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Ultraviolet Spectral Radiant Energy Reflected From the Moon

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Results are given of some measurements on the ultraviolet and short-wavelength visible spectral radiant energy reflected from the surface of the full moon, made from October to December 1952, at Washington, D. C. Although the reflected lunar spectrum contains all the Fraunhofer bands as found in direct sunlight with approximately the same relative intensities in the visible spectrum, intense absorption occurs for some of the ultraviolet wavelengths. Selective absorption for wavelengths in the spectral regions of 380 to 390 millimicrons and less than 360 millimicrons indicates the possibility of a lunar reflecting surface similar to that of powdered glassy silicates.

1. Introduction

Man has long speculated about the moon—its origin, its surface features, and its path in space. This interest has stimulated the search for facts regarding the exact nature and origin of the surface panorama visible through the telescope.

It is, however, generally agreed that the lunar surface features have been sculptured by catastrophic agents (either meteoric or volcanic, or both) [1 to 10, inclusive].[1] The resulting surface features differ greatly from anything on the earth, except for a certain resemblance to the few known terrestrial meteor craters. Because gravity on the moon is only about one-sixth that on the earth and there is an absence of an atmosphere, the lunar craters are probably 25 to 50 times as large [11] as would result on the earth.

As the result of the absence of an atmosphere and moisture and, hence, of the usual types of weathering and erosion, the moon has retained records of many of its early catastrophic experiences. During its history about 16 times as many meteorites have collided with the earth, but their records have been largely erased [1], unless we conclude that the encounters with the larger ones resulted in some of the geologic transitions indicated by abrupt changes between certain layers of the earth's strata.

The surface of the moon does change, however. It is affected by the sun's rays, by gravity, and by tidal forces, by the temperature change from about 250° F [15 to 18, inclusive] during the lunar day to about −150° F during its night, and by attrition due to falling meteorites, estimated at over one million per day [2]. These effects combine to produce a pulverization of the surface layer, which acts as the efficient insulating surface indicated by the character of the temperature changes on the moon's surface observed during solar eclipses [19].

The blackening of the old surface areas, or "maria", may be due in part to exposure of the surface materials to high frequency (short wavelength) radiant energy. Oxygen, ozone, and other components of the earth's atmosphere act as a blanket that prevents the earth from receiving ultraviolet and other solar radiant energy of wavelengths shorter than about 295 mμ. Laboratory experiments show that many crystalline and glassy substances on the earth darken upon exposure to wavelengths within the spectral range incident on the moon. The collection of a thin layer of fine meteoric material containing iron and other dark substances may be expected also to darken the lunar surface.

The study of the moon through measurement of its effect upon reflected sunlight may be approached from several angles: through changes in intensity or polarization [11 to 14, inclusive] of the reflected radiant energy as a function of the angle of incidence, or through changes in the reflected spectrum caused by the lunar surface. This report deals with the integrated ultraviolet spectral intensities reflected for the fixed angular incidences corresponding to near full moon and with the moon near its most northern position in the sky.

The observed relative spectral distribution of ultraviolet radiant energy reflected from the moon is very similar in quality to that emitted by the sun itself. All the Fraunhofer lines appear and with approximately the same relative intensities. Any differences in the two spectra result from selective optical absorption by the lunar surface. Except for a slight yellowing of the lunar image and for variations in the ultraviolet and visible spectrum over its surface features [20], nothing has been reported in the available literature noting any other differences between the two spectra.

2. Instruments and Procedure

The apparatus employed in this investigation consists of a Carl Leiss double quartz-prism mirror spectrometer, using an RCA 1P28 photomultiplier as a detector. The light beam is modulated at 510 c/s, and the output of the photomultiplier is fed into a tuned amplifier [21] and recorder (see fig. 1). A siderostat was employed for reflecting the beam of light from the moon into the spectroradiometer in a manner similar to that previously used with sunlight [22].

No condensing lens or mirror was employed, so that the resultant measurement was that for the integrated surface of the moon. The spectral-energy-response characteristic of the complete instrument, including the siderostat and photomultiplier, was determined by using a special tungsten-filament-in-quartz lamp [21, 23], together with a number of optical filters to reduce the lamp energy for the various parts of the spectrum (see fig. 2) to values approximating that of the moonbeam at the spectrometer slit. The radiant energy from the

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[1] Figures in brackets indicate the literature references at the end of this paper.

lamp was reflected into the spectrometer by the same siderostat mirrors, so that the spectral energy calibration for the moonbeam reduced to a simple comparison of the recorder indications in the two cases.

The high sensitivity of the detecting and recording equipment permitted the use of relatively narrow slit widths (spectral width approximately 1 mμ at 310 mμ and 2 to 3 mμ at longer wavelengths). These values are comparable to those employed in previous work with sunlight [24], so that the Fraunhofer structure of the measured radiant energy in the two cases is quite similar (see fig. 5), although different spectroradiometers were employed.

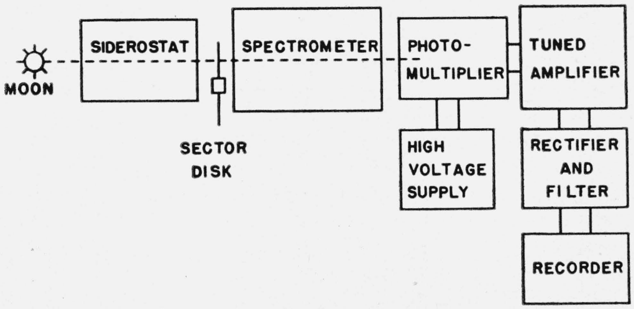

FIGURE 1. *Instrumental layout.*

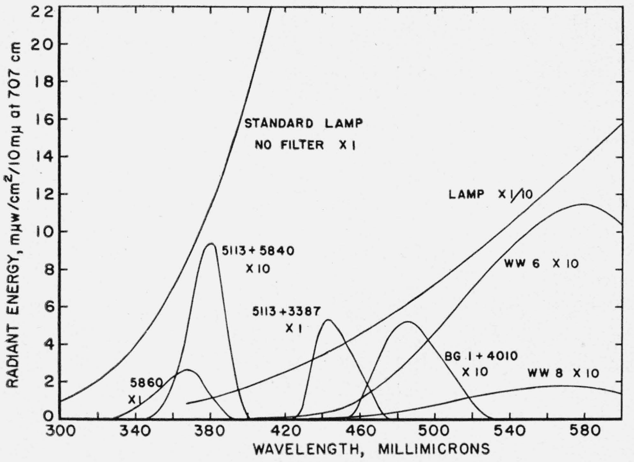

FIGURE 2. *Spectral energy distribution of the standard lamp through the filters used in the calibration of the instrument.*

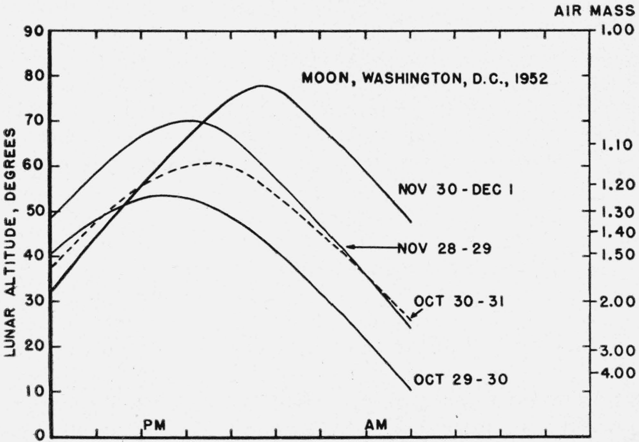

FIGURE 3. *Changes in air mass for the ascent and descent of the moon for the different evenings.*

Measurements were made during four nights near the ends of October and November 1952, when the moon was near its full phase and also near its maximum northern position, hence near its highest altitude at the latitude of Washington, D. C. The best data were obtained during the night of November 30–December 1, when the moon was not only nearest its full phase but was also at the highest altitude for any night during the series of measurements. Also, the atmosphere was entirely free of clouds and showed least dust or haze scattering on this night. Data on the lunar altitude and air mass for the four nights were calculated in the usual manner by means of the celestial triangle through the use of the pertinent data published in the American Ephemeris and Nautical Almanac for 1952 for the solar and lunar positions. The resulting data are charted in figure 3.

3. Spectral Radiant Energy Reflected From the Moon

The spectral radiant energy reflected from the moon depends upon the optical and other physical characteristics of the lunar surface. Changes in the solar radiant energy are admittedly small [25] for all wavelengths penetrating the terrestrial atmosphere. Variations at the moon as a function of time may be considered insignificant. In view of the fact that previous observers have found a marked variation in the light reflected from the moon as a function of the angles of incidence and reflection [11, 15], a similar behavior might be expected for the ultraviolet rays. However, at present the amount of this effect is unknown. Furthermore, variations in ultraviolet intensities over the lunar surface are known to be appreciable [20]. Future studies for specific areas of the moon and at various angles of incidence and reflection should be interesting and informative.

Terrestrial atmospheric absorption further modifies the lunar reflected radiant energy. Mean spectral values (for ascending and descending moon) for a lunar altitude of 65 degrees (air mass 1.10) are given in figure 4. When spectral radiant energy data are taken over a range of ascending (or descending) positions of the moon and plotted logarithmically [24] as a function of air mass and extrapolated to air mass equals 0, the intercepts represent the logarithms of the spectral intensities outside the terrestrial atmosphere. The data illustrated in figure 5 were obtained in this manner.

In order to illustrate better the similarity between the spectral radiant energy reflected from the moon as compared with that emitted by the sun, the data obtained for the sun at Climax, Colorado, in September 1951, are taken from the previous publication [24] and reproduced in figure 5. Although these data were obtained with different spectroradiometers at different times and places, the similarity in the two curves is striking. This is partly because the dispersions for the two instruments were not appreciably different. However, slight differences re-

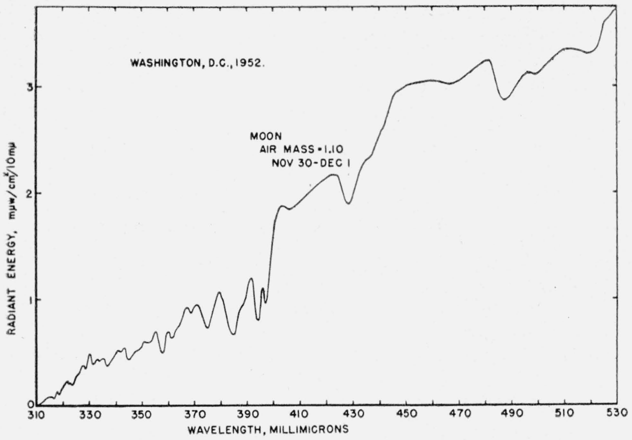

FIGURE 4. *Spectral distribution of the radiant energy reflected from the moon.*

sult in greater scattering of the data plotted in figure 6.

An inspection of the lunar relative to the solar radiant energy curve (fig. 5) discloses greater differences between the two toward the shorter wavelengths. A quantitative plot of this ratio (fig. 6) gives the relative spectral reflectivity of the lunar surface. Much of the scatter of the data, as indicated above, results from slight differences in the dispersions of the two spectroradiometers, inasmuch as a close inspection of the individual plotted points discloses that the higher values result from ratios between peaks on the curves, whereas the lower values are associated with the Fraunhofer absorption bands.

Three important characteristics of this reflectivity curve are worthy of note. First, the curve decreases in ordinate value with wavelength, thus indicating that the lunar surface has a lower reflectivity for the shorter wavelengths. Second, the band at 380 to 390 mμ indicates selective absorption of the lunar surface materials. Third, the sharp cutoff beginning at about 360 mμ may be considered indicative of some special composition.

If the three special characteristics of the lunar reflectivity curve are considered in terms of possible materials present, and other known factors about the moon, such as its albedo, polarization, and heat conductivity are kept in mind, it appears not unlikely that a yellowish glass-like composition could be responsible for the observed phenomena. Certain silica glasses [26] have an ultraviolet cutoff corresponding closely with the observed curve. In a splintered or crushed form they would reflect a measurable amount of radiant energy after transmittance through an appreciable thickness of material. A small iron content would result in selective absorption at 380 to 390 mμ and would give the material a slightly yellowish color. A pulverized glassy silicate lunar surface would be highly insulating and would produce characteristics compatible with temperature measurements obtained during eclipse and with lunar phase changes [15, 16, 19]. The low average albedo [7, 27 to 30, inclusive], about 7.3 percent, corresponds closely to the expected reflectivity from glassy material. Although measurements of the albedo of the moon are not precise, most of them fall below about 12 percent. Hence, the surface of the moon may be composed, at least in part, of powdered glassy silicates. Incidentally, the high percentage of SiO_2 in the earth's crust might suggest the possibility of a terrain similar to that of the moon had not air, water, erosion, etc., been present.

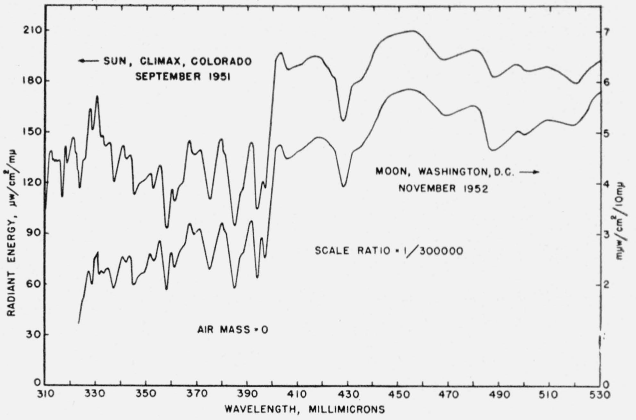

FIGURE 5. *A comparison between the spectral distribution of the radiant energy from the sun and the reflected energy from the moon.*

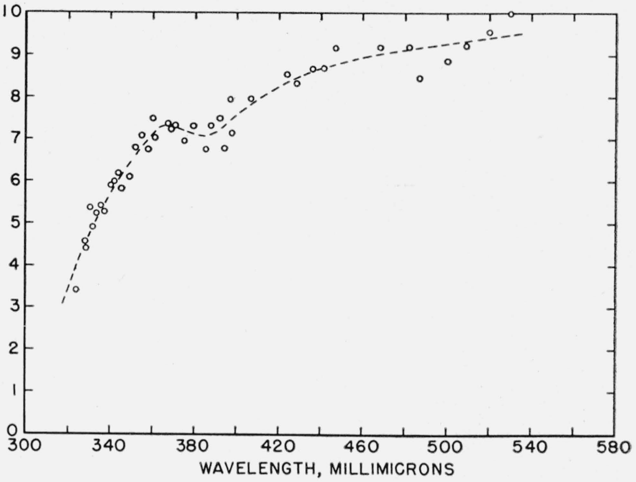

FIGURE 6. *Relative spectral reflectivity of the moon.*

The observations on polarization at the surface of the moon by Wright [12] indicate reflection by a fine texture and "point to pumiceous substances high in silica, to powders of transparent substances and to quartz porphyries and possibly to trachytes and granites as the materials we see at the moon's surface." Similarly, the relative spectral reflectivity curve for the moon obtained in the present investigation points to the possibility that the surface materials are, at least in part, composed of powdered glassy silicates. Further refinements in the observations of this interesting satellite are needed, however, before definitive conclusions can be drawn.

4. Atmospheric transmittance and ozone

The atmospheric transmission curve depicted in figure 7 is plotted in the usual way in terms of the

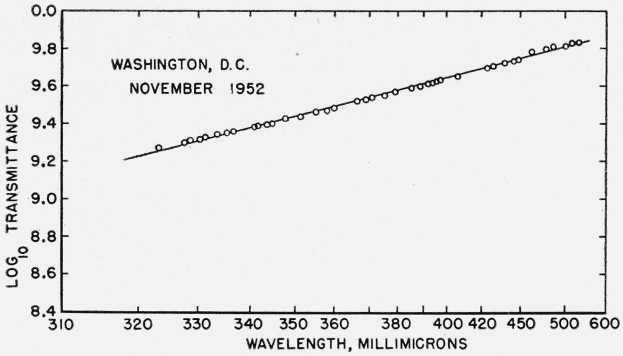

FIGURE 7. *Atmospheric transmittance (from moon data).*

logarithm of the observed transmittances of unit atmosphere (at Washington) for the different wavelengths as a function of the wavelengths. This, in turn, is expanded [31] according to the function $-(\mu-1)^2\lambda^{-4}$ of the Rayleigh law of molecular scattering,

$$\log Tr = -\frac{32\pi^3(\mu-1)^2 H \log e}{3N\lambda^4},$$

in which λ is the wavelength of the radiant energy, and μ is the index of refraction of the atmosphere. Since, for the zenith position the atmospheric depth, H, and the molecular density, N, are constant, the resulting plot of the logarithm of the atmospheric transmittances becomes a straight line in those spectral regions wherein the Rayleigh law of pure molecular scattering is applicable. In as much as appreciable ozone absorption occurs only at wavelengths shorter than about 330 mμ, the data herein recorded are inadequate for use in ozone determinations. Between 300 and 330 mμ (fig. 4), the observed intensities were extremely low and the instrumental noise levels relatively high. With certain improvements in the equipment, it is hoped to reach sensitivities adequate for use of the apparatus in ozone determinations at night. As an alternative, the use of a condensing lens or mirror may be advantageous in supplying sufficient radiant energy from the moon for this purpose.

5. Summary and Conclusions

This report presents the first observed ultraviolet photometric curve of moonlight from data obtained primarily on a single night, although measurements were made on three additional nights when the moon was near its full phase and at high altitudes. Despite the fact that the measurements were made through the dense blanket of atmosphere over a sea-level station, interesting information was obtained having a bearing on the composition of the lunar surface. Further nighttime measurements at higher altitude stations with improved equipment should result in additional information not only on lunar reflectivity but also on ozone concentration.

The extremely high sensitivity of the equipment lends its usefulness in other fields of research, in particular to stellar investigations. With telescopic magnification sufficient radiant energy from many stars, and also from small areas on the moon should be available to permit precise determinations of ultraviolet spectral intensities. Preliminary tests already made of weak fluorescent sources, reflections from dull surfaces, and of radiant energy from small sky areas (even during rainfall or after sundown) indicate a wide range of possible application for the equipment.

6. References

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