Reports

A Search for Far-Ultraviolet Emissions from the Lunar Atmosphere

Abstract. *An ultraviolet spectrometer aboard the Apollo 17 orbiting spacecraft attempted to measure ultraviolet emissions from the lunar atmosphere. The only emissions observed were from a transient atmosphere introduced by the lunar landing engine. The absence of atomic hydrogen implies that solar wind protons are converted to hydrogen molecules at the lunar surface.*

The Apollo 17 orbiting far-ultraviolet spectrometer experiment had as its primary objective the measurement of the density and composition of the lunar atmosphere based on observations of the resonance scattering and fluorescence of solar far-ultraviolet radiation. This technique can provide density measurements in the range from 10^1 to 10^4 cm^{-3} for H, H_2, O, C, N, CO, Kr, and Xe, all of which may be present as important constituents of the lunar atmosphere (*1*). The results presented here indicate that the surface concentration of H is less than 10 cm^{-3}, almost three orders of magnitude less than predicted (*2*), whereas the concentration of H_2, if present, is less than 1.2×10^4 cm^{-3}. This is consistent with the hypothesis that the solar wind protons are completely converted into H_2 at the lunar surface. None of the other observable constituents was detected. A transient atmosphere was observed shortly after lunar module touchdown, but this disappeared in a matter of hours. No evidence of outgassing was detected in the vicinity of the crater Aristarchus, where many transient optical phenomena have been reported.

Earlier measurements of the lunar atmosphere made by means of an in situ pressure gauge (*3*) indicated that the total surface density at the subsolar point may be as large as 10^7 cm^{-3}. More recently, mass spectrometer measurements from lunar orbit (*4*) and from the lunar surface (*5*) have resulted in the detection of Ne, Ar, and He. Lunar outgassing, the only possible source of a substantial atmosphere, occurs at a rate several orders of magnitude less than the corresponding rate on Earth (*6*). Apart from radiogenic ^{40}Ar and He (*7*), the lunar atmosphere may consist only of neutralized solar wind ions. Thus the lunar atmosphere would be expected to be made up primarily of Ne, Ar, H, and He, whose subsolar surface concentrations would lie in the range from 2×10^3 to 7×10^3 cm^{-3} (*7*).

The Apollo 17 spectrometer, designed to scan the wavelength region from 1180 to 1680 Å every 12 seconds, with a resolution of 10 Å, is described in detail elsewhere (*8*). Observations were made in various command module attitudes as shown in Fig. 1. The principal mode of operation (mode A in Fig. 1) was the observation through $\approx$ 120 km of illuminated atmosphere above the terminator against the dark side of the moon. A total of 1200 of these terminator spectra were obtained.

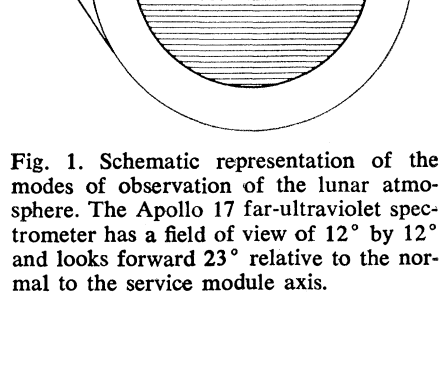

Fig. 1. Schematic representation of the modes of observation of the lunar atmosphere. The Apollo 17 far-ultraviolet spectrometer has a field of view of 12° by 12° and looks forward 23° relative to the normal to the service module axis.

Two additional modes were employed to enhance the sensitivity. These modes provide most of the upper limits quoted herein. In mode B in Fig. 1 the spectrometer was pointed at a fixed point in space, and, as the spacecraft moved in its orbit, the line of sight extended through a tangential slice of illuminated atmosphere. The enhancement provided by this mode is $\approx$ 20 for H and H_2 and $\approx$ 10 for O, based on an exospheric model with the lunar surface as the critical level (*9*). Mode C in Fig. 1 was used immediately after transearth injection and is similar to mode A except for the much greater optical path length ($\approx$ 550 km).

For all wavelengths other than H Lyman-α (1216 Å), the limit on sensitivity was set by the background count rate ($\approx$ 25 count sec^{-1}) which was caused by solar cosmic-ray protons. At 1216 Å, solar radiation resonantly scattered from hydrogen atoms in the interplanetary medium produces a background between 200 and 400 rayleighs (depending on the viewing direction), in good agreement with earlier measurements (*10*), or 6 to 12 rayleighs (450 to 900 count sec^{-1}) when observed reflected from the surface of the dark side of the moon. Solar Lyman-α radiation scattered from the earth's hydrogen geocorona and then reflected from the moon beyond the lunar terminator adds a 1-rayleigh contribution to the background for crossings of the terminator facing Earth. During the transearth coast, the fixed areas of space observed during the tangential mode (mode B in Fig. 1) were again observed in order to provide a sky background correction for the atmospheric observation in this mode. Figure 2 shows the result of applying this correction to the tangential mode data obtained near the

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Table 1. Experimental upper limits for species in the lunar atmosphere.

Species	Transition	Wave-length (Å)	g Factor (photon sec^{-1} molecule^{-1})	Mode of observation*	Sensitivity (photo-electron sec^{-1} rayleigh^{-1})	Observed surface density† (cm^{-3})
H	^2S–^2P (Lyman-α)	1216	2.2×10^{-3}	C	75	< 10
O	^3P–^3S	1304	2×10^{-5}	B	99	< 80
N	^4S–^4P	1200	3.6×10^{-6}	B	70	< 600
C	^3P–$^3P^0$	1657	2.1×10^{-4}	B	25	< 30
Kr	^1S–^3P	1236	1.6×10^{-7}	A	85	$< 20,000$
Xe	^1S–^3P	1470	1.5×10^{-6}	A	75	$< 2,000$
H_2	$B\,^1\Sigma_u^+$–$X\,^2\Sigma_g^+$ (6, 9)	1462	4.0×10^{-8}	B	75	$< 12,000$
CO	$A\,^1\Pi$–$X\,^1\Sigma^+$ (1, 0)	1510	7.5×10^{-8}	B	60	$< 40,000$

* See Fig. 1. † Except for H, Kr, and Xe (which are terminator values), these values correspond to measurements obtained at the subsolar point and are based on a 2 σ level in the observed counting rate.

subsolar point and with the spacecraft altitude varying between 45 and 70 km. The error bar represents one standard deviation (1 σ) in the observed counting rate. The H Lyman-α points, representing the difference (Δ) between two large counting rates, have a statistical uncertainty of $\approx$ 60 count sec^{-1} and are not shown in Fig. 2.

Table 1 lists the transitions of interest, the resonance g factors (*11*), the instrument sensitivity, and the upper limits of the surface concentrations, based on a 2 σ level. For H the upper limit is derived from the difference between two terminator observations from different altitudes above the lunar surface (modes A and C in Fig. 1). The only positive emission detected was a slight enhancement ($\approx$ 3 σ) at 1304 Å (O) and at several wavelengths of the CO fourth-positive bands observed 2 hours after the landing of the lunar module. None of these spectral features appeared at any other time during the lunar observations.

The most surprising result is the absence of H in the lunar atmosphere. We believe that nearly 100 percent of the solar wind protons are converted to H_2 at the lunar surface. The expected H_2 density of 3.6×10^3 cm^{-3} at the subsolar point and 2.3×10^4 cm^{-3} at the antisolar point (*12*) would have so far escaped detection (*5*).

On the basis of the Apollo 17 observations, we would expect that H_2 will predominate over H in Mercury's atmosphere if it is thin enough to allow the direct impact of the solar wind on the surface. A related problem on which this result may bear is the formation of H_2 on interstellar dust particles (*13*). The upper limits reported here for H, O, C, N, and CO are important in setting new upper limits for the average outgassing rates for H_2O, CO_2, CO, NO_2, N_2, H_2S, and SO_2 (*14*).

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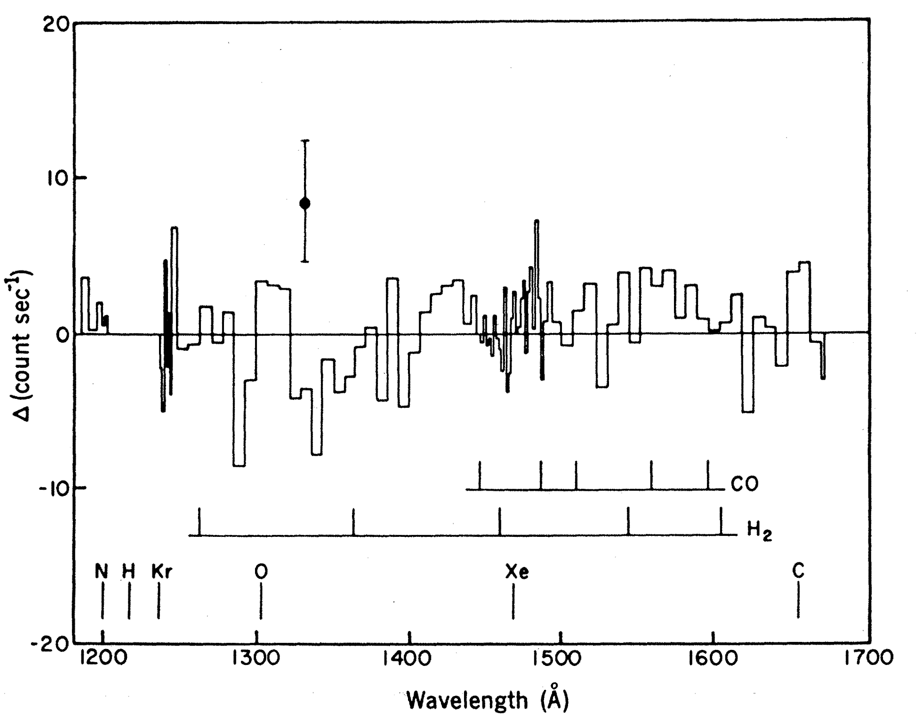

Fig. 2. The average of 70 spectra obtained during a tangential mode (mode B in Fig. 1) observation with the sky background, observed during transearth coast, subtracted. The wavelengths of the principal emission features expected are indicated.

References and Notes

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14. The limits on the outgassing rates will be described in detail by G. E. Thomas *et al.*, in preparation.
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