Reports

Density of the Lunar Atmosphere

Abstract. The minimum possible density of the lunar atmosphere at the surface is shown to be essentially the value for the interplanetary medium. This value, when combined with the observed maximum, places the particle density between 10^3 and 10^6 per cubic centimeter, while the electron density must be about 10^3 to 10^4 per cubic centimeter. These results are markedly different from those recently obtained by Firsoff.

It has long been known that the lunar atmosphere must be very tenuous (*1*), as is indicated in many ways, including observations of the moon near the lunar cusps (*2*). In 1952, Dollfus (*3*) established an upper limit for the density of the lunar atmosphere of 10^{10} particles per cubic centimeter from polarimetric observations. This value remained the upper limit for the lunar atmosphere until 1956, when the limit was lowered by a factor of 10^4 from radio observations of a lunar occultation of the Crab nebula (*4*). Öpik (*5*) has pointed out that the radio method is about 10^4 times more sensitive than the polarimetric method, and hence it is interesting that the upper limit of the lunar atmosphere has been lowered by the amount of the increased precision. It may then be illustrative to assume (following Öpik) that the moon has no exhaled atmosphere of its own but that the lunar atmosphere is simply a gravitational condensation of the interplanetary medium. We may then calculate the lower limit for the density of the lunar atmosphere.

An isothermal atmosphere in hydrostatic equilibrium about the moon follows the density law,

$$N(r)/N(r_0) = \exp\left[-\frac{G\mathscr{M}M}{kT}\left(\frac{1}{r_0} - \frac{1}{r}\right)\right] \quad (1)$$

where M is the mean mass per particle, k the Boltzmann constant, G the gravitational constant, $\mathscr{M}$ the mass of the moon, T the atmospheric temperature, and r the distance from the center of the moon, r_0 being the lunar radius. This distribution reaches a limit for $r \gg r_0$, and if we can observe the density at large distances from the moon, we can then calculate the density at the surface. The quantity of interest is $N(r_0)/N(r = \infty)$. For the moon, Eq. 1 yields

$$N(r_0)/N(r = \infty) = \exp\left[\frac{340}{T}\mu\right] \quad (2)$$

where μ is the mean molecular weight of the atmosphere. The interplanetary medium may be regarded as a tenuous extension of the solar corona and hence as a proton-electron gas of molecular weight ½. The temperature of the ionized lunar atmosphere (gravitationally condensed from the interplanetary medium) will be nearly isothermal at essentially the temperature of the interplanetary medium itself. The temperature in the vicinity of the orbit of Earth can be calculated from consideration of the properties of a solar exosphere. In a recent investigation, Chamberlain (*6*) has shown that the temperature of the interplanetary medium at the orbit of Earth is between 10,000 and 100,000°K, depending on the number of high velocity particles available at the base of the exosphere. With the values of μ and T mentioned above, we find from Eq. 2 that $N(r_0)$ is, at most, a few percent higher than $N(r = \infty)$. Since $N(r = \infty)$ can be shown in a variety of ways (*7*) to be $\approx 10^3$ particles per cubic centimeter, we may combine this value with the observed upper limit to show that the density of the lunar atmosphere at the surface must be between 10^3 and 10^6 particles per cubic centimeter. From the radio observations an upper limit for the electron density at the surface of the moon of 10^3 to 10^4 per cubic centimeter was derived. This allows us to infer that the electron density is near 10^3 to 10^4 per cubic centimeter, and also to place limits on the number of electrons that the exhaled component of the lunar atmosphere can add to the interplanetary component (*8*).

In a recent investigation, Firsoff (*9*) has also made a calculation of the minimum density of the lunar atmosphere arising from the concentration of interplanetary gas. He obtains a value for $N(r_0)$ of 10^7 particles per cubic centimeter, which is above the observed upper limit by a factor of 10. His value is clearly erroneous since he uses a mean molecular weight of 25 and a temperature of 250°K. These values may apply to an exhaled lunar atmosphere but certainly do not apply to an atmosphere condensed from the interplanetary medium. Equation 2 for $\mu = 25$ and $T = 250$°K gives a value for $N(r_0)$ of 6×10^{17} particles per cubic centimeter. This value differs from Firsoff's value because Firsoff cuts off the lunar atmosphere 1000 km above the lunar surface, and because he has made some numerical errors; for example, he has used a value for the radius of the moon which is too small by a factor of about 2. Firsoff also discusses three "important factors" which he claims have been neglected in the theory of dissipation of planetary atmospheres. His first factor is inherent in the concept of the base of an atmosphere, his second factor is incorrect (*10*), and his third factor is well known (*5*).

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References and Notes

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4. C. H. Costain, B. Elsmore, G. R. Whitfield, *Monthly Notices Roy. Astron. Soc.* **116**, 380 (1956).
5. E. J. Öpik, *Irish Astron. J.* **4**, 186 (1957).
6. J. W. Chamberlain, *Astrophys. J.* **131**, 47 (1960). It is a pleasure to thank Chamberlain for conversations concerning this problem.
7. H. Elsässer, *Mitt. Astron. Ges.* **2**, 61 (1957).
8. This work was performed while I held a National Science Foundation cooperative graduate fellowship; it was supported in part by the Geophysics Research Directorate of the Cambridge Research Center, Air Research and Devlopment Command, under contract AF 19(604)-3044 with the University of Chicago.
9. V. A. Firsoff, *Science* **130**, 1337 (1959).
10. H. C. Van de Hulst, in *The Sun*, G. P. Kuiper, Ed. (Univ. of Chicago Press, Chicago, 1954), p. 306.

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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.

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