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THE ATMOSPHERE OF MERCURY

Wayne E. McGovern

The completion of the investigation mentioned in previous reports on the atmosphere of Mercury, in conjunction with Drs. S. I. Rasool and S. H. Gross, resulted in the following conclusions:

1. An atmosphere of pure argon cannot be stable against gravitational escape since argon with its poor radiative transfer characteristics will produce prohibitively high exospheric tempteratures, ($T_{ex} > 10,000$°K).

2. If Moroz's observations are correct and CO_2 is present in the atmosphere of Mercury, then the production of CO by photodissociation in the upper atmosphere will produce a cooling mechanism of sufficient strength that exospheric temperatures will result which are stable against thermal escape. The calculated exospheric temperatures were between 800°K. and 1800°K. The large tolerance is mainly due to the uncertainty in the value of the solar ultraviolet flux, efficiency factor for the transfer of energy in the atmosphere, the scale height at which CO emission becomes dominant and the level of maximum absorption of ionization energy.

It is interesting to note that if the exospheric temperature is near our lower limit, then the CO_2 on Mercury may be of primordial origin; while an exospheric temperature near 1800°K. would indicate that the observed CO_2 concentration was due to equilibrium between outgassing from the interior and gravitational escape from the top of the atmosphere.

In summaryit is suggested that the presence of CO_2 in the atmosphere of Mercury is an essential condition for any substantial amount of atmosphere to exist on the planet.

A second area of investigation concerning the planet Mercury was the re-analysis of the data concerning the rotation period of the planet. From this review the rotation period of Mercury was narrowed down from the previous 58.4 ± 0.4 days to 58.65 ± 0.10 days.

These conclusions, as well as a summary of polarimetric, spectroscopic and temperature studies of Mercury were incorporated into a paper and submitted jointly with Drs. Rasool and Gross, to Space Science Reviews for publication.

THE ATMOSPHERE OF MARS

Wayne E. McGovern

The Mariner IV occultation experiment, when combined with recent spectroscopic measurements, indicates that Mars' atmospheric pressure is between 5 and 10 mb, with CO_2 a major component in the atmosphere.

Based upon these measurements a temperature profile for Mars was constructed, assuming a surface composition of 8 mb of pure CO_2. Up to 80 km a temperature profile was calculated from the method described by Prabhakara and Hogan (1965), and above this level it was assumed that the dissociative products of CO_2 and CO were in diffuse equilibrium. The results of this investigation indicated that the exospheric temperature of Mars is $550° \pm 150°K$, with the margin of error resulting from the same uncertainties as indicated in the calculations of the exospheric temperatures for Mercury. As in the atmosphere of Mercury, CO was found to be extremely effective in the reduction of exospheric temperatures and on both planets CO appears to act as a "thermostat" in controlling the exospheric temperature.

A further investigation of the Mariner IV occultation experiment indicated that the electron-density scale height above 125 km on Mars was 25 km; and if the principle ion is 0^+, then for an isothermal atmosphere the temperature would be 85°K, a surprisingly low result. However, for an atmosphere with a lapse rate other than zero, and in hydrostatic equilibrium the actual and isothermal scale heights, H and H' respectively, are related by the following equation:

$$H = \frac{H'}{1 - \frac{H'}{T}\frac{\partial T}{\partial Z}}$$

where

T = Temperature

$-\frac{\partial T}{\partial Z}$ = Lapse rate

Our results indicated a lapse rate of 2°K km^{-1} at 125 km and a temperature of 180°K; a result consistent with the occultation experiment, because our model is an average for the planet while the occultation experiment was at 55°S, winter hemisphere, local afternoon.

These results and their possible implications were prepared in conjunction with Drs. S. I. Rasool and S. H. Gross and were published in Science, 151, p. 1216.

Joseph S. Hogan

The study of the Martian atmosphere described in previous reports was continued with attention being given to the problem of photochemical and diffusive processes and their interaction.

It is well known that CO_2 will dissociate in the presence of solar ultraviolet radiation into CO and O and that, as a result of various recombination processes, O_2 and O_3 may be produced. Since sizeable quantities of CO_2 are present in the atmosphere of Mars, and since this constituent and its photochemical products are important heating and cooling agents throughout the atmosphere (Prabhakara and Hogan, 1965), an accurate estimate of the height distribution of these gases is prerequisite to the determination of the temperature structure.

Therefore, a numerical scheme was developed to calculate the vertical distribution of CO_2 and its products for any desired structure of atmospheric pressure and temperature, for the case of pure photochemical equilibrium. The scheme employs a doubly iterative procedure incorporating the standard Newton-Raphson technique to obtain a convergent solution for the concentrations of the five gases simultaneously. A method was also found for making an arbitrary first approximation to the solution a "good" one so that the scheme converges very rapidly. A partially analytic solution was also found for the case when only photochemical processes act, but its extreme complexity as compared with the speed of the totally numerical method discouraged its use. Therefore, the numerical procedure was used to test the sensitivities of the equilibrium photochemistry to changes in the values of the various input parameters.

However, this scheme in itself was seen to be inadequate for calculating the composition as a function of height on Mars since diffusive processes also play an important role in determining the chemical structure of the upper atmosphere. Therefore, a study of molecular diffusion of the photochemically produced gases in the Martian atmosphere was undertaken.

In the case of pure diffusive equilibrium when no photochemical sources and sinks are present the expected analytic solution was found with each constituent present distributed according to its own scale height. This case and the case of pure photochemical equilibrium represent two extremes, with the more realistic case, in which both photochemical and diffusive processes operate, lying between the two.

For the situation in which both photochemical and diffusive processes act together and are in equilibrium so that there is no net change in the concentrations of the various constituents with time, an extremely complicated system of five second-order inhomogeneous partial differential equations was derived. For the case in which the fractional concentration of carbon dioxide in the atmosphere is less than approximately 0.1, four of these equations may be considered linear while one remains nonlinear. When carbon dioxide comprises more than ten percent of the atmosphere, all five equations are nonlinear. At the present time a numerical technique is being sought to solve this system of equations for the equilibrium concentrations of the important constituents of the Martian atmosphere. This solution will eventually become a part of a larger scheme designed to compute an equilibrium temperature structure.

DARK SIDE EMISSION FROM VENUS - THE ASHEN LIGHT

Joel S. Levine

The ashen light is a faint luminous glow observed from time to time on the dark or unlit portion of Venus. Several investigators have tried to explain the origin of this luminous glow:

1. It has been suggested that the ashen light is an auroral phenomenon in the atmosphere of Venus (Moore, 1959).
2. The ashen light may arise from lightning discharges near or even below the clouds on Venus (Chamberlain and Goody, 1965).
3. It has also been suggested that a layer of ice is responsible for the ashen light (Barker, 1954).

We have collected and analyzed the total number of observations of the ashen light phenomenon from 1959 to 1962 - altogether 49 independent and confirmed observations. The method of analysis has previously been described (Hiam Report, June-November 1965, p. 5).

Our study has shown that there is a statistically significant increase in geomagnetic index at inferior conjunction (when Venus is in a direct line between the sun and earth) at times of ashen light occurrence. This is contrary to the observed tendency of a significant decrease in geomagnetic activity at inferior conjunction in general (Houtgast and van Sluiters, 1962; Bigg, 1963).

If the ashen light is actually an auroral phenomenon on Venus, then we would expect the following to occur:

(1) An increase in geomagnetic activity to follow an ashen light occurrence only when Venus and earth are in a straight line, with respect to the sun, i.e., at inferior conjunction.

(2) A decrease in geomagnetic activity at other times at inferior conjunction, when the solar corpuscular flux is insufficient to produce any auroral activity on Venus, and there is a geometric shielding effect of Venus on the solar particles.

Assumption (2) has been substantiated by Houtgast, Van Sluiters and Bigg, and we have verified (1), at least for the 1959-1962 period.

It is generally assumed that a planetary magnetic field is needed for the auroral process, although the exact nature of the auroral mechanism is not even completely understood in the case of the terrestrial atmosphere (Hess, Mead and Nakada, 1965; and O'Brien, 1965). In the case of Venus, magnetometer data, obtained as Mariner II flew past the planet, at a distance from its center of about 7 planetary radii, gave no evidence of a Venusian magnetic field at any point on the trajectory. However, it is possible that the field may be highly non-polar in character, and would not be detected on the Mariner II trajectory (Hide, 1965).

In conclusion, this study has shown that there was a pronounced increase in geomagnetic activity at inferior conjunction during times of the ashen light occurrence for the 1959-1962 period. We believe that this finding suggests an auroral origin of this glow.

We have submitted for publication a paper describing this entire study to the <u>Journal of the association of lunar and planetary observers.</u>

Assisting on this study were Messrs. Jerry McCaffrey and Robert Michalove, high school students taking part in a research experience program at the School of Engineering and Science, New York University.

26-MONTH OSCILLATION OF OZONE CONCENTRATION

<u>Robert Rabinoff</u>

Temperature data at various heights over the United States and at certain ocean stations have been collected for the purpose of comparing temperature periodicities with the 26-month oscillation of ozone concentration. A computer program is being prepared for a power spectrum analysis of the temperatures. If a significant cycle near 26 months is found, its phase will be compared to the phase of the ozone cycle.

CALCULATION OF AVERAGE SINGLE PARTICLE SCATTERING FUNCTIONS FOR CLOUDS AND AEROSOLS

Howard Cheyney

This study involved extension and rework of a computer program which had been developed by the author while at Lockheed Missiles and Space Corp. The program calculates scattering phase matrices for aerosols and water droplets. The program is based upon Mie theory for spherical particles. The results of these calculations will be used to study the scattering properties of planetary atmospheres and infrared emission and reflection measurements of the planets, including the Tiros measurements of radiation from the Earth's atmosphere. In addition to this rather general program, I specifically propose running computations for a number of different cloud types over the range 0.3 to 18μ. Results of this type could be useful for automatic recognition and analysis of cloud types and patterns from satellite observations.

After some work it developed that, although our results were in substantial agreement with those of other investigators, notably Fraser and Deirmendjian, the program with its present capacity does not reproduce the sharp forward scattering peak due to the large particles in the size distribution. An extension to a very much larger capacity program was undertaken. At the same time, because of the Institute's replacement of their IBM 7094 with a 360/75, a program conversion was necessary. The increased capacity of the 360/75 made it possible to enlarge the program so that it can carry enough terms to handle the large particles. The expansion proved to entail fundamental mathematical difficulties and the conversion proved to be long and tedious because of system difficulties with the 360 and because of the very unsatisfactory compiler available for the 360, but it is now almost complete and ready to go.

CALCULATION OF THE DISTRIBUTION OF SCATTERED RADIATION IN A PLANE PARALLEL ATMOSPHERE

Howard Cheyney

This work centered primarily on various techniques for numerical integration of the transport equations. Numerical solutions for isotropic and Rayleigh phase functions are obtainable in a straightforward manner by many techniques that have been developed in the last 20 years. Extension to the case of highly anisotropic (sharply peaked) phase functions - representing aerosols and cloud particles - presents numerical problems which have not been completely solved. One particular method that is being investigated looks very promising and it may produce accurate answers with much less computer time than conventional methods. This is the component method developed by Chandrasekhar for the Rayleigh phase function. The extension to more general phase functions is proceeding satisfactorily and should be in a form ready for programming in a few weeks.

HEAT BUDGET OF THE EARTH

Richard O. Mackie

Rasool and Prabhakara (1965) found from Tiros radiation data that the earth was nearly in radiative equilibrium with respect to the hemispheres. Actually, there was a slight difference which would indicate a net transfer of heat across the Equator. This is quite small when compared with the incoming and outgoing radiation. Consider the effect of latent heat carried by water vapor across the Equator. Use of latitudinal and monthly values of evaporation and precipitation for the hemispheres indicated an excess of evaporation over precipitation in the Southern Hemisphere (0°-50°S) leading to a net latent heat storage. This indicates a northward flux will be present. As a result, the northward flux should be compensated by a southward transport of heat across the Equator by the atmosphere and oceans.

Bryan (1962) suggested that there may be a net southward transport of heat across the Equator by the ocean currents. The results of Rasool and Prabhakara indicated that Bryan's suggestion may be valid. The main months of southward transport occur during the months of March to November according to their study.

At this point, the work conducted by Bryan was examined. It was concluded, after a study of the current systems in the Pacific and Indian Oceans, that the Indian Ocean would prove a more interesting case to approach. The Atlantic was ruled out because the current system showed quite predominantly a northward transport. A word should be said about the area to be explored. The region extends from 20°N to 20°S. The area was selected for two reasons: (1) little or no data on oceanic transports exist; (2) Rasool and Prabhakara's results suggest that the transport begins in this region. Of the Pacific and Indian Oceans, the Pacific doesn't seem to be too promising from ocean-current considerations.

Bryan (1962) formulated a method to determine heat transport by the transfer of thermal energies alone. Jung (1952) showed this approximation to be very accurate for all forms of energy. The total energy transport is approximated by

$$\int_{o}^{l} \int_{-H}^{o} C_p \, \theta \, \rho v \, dx \, dz$$

where x is the east-west direction, z is the vertical and v the meridional velocity, θ is the potential temperature, and ρ is the density. Since direct measurements are not available, a method using oceanographic station data and climatological wind stress calculations to compute the currents indirectly was obtained.

At the present time, the only difficulty remains in getting the data from the Indian Ocean area.

THE EARTH'S ALBEDO

Joel S. Levine

The determination of the earth's albedo is of fundamental importance in meteorology in order to determine the energy balance of our planet and atmosphere. The capability to observe reflected and scattered solar radiation, as well as terrestrial infrared flux by Tiros satellites has given scientists their first opportunity to determine the planetary albedo on a continuous time basis (Rasool and Prabhakara, 1965; NASA, 1966).

The value for the planetary albedo, as measured by the Tiros satellites (Tiros II, III, IV and VII) has been consistently lower, by about a factor of two, than expected from theoretical methods, as well as other observational techniques [Nordberg (1963) obtained a planetary albedo of 17-18 percent based on Tiros III data; Bandeen, Halev and Strange (1965) found a planetary albedo of 20.1 percent based on Tiros VII data; compared with an "expected" planetary albedo of about 35 percent (London, 1957)]. There may be two possible reasons or a combination of them, to account for the low Tiros values of the planetary albedo:

(1) In all Tiros radiometers (both visible and infrared channels) there has been a steady degradation observed in the instrumental response with time. The reason for this deterioration in instrumental response is not known, but may be due to the space environment.

(2) Investigators using Tiros visible radiation data have assumed that the scattering and reflection of solar radiation by the earth's surface and by the atmosphere is isotropic. Under the assumption of isotropy, the reflectance and the albedo are the same. However, it has been pointed out that appreciable errors may result, if the angular dependence of the reflected and back scattered solar radiation is not included (Arking, 1964).

DEGRADATION OF THE TIROS VII RADIOMETERS

Three methods are being used to determine the rate of degradation of the radiometers on Tiros VII:

1. Robert Rabinoff

It has been noticed that the readings of two of the radiometers have dropped off steadily with time. By fitting a linear regression equation to the readings, we hope to be able to make useful corrections to the observed data.

2. Stanley E. Wasserman

We are attempting to make a quantitative statement about the degradation of the channel 2, 8-12μ, radiation values obtained by Tiros VII.

The method is a comparison of the uncorrected channel 2 temperatures, as derived to fit the radiation energy received, with sea water temperatures reported in ship reports that have also reported clear skies. It is hoped that a chronological comparison of the two values will reveal information about the degradation.

The first attempt was an evaluation of the weather reported by the weather ship "E" in the Atlantic and the weather ship "N" in the Pacific. Data was evaluated for the period beginning with the Tiros VII launch date of June 19, 1963 and terminating in August 1964. Searching through the ship's weather reports, hour by hour, for ship "E", only 300 hours of clear skies prevailed during which time there were only five cases with simultaneous Tiros VII radiation measurements. For ship "N" there were only 111 hours of clear skies during the 14 month period and only two cases with simultaneous Tiros VII radiation measurements.

The total number of seven cases was far too few to conduct the originally intended investigation. Additional data was requested from the Weather Record Center, this time for observations taken by transient ships in the Mediterranean Sea. The data arrived in the latter part of May. It consists of observations taken by many ships for the months of June, July, August and September 1963, and the same months in 1964. A preliminary investigation revealed that the Mediterranean Sea has a high frequency of cloud-free hours during these months, and a glance at the ship data substantiated this. Currently the dates, times and locations of the ships reporting clear skies are being tabulated. It is hoped that when the information is fed into a computer storing the radiation data, a sufficient number of simultaneous Tiros VII radiation measurements will be found.

Further evaluation is being carried out for the seven good cases found for ships "E" and "N". From this evaluation it is hoped that limits can be established for acceptable nadir angles. In the 8-12μ region there is some absorption by water vapor. If the nadir angle is too large, the effects of any degradation would be masked out by the absorption of energy by water vapor. In the original attempt to utilize the stationary weather ships "E" and "N", it would have been possible to make statements about the total amount of water vapor present in the troposphere. Radiosonde observations are taken four times daily by these weather ships. Observations of the water vapor present in the troposphere above the transient ship locations are not available.

3. Joel S. Levine

For the case of Tiros VII, degradation in the visible channel 5 (0.55 to 0,75μ) it was found that under the assumption of annual planetary radiative equilibrium, the planetary albedo required to balance the outward terrestrial infrared flux, based on the 8 to 12μ channel (whose instrumental response was also deteriorating), was 32.2 percent, as compared to the actual planetary albedo of 20.1 percent based on Tiros VII reflectance observations (Bandeen et al., 1966). The ratio of the infrared-inferred albedo (under the assumption of annual planetary radiative equilibrium) to the actual observed albedo (reflectance, under isotropic assumption) is 32.2/20.1 or 1.60. The degradation correction for the channel 5 data of Tiros VII has the form: $\overline{W} = K^i[W^1 + \rho^i]$ where W^1 is the effective radiant emittance actually observed by the satellite, $\overline{W}$ is the corrected value, K^i and ρ^1 are normalizing factors that depend on the orbit number that the measurements were made on, i.e., for orbit number 1 (June 19, 1963).

$K^i = 1.60$ and increases linearly with each orbit to about $K^i = 2.23$ for orbit number 6400 (August 25th, 1964); and ρ^i is close to zero for this period (Staff Members, 1964, 1965).

We are analyzing Tiros VII visible data to check the validity of the degradation corrections based on the assumption of annual planetary radiative equilibrium, as well as looking into the non-isotropic nature of the scattered and reflected solar radiation. In order to minimize variations in the reflecting surface (ground albedo) and cloud-cover, we have begun to analyze data over a relatively cloud-free uniform surface, the Sahara desert (18°N to 30°N and 10°W to 30°E). To determine the angular dependence of the scattered and reflected solar radiation we are using a technique devised by Dr. A. Arking, which gives the reflectance as a function of the solar angle, satellite angle and the relative azimuthal angle between them. We have also divided the Sahara desert into 1° x 1° and 4° x 4° regions, and based on our energy-angle distribution study have determined a number of small angular intervals over which we can safely assume isotropy. By comparing these smaller regions over a 12-month period, we hope to be able to determine some new degradation corrections, without the assumption of annual planetary radiative equilibrium, as had been done earlier, and then use the new corrections to calculate the earth's albedo under non-isotropic conditions.

OPTICAL CONSTANTS OF AMMONIUM SULFATE AND SULFURIC ACIDS

Eugene E.A. Chermack

During the past six months most of the research on this project has been devoted to design and checking of the sampling apparatus and procedures.

In the last report it was mentioned that in addition to ammonium sulfate, sulfuric acids were to be studied. It was anticipated that cell design for transmission studies of the acids might present difficulties due to the acid's extremely corrosive nature. The cell decided upon is a very simple fixed thickness cell consisting of teflon spacers which will comprise the body of the cell (and control the thickness) and IRTRAN-2 windows. Teflon resists all strong acids extremely well and IRTRAN-2, while possessing some slight disadvantages, is also extremely resistant to corroding acids, specifically H_2SO_4. IRTRAN-2, while a good transmitter far into the infrared, has an unfortunately high refractive index ($n \sim 2.3$). This high index will cause a large reflection loss in two cell windows; however, because of IRTRAN2's generally good transmittance, sufficient energy will pass the cell for sampling needs. Windows and spacers have been purchased.

In order to obtain the reflectance spectra of the liquid samples (H_2SO_4) the standard reflectance apparatus had to be reoriented, re-aligned and the monochromator source refocused. This was accomplished, and in order to check the new alignment and orientation a reflectance spectrum of liquid water was run. Results of this run compared favorably with values of IR water reflectance cited by Centeno (1941) so that it appears that this reflectance system will work. It will be necessary to provide an exhaust hood for the sample work and a slight positive dry nitrogen pressure through the monochromator in order to protect the monochromator and reflectance optics from the acid sample fumes.

Trial reflectance and transmission measurements have also been run on the solid sample (crystals of $(NH_4)_2SO_4$). Initially a reflectance spectrum was taken for a crystal of 2 mm thickness. Results of this experiment are in good agreement with a reflectance curve for ammonium sulfate which appears in R. W. Wood's Physical optics. Trial transmission measurements thus far have yielded no data beyond the 5-6μ region. There are at least two reasons for this. Beyond about 5μ sample emission seems to be a significant part of the signal and thus it becomes difficult to separate transmitted radiation from emitted radiation. Transmission can be enhanced by going to thinner samples and/or optically flatter samples. The samples were returned to the vendor (Semi-Elements, Inc.) for reduction in thickness and polishing to 3-wavelength flatness. These adjustments have been made and the new crystals are in the process of being checked. In addition the samples will be cooled during spectral runs in order to minimize the emission of radiation. Sample thinning and cooling thus should combine to yield a more favorable transmission-to-emission ratio and transmission measurements will be pushed out beyond 6μ.

ATMOSPHERIC BREAKING WAVES

(Abstract of Ph.D. Disseration, New York University)

Richard S. Greenfield

An attempt has been made to investigate the effect of a sloping lower boundary on one particular feature of a disturbance generated on an inversion by an acclerating front. The feature considered is the point at which the leading edge of the disturbance first becomes vertical. This point has been called the breaking point or the point of initiation of the pressure jump.

By neglecting the compressibility of the air, friction, earth's rotation, non-hydrostatic pressure variations and motions in the upper layer, a two layer model is described by a system of hyperbolic non-linear partial differential equations. The disturbance is generated on the interface by an accelerating piston acting as an idealized analogue of a front. By means of the method of characteristics the equations are put in a form which permit an analytical solution for the breaking point.

The effect on the breaking point of the slope of the inclined plane lower boundary is examined through the derived solution. The results indicate that for a given effective gravitational acceleration, g', and negative slope, s, there is a minimum frontal accleration, α, required for breaking to occur. Moreover a positive slope is a realistically important factor in determining the breaking point only when the dynamic parameter, $g's/2\alpha$, is of the order of unity.

Despite the highly restrictive nature of the model, it is believed that the results are qualitatively applicable to the atmospheric phenomenon, namely, the initiation of a pressure jump.

James E. Miller
Principal Investigator

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