**NASA TECHNICAL MEMORANDUM**

NASA TM X-53138

September 30, 1964

NASA TM X-53138

N65-12316

(ACCESSION NUMBER)

23

(PAGES)

TMX 53138

(NASA CR OR TMX OR AD NUMBER)

(THRU)

1

(CODE)

30

(CATEGORY)

FACILITY FORM 602

# THE THERMAL ENVIRONMENT OF THE TERRESTRIAL PLANETS

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GPO PRICE $ ________

OTS PRICE(S) $ ________

Hard copy (HC) $1.00

Microfiche (MF) 0.50

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*George C. Marshall Space Flight Center, Huntsville, Alabama*

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(Supplement 4)

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Klaus Schocken

## ABSTRACT

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An atmosphere of Mercury of a light gas such as hydrogen would hardly seem 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 98 $\mu$ deep. The uncertainty amounts to $\pm$ 5%.

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.

Denoting the water content of the Martian atmosphere along the vertical by W , the following value was found:

$$W(H_2O) = 14 \pm 7\mu .$$

The following value has been obtained for the surface pressure P:

$$P = 25 \pm 15 \text{ mb}$$

Author

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SPACE THERMODYNAMICS BRANCH

RESEARCH PROJECTS DIVISION

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## SUMMARY

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The amount of water in Venus' atmosphere above its cloud layer is equivalent to a layer of liquid water 98$\mu$ deep. The uncertainty amounts to $\pm$ 5%.

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.

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Denoting the water content of the Martian atmosphere along the vertical by W , the following value was found:

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## I. MERCURY

The microwave temperature has been derived in the 3.5 cm region under the assumptions that the emission is thermal, that the contribution of radiation from the dark hemisphere is negligible, and that the zenith-angle dependence can be specified as $T = T_O \cos^{\frac{1}{4}} \theta$, where $T_O$ is the temperature at the subsolar point and $\theta$ is the angle between the local planetary normal and the angle of incidence of solar radiation. The value of the resulting temperature is $T_O = 1050 \pm 350°K$. This value should be compared with the average temperature over the illuminated disk obtained from infrared radiation measurements of 611°K [1].

The changes in the contours of Mercury's hydrogen lines establish the presence of atomic hydrogen on the planet. At moderate temperatures, the hydrogen would be in molecular form. But the unexcited hydrogen molecule has no infrared absorption bands, so it would be unable to absorb thermal radiation from the planet's surface. 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. This low temperature is confirmed by spectroscopic observation of the planet's vicinity.

From a theoretical point of view, an atmosphere of this planet of such a light gas as hydrogen would hardly seem 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. To make up losses, a long-term average influx of 100 particles per $cm^3$ is provided by the solar corpuscular radiation, which is composed mainly of protons moving at about 1 000 km $sec^{-1}$. Without this compensation, Mercury's atmosphere would dissipate in $10^5$ years.

Other gases may occur in Mercury's atmosphere, by escape from the interior of the planet. But they can form only a small fraction, because otherwise the atmosphere could not be cold and would have lost the properties ensuring its stability [2].

## II. VENUS

High-resolution brightness-temperature contour maps have been constructed on four successive nights. Preliminary results have been reported in Supplement 2, MTP-RP-63-6.

The observations were collected at the east-arm Cassegrain focus of the 200-inch telescope during the morning twilights of December 14-17, 1962.

The mean brightness temperature for the center of the disk on the four nights was $208^\circ K \pm 2^\circ$ (s. d.), about $28^\circ K$ lower than the commonly accepted value. The importance of the observations is not in the absolute value of the central temperature, but in the two-dimensional picture of the infrared radiation of Venus.

Figures 1 to 4 display the brightness temperature contour maps for the four nights of observation. Features common to all maps are: (1) a general decrease in brightness from center to limb; (2) no night-to-day effect except a very slight wedging of the contours, diverging toward the dark side; (3) a bilateral symmetry of the contour pattern about the diameter in the orbital plane. The map for December 15 shows a well-defined hot area whose existence was also evident on a declination scan across Venus the same morning. Because of the temporal and geographic variation of this anomalous feature it fulfills the usual definition of a storm [3].

On February 21, 1964 observations on the water vapor content of the Venus atmosphere were made during a daylight balloon ascent to about 26 700 m in New Mexico. The planet was observed spectroscopically with a 16-inch primary mirror for two hours. Later, the gondola descended by parachute, and the next day the data recorder was recovered intact. During the observations, the telescope was above all but 0.03% of the terrestrial water vapor. The spectrometer

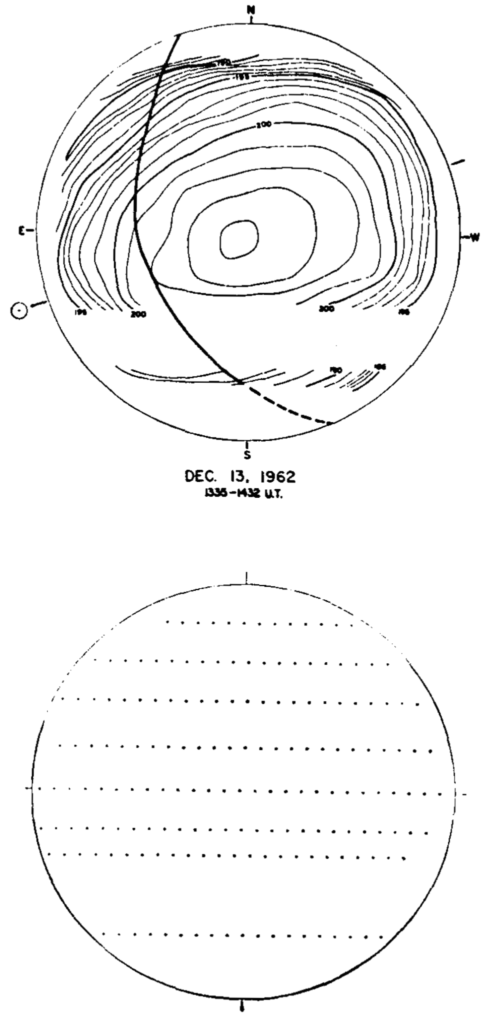


Fig. 1 - Eight- to 14-micron brightness-temperature map of Venus for the morning of December 13, 1962. Lower chart indicates location of data points used to construct map. The terminator and the projected direction to the sun are indicated, respectively, by a heavy line and by the symbol for the sun. The brightness temperatures shown are systematically $7^{o}$ to $28^{o}$ (?) K too low because of uncertain telescope transmission losses.

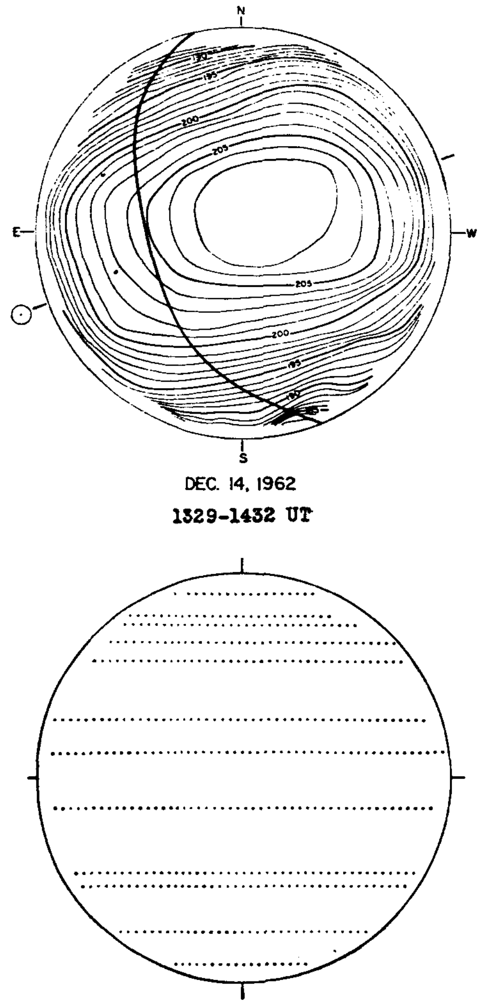


Fig. 2 - Eight- to 14-micron brightness-temperature map of Venus for the morning of December 14, 1962. Lower chart indicates location of data points used to construct map. The terminator and the projected direction to the sun are indicated, respectively, by a heavy line and by the symbol. The brightness temperatures shown are systematically $7^{\circ}$ to $28^{\circ}$ (?) K too low because of uncertain telescope transmission losses.

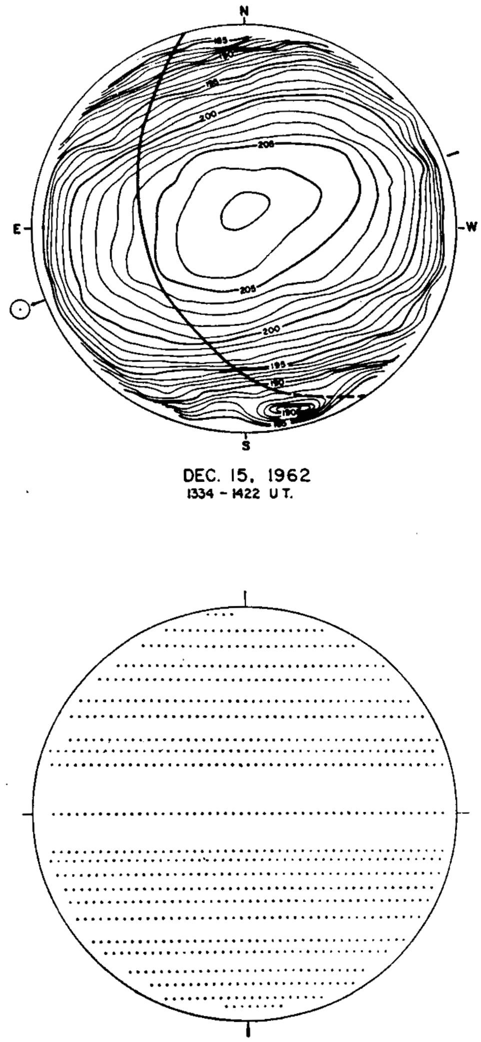


Fig. 3 - Eight- to 14-micron brightness-temperature map of Venus for the morning of December 15, 1962. Lower chart indicates location of data points used to construct map. The terminator and the projected direction to the sun are indicated, respectively, by a heavy line and by the symbol. The brightness temperatures shown are systematically 7° to 28° (?) K too low because of uncertain telescope transmission losses.

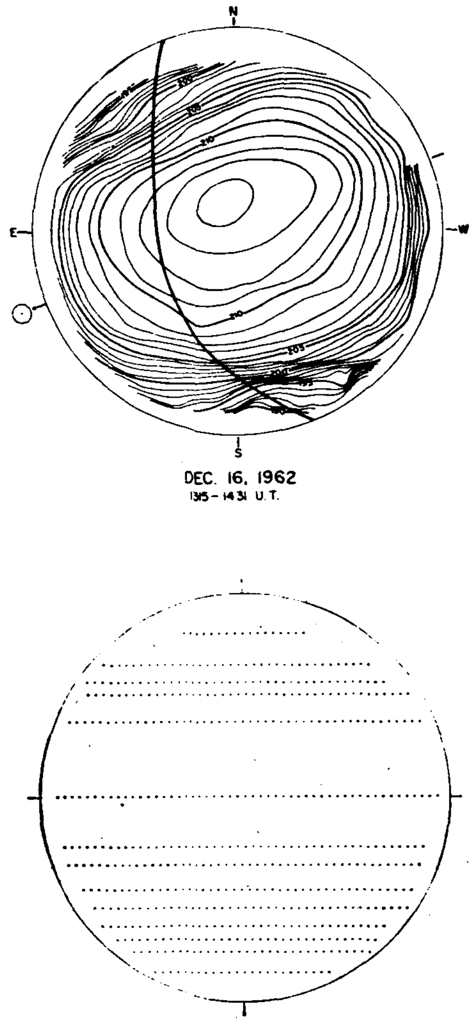


Fig. 4 - Eight- to 14-micron brightness-temperature map of Venus for the morning of December 16, 1962. Lower chart indicates location of data points used to construct map. The terminator and the projected direction to the sun are indicated, respectively, by a heavy line and by the symbol. The brightness temperatures shown are systematically $7^{\circ}$ to $28^{\circ}$ (?) K too low because of uncertain telescope transmission losses.

scanned Venus infrared spectrum in the region of the water vapor absorption band at 1.13 microns.

It was found that the amount of water in Venus' atmosphere above its cloud layer is equivalent to a layer of liquid water 98 microns deep. The uncertainty amounts to $\pm$ 5%. J. C. Strong suggests that the clouds of Venus might well be composed of water [ 4 ].

## III. EARTH

An analysis of the monthly mean humidity data from the USSR and from Sweden covering the period January 1961 to May 1962 reveals the following:

(1) The highest concentration of water vapor in the lower stratosphere is found near the summer pole and attains values of about 200 to 300 mg $kg^{-1}$ at the 100 mb level (16 km).

(2) There exists an annual cycle in the water vapor concentration at all stations to the north of latitude 45°N with a maximum in summer and a minimum in winter.

(3) The amplitude of the annual variation is the highest near the summer pole and decreases with decreasing lititude.

(4) Water vapor mixing ratio increases with altitude for the greater part of the year at the high latitude stations.

(5) The annual cycle of mixing ratio in the antarctic stratosphere is similar to those in the Arctic in the corresponding season.

(6) At stations to the south of about latitude 45° there is a reversal in the phase of the annual cycle.

These observed features cannot be accounted for by the prevailing concept that the entire water vapor in the lower stratosphere has its ultimate source in the earth's surface. A secondary source of water vapor in the upper 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 water vapor formed at high levels could be transported downward by turbulence [5].

An experiment on the first Orbiting Solar Observatory (OSO-I) produced data on the albedo of the earth. Because solution of the albedo equation requires knowledge of the earth radiation, the average of the previously deduced values was employed, 327.4 watt $m^{-2}$. The values of the albedo are presented in Table I as a function of date, latitude, longitude, and station near which the satellite was located at the times of data acquisition [6].

## IV. THE MOON

Using a pyrometer attached to the 42-inch Lowell reflector, the temperature of Tycho was observed during the total eclipse on September 5, 1960. The measurements were made with a 1.5-M bandwidth at 8.8 M, and calibration was made by direct comparison with blackbodies of known temperature. The curve for thick dust agrees well with measurements of the Tycho environment. From the observed eclipse temperature of Tycho, the thickness of the dust layer is 0.3 mm [7].

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.

The lunar surface layer is porous with many interconnecting cavities into which light from any direction can penetrate freely. Cavities occupy the volume of the layer to the order of 90%. The objects composing the surface are larger than a wavelength of light, absorb 70% or more of the light incident on them, and are opaque, with rough surfaces. Few objects which either are semitransparent or have smooth surfaces can be present. Differences in brightness of various areas on the moon are caused by variations in the absorbing properties of the objects. These variations are due to differences of the chemical composition and of times of exposure to the darkening effect of solar corpuscular radiation.

TABLE I

Albedo Values Deduced from OSO-I Measurements

| Date | Station | Latitude of OSO deg | Longitude | Albedo % |
|---|---|---|---|---|
| March 8, 1962 | Quito, Ecuador | -6 | -75 | 23 |
| March 9, 1962 | Quito | 5 | -74 | 26 |
| March 10, 1962 | Ft. Myers, Fla | 23 | -86 | 12 |
| March 11, 1962 | Quito | -2 | -78 | 23 |
| March 11, 1962 | Antofagasta, Chile | -22 | -69 | 20 |
| March 12, 1962 | Quito | -5 | -81 | 23 |
| March 12, 1962 | Antofagasta | -24 | -71 | 27 |
| March 13, 1962 | Lima, Peru | -10 | -80 | 17 |
| March 13, 1962 | Antofagasta | -27 | -71 | 28 |
| March 19, 1962 | Antofagasta | -23 | -73 | 38 |
| April 3, 1962 | Antofagasta | -26 | 67 | 34 |
| April 16, 1962 | Ft. Myers | 27 | -88 | 23 |
| April 16, 1962 | Ft. Myers | 32 | -83 | 20 |
| April 19, 1962 | Ft. Myers | 32 | -84 | 25 |
| April 21, 1962 | Ft. Myers | 30 | -87 | 10 |
| April 23, 1962 | Ft. Myers | 25 | -82 | 19 |
| May 3, 1962 | Quito | -1 | -82 | 20 |

These requirements exclude a surface of bare rock perforated by cracks or craters, and also layers of volcanic foam, since in such materials the cavities are isolated. However, finely divided dielectric powders can build a dendritic surface with the required topography. The photometric properties of the moon can be accounted for by a layer of darkened, pulverized rock dust covering the lunar surface [ 8 ].

The aging process of the rayed craters involves not only darkening but a change from conducting to insulating surface conditions; it also produces a change from a very rough surface to a smooth one on a meter scale. The smoothing and insulating effects require weathering, erosion, transport, and sedimentation processes to occur on the present lunar surface over a range of at least 10 m. The redistribution processes appear to be contained in the 0.01 to 1 km range [ 9 ].

Proton bombardment causes the achondritic enstatite meteorites to luminesce brightly over a broad range of wavelengths near 6 700 A. It seems possible that this red glow might occur in regions of the moon where meteoritic material is present [ 10 ].

Twice on the night of November 1-2, 1963, a large region on the moon near the crater Kepler glowed red, as recorded on photographs made at Pic du Midi Observatory. The area affected was about 0.17 of the lunar surface, more than 60 000 $km^2$ . At the peak of the second brightening, the relative enhancement in red light amounted to 86 $\pm$ 3% for the Kepler region.

The inadequacy of alternative hypotheses suggests solar activity as the cause of the short-lived enhancements. On November 1, two small flares appeared on the same part of the sun. If these flares were responsible, the sun-to-moon travel time would be about $8\frac{1}{2}$ hours, leaving the possibility of solar corpuscular radiation traveling 5 000 km $sec^{-1}$. To provide enough energy for the observed luminescence, about 500 protons $cm^{-3}$ would suffice, if they moved at that speed. The observed event, however, can be related to a large number of possible flares on the sun, with time delays ranging from a few hours to several days. A decision can be made only after a statistically significant number of events on the moon has been observed [ 11 ].

Kozyrev's observation of the Swan band with maximum intensities at 4737 and 4715 A being emitted by $C_2$ molecules emanating from the lunar crater Alphonsus on November 3, 1958 at 01 h U. T. is now widely accepted, but his assertion that the gas evolved as a result of volcanic eruption is not generally accepted. There exist more plausible explanations than volcanic eruption to account for the gas emanating periodically from Alphonsus. It is possible that Kozyrev observed outgassing from the major fault bisecting Alphonsus, and that the gas had its source deep within the moon's surface where it is slowly being ejected as a result of radioactive heating. Urey has pointed out the black areas on the crater floor of Alphonsus and suggests they may be due to explosion of acetylene which could produce graphite and hydrogen; the source of the acetylene could be a stable solid carbide such as calcium carbide. The only positive evidence for a specific molecule present on the moon is one which exists there probably in a small quantity [12] .

## V. MARS

In Supplement 3 (TMX-53016), probably limits established by Schilling for the variation of atmospheric pressure and density in the upper atmosphere of Mars up to 2 700 km above the surface were reported. The numerical model integrations were extended upward by limiting the calculations to the probably radial distribution of the atmosphere in the equatorial plane of Mars. Numerical results were obtained for atmospheric pressure and mass density to altitudes of 7 000 km above the equatorial surface for a series of possible models. At an altitude of 6 000 km above the equatorial surface, the limits of probable extreme values of atmospheric mass density ranged from $3 \cdot 10^{-15}$ to $6 \cdot 10^{-19}$ g cm$^{-3}$, with the values tending to fall toward $10^{-16}$ g cm$^{-3}$ for the exospheric temperature and composition regimes most likely to exist.

The calculations assumed the following planetary properties for Mars:

planetary mars $6.43484 \cdot 10^{26}$ g

equatorial radius, 3 380 km

angular rotation $7.08822 \cdot 10^{-5}$ rad sec$^{-1}$

mean atmospheric surface temperature over equator, between 250° to 300° K

mean atmospheric surface pressure over equator,

between 85 and 133 mb;

and of Phobos:

radius 8 km

semimajor axis of orbit 9348 km

orbital inclination from planet's equator 1.8°

orbital excentricity 0.019

[13].

In Supplement 3 (TMX-53016), a preliminary value for the water content of the Martian atmosphere was given. From the same measurement, a more precise value has been established. Denoting the amount of water along the vertical by W, the following value was found:

$$W(H_2O) = 14 \pm 7 \text{ M}$$

The following value has been obtained for the surface pressure:

$$P = 25 \pm 15 \text{ mb}$$

The abundances likely to be present in the Martian atmosphere are shown in Table II. The assumption has been made that the net $A^{40}$ content of Mars's atmosphere is to that of the earth as the ratio of the corresponding planetary masses [14].

## VI. INTERPLANETARY SPACE

The most effective range of the X-ray spectrum in terms of its ionospheric effect appears to be the wavelength band from 1 to 8 Å, in which the dependence of X-ray emission on the quality of solar activity is summarized by Table III.

The best available flux data on solar ultraviolet emission lines between about 1 900 and 100 Å are summarized in Table 4 [1].

TABLE II

Surface Pressures for the Possible Major Constituents of the Martian Atmosphere

| Pressure | Low | Mean mb | High |
|---|---|---|---|
| $CO_2$ | 6 | 4 | 3 |
| $A^{40}$ | 2 | 2 | 2 |
| $N_2$ | 2 | 19 | 38 |
| Total | 10 | 25 | 40 |

TABLE III

X-ray Intensities for Various States of Solar Activity for Wavelength Intervals ± 1 Å Centered at the Indicated Wavelengths

| | 2 Å | 4 Å<br>watt $cm^{-2}$<br>$10^{-7}$ | 6 Å |
|---|---|---|---|
| Completely quiet | $10^{-8}$ | $10^{-7}$ | $10^{-6}$ |
| Quiet | $10^{-7}$ | $10^{-6}$ | $10^{-5}$ |
| Slightly disturbed | $10^{-6}$ | $10^{-5}$ | $10^{-4}$ |
| Disturbed | $10^{-5}$ | $10^{-4}$ | $10^{-3}$ |
| Flares, Class 2 | $10^{-4}$ | $10^{-3}$ | $10^{-2}$ |
| Flares, Class 3 | $10^{-3}$ | $10^{-2}$ | $10^{-1}$ |

TABLE IV

Intensity at 1 AU Produced by the Strongest Solar Emission Lines

| λ Å | Flux watt $cm^{-2}$ $10^{-7}$ |
|---|---|
| 1892.03 | 0.10 |
| 1817.42 | 0.45 |
| 1808.01 | 0.15 |
| 1670.81 | 0.08 |
| 1657.00 | 0.16 |
| 1640.47 | 0.07 |
| 1561.40 | 0.09 |
| 1550.77 | 0.06 |
| 1548.19 | 0.11 |
| 1533.44 | 0.041 |
| 1526.70 | 0.038 |
| 1402.73 | 0.013 |
| 1393.73 | 0.030 |
| 1335.68 | 0.050 |
| 1334.51 | 0.050 |
| 1306.02 | 0.025 |
| 1304.86 | 0.020 |
| 1302.17 | 0.013 |
| 1265.04 | 0.020 |
| 1260.66 | 0.010 |
| 1242.78 | 0.003 |
| 1238.80 | 0.004 |
| 1215.67 | 5.1 |
| 1206.52 | 0.030 |
| 1175.70 | 0.010 |
| 1139.89 | 0.003 |
| 1085.70 | 0.006 |
| 1037.61 | 0.025 |
| 1031.91 | 0.020 |
| 1025.72 | 0.060 |
| 991.58 | 0.010 |
| 989.79 | 0.006 |
| 977.03 | 0.050 |
| 949.74 | 0.010 |
| 937.80 | 0.005 |
| 835 | 0.010 |

The sun's spectrum has been mapped to shorter and shorter wavelengths with steadily increasing resolution. Observations were made during two Aerobee rocket flights. On the first one, May 10, 1963, the region from 44 to 630 A was recorded with a grating having 600 lines per mm. On September 20, 1963 spectra from 33 to 188 A were secured with a grating having 2 400 lines per mm.

The line of shortest wavelength is of C VI at 33. 74 A carbon whose atoms have each lost 5 electrons and therefore emit a spectrum analogous to that of hydrogen. Other new identifications include C V at 40. 3 and 40. 7 Å, Si X at 50. 5 and 50. 7, Si XI at 303, and Al X at 333 A. For the most part, the strongest lines are unidentified. Possibly many will prove to be iron in intermediate stages of ionization [15].

## REFERENCES


1. L. Goldberg (ed.): Annual Review of Astronomy and Astrophysics. Vol. 1 Palo Alto, Cal. 1963.

2. N. A. Kozyrev: Sky and Telescope 27: 339-341; 1964.

3. B. C. Murray, R. L. Wildey, and J. A. Westphal: Journ. Geophys. Res. 68: 4813-4818; 1963.

4. Editorial: Sky and Telescope 27: 331; 1964.

5. S. Rangarajan: Nature 197: 1099-1101, 1963

6. J. P. Millard and C. B. Neel: AIAA Paper No. 64-317; 1964.

7. W. M. Sinton: Lowell Observatory Bulletin No. 108, Vol. 5, No. 3; 1960.

8. B. W. Hapke: Journ. Geophys. Res. 68: 4571-4586; 1963.

9. B. C. Murray and R. L. Wildey: Astrophys. Journ. 139: 734-750; 1964.

10. Z. Kopal and T. W. Rackham: Sky and Telescope 27: 140-141; 1964.

11. S. P. S. Anand, L. Oster, and S. Sofia: Nature 202: 1097-1098; 1964.

12. A. J. Cohen: Nature 201: 1015-1016; 1964.

13. G. F. Schilling: Journ. Geophys. Res. 69: 1825-1829; 1964.

14. L. D. Kaplan, G. Muench, and H. Spinrad: Astrophys. Journ. 139: 1-15; 1964.

15. American Astronomers Report: Sky and Telescope 27: 213-216; 1964.

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TM X-53138

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Office. This report, in its entirety, has been determined to be unclassified.

Gerhard B Heller

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