# Reports

## Effect of the Solar Wind on the Lunar Atmosphere

*Abstract*. The extent of the lunar atmosphere is severely limited by collision with the protons of the solar wind.

The composition and extent of the lunar atmosphere have been the subject of considerable speculation by physicists and astronomers (*1–5*). We have carried out calculations which indicate that the lunar atmosphere will be limited by collisions with protons in the solar wind, if the flux of particles in this wind has the value given by Biermann (*6*). We find, in fact, that for a typical constituent, the limiting density of the lunar atmosphere is lower by a factor of $10^{11}$ than would be estimated in calculations neglecting the solar wind.

The properties of the lunar atmosphere are usually assumed to be governed by two competing processes: (i) the accumulation of gases from the surface of the moon, and (ii) the loss from the atmosphere of a certain fraction of those molecules whose thermal energies are sufficient to permit their escape from the gravitational attraction of the moon.

If we assume an isothermal atmosphere and a Maxwellian distribution of particle velocities, with an infinite mean free path, then a calculation based on the balance between these two processes leads to the following result for the equilibrium number density of atmospheric molecules at the lunar surface (*7*):

$$n_0 = J\sqrt{\frac{\pi m}{2kT}}\left(1+\frac{mMG}{kTR}\right)^{-1}\cdot \exp\left(\frac{mMG}{kTR}\right) \quad (1)$$

In Eq. 1, $J$ is the number of molecules ejected from the lunar surface per square centimeter per second. $T$ is the lunar atmospheric temperature; $m$, the mass of an atmospheric particle; $M$, the mass of the moon; and $R$, its radius.

Probable sources for the lunar atmosphere are: (i) argon produced by the radioactive decay of potassium, and (ii) the production of such gases as $SO_2$, $CO_2$, and $H_2O$ by residual volcanic activity. Estimates of the emission of these gases based on terrestrial data suggest $J \simeq 5\times10^5/\text{cm}^2$ sec for argon, and $J \simeq 10^{10}/\text{cm}^2$ sec for volcanic gases (*5*).

The rate of escape from the atmosphere is determined by the maximum temperature, for which thermocouple measurements indicate a value of 370°K (*8*). Substituting these values of $J$ and $T$ into Eq. 1, we find $n_0 \simeq 5\times10^{15}/\text{cm}^3$ or $10^{-4}$ atm of argon. A similar calculation for the volcanic gases leads to pressures greater than 1 atm for $SO_2$ and $CO_2$, and to $4\times10^{-8}$ atm for $H_2O$. However, the latter values will be substantially reduced when allowance is made for the effects of photodissociation and chemical reactions with the crust, and for the fact that the age of the moon ($\simeq 4.5\times10^9$ yr) does not allow enough time for $SO_2$ and $CO_2$ to build up to equilibrium (*5*).

In addition to the above gases, we also expect traces of xenon and krypton. Using the ejection rates for these gases as calculated by Edwards and Borst (*9*) in Eq. 1, we find their contribution to the lunar atmosphere to be negligible, compared to that of the above gases.

The above calculations neglect the solar wind. The solar wind is usually assumed to consist of protons with a number density of $10^3/\text{cm}^3$ and velocity of $10^8$ cm/sec (*6*). In an elastic collision with an atom these protons will transfer an average of 1 kev of kinetic energy, which is sufficient for the escape of the atom. If we assume that every atom struck by a proton escapes, the rate of ejection of particles from the atmosphere is (per cubic centimeter),

$$R_p = n_a n_p V_p \sigma_{el} \quad (2)$$

In Eq. 2, $n_p$ is the number density of protons, $V_p$ is their velocity, and $\sigma_{el}$ is the proton-particle elastic cross section. We may now estimate the equilibrium particle density at the lunar surface by equating the rate of ejection of particles from a vertical column 1 cm² in cross-sectional area, as calculated by Eq. 2, to the rate of injection of particles, $J$, into the column at the surface. This gives:

$$n_0 = \frac{J}{n_p V_p \sigma_{el} h} \quad (3)$$

In Eq. 3, $h$ is the scale height of the isothermal atmosphere ($kTR^2/mMG$).

Taking $\sigma_{el}$ to be $10^{-16}$ cm², we find $n_0 \simeq 10^4/\text{cm}^3$ or $10^{-15}$ atm for argon. For the volcanic gases we find $n_0 \simeq 10^8/\text{cm}^3$ or $10^{-11}$ atm. This value represents an upper limit for these gases because photodissociation has been neglected.

Comparing these values with the results obtained above, we see that the solar wind reduced the density of the lunar atmosphere by a factor of $10^{11}$ for argon, $10^4$ for $H_2O$, $10^{15}$ for $CO_2$, and $10^{22}$ for $SO_2$.

Our remarks depend on the assumption that the moon's magnetic field is too feeble to shield the atmosphere effectively from the solar wind. The magnetic field of the moon has been estimated to be less than 200 γ's (*10*). A comparison of the magnetic pressure of such a field with the pressure of the solar wind indicates that a field of this intensity at the surface of the moon would have practically no shielding effect for the atmosphere.

Finally, we note that the estimates of the lunar atmosphere based on the limiting effect of the solar wind are consistent with the experimental upper bound of $10^{-8}$ atm established by coronograph measurements (*11*). The respective values for argon and the volcanic gases bracket the estimate of $10^{-13}$ atm, which has been reported by Ellsmore and Whitfield (*2*), on the basis of measurements of the lunar occultation of radio sources (*12*).

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### References and Notes

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12. We thank R. Jastrow and I. Harris for several discussions during the course of this investigation.

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Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to Contributors" [*Science* 125, 16 (1957)].