

THE LUNAR ATMOSPHERE, R. R. Hodges, Jr., J. H. Hoffman
and F. S. Johnson, The University of Texas at Dallas, Dallas, Texas.

The atmosphere of the moon is so tenuous that it can be regarded as a collisionless exosphere in which atoms and molecules are gravitationally bound in ballistic trajectories between encounters with the lunar surface. Despite the small amount of gas, the vestige of atmosphere is an important indicator of lunar processes which produce atmospheric gases. Lack of a significant amount of lunar atmosphere can be attributed mainly to an efficient escape mechanism for particles that are too heavy to escape thermally. Neutral gas molecules or atoms are photoionized by solar radiation and then, in the absence of significant magnetization of the moon, the $\mathbf{v} \times \mathbf{B}$ field of the impinging solar wind accelerates the resultant ions. Roughly half of these ions impact the lunar surface, but the other half escape. The geomagnetic field inhibits this escape process over the earth, while induced ionospheric currents apparently cause a deflection of the solar wind around both Mars and Venus, thus causing ions produced below the deflection boundary to remain in the planetary atmosphere.

A summary of present knowledge of lunar atmospheric parameters is given in Table 1. Theoretical values for hydrogen and helium are based on calculations by Hodges (1), which are in close agreement with independent calculations of Hartle and Thomas (2). Daytime concentrations of hydrogen and helium may be expressed in two ways - in terms of downcoming bound particles which have completed at least one ballistic trajectory or as the total of bound and newly created upgoing molecules in initial trajectories. Owing to long residence times for neon and argon, differences between their respective bound and total concentrations are negligible.

Amounts of helium, ^{20}Ne and ^{36}Ar , which are known from Apollo 16 (3) and Apollo 17 (4) mass spectrometer data are in balance with the solar wind influxes of these species. The lack of a large accumulation of hydrogen in the lunar soil suggests that the solar wind influx of protons is similarly converted to a neutral gas, presumably H_2 , to equalize rates of accretion and escape. Solar abundances of O, C and N probably exceed that of Ne, but atomic and molecular forms of these elements derived from the solar wind do not show evidence of a recognizable diurnal atmospheric oscillation in the Apollo 17 mass spectrometer data. The only reasonable interpretation of this fact is that ambient levels are small compared to the artifact background.

Atomic oxygen ions of the solar wind probably react with lunar materials even though oxygen is the major constituent of the moon. Thus the lack of evidence of O or O_2 in the atmosphere is understandable. Atmospheric forms of C and N are more reasonably expected. By analogy with the previously discussed hypothesis of the formation of H_2 , it is expected that CH_4 and NH_3 should also be formed and released to the atmosphere (3,5). The large amount of oxygen in the soil may lead to production of CO, CO_2 and NO, but these reactions may also be reversible. The alternative to atmospheric forms of C or N is that most of the solar wind influx of these elements is now being permanently implanted in the soil.

THE LUNAR ATMOSPHERE

Hodges, R. R. et al

The presence of excess amounts of ^{40}Ar trapped in returned lunar samples has been recognized by Manka and Michel (6), as evidence of ^{40}Ar as an atmospheric gas. More recently, ^{40}Ar has been identified in the lunar atmosphere by the Apollo 17 mass spectrometer (3,4,5). Since the only important source of ^{40}Ar is radiogenic decay of ^{40}K within the moon, its presence in the atmosphere is evidence of a venting or degassing process, which surprisingly corresponds to about 0.4% of the total rate of production of ^{40}Ar in the moon (5).

One possible explanation of the large rate of release of ^{40}Ar is that most of the atmospheric argon is produced deep in the lunar interior. Latham et al. (7), have identified a highly attenuating zone for seismic shear waves beginning at a depth of about 1000 km. If the attenuation is due to high temperatures and partial melting, then an outflow of argon from the core could result. This would undoubtedly result in trapping of the gas in some regions and in a global venting rate that depends on the distribution of deep fissures. Alternatively, radiogenic argon could have diffused into voids within the moon over a long period and some of these reservoirs could now be venting argon into the atmosphere. An attractive feature of either hypothesis is that it can explain, through seismic changes in venting rates, a great variability in the level of ^{40}Ar in the lunar atmosphere over geologic time. Yaniv and Heymann (8), have proposed such variations to explain the dispersion of the ^{40}Ar to ^{36}Ar ratio in the lunar soil samples.

The regolith must be ruled out as an important source of atmospheric argon simply because of the magnitude of the loss rate, which corresponds to release of ^{40}Ar at its rate of production throughout the upper 3 km of soil (5). Impact gardening may release a small fraction of the trapped argon from the soil, but the depth of this effect cannot be great enough to make a substantial contribution. Diffusion of argon out of small grains to a great depth also seems an unlikely explanation because this mechanism would not have produced a varying supply of argon.

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TABLE 1
SUMMARY OF LUNAR ATMOSPHERE PARAMETERS

	H_2	4He	^{20}Ne	^{36}Ar	^{40}Ar
Solar wind influx(ions/sec)		1.3×10^{24}	2.2×10^{21}	8.0×10^{19}	-
Lunar venting (atoms/sec)	-	-	-	-	8.7×10^{20}
Photoionization time (sec)	10^7	10^7	6×10^6	1.6×10^6	1.6×10^6
Residence time (sec) §	7×10^3	8×10^4	4×10^7	10^7	10^7
Concentration (cm^{-3}):					
Theory	day bound	2×10^3	1.7×10^3	4×10^3	1.3×10^2
	total	3.5×10^3	1.9×10^3	1.3×10^2	1.6×10^3
	night	1.2×10^4	4×10^4	$3 \times 10^3+$	$4 \times 10^4+$
Experiment*	day	$< 6 \times 10^3$	2×10^3	-	-
	night	$< 3.5 \times 10^4$	4×10^4	10^5	$3 \times 10^3+$

§ Hydrogen and helium escape thermally, while photoionization controls lifetimes of the other gases.

* Daytime upper bound on H_2 is from Apollo 17 orbital ultraviolet spectrometer results (9) while the remaining data are from Apollo mass spectrometer experiments.

† Sunrise terminator maxima are given for argon. Surface adsorption removes most of the nighttime argon.

THE LUNAR ATMOSPHERE
Hodges, R. R. et al