THE ESCAPE OF SOLAR WIND CARBON FROM THE MOON

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The solar wind is probably the dominant source of carbon on the moon. Assuming the solar wind carbon abundance to be 0.52% (1), its flux at the moon is about $1.6 \times 10^5$ carbon ions/cm$^2$/sec, except for the 4 days per lunation when the moon is in the geomagnetic tail. The resulting average carbon inflow is about $2.6 \times 10^{23}$ atoms/sec. Bibring et al. (2) have concluded that the typical carbon abundance found in returned lunar samples (about 200 ppm) represents a saturation level. In essence, the total rate of implantation of carbon ions, from both the solar wind and atmospheric photoions, in soil grains is balanced by loss of carbon to the atmosphere due to weathering or diffusion. In turn the atmospheric molecules eventually become photoionized and then accelerated by the solar wind. By analogy with atmospheric argon escape data (3), about 10% of these photoions are probably retrapped in the soil while the rest escape from the moon. As a result the rate of photoionization exceeds the total carbon inflow rate by about 10%, i.e. the rate of ionization of lunar atmospheric carbon molecules must be about $2.9 \times 10^{23}$/sec.

In Table 1 the photoionization time constant, total number of atmospheric ions in sunlight, and average daytime concentration for three candidate atmospheric carbon gases are given. For each case the amount of gas corresponds to what would be present if it were the only carbon gas. Thus each represents an upper bound. The concentrations are based on an average daytime surface temperature of 300°K.

<table>
<thead>
<tr>
<th>Molecular Species</th>
<th>Photoionization Time (sec)</th>
<th>Molecules in Sunlight</th>
<th>Average Daytime Surface Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_4$</td>
<td>$1.7 \times 10^6$</td>
<td>$5 \times 10^{29}$</td>
<td>$2.7 \times 10^5$</td>
</tr>
<tr>
<td>CO</td>
<td>$3 \times 10^6$</td>
<td>$8.7 \times 10^{29}$</td>
<td>$8.4 \times 10^5$</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>$5 \times 10^6$</td>
<td>$1.5 \times 10^{30}$</td>
<td>$2.2 \times 10^6$</td>
</tr>
</tbody>
</table>

Measurements of lunar atmosphere made by the mass spectrometer at the Apollo 17 landing site suggest that both CH$_4$ and CO exist on the moon. These data do not, however, rule out CO$_2$. What the experiment shows is that at night all molecular gases are adsorbed on the lunar surface, resulting in
atmospheric concentrations below the artifact contaminant background level of 2-5 x 10^3 molecules/cc. Just prior to sunrise, when the terminator is about 10° in longitude from the instrument, the levels of CH₄ and CO begin to increase. This effect has been explained (3,4) as being due to ballistic lateral transport of gas from daytime to night across the sunrise terminator. The source of the excess daytime molecules is thermal desorption of gas that was previously adsorbed on the surface at night. Presunrise atmospheric levels the order of 10^3 molecules/cc exist for both CH₄ and CO. The amount of CO₂ at sunrise is probably at least an order of magnitude less. After sunrise the artifact background rises rapidly to levels in excess of 10^7 molecules/cc due to degassing of spaceflight hardware at the landing site, precluding meaningful daytime measurements.

The necessity of a large average daytime concentration of carbon molecules, coupled with very low terminator levels suggests that the adsorption mechanism firmly binds molecules to the lunar surface, so that desorption occurs only after the surface temperature increases to about 300°K. This contrasts with the photodesorption process which releases adsorbed argon from the surface almost instantaneously at sunrise (3).

Some important ramifications of the atmospheric carbon data include the necessity of large deposits of condensed gas in polar regions. As a result maxima of atmospheric concentration should occur over the poles. A diurnal maximum of concentration should extend from pole to pole, slightly to the sunrise side of the subsolar meridian.

Preliminary work on a carbon monoxide atmospheric model suggests concentrations on the order of 2 x 10^6 cm^-3 at the poles, decreasing to 6 x 10^5 cm^-3 at the equator. Owing to the long desorption time, the mean molecular lifetime should be the order of 100 years. This is quite long as compared with ⁴⁰Ar, which escapes in about 80-100 days (2), and helium which has a lifetime of about 3 days (5).

The alternative to atmospheric loss of carbon due to molecular photodization is the direct escape of superthermal atoms produced by the solar wind weathering of rock surfaces. However, the atmospheric measurements of helium on the moon indicate that 70% of the solar wind inflow can be accounted for by escape from a thermalized atmosphere (5). The remainder of the escape rate may be due to superthermal energies of new atoms, but the necessary release temperature is only about 1000°K. An alternative explanation requires a small thermal accommodation coefficient (~0.3) for helium encounters with the lunar surface. Applied to carbon, neither of these mechanisms could produce a significant increase in the carbon escape rate.

Lacking a rapid escape mechanism for carbon, it seems likely that the daytime lunar atmosphere contains a significant amount of carbon in molecular form. An obvious ramification of this relatively dense daytime atmosphere is that photod ion concentrations in the lunar ionosphere may be greater than previously postulated.
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REFERENCES


