, 1961, p. 469.

Not abstracted.

40. Danjon, A.,
PHOTOMETRIE ET COLORIMETRIE DES PLANETES MERCURE ET VENUS, Bulletin Astronomique, Vol. 14, 1949, p. 315.

Not abstracted.

41. Danjon, A.,
MAGNITUDE ET ALBEDO VISUELS DE LA PLANETE MERCURE (RECTIFICATIF), Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences, Vol. 238, 1954, pp. 1371-1372.

Not abstracted.

42. de Vaucouleurs, G.,
GEOMETRIC AND PHOTOMETRIC PARAMETERS OF THE TERRESTRIAL PLANETS, Icarus, Vol. 3, September 1964, pp. 187-235, A64-27096, Contract No. NASr-21(04).

Critical examination of the diameters, ellipticities, and spectral albedos of Mercury, Venus, and Mars, derived by various observers in the course of the past 100 years. The systematic and accidental errors in the various methods are discussed, and the results are weighted accordingly to produce best estimates of the diameters, ellipticities, and albedos for the three planets.

43. de Vaucouleurs, G.,
RECONNAISSANCE OF THE NEARER PLANETS --- A SURVEY OF PLANETARY PROBLEMS IN THE SPACE AGE, USAF OSR DRA-61-1, November 1961, AD 276833, MSD Document No. 92513.

This report is divided into two parts. The first part is a summary of the best present information on the planets Mercury, Venus, and Mars, gained almost entirely from ground-based observatories. The second part outlines how these methods could be extended to observations from balloon observatories, and especially from space probes and orbiters in the immediate vicinity of the planets.

44. Dollfus, A.,
OBSERVATION OF AN ATMOSPHERE AROUND THE PLANET MERCURY, Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences, Vol. 231, 1950, p. 1430.

Not abstracted.

45. Dyce, R. B. and Pettengill, G. H.,
RADAR OBSERVATION OF THE MOON AND THE FOUR NEAREST PLANETS USING THE ARECIBO ANTENNA, Institute of Electrical and Electronics Engineers, Boston Section, 1965, p. 182, A66-25535, (Nerem Record 1965; Northeast Electronics Research and Engineering Meeting, Boston, Massachusetts, 3-5 November 1965, Papers, Vol. 7, (A66-25501 13-09).

This paper is the results of an investigation of the Moon, Mercury, Venus, Mars, and Jupiter by pulse radar at 430.0 milliseconds between 1963 and 1965 at the Arecibo Ionospheric Observatory. A principal objective of the planetary observation was to determine values of round-trip-delay to a few parts in 10^8 and values of bulk Doppler shift approaching 0.1 cycle per second accuracy, both of which were incorporated into a cooperative program to improve the orbital ephemerides. Simultaneous analysis of the delay and frequency dispersion of echoes returned from Venus permitted its angular rotation to be determined in spite of the optical obscuration of the Venusian cloud layer. The spectral breadth measurements of the rotation rate of Mercury were not compatible with its accepted synchronous rotation, but favored a 59 ± 5 day, direct sidereal rotation period. Frequency spectrum measurements of Mars taken within each 10-millisecond pulse indicated that its surface is smoother generally than that of Venus, and that regions of unusual smoothness pass across its subradar point.

46. Epstein, E. E.,
DISK TEMPERATURES OF MERCURY AND MARS AT 3.4 MM, Astrophysical Journal, Vol. 143, February 1966, pp. 597-598, A66-22786, Contract No. AF 04(695)-469.

Determination of the disk temperatures of Mercury and Mars on the basis of observations made at 3.4 millimeters in April 1965 are discussed. A blackbody disk temperature of 190° ± 40° K is obtained for Mars, while in the case of Mercury the daily values of the blackbody disc temperature ranged from 130° to 320° K, the average value being 220° ± 35° K.

47. Epstein, E. E.,
MERCURY: ANOMALOUS ABSENCE FROM THE 3.4-MILLIMETER RADIO EMISSION OF VARIATION WITH PHASE, Science, Vol. 151 (3709), 28 January 1966, pp. 445-447.

DLC reports that during observations of Mercury from 16 July through 17 October 1965 at 3.4 millimeters with the 15-foot (4.57 meters) antenna of the Space Radio Systems Facility of Aerospace Corporation, no significant variation with phase was recorded, even though the observations covered almost a complex revolution of Mercury. The phase curve of Mercury is shown graphically. The most significant features are the brightness temperature of only ≈200° K that was recorded when major fractions of the illuminated hemisphere were visible and the apparent absence of any strong variation with phase. Both features were completely unexpected.

48. Erickson, W. C. and Brissenden, P.,
A SEARCH FOR DECAMETRIE RADIATION FROM SEVERAL PLANETS, The Astrophysical Journal, Vol. 136, 1962, p. 1140.

An upper limit of 3×10^{24} wm^{-2} $(c/s)^{-1}$ at 26.3 megacycles per second was established for Mercury.

49. Evans, J. V., Brockelman, R. A., Henry, J. C., Hyde, G.M., Kraft, L. G., Reid, W. A., and Smith, W. W.,
RADIO ECHO OBSERVATIONS OF VENUS AND MERCURY AT 23 CM WAVELENGTH, Astronomical Journal, Vol. 70, September 1965, pp. 486-501, A65-35290.

Radar observations in 1964 of the planets Venus and Mercury conducted at the Millstone Hill radar observatory are discussed. The radar equipment employed for this work, together with details of its operation, and the data gathering and reduction procedures are described. Venus was observed from March to October at approximately weekly intervals. The distance to Venus was determined with an accuracy of about ± 75 kilometers at the beginning and end of this period and ± 1.5 kilometers throughout June and July. The velocity of Venus with respect to the Earth was also measured, the accuracy varying between ± 10 to ± 1 centimeter per second. These values which are tabulated are currently being employed to refine some of the elements of the orbits of Earth and Venus and the value for the AU. Echoes from Mercury were obtained on five days around the inferior conjunction occurring on 30 April 1964. The radar cross section appeared to be about 10 percent of the projected area of the disk. The radar cross section for Venus had an average value of 15 percent, which is close to most other values at meter and decimeter wavelengths. The scattering properites of Venus were explored using a variety of pulse lengths to fully resolve different regions. It is concluded that Venus has a surface that is considerably smoother than the Moon's. The average slope of surface elements in the range of about 5 to 50 meters across appears to be eight degrees. There are, however, regions that are distinctly rough and cause a lowering of the radar cross section when rotated under the subradar point. By contrast, Mercury appears somewhat rougher than the Moon. Attempts to obtain echoes from Mars during opposition in 1965 are briefly summarized. A statistically significant echo was obtained after integrating the signals for four nights.

50. Ewing, A.,
MERCURY CROSSES SUN'S FACE, Science News Letter, Vol. 64, 7 November 1953, pp. 298-299.

Not abstracted.

51. Field, G. B.,
ATMOSPHERE OF MERCURY, The Astronomical Journal, Vol. 67, 1962, pp. 575-576.

Kuiper pointed out that radiogenic argon might be retained on Mercury. This would explain the polarization measurements of Dollfus. The quoted mass of argon is 1.0×10^{-8} times the mass of Mercury, and the same ratio for the earth is 1.1×10^{-8}. Is this because the mass and constitution of the mantle, the effectiveness of degassing, and the lack of exospheric escape are all similar for the two planets.

52. Field, G.,
THE ATMOSPHERE OF MERCURY, New York, John Wiley and Sons, Inc., 1964, pp 269-276, The Origin and Evolution of Atmospheres and Oceans, Proceedings of a Conference, NASA, Goddard Space Flight Center, Goddard Institute for Space Studies, New York, New York, 8, 9 April 1963, (A65-33289 21-30, A65-33300).

This paper is a description of evidence that the planet Mercury has an atmosphere, and a tentative interpretation of this evidence. It was thought that no atmosphere would exist because the escape velocity of such a body (with a radius 30 percent greater than that of the Moon, but with 4.2 times more mass) is small and the high surface temperature approaches the critical value for the exospheric escape of light gases. Measurements by Dollfus over the surface of Mercury revealed differential polarization effects. Unlike observations of the moon, the polarization depended on the inclination of the surface to sunlight - an effect which is explainable by the presence of an atmosphere. A second factor in support of a Mercurian atmosphere is the systematic tendency of the measurements of brightness temperature in the three centimeter wavelength made in 1960 (Michigan University) to lie above the theoretical curve assuming a dark-side temperature of 0° K. One interpretation of these measurements is that Mercury may have an argon atmosphere.

53. Fitzgerald, A. P.,
MERCURY: AN HISTORICAL ERROR, Irish Astronomical Journal, Vol 1, 1960, pp. 15-17.

Not abstracted.

54. Foreign Technology Division, Wright-Patterson Air Force Base, Ohio,
NEWS ABOUT MERCURY (CARBON DIOXIDE HAS BEEN REVEALED IN THIS PLANET'S ATMOSPHERE), October 1965, TT-65-64151, AD-622 361, FTD-TT-65-1240, (Unclassified).

Vasiliy Moroz, while observing Mercury made a new and interesting discovery. He investigated the far infrared region of the spectrum of Mercury on long waves, 1.1 to 3.9 microns. No photoplates are sensitive to these rays, and the spectrum was not photographed, but recorded by a photoelectric spectrometer connected to a 125 centimeter telescope reflector. An analysis of the recordings revealed a band of carbon dioxide at wavelengths of 1.575 to 1.606 microns. Calculations showed that 5.2 grams of carbon dioxide was contained over each square centimeter of Mercury's surface. The atmospheric pressure on the planet was established to be 1.9 millibars.

55. Gaherty, G., Jr.
INTERIM REPORT ON MERCURY IN 1958 AND 1959, Strolling Astronomer, Vol. 14, 1960, p. 96.

Not abstracted.

56. Gaherty, G., Jr.
MERCURY IN 1960, Strolling Astronomer, Vol. 15, November - December 1961, pp. 187-191.

Not abstracted.

57. General Electric Company, Missile and Space Division, Philadelphia, Pennsylvania,
FURTHER STATISTICAL EVIDENCE FOR ASSUMING THAT THE PLANET MERCURY HAS A MAGNETIC FIELD by R. C. Good, Jr., July 1966, Report No. R66SD42, AD-487 031, (Unclassified).

The heliographic longitude of the planet Mercury has been noted for each solar proton event recorded on Earth. When compared with the heliographic longitude of the attending solar flares, 14 (instead of the average 6) out of the 30 events occurred when Mercury was within 40 degrees. This phenomenon is taken to indicate that a magnetic field about the planet Mercury may influence the solar flare proton trajectories to increase the flux striking the Earth. The deflection angle required for the protons to be turned towards Earth are not large (60 - 80 degrees). Comparable data for Venus indicate it was not close to the flares and would require a large deflection in proton trajectories.

58. General Electric Company, Missile and Space Division, Philadelphia, Pennsylvania,
STATISTICAL EVIDENCE FOR A MAGNETIC FIELD OF MERCURY by R.C. Good, Jr., March 1966, R66SD8, AD-487 031, (Unclassified).

The heliographic longitude of the planet Mercury has been noted for each solar proton event recorded on Earth. When compared with the heliographic longitude of the attending solar flares, 14 (instead of the average 6) out of the 30 events occurred when Mercury was within 40 degrees. This phenomenon is taken to indicate that Mercury may influence the solar flare proton trajectories to increase the flux striking the Earth. The differential equations of motion for 100 million electron volts protons in a restricted magnetic dipole-type field are solved for trajectories on the magnetic equator. The exit angle (deflection from original direction) is found to have a broad maximum near 80 degrees. This compares well with astronomical data on the position of the planet Mercury. An estimation

of the magnetic moment necessary to accomplish such deflections is shown to be reasonable since it would produce a magnetic field of 0.008 gauss on the surface of Mercury.

59. General Electric Company, Missile and Space Division, Philadelphia, Pennsylvania,
THE PLANET MERCURY: A TWENTY-YEAR SURVEY OF THE LITERATURE by R. Bernstein, March 1964, R64SD20, N66-10436, (Unclassified).

A bibliography is presented on the planet Mercury and includes 145 references published over the past 20 years, 37 of which have abstracts. This collection was intended as a starting point for a preliminary study to consider sending an unmanned scientific probe to the planet.

60. Georgetown College Observatory, Washington, D. C.,
RECENT STUDIES OF THE KNOWN PHYSICAL CHARACTERISTICS OF THE MOON AND THE PLANETS by C. C. Kiess and D. S. Birney, December 1960, Report No. AFCRL TN-60-666, AD-253 575, Contract No. AF-19(604)-7203, (Unclassified).

Not abstracted.

61. Gingerich, O.,
VENUS AND MERCURY, Canadian Nature, Vol. 19, 1957, pp. 188-190.

Not abstracted.

62. Goldreich, P.,
TIDAL DE-SPIN OF PLANETS AND SATELLITES, Nature, Vol. 208, 23 October 1965, pp. 375-376, A66-12892.

Analysis of the effects of tidal friction on the rotation of Mercury and the Moon. The results for Mercury indicated that, contrary to the belief expressed by Peale and Gold, the solar torque exerted on the tidal bulge does not exceed that exerted on any permanent deformation from axial symmetry, except for the case of an axisymmetric planet. A possible explanation for the synchronous orbit of the moon is noted.

63. Gossner, S. D.,
MEDIEVAL ASTRONOMERS ERRED IN DESCRIBING MERCURY AND VENUS, Natural History, Vol. 72, February 1963, pp. 18-19.

Not abstracted.

64. Haas, W. H.,
A TEN-YEAR STUDY OF MERCURY AND ITS ATMOSPHERE, Popular Astronomy, Vol. 55, 1951, pp. 137-148.

Not abstracted.

65. Haddock, F. T.,
RADAR AND RADIO STUDIES OF THE MOON AND THE PLANETS RECENT PROGRESS (1960-1963), New York, American Elsevier Publishing Co., Inc., 1966, pp. 86-108, A66-21063, Contract No. Nonr-1224(16), Progress in Radio Science 1960-1963, Vol. 5 - Radio Astronomy; Proceedings of Commission V on Radio Astronomy during the 15th General Assembly of URSI, Tokyo, Japan, September 1963. (A66-21058 10-30).

This paper is a discussion of some of the highlights of recent discoveries and measurements of the moon and planets from 1960 to 1963. Radar studies of the Moon and Venus, radar echoes from Mars and Mercury, radio emission from the Moon, Mercury, and Venus are considered together with microwave emission from Jupiter, and radio emission from Saturn.

66. Heath, M. B. B.,
THE BRIGHTNESS OF MERCURY AT ITS GREATEST ELONGATIONS, Journal of the British Astronomical Association, Vol. 68, 1958, pp. 30-32.

Not abstracted.

67. Heath, M. B. B.,
THE ELONGATIONS OF MERCURY, 1956 TO 2000, Journal of the British Astronomical Association, Vol. 66, 1956, pp. 68-71.

Not abstracted.

68. Heath, M. B. B.,
THE LIBRATION OF MERCURY, Journal of the Bristish Astronomical Association, Vol. 69, 1959, pp. 16-48.

Not abstracted.

69. Heath, M. B. B.,
THE PHASES OF MERCURY AT ITS GREATEST ELONGATIONS, Journal of the British Astronomical Association, Vol. 67, pp. 318-320.

Not abstracted.

70. Heath, M. B. B.,
TABLES OF MERCURY, Journal of the British Astronomical Association, Vol. 69, 1959, pp. 42-46.

Not abstracted.

71. Heath, M. B. B.,
THE VISIBILITY AND BRIGHTNESS OF THE PLANET MERCURY, Journal of the British Astronomical Association, Vol. 61, 1951, pp. 43-45.

Not abstracted.

72. Hess, L.,
ATMOSPHERES OF OTHER PLANETS, Science, Vol. 128, 10 October 1958, pp. 809-814.

Not abstracted.

73. Hodge, P. W.,
THE ATMOSPHERE OF THE PLANET MERCURY, Transactions of the American Geophysical Union, Vol. 45, 1964, p. 631.

The optical and radio observations of the planet Mercury place rough upper limits on the total amount of atmosphere the planet can have. The smallest upper limit is that imposed by consideration of meteoritic erosion, which can be interpreted to indicate an upper limit of 0.1 millibar surface pressure. This can be compared with a recent negative result in a search for atmospheric lines using the very high dispersion of the 120-inch Lick telescope's coude spectrograph. The three previously reported measurements of Mercury's atmosphere, together, are inconsistent with the above. At least two of them must be incorrect.

74. Hodge, P.,
INTERACTION OF THE PLANET MERCURY WITH INTERPLANETARY MATERIAL, Société Royale des Sciences de Liège, Mémoires, Cinquième Série, Tome 7, 1963; Physics of Planets; Proceedings of the Eleventh International Astrophysical Symposium, Liège, Belgium, 9-12 July 1962, University of Liège and United States Air Force, Institut d'Astrophysique, Liège, Belgium, 1963, pp. 261-268, A63-25349.

This paper is an evaluation of the rate of erosion of Mercury's surface due to meteoritic encounters, assuming that Mercury has no appreciable atmosphere. There is some evidence that a small atmosphere on the bright side is detected by polarization measures. The erosion rate on this side would be unaffected by an atmosphere of less than about 0.1 millibar pressure, which is approximately the pressure at the level at which meteoroids are decelerated by the Earth's atmosphere. An atmosphere of 10^{-4} times the Earth's is the maximum allowable if Mercury's sunward surface is extensively eroded meteoritically. Dollfus' value of 3×10^{-3} Earth atmospheres is so great that most meteroids would never reach Mercury's sunward surface.

75. Howard, W. E., Barrett, A. H., and Haddock, F. T.,
MEASUREMENT OF MICROWAVE RADIATION FROM THE PLANET MERCURY, The Astrophysical Journal, Vol. 136, 1962, pp. 995-1004.

The microwave emission from the planet Mercury has been measured relative to the flux density of three radio sources at wavelengths of 3.45 and 3.75 centimeters. A subsolar point temperature of 1100° ±300°K is derived if it is assumed that the temperature distribution of the sunlight surface varies as the one-quarter power of cos θ, where θ is the angle of incidence of solar radiation, and that the temperature of the dark hemisphere is zero. A lower subsolar temperature is obtained if radioactive heating and lunar-type insulating dust layer on the surface are assumed.

76. IIT Research Institutuion, Astro Sciences Center, Chicago, Illinois, SCIENTIFIC OBJECTIVES FOR MERCURY MISSIONS, DIGEST REPORT by T. C. Owen, 30 April 1964, NASA-CR-58121: P-6, N64-26599, Contract No. NASr-65(06) (Unclassified).

Work in the following areas is summarized: (1) solid state device design; (2) materials research; (3) band structure and spectroscopy of solids; (4) spectroscopy of magnetic solids; (5) transition-metal and rare-earth compounds; and (6) optics and infrared.

77. Jastrow, R. and Rasool, S. I., PLANETARY ATMOSPHERES, New York, Gordon and Breach Science Publishers, Inc., 1965, pp. 669-699, A66-15759, (Introduction to Space Science).

A study of the properties and characteristics of the atmospheres of the planets and their composition is discussed. The effect of gravitational escape on the composition of a planet's atmosphere is examined in terms of density distribution in the exosphere. Temperature, density, and composition are the basic atmospheric data. Of these, temperature is the most important because it directly reflects the processes of absorption of solar energy which, in turn, determine atmospheric structure. The probable composition and properties of the atmospheres of Mercury, Mars, Venus, and Jupiter are described.

78. Jefferys, W. H., ROTATION OF THE PLANET MERCURY, Science, Vol. 152, 8 April 1966, pp. 201-202, A66-26287.

The equations of motion for the rotation of Mercury are solved for the general case by an asymptotic expansion. The findings of Liu and O'Keefe, obtained by numerical integration of a special case, that it is possible for Mercury's rotation to be locked into a 2:3 resonance with its revolution, are confirmed in detail. The general solution has further applications.

79. California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California,
ASTRONAUTICS INFORMATION, RADIOMETRY AND PHOTOMETRY OF THE MOON AND PLANETS by E. Barber, September 1961, LS345, NASW6, AD-264 330 (Unclassified).

Material is presented on photometry, spectrophotometry, colorimetry, and other methods of studying the surfaces and atmospheres of the planets in the visual, ultraviolet, and infrared regions. The material is divided into nine sections covering the major planets, the moon, and lunar eclipses.

A general section contains survey articles and some selected references on instrumentation. An author index is included. In each section, with the exception of lunar eclipses, the material is divided into books, reports, and periodicals. Books are arranged in alphabetical order by author and reports in alphabetical order by source. Beginning with the most recent articles, periodicals are listed in chronological order by year, and within each year in alphabetical order by journal. Lunar eclipses are arranged in chronological order by date of eclipse, with the most recent eclipse appearing first. Abstracts found in the reference source are published in whole or in part, and the source is noted whenever possible.

80. Kellermann, K. I.,
RADIO OBSERVATIONS OF MERCURY, VENUS, MARS, SATURN, AND URANUS, Journal of Research, Section D - Radio Science, Vol. 69D, December 1965, pp. 1574-1575, (Symposium on Planetary Atmospheres and Surfaces, Dorado, Puerto Rico, 24-27 May 1965, Paper.), A66-20110.

Summary of the results of observations of radio emission from Mercury, Venus, Mars, Saturn, and Uranus made with the CSIRO 210-foot radio telescope at Parkes is discussed. A description of the main results for each planet is given. The blackbody temperature for Mercury is plotted as a function of planetocentric phase angle. The blackbody temperature of Venus at 11, 21, 30, and 50 centimeters is given and that of Mars and Saturn both at 6, 11, and 21 centimeters is also tabulated.

81. Kellermann, K. I.,
11-CM OBSERVATIONS OF THE TEMPERATURE OF MERCURY, Nature, Vol. 205, 13 March 1965, pp. 1091 - 1092, A65-22205.

Determination of the temperature distribution at the surface of Mercury, based on measurements of the mean disk temperature over a wide range of phase angles as the planet moves in its orbit around the Sun is discussed. Observations were made on 10 separate days during May and June 1964 at a wavelength of 11 centimeters for planetocentric phase angles θ from 29 degrees to 149 degrees (θ is the angle between the Sun and the Earth as seen from Mercury). The observations were made by scanning back and forth in declination over a range of about 45 minute of arc approximately centered on the declination of Mercury. It is found that the surface temperature does not exhibit the strong dependence on phase angle that it was expected to. In particular, the observations at large phase angles, where only 10 to 15 percent of the visible disk was illuminated by the Sun, indicate a temperature of about 250° K on the dark hemisphere. This, taken with other considerations, seems to indicate that atmospheric convection plays an important role in determining the temperature distribution on the surface of Mercury.

82. Kopal, Z.,
STRESS HISTORY OF THE MOON AND OF TERRESTRIAL PLANETS, Icarus, Vol. 2, 1963, pp. 376-395.

The author studies the effects of nonuniform expansion or contraction of elastic globes of planetary size and mass caused by the secular escape of their primodial heat and radiogenic heating. The coupling of the mechanical and thermal phenomena is formulated exactly, and first approximation solutions of the problem are given in the form of series expansions. These, in turn, are used as a basis of numerical computations to reconstruct the thermal and stress history (as well as the future) of the Moon, Mercury, and Mars. It is shown that, within the scheme of these approximations, the secular changes in external radii of these three celestial bodies probably did not exceed 0. 6 ± 0. 1 percent of their present values throughout their long astronomical past; but whether or not such changes as did take place were monotonic or oscillatory remains as yet impossible to say.

83. Kotel'nikov, V. A., et al,
RADAR PROBES OF THE PLANET MERCURY (Foreign title not available) Translated into English from Russian by Joint Publications Research Service, Washington, D. C., Doklady Akad, Nauk SSSR (Moscow), Vol. 147, No. 6, 21 December 1962, pp. 1320-1323, JPRS-18211, OTS-63-21357, N64-10498.

In June 1962, the USSR carried out a radar survey of the planet Mercury. The measurements were made at Mercury's perigee. The distance to Mercury during the measurements was 83 to 88 million kilometers, twice that of the radar survey of Venus in 1961. The materials obtained in 53 sessions over the period from 10 through 15 June 1962, were treated. The average spectrum of signals reflected by Mercury during that period, the distribution of probabilities for values of the reflection coefficient with respect to energy in the 4 and 12 cycle frequency bands, and the accumulation of difference energy for various values of the astronomical unit are presented. Statistical analysis of the data indicates that the correctness of the astronomical unit cannot be guaranteed. However, the results of the completed radar observations of Mercury confirm the value of the astronomical unit obtained in the Venus survey in 1961, and yield a coefficient of reflection for Mercury which is close to that of the lunar surface.

84. Kozyrev, N. A.,
THE ATMOSPHERE OF MERCURY, Sky and Telescope, Vol. 27, 1964, pp. 339-341.

The author discusses evidence for the existence of an atmosphere on Mercury. From hydrogen line spectra, he estimates an atmospheric density of 0.0001 of the Earth's is of the composition of air and 0.01 of the Earth's is of hydrogen. It is suggested that the influx of solar protons could replenish hydrogen which escaped from Mercury's atmosphere.

85. Kozyrev, N. A.,
THE ATMOSPHERE OF MERCURY, The Journal of the British Astronomical Association, Vol. 73, 1963, pp. 345-346.

The density of the hydrogen atmosphere on Mercury, determined spectroscopically, is given at 10^{16} particles per cubic centimeter. The author suggests that the solar proton flux replenishes the Mercurial atmosphere at the same rate as the hydrogen escapes into space.

86. Kuiper, G. P.,
MERCURY, Encyclopedia Britannica, Vol. 15, 1964, p. 271.

Not abstracted.

87. Kuiper, G. P. and Middlehurst, B. M.,
PLANETS AND SATELLITES, Chicago, The University of Chicago Press, Vol. 3, 1961.

Not abstracted.

88. Laslett, L. J. and Sessler, A. M.,
ROTATION OF MERCURY - THEORETICAL ANALYSIS OF THE DYNAMICS OF A RIGID ELLIPSOIDAL PLANET, <u>Science,</u> Vol. 151, 18 March 1966, pp. 1384-1385, A66-24237.

Development of the second-order nonlinear differential equation for the rotation of Mercury is discussed. This equation implies locked-in motion when the period is within the range $[2\ T/3][1 - \lambda \cos(2\ \pi t/T) \pm (2/3)(21 \lambda\ e/2)^{1/2}]$ where e is the eccentricity and T is the period of Mercury's orbit, the time t is measured from perihelion, and λ is a measure of the planet's distortion. For values near 2T/3, the instantaneous period oscillates about 2T/3 with period $(21\lambda e/2)^{-1/2}$ T.

89. Liu, Han-Shou and O'Keefe, J. A.,
THEORY OF ROTATION FOR THE PLANET MERCURY, <u>Science,</u> Vol. 150, 24 December 1965, pp. 1717, A66-16732.

The theory of the rotation of the planet Mercury is developed in terms of the motion of a rigid system in an inverse-square field. It is possible for Mercury to rotate with a period exactly two-thirds of the period of revolution; there is a libration with a period of 25 years.

90. Lomnitz, C.,
ON THERMODYNAMICS OF PLANETS, <u>The Geophysical Journal of the Royal Astronomical Society,</u> Vol. 5, 1961, pp. 157-161.

A thermodynamical theory of planets is outlined. General results by Prigogine, de Groat, and others are applied to the case of a steady-state system with a constant temperature

distribution. An "excited state" is defined by pressure perturbation introduced by a seismic shock at the surface of the planet. The resulting transient flows towards the perturbed region are analyzed, and it is shown that the energy transient is logarithmic in time. A condition of realizability of the seismic problem is defined. For a given planet type there is a critical size below which no seismic activity can occur on the planet.

91. Lowell Observatory, Flagstaff, Arizona,
PHYSICAL RESEARCHES ON THE BRIGHTER PLANETS, Final Report by W. M. Sinton, 30 September 1964, AFCRL-64-926, AD-609547, N65-15288, Contract No. AF 19(604)-5874 (Unclassified).

Observational studies of the planets and the moon through the use of photography, photoelectric photometry, infrared radiometry, and infrared spectroscopy were made. The resulting data include the measurements of the thickness of dust on the floors of 16 lunar craters; the infrared radiometric temperatures of Mercury, Venus, Mars, Jupiter, Saturn, and Uranus; and extensive photoelectric photometry of Mars. Some of the important conclusions that have been previously published are included.

92. MacDonald, G. J. F.,
ON THE INTERNAL CONSTITUTION OF THE LUNAR PLANETS, Journal of Geophysical Research, Vol. 67, 1962, pp. 2945-2974.

On the hypothesis that the initial angular velocity of Mercury is equal to that of the Earth, we require either that (1) Mercury was initially molten and during this early time its periods of rotation and revolution were made equal by solar tidal friction, or that (2) the present thermal state of Mercury is such as to allow much greater dissipation of energy than in the Earth. The thermal conditions within Mercury are highly uncertain. The mean density makes unlikely the hypothesis that the radioactive composition of Mercury is similar to that of chondrites. Indeed, it would seem that Mercury is largely metallic, and if it is, a lower concentration of radioactive elements is indicated. Since the effect of pressure on the melting point is far less in a planet the size of Mercury than in larger bodies such as Venus and Earth, a lower concentration of radioactive elements (1/2-1/3) would still melt the small body or make it largely molten.

93. National Aeronautics and Space Administration,
STRUCTURE AND STRENGTH OF INNER PLANETS by
G. J. F. MacDonald, 1963, Report No. R-173 (Unclassified).

This report examines internal structures of Moon, Mars, Venus, and Mercury in light of what is known about internal constitutions of the Earth. Observations of the Moon's orbital and rotational motions provide data on its gravitational figure; astronomical information on mean density and the gravitational figure of Mars is examined. Internal structures of Mercury and Venus are studied in terms of their inferred rotational history. It is concluded that inner planets differ in their abundance of heavy elements and of potassium, uranium, and thorium. Chrondritic meteorites provide satisfactory chemical model for the Earth, but not for other planets, with possible exception of Venus.

94. MacDonald, G. J. F.,
TIDAL FRICTION, Reviews of Geophysics, Vol. 2, 1964,
pp. 467-541.

The rotational parameters of the Moon, Mars, Venus, and Mercury are discussed in terms of the dynamical theory. The distribution of rotational angular momentum of the solar system is described, and it is proposed that the major planets and Mars have lost only a very small proportion of their initial rotational angular momentum. The author argues that the current phase lag in the elastic component of the tidal bulge raised by the sun and the moon is not consistent with the hypothesis that the earth-moon system has existed throughout geologic time.

95. Makhover, S. G. and Bokhan, N. A.,
MOTION OF COMET ENCKE-BACKLUND DURING 1898-1911
AND A NEW DETERMINATION OF THE MASS OF MERCURY,
Soviet Physics: Doklady, Vol. 5, March-April 1961,
pp. 923-925.

Comet Encke-Backlund approaching Mercury closer than any other celestial body can be used for determination of the mass of this planet. The difference in its old value of 1:9, 700, 000 and the present one of 1:600,000 is due to secular acceleration of the mean motion, and decrease of the eccentricity of the comet, probably due to retarding forces of its nucleus. The perturbations due to other planets could not be

taken into account in Backlund's time (1894) with sufficient accuracy. The residual deviations of the normal position for 1908 were too large in Backlund's analysis. Makhover's analysis of the motion during 1937-1954 led to a new value of the mass of Mercury. A new determination based on five appearances of the comet during 1908-1911 improved the orbit elements by recalculation of the perturbations, the results of which are presented in tables. The recent determinations of the mass of Mercury are in good agreement with each other but disagree with Backlund's determination.

96. Massachusetts Institute of Technology, Research Laboratory of Electronics, Cambridge, Massachusetts,
PASSIVE RADIO OBSERVATIONS OF VENUS, SATURN, MERCURY, MARS, AND URANUS, SESSION III by A. H. Barrett, 1966, DA-36-039-AMC-03200(E), NSG-419, AD-633 794 (Unclassified).

The radio observations of Mercury, Venus, Mars, Saturn, and Uranus are reviewed and discussed in relation to knowledge of these planets acquired by other means. In the case of Mercury, it is shown that the radio observations imply a temperature of approximately 300°K for the unilluminated hemisphere. A result which appears to be in sharp disagreement with infrared measurements of Mercury. Two detailed measurements of the Venus spectrum near one-centimenter wavelength are presented and compared.

97. Massachusetts Institute of Technology, Lincoln Laboratory, Lexington,
RADIO ECHO OBSERVATIONS OF VENUS AND MERCURY AT 23 CM WAVELENGTH by J. V. Evans, R. A. Brockelman, J. C. Henry, G. M. Hyde, and L. G. Kraft, May 1965, ESD-TDR-65-545, JA-2573, AD-624 731, Contract No. AF 19(628)-5167, (Unclassified).

Radar observations in 1964 of the planets Venus and Mercury conducted at the Millstone Hill radar observatory are presented. The radar equipment employed for this work, together with details of its operation, and the data gathering and reduction procedures are described. Venus was observed from March to October at approximately weekly intervals.

The distance to Venus was determined with an accuracy of about ± 75 kilometers at the beginning and end of this period and ± 1.5 kilometers throughout June and July.

The velocity of Venus with respect to the Earth was also measured, the accuracy varying between ±10 to ±1 centimeter per second. These values are tabulated here and are currently being employed to refine some of the elements of the orbits of Earth and Venus and the value for the astronomical unit. Echoes from Mercury were obtained on five days around the inferior conjunction occurring on 30 April 1964.

The radar cross section appeared to be about 10 percent of the projected area of the disk. The radar cross section for Venus had an average value of 15 percent, which is close to most other values at meter and decimeter wavelengths. The scattering properties of Venus were explored using a variety of pulse lengths to fully resolve different regions. It is concluded that Venus has a surface that is considerably smoother than the Moon's.

98. Mayer, C. H.,
GENERAL REPORT ON PLANETARY RADIO ASTRONOMY, Société Royale des Sciences de Liège, Mémoires, Cinquième Série, Tome 7, 1963; Physics of Planets; 1963, pp. 99-111, A63-25338 (Proceedings of the Eleventh International Astrophysical Symposium, Liège, Belgium, 9-12 July 1962, University of Liège and United States Air Force, Institut d'Astrophysique, Liège, Belgium).

This paper is a discussion of the results of radio observations of the very weak radio radiation from Mercury, Mars, Saturn, Venus, and Jupiter. At wavelengths near 3, 10, and 21 centimeters, the observed intensity is nearly twice that predicted for the thermal radiation of the surface of Venus. A possible separation of the thermal and nonthermal components of the spectrum of Jupiter is given, based on the assumption that all the wavelengths contribute to the thermal radiation at 130° K. Observations of apparently significant changes in the decimeter emission of Jupiter with time are discussed.

99. Mayer, C. H., McCullogh, T. P., and Sloanaker, R. M., MEASUREMENTS OF PLANETARY RADIATION AT CENTIMETER WAVELENGTHS, Proc. IRE, Vol. 46, No. 1, pp. 260-266.

Not abstracted.

100. McEwen, H., TITLE NOT AVAILABLE, Journal of British Astronomical Association, Vol. 45, 1935, p. 240.

Not abstracted.

101. McGovern, W. E., Gross, S. H., and Rasool, S. I., ROTATION PERIOD OF THE PLANET MERCURY, Nature, Vol. 208, 23 October 1965, p. 375, A66-12891.

This paper is a determination of the rotation period of the planet Mercury, based on an analysis of the results of visual observation by Antoniadi (1924 to 1929), Lyot and Dollfus (1942, 1950), and Baum (1952, 1953). Nearly 50 drawings were examined, and from these, six pairs were chosen, each pair showing near duplication of markings and phase. The time intervals between the observations of each pair are listed. It is noted that there appears to be a large discrepancy between radar and visual determinations of the period. It is shown that this is so because the visual data do not provide a unique solution, but permit a number of possible rotation periods. One of these is the 88 days previously accepted in the literature. Another, however, 58.4 ± 0.4 days, is found to be in accordance with radar results which place the value at 59 ± 5 days.

102. Meglis, A. J. and Thuronyi, G., SELECTIVE ANNOTATED BIBLIOGRAPHY ON PLANETARY ATMOSPHERES. II. MERCURY, VENUS, AND MARS, Meteorological and Geoastrophysical Abstracts, Vol. 12, October 1961, pp. 2061-2114.

Not abstracted.

103. Mintz, V., THE ENERGY BUDGET AND ATMOSPHERIC CIRCULATION ON A SYNCHRONOUSLY ROTATING PLANET, Icarus, Vol. 1, 1962, p. 172.

Not abstracted.

104. Moore, P.,
CONDITIONS ON THE SURFACE OF MERCURY, Journal of the British Interplanetary Society, Vol. 13, 1954, pp. 318-324.

Not abstracted.

105. Moore, P.,
CONDITIONS ON THE SURFACE OF MERCURY, Journal of the British Interplanetary Society, Vol. 13, 1954, pp. 392-393.

Not abstracted.

106. Moore, P.,
MERCURY, THE BARREN PLANET, Journal of Astronautics, Vol. 2, 1955, pp. 145-148.

Not abstracted.

107. Moore, P.,
MYSTERIES OF MERCURY, Time, Vol. 62, 30 November 1953, p. 84.

Not abstracted.

108. Moore, P.,
THE MOTION OF VENUS AND THE MASS OF MERCURY, Sky and Telescope, Vol. 15, 1956, p. 206.

Not abstracted.

109. Moore, P.,
THE PLANETS, New York, Norton, 1962.

Not abstracted.

110. Moroz, V. I.,
INFRARED SPECTRUM OF MERCURY (λ 1.0 - 3.9μ) INFRAKRASNYI SPEKTR MERKURIIA (λ 1.0 - 3.9μ), Astronomicheskii Zhurnal, Vol. 41, November - December 1964, pp. 1108-1117, A65-15676 (In Russian).

This paper is a report on the observation, in October 1963, of the Mercury spectrum in the region 1.0 to 3.9μ, by means of a 125-centimeter reflector and two IR spectrometers with

PbS-photoresistances cooled with solid CO_2 or liquid N_2. The CO_2 lines are found to be more pronounced in Mercury's atmosphere as compared to the telluric lines, and a CO_2 content of 0.3 to 7 gm/cm^{-2} is established. A model of Mercury's atmosphere is designed, assuming 10 percent of CO_2 and 90 percent of N_2 contents. The critical level temperature is found to be relatively low as a result of a heat flux from the illuminated hemisphere into the obscured hemisphere, despite the intensive ionizing radiation. The upper content level in the planet's atmosphere for CO, N_2O, NH_3, and CH_4 and the relative energy distribution in the planet's spectrum are estimated.

111. Muhleman, D. O., Goldstein, R. M., and Carpenter, R. L., A REVIEW OF RADAR ASTRONOMY, II., IEEE Spectrum, Vol. 2, November 1965, pp. 78, 83-89, A66-13963.

A comprehensive review of the radio astronomy investigations of Venus, Mars, Jupiter, Mercury, and the Moon is discussed. Results concerning surface features, radar cross sections, and echo bandwidths, and rotational speeds are discussed and compared. The primary reason for undertaking the highly expensive planetary radar experiments is identified as the establishment of a single astronomical constant, the astronomical unit. Data from several sources are compared, and it is concluded that the agreement as to the figure for the astronomical unit is relatively good (149, 597, 850 kilometers ± 400 kilometers).

112. Murray, B. C., A REEXAMINATION OF SOME EARLY PLANETARY TEMPERATURE MEASUREMENTS, Journal of Geophysical Research, Vol. 67, 1962, p. 1649.

Because atmospheric absorption is relatively low in the 8- to 14-μ region, this "window" has been used for many years for direct determination of the temperatures of the outer surfaces of the terrestrial planets, the moon, and some of the Jovian planets. Recently, however, atmospheric emission in the 8- to 14-μ region has been shown to be significant. In particular, the 8- to 14-μ "sky brightness" appears to be one to two orders of magnitude greater than the reported brightness of Jupiter (140° K), of the dark side of the Moon and Saturn (120° K), and of Uranus (100° K). These early observations are now reevaluated in terms of the necessary instrumental sensitivity, signal-to-noise ratio, and freedom from systematic errors arising from atmospheric emission or other sources. It is concluded that planetary objects whose surface temperatures are believed to be colder than about 200°K should be reobserved.

113. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland,
THE STRUCTURE AND STRENGTH OF THE INNER PLANETS by G. J. F. MacDonald, December 1963, NASA TR R-1731, N64-17518.

This report examines the internal structures of the Moon, Mars, Venus, and Mercury in the light of what is known about the internal constitution of the Earth. A review of the seismic determination of the elastic constitution of the Earth's mantle, based on new results on the stability of silicates at high pressures, leads to the interpretation that the rapid increase of plastic wave velocity beginning at a depth of 200 kilometers depends on the olivine-spinel transition and the breakdown of silicates to oxides. The Earth's gravitational figure, as obtained from satellite orbits, is used to estimate the possible deviation from hydrostatic equilibrium in other planets. The Earth's response to tidal excitation provides information regarding the deviations of elasticity within the Earth. The near coincidence of the present rate of heat production of a chondritic Earth and the present surface heat flow is discussed as a limiting condition on the Earth's internal thermal structure.

114. National Aeronautics and Space Administration, Marshalll Space Flight Center, Huntsville, Alabama,
THE THERMAL ENVIRONMENT OF THE TERRESTRIAL PLANETS (SUPPLEMENT 4) by K. Schocken, 30 September 1964, NASA-TM-X-531 138, N65-12316.

An atmosphere of a light gas such as hydrogen for Mercury hardly seems possible. However, since a hydrogen atmosphere is cold, its dissipation occurs slowly, and the loss of hydrogen can be compensated by the interception of solar protons. The amount of water in Venus' atmosphere above its cloud layer is equivalent to a layer of liquid water 98μ deep. The uncertainty amounts to ± 5 percent. A secondary source of water vapor in the upper terrestrial atmosphere may be the solar origin of the entire hydrogen content of the earth's oceans. The protons contained in the solar wind are trapped by the earth's magnetic field and, after a process of accretion throughout the age of the earth, are oxidized as water. The law of scattering of light from a dark, intricate surface has been derived theoretically by B. W. Hapke. The success of the model in duplicating the measured lunar photometric data makes it possible to draw conclusions regarding the microstructure of the lunar surface.

115. Naval Observatory, Washington, D. C.,
OBSERVATIONS OF THE SUN, MOON, AND PLANETS SIX-INCH TRANSIT CIRCLE RESULTS by A. N. Adams and D. K. Scott, 1 July 1965, Report No. Circular No. 108, AD-626 267 (Unclassified).

This circular contains positions of the sun, moon, and planets observed with the six-inch transit circle between 7 July 1964 and 24 December 1964. These results are provisional. Definitive results will be published later in a volume of Publications of the U. S. Naval Observatory.

116. Naval Observatory, Washington, D. C.,
OBSERVATIONS OF THE SUN, MOON, AND PLANETS SIX-INCH TRANSIT CIRCLE RESULTS CIRCULAR NO. 103 by A. N. Adams and D. K. Scott, 9 October 1964 N65-16082 (Unclassified).

A provisional tabulation of the positions of the sun, moon, and planets is presented. The observed positions are geocentric, and received the usual corrections for instrumental errors, refraction, diurnal aberration, parallax, and orbital motion. The FK3 system was used as a basis for computations. Explanations of computations for the tables are given.

117. Naval Observatory, Washington, D. C.,
RECTANGULAR COORDINATES OF MERCURY 1800-2000 by R. I. Duncombe, Z. Tufekeioglu, and G. Larson, 2 April 1965, Report No. Circular No. 106, AD-625 910, (Unclassified).

The rectangular heliocentric equatorial coordinates in this circular are intended chiefly for use in the numerical integration of orbits of celestial bodies, natural or artificial, which approach closely to Mercury. They are referred to the

mean equinox and equator of 1950.0. They have been calculated from Newcomb's general theory of the motion of Mercury.

118. Newburn, R. L., Jr.,
THE EXPLORATION OF MERCURY, THE ASTEROIDS, THE MAJOR PLANETS AND THEIR SATELLITE SYSTEMS, AND PLUTO, Advances in Space Science and Technology, New York Academic Press, 1961, Vol. III, pp. 195-272.

Some less famous major and minor members of the solar family are described, as well as the use of space probes for gaining more information about their features. Known physical data on Mercury are tentative, because reliable information cannot be obtained from Earth-based observatories, due to the proximity of the planet to the Sun. The possibility to observe Mercury from a probe will prove of great significance. The asteroids, their origin and orbits, number and distributions are given.

119. Nourse, A. E.,
NINE PLANETS, New York and Evanston, Harper & Row Publishers, 1960.

In this book, an attempt is made to develop step by step a complete, realistic, and stimulating picture of the physical nature of our solar system, the nine known planets, their satellites, and their sun. There is speculation about the things we may reasonably expect to find in the course of the forthcoming exploration of that solar system. An enormous gulf exists between the tables of statistics about the planets and a real understanding of what those statistics may mean to the landing parties going there. Here, an attempt is made to bridge that gulf, both with words and pictures, to try to see the planets and statellites as the landing parties will see them, and to guess what manner of things those landing parties may find.

120. O'Toole, D. G.,
A MAP OF MERCURY BASED ON OBSERVATIONS IN APRIL, Strolling Astronomer, Vol. 5, 1951, pp. 3-4.

Not abstracted.

121. O'Toole, D. G.,
MERCURY IN THE SECOND HALF OF 1950, Strolling Astronomer, Vol. 5, 1951, pp. 3-6.

Not abstracted.

122. O'Toole, D. G.,
RADAR OBSERVATIONS OF MARS AND MERCURY, Sky and Telescope, Vol. 25, April 1963, pp. 191-195.

The radar contact with Mars reported by the Jet Propulsion Laboratory and the contact with Mercury reported by a team of Soviet Scientists are described.

123. Peale, S. J. and Gold, T.,
ROTATION OF THE PLANET MERCURY, Nature, Vol. 206, 19 June 1965, pp. 1240-1241, A65-27014.

This paper is a description of the effect of solar tidal friction on the rotation of Mercury. The recently observed value of 59 ± 5 days for the rotational period of Mercury is explained in terms of the influence of tidal friction on a planet with substantial orbital eccentricity. It is concluded that Mercury's orbital period has reached, and will remain at, that value which is enforced in the absence of any permanent body asymmetry.

124. Pettengill, G. H.,
RECENT ARECIBO OBSERVATIONS OF MERCURY, Journal of Research, Section D- Radio Science, Vol. 69D, December 1965, pp. 1627-1628, A66-20119 (Symposium on Planetary Atmosphere and Surfaces, Dorado, Puerto Rico, May 24-27, 1965, Paper).

A brief discussion of procedures used at Arecibo to determine the rotation of Mercury is discussed. Using short pulses (0.5 millisecond), enough echo strength was available from the planetary surface several pulse widths behind the nearest point to measure the Doppler frequency spectrum at known relative delays. It appears that the accepted synchronous rotation does not fit the radar observations, and the best estimate appears to be a sidereal rotation period of 59 ± 5 days in a direct sense.

125. Pettengill, G. H. and Dyce, R. B.,
A RADAR DETERMINATION OF THE ROTATION OF THE PLANET MERCURY, Nature, Vol. 206, 19 June 1965, p. 1240, A65-27013, AD 629 334.

A summary of the results of radar observations of Mercury's surface during the inferior conjunction in April 1965 is discussed. The radar system, which operated at a frequency of 430 megacycles, was sufficiently sensitive to obtain results which showed the rotational period of the planet to be 59 ± 5 days. That this value differs from the orbital period is seen to indicate either that Mercury has not been in its present orbit for the full period of geological time or that the tidal forces acting to slow the initial rotation have not been correctly treated previously.

126. Pettingill, G. H. and Dyce, R. B.,
TITLE NOT AVAILABLE, Sky and Telescope, Vol. 29, 1965, p. 339.

The newly derived rotation period of Mercury reported by Pettingill and Dyce casts some doubt on the long-term changes reported by Antoniadi because his conclusions were based on the assumed 88-day period.

127. Pettit, E.,
PLANETARY TEMPERATURE MEASUREMENTS, THE SOLAR SYSTEM, 3, PLANETS AND SATELLITES, Chicago, University of Chicago Press, 1961.

Not abstracted.

128. Pettit, E. and Nicholson, S. B.,
RADIATION FROM THE PLANET MERCURY, Astrophysical Journal, Vol. 83, 1936, pp. 84-102.

The following topics are discussed: method of measurement, reduction of the measurements, radiation as a function of phase, apparent temperatures, temperature of the subsolar point, and the radiometric albedo.

129. Plagemann, S.,
A MODEL OF THE INTERNAL CONSTITUTION AND TEMPERATURE OF THE PLANET MERCURY, Journal of Geophysical Research, Vol. 70, 15 February 1965, pp. 985-993, A65-18012, Grant No. NsG 101-61.

This paper is a review of the astronomical data concerning the internal structure of Mercury, assumed similar to that of Earth. Assigned an overall mean radius of 2446 kilometers and a mean density of 5.31 g/cm^3, the planet is seen to have both a core and a mantle. An iterative procedure gives a core radius of 2112 kilometers. The pressure, density, and gravity are calculated for a small mantle and core. Numerical integration of the equation of hydrostatic equilibrium yields 7.37 g/cm^3 as the density and 0.327×10^{12} $dynes/cm^2$ as the pressure at the center. From the structural model of Mercury, the temperature distribution in the interior is calculated. Two extreme values of the temperature are calculated because of the uncertainty in the heat generation and thermal conductivity terms. The highest temperature (1380° K) occurs on the sunward side at the core-mantle boundary. This indicates that neither the core nor the mantle is molten. Certain geophysical and astronomical effects may arise because of the peculiar temperature distribution and the synchronous rotation of Mercury about the Sun.

130. Ranck, O. C.,
MERCURY OBSERVATIONS FROM OCTOBER 1956 to MAY 1957, Strolling Astronomer, Vol. 11, 1957, pp. 109-111.

Not abstracted.

131. Ranck, O. C.,
REPORT OF THE A. L. P. O. MERCURY SECTION, Strolling Astronomer, Vol. 13, 1959, pp. 20-22.

Not abstracted.

132. Ranck, O. C.,
SUMMARY OF WORK ON MERCURY 1951-1956, Strolling Astronomer, Vol. 9, 1955, pp. 131-132.

Not abstracted.

133. Rand Corporation, Santa Monica, California, ATMOSPHERES OF THE PLANETS by G. F. Schilling, September 1964, Report No. P-2964, AD606 026 (Unclassified).

Not abstracted.

134. Rand Corporation, Santa Monica, California, GEOMETRIC AND PHOTOMETRIC PARAMETERS OF THE TERRESTRIAL PLANETS by G. de Vaucouleurs, March 1964, NASA CR-53507, RM-4000-NASA, N64-19984, NASA Contract NASr-21(04).

A critical examination is presented of the diameters, ellipticities, and spectral albedos of Mercury, Venus, and Mars derived by many observers in the course of the past 100 years. The systematic and accidental errors in the various methods are discussed, and the results are weighed accordingly, to produce best estimates of the diameters, ellipticities, and albedos.

135. Kingnes, T. R., MERCURY HAS AN ATMOSPHERE (MERKUR HAR ATMOSFARE), Naturen, Bergen, Vol. 74, No. 4, 1952, p. 127.

DLC - Whether or not Mercury has an atmosphere was never determined until the astronomer A. Dollfus, through his studies of polarization of Mercury's light at Pic-du-Midi in southern France, gave definite evidence of its existence. If one assumes that Mercury's atmosphere has the same composition as the Earth's, its density is but 0.003 of the Earth's atmosphere density or a pressure of about 1 millimeter mercury. The escape velocity at Mercury's surface is 3.6 kilometers per second.

136. Roberts, J. A., RADIO EMISSION FROM THE PLANETS, Planetary and Space Science, Vol. 11, 1963, pp. 221-259.

Present knowledge of planetary radio emission is reviewed. In the case of Mars and Saturn, simple heating of the planet by solar radiation can explain the observed radio emission. For Mercury, an internal source of heat (radioactive heating) has been suggested, while for Venus there are a variety of theories in which the energy derives indirectly from radiation or corpuscular bombardment from the Sun. In the case of Jupiter, the excess microwave emission is almost certainly synchrotron emission from relativistic electrons in a radiation belt of magnetically trapped particles. The decametric bursts of radiation from Jupiter may be associated with "dumping" of particles from the radiation belt. Major areas for future work are indicated.

137. Roth, G. M. and Shaw, H. S.,
THE FEASIBILITY OF A VEHICLE USING ATMOSPHERIC BRAKING TO LAND ON THE PLANET MERCURY, American Institute of Aeronautics and Astronautics, Annual Meeting, 2nd, San Francisco, California, 26-29 July 1965, Paper 65-494, A65-29684.

Postulation of atmospheres based on Kozyrev's observations of a possible hydrogen-rich composition to investigate the feasibility of using atmospheric braking to land a payload on Mercury is discussed. The atmospheres are compared to an atmosphere composed of such heavy inert gases as krypton and argon, which, until recently, were believed to comprise the planet's atmosphere. Entry trajectory analysis indicates that a high-drag lander configuration such as a Langley Research Center Tension Shell entering the hydrogen atmosphere can achieve impact velocity values of approximately one-half the initial entry velocity for a low W/C_DA (~ 1 to 3 psf) and entry path angles $\gamma_e = -60$ degrees. It is further shown that by using this atmospheric braking in a grazing trajectory coupled with a retardation system, the descent velocity can be reduced sufficiently to allow safe impact of an instrument payload.

138. Rubashev, B. M.,
TRACES OF AN ATMOSPHERE ON MERCURY (Sledy Atmosfery na Merkurii), Privoda, Moscow, Vol. 40, No. 11, 1951, pp. 47-48.

The physical conditions on Mercury preventing the existence of an atmosphere are stated, the application of the polarimetric method for studying planetary atmospheres is described, and the investigations of A. Dollfus which indicate the existence of traces of an atmosphere on Mercury are discussed in detail.

139. Sagan, C. and Kellogg, W. W., .
THE TERRESTRIAL PLANETS, Annual Review of Astronomy and Astrophysics, 1963, pp. 235-266, A63-24346.

This paper is a review of research concerning Mars, Venus, and Mercury. Discussed are observations and interpretations of the physical environments of these planets. Tabulated are the instrumentation and the experimental objectives of the U. S. Venus probe Mariner (1962 Alpha Rho 1) and the Soviet probe Mars 1 (1963 Beta Nu 3).

140. Salisbury, J. W.,
PLANETARY ENVIRONMENTS, Air Force Surveys in Geophysics, No. 139, January 1962, pp. 127-161.

The best available knowledge of the planetary of our universe is reviewed. For Mars and Venus, the author describes the composition of the atmosphere, the pressure distribution and the atmospheric circulation, the atmospheric temperature distribution, its vertical, diurnal and seasonal variation, the magnetic field: surface features, and satellites. Similar information insofar as it is available is given also for Mercury, the asteroids, Jupiter, Saturn, Uranus, and Neptune. Data on the various characteristics are presented in tables and graphs.

141. Salomonovich, A. E.,
OBSERVATIONS OF RADIO EMISSION FROM THE PLANETS MERCURY, MARS, AND SATURN AT WAVELENGTH OF 8 MM, U. S. National Bureau of Standards, Journal of Research Section D, Radio Science, Vol. 69, No. 12, December 1965, p. 1576.

This paper summarizes and describes briefly the main results for each planet. A more complete discussion will be published elsewhere. The observed blackbody temperatures for Mercury (night and daytime) as a function of planetocentric phase angle ϕ are shown in curves.

142. Sandner, W.,
THE PLANET MERCURY, London, Faber and Faber, 1963.

Not abstracted.

143. Scott, J. C. W.,
THE GRAVITOKINETIC FIELD AND THE ORBIT OF MERCURY, Canadian Journal of Physics, Vol. 44, May 1966, pp. 1147-1156, A63-31011.

A new Lorentz-invariant gravitational field theory is introduced according to which space-time is always flat. The gravitational field is of Maxwellian form with potential and kinetic components analogous to the electric and magnetic components of the electromagnetic field. New mathematical entities named scaled tensors are developed. While the electromagnetic force is represented by an unscaled tensor, the gravitational force is properly described by a scaled tensor. The precession of the orbit of the planet Mercury establishes the scale of the gravitational force as -5. Since the force on a body is found to be proportional to its total mass, the null results of Eotvos and Dicke are confirmed. However, the theory requires that the force depends on velocity so that new very small effects analogous to electromagnetic phenomena are predicted. In a following paper, "Photons in the Gravitational Field," the gravitational red shift and the gravitational deflection of a light ray are deduced correctly.

144. Sekera, Z.,
DISTRIBUTION OF LIGHT INTENSITY AND POLARIZATION OVER THE OBSERVED PLANETARY DISK, Journal of Geophysical Research, Vol. 67, 1962, p. 1656.

The finite disk of a planet surrounded by a molecular atmosphere of a given mass, observed at a distance, will show a continuous distribution of brightness and polarization which varies with the planetary phase. These distributions have been approximated on the basis of the diffuse reflection on a plane-parallel atmosphere of finite optical thickness, full consideration being given to all orders of scattering and polarizations. The results are presented in the form of isophots and contours of equal polarization indicating the plane of polarization, under different planetary phases, optical thicknesses, and surface Lambert reflections. Applications of this type of analysis by means of narrowband photometry and polarimetry of planets from a fly-by probe are also discussed.

145. Sharanov, V. V.,
DUST COVERS ON THE SURFACE OF PLANETS AND SATELLITES, Amsterdam, North-Holland Publishing Co. and New York, Interscience Publishers, 1964, pp. 171-177, Life Sciences and Space Research II; International Space Science Symposium, 4th, Warsaw, Poland, 3-12 June 1963, A64-24957.

Consideration of the problem of the existence of extensive dust covers on the Moon, Mars, and other planets is discussed. It is stated that, as is generally known, photometric observations of the moon give a reflectivity diagram that is sharply elongated towards the sun. Since a powdery material cannot posses such a diagram, the existence of an extensive dust cover on the moon is said to be unlikely. The hypothesis is expressed that the lunar surface throughout consists not of dust, but of a slag-like material, as recently confirmed from the analysis of radio-astronomical observations. The surface of Mercury should resemble that of the moon; therefore, there is no reason to suppose that there are dust covers on it. As to Mars, it is noted that photometric data indicate that the reflectivity is nearly orthotropic. The orange or reddish dust mist or fog observed in the planet's atmosphere is said to warrant the supposition that the surface of the planet is mostly covered with dust which, on account of its color, consists in all probability of powdery limonite or ochre. That this material remains uncemented is said to be a result of the lack of moisture.

146. Smith, A. G. and Carr, T. D.,
RADIO EXPLORATION OF THE PLANETARY SYSTEM, Princeton, Van Norstrand, 1964.

Not abstracted.

147. Smithsonian Astrophysical Observatory, Cambridge, Massachusetts,
THE ROTATION OF THE PLANET MERCURY by G. Colombo and I. I. Shapiro, 15 November 1965, Grant NSG-87-60, NASA-CR-68703; SAO Special Report - 188-R, N66-13573.

Reliable radar observations and some of the generally unreliable optical observations of Mercury are shown to be consistent with its rotating in a direct fashion with a period just two-thirds of its orbital period. This possibility may be understood as a consequence of the combined solar torques exerted on tidal deformations and on a permanent asymmetry in Mercury's equatorial plane, as suggested by Colombo. A simple model illustrating this superharmonic resonance phenomenon is developed in some detail; several alternative paths by which Mercury could have reached its present state of motion are discussed briefly.

148. Soter, S. L.,
MERCURY - INFRARED EVIDENCE FOR NONSYNCHRONOUS ROTATION, Science, Vol. 153, 2 September 1966, pp. 1112-1113, A66-40305.

Review of infrared observation of Mercury as evidence of its nonsynchronous rotation is discussed. Early measurements, if taken at face value, would imply a brightness temperature of about 180° K for the dark side, although this value will undoubtedly be revised downward as further infrared observations are reported. The thermal energy curve for the whole disk of the planet is markedly asymmetrical. It was estimated that Mercury , when west of the Sun, radiates 20 degrees more energy than when east of the Sun. An asymmetrical phase curve may perhaps be explained in terms of the direct rotation of Mercury because the dark portion of the planet observed in western phases has recently rotated out of sunlight and is warmer than the corresponding dark portion in eastern phases.

149. Speed, R. C., Conel, J. E., Kovack, R. L., and Loomis, A. A.,
GEOLOGICAL EXPLORATION OF THE MOON AND PLANETS: LUNAR AND PLANETARY SCIENCES IN SPACE EXPLORATION, 1962, NASA-SP-14, pp. 63-85.

A 1962 state-of-the-art paper concerning the lithospheres of the Moon, Venus, Mars, and Mercury is discussed. Present knowledge is summarized and a discussion of current theoretical models of the planets is presented. Areas in which future research should be directed are outlined.

150. Spinrad, H., Field, G. B., and Hodge, P. W.,
SPECTROSCOPIC OBSERVATIONS OF MERCURY, Astrophysical Journal, Vol. 141, 1 April 1965, pp. 1155-1160, A65-25226.

This paper is a review of evidence for a Mercurian atmosphere. New high-dispersion spectra of the planet Mercury in the near-infrared make it possible to place upper limits on the abundances of CO_2 (< 57 meter-atmospheres), O_2 (< 1 meter-atmosphere), and H_2O (< 30μ precipitable). The strength of the 1.6 -μ absorption band of CO_2 found by Moroz can be explained only if Mercury possesses a considerable atmosphere (P_S > 3.3 millibars) which can pressure-broaden that band. While this lower limit and the obtained upper limit are marginally compatible with a pure CO_2 atmosphere of about 4-millibar surface pressure, such an atmosphere would be accompanied by a Rayleigh scattering which would lead to a polarization six times larger than the amount detected by Dollfus. Admixture of other constituents would be consistent with both spectroscopic observations, and argon in particular would give the smallest discrepancy with Dollfus' polarization observations. The relationship of the pressure estimates obtained to the requirements of the theory which attributes surface features to meteoritic erosion are discussed. It is considered possible that the tenuous atmosphere of Mercury may be time-variable.

151. Spinrad, H. and Hodge, P. W.,
AN EXPLANATION OF KOZYREV'S HYDROGEN EMISSION LINES IN THE SPECTRUM OF MERCURY, <u>Icarus</u>, Vol. 4, April 1965, pp. 105-108, A65-23491.

This paper is an examination of data obtained from several high-resolution near IR spectrograms of Mercury taken through the 120-inch coudé of the Lick observatory. It was found possible to place quantitative upper limits on possible gaseous constituents of the Mercurian atmosphere. A microphotometer tracing is presented which was made of the spectrum. A strong IR Ca II line λ8542 is shown, and double absorption peaks are clear. If the significance of a sky component to the Mercury spectrum were not realized, the hump between the two absorption lines might well suggest an emission core feature, and therefore this spurious core "emission" between the two absorption components of all strong Fraunhofer lines may be the source of Kozyrev's claim of an accreted atomic hydrogen atmosphere.

152. Stephenson, C. B.,
MERCURY IN AUGUST AND SEPTEMBER 1949, <u>Strolling Astronomer</u>, Vol. 4, 1950, pp. 4-7.

Not abstracted.

153. Stolley, J.,
MERCURY SEEN AT DUSK, Science News Letter, Vol. 71, 23 March 1957, pp. 186-187.

Not abstracted.

154. Stolley, J.,
MERCURY VISIBLE BRIEFLY, Science News Letter, Vol. 67, 23 April 1955, pp. 266-267.

Not abstracted.

155. Suess, H. E.,
THERMODYNAMIC DATA ON THE FORMATION OF SOLID CARBON AND ORGANIC COMPOUNDS IN PRIMITIVE PLANETARY ATMOSPHERE, Journal of Geophysical Research, Vol. 67, 1962, p. 1659.

Atmospheres of terrestrial planets lose the hydrogen originally present and produced by photolysis of CH_4, NH_3, and H_2O. With increasingly oxidizing conditions the gases may pass through a phase during which elementary carbon and various organic compounds are thermodynamically stable. Numerical calculation of the equilibrium concentrations of H_2, CH_4, CO, CO_2, and H_2O as a function of total H is difficult, but it has been carried out for various temperatures, pressures, and oxygen/carbon ratios. The results show that at temperatures below 500° K, and in case of an oxygen/carbon ratio of three (or less), a range of total H will exist at which elementary carbon is thermodynamically stable. It seems possible that the surface rocks of Venus contain much more elementary carbon than those of the Earth. This would explain the presence of large amounts of CO_2 in the absence of oxygen on Venus.

156. Suvorov, N. D.,
Die Entstehung des Planeten des Sonnensystems: THE ORIGIN OF THE PLANETS OF THE SOLAR SYSTEM, Naturwiessenchaften, Vol. 48, No. 7, 1961, p. 214.

The planets originated between spectral type stages gF and dF of the sun's evolution, when the sun increased abruptly in mass and decreased in density and angular momentum, with concomitant drastic increase in gravitational acceleration at its surface and decrease in centrifugal force. Probably the

flashing of a nova announces the formation of planets. The ages of the members of the solar system are tabulated as follows: (in 10^9 year): Sun 4.67, Jupiter 2.05, Saturn 2.04, Uranus 2.03, Neptune 2.02, Pluto 2.01, asteroids 1.95, Mars 1.94, Earth 1.91, Venus 1.90, and Mercury 1.88.

157. Urey, H. C.,
THE ATMOSPHERES OF THE PLANETS, Encyclopedia of Physics, Vol. III, Astrophysics, III, The Solar Systems, Berlin, Springer-Verleg, 1959, pp. 363-418.

Not abstracted.

158. Urey. H. C.,
THE PLANETS, THEIR ORIGIN AND DEVELOPMENT, New Haven, Yale University Press, 1952.

Not abstracted.

159. Van Tassel, R. A. and Salisbury, J. W.,
PLANETARY ENVIRONMENTS, Handbook of Geophysics and Space Environment, 1965, N56-10996, 10976 02-13.

Brief descriptions and tabulated data are presented on the environments of Mercury, Jupiter, Saturn, Uranus, Neptune, and Pluto. More detailed information is presented for Venus and Mars and includes discussions on their atmospheres, thermal environments, magnetic fields, surface features, satellites, and other tabulated data.

160. Rand Corporation, Santa Monica, California,
SOME ASPECTS OF THE SURVEY OF THE MAGNETIC FIELD OF THE MOON AND THE PLANETS by H. H. Vestine, December 1962, RM-3140-NASA.

A preliminary plan for magnetic surveys of other planets and the magnetic instrumentation to be employed is described. It is concluded that an impacting probe carrying available instruments together with one or a small number of magnetic observatories on the surface of the planet would be adequate for most scientific purposes. The steady-state magnetic fields of a number of planets and satellites are estimated.

161. Vetterlein, J. C.,
THE PHASE OF MERCURY, Journal of the British Astronomical Association, Vol. 71, 1961, pp. 156-157.

The observer found the phase of Mercury to be less than that extrapolated in the Ephemeris.

162. Wahnl, M.,
THE INNER PLANETS, MERCURY AND VENUS, Astron. Mitt. Urania - Sternwarte, Vienna, Vol. 4, 1961, pp. 30-38.

Not abstracted.

163. Walker, J. C. C.,
THE THERMAL BUDGET OF THE PLANET MERCURY, Astrophysical Journal, Vol. 133, January 1961, pp. 274-280.

Assuming that the interior of Mercury is in thermal steady state, that the specific rate of radioactive heat production in the planet is equal to that in chrondritic meteorites, that the thermal conductivity equals 1.33 cal deg^{-1} min^{-1} and that the Mercury day equals the Mercury year, the surface temperatures on Mercury range from 621°K at the sub-solar point to 28° K at the anti-solar point. These temperatures are relatively insensitive to changes in conductivity and rate of heat production.

164. Watts, C. B. and Adams, A. N.,
RESULTS OF OBSERVATIONS MADE WITH THE SIX-INCH TRANSIT CIRCLE 1925-1941. OBSERVATIONS OF THE SUN, MOON, AND PLANETS. Publications of the U. S. Naval Observatory (2), Vol. 16, Part 1, 1949, pp. 1-55, 138-153.

Not abstracted.

165. Watts, C. B., Scott, F. P., and Adams, A. N.,
RESULTS OF OBSERVATIONS MADE WITH THE SIX-INCH TRANSIT CIRCLE 1941-1949. OBSERVATIONS OF THE SUN, Publications of the U. S. Naval Observatory, Vol. 16, Part III, 1952, pp. 365-445.

Not abstracted.

166. Wegner, G. A.,
AN AMATEUR'S PORTRAIT OF MERCURY, Sky and Telescope, Vol. 23, June 1962, pp. 333-334.

A map of Mercury is presented, together with several sketches. The author notes that lunar markings tend to be circular, while those of Mercury may be less mountainous than the Moon in view of the apparent smoothness of the terminator.

167. Welch, W. J. and Thornton, D. D.,
RECENT PLANETARY OBSERVATIONS AT WAVELENGTHS NEAR 1 CENTIMETER, Astronomical Journal, Vol. 70, No. 2, 1965, pp. 149-150.

Not abstracted.

168. Whipple, F. L.,
EARTH, MOON, AND PLANETS, New York, Grosset & Dunlap, 1958.

Not abstracted.

169. Wood, H.,
OBSERVATION OF SYDNEY OBSERVATORY OF THE TRANSIT OF MERCURY 1957, May 5-6, Observatory, Vol. 77, 1957, p. 149.

Not abstracted.

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13. ABSTRACT

This summary and bibliography is a selection of the more accepted literature from the sizable quantity which covers the range of hypotheses as to rotation of the planet Mercury, temperature, atmosphere, surface, and terrain. Various hypotheses and the few generally accepted facts are discussed. Included is a selected bibliography and author index.

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