Abstract. The solar-wind interacts directly with the lunar surface due to tenuous atmosphere and magnetic field. The interaction results in an almost complete absorption of the solar-wind corpuscles producing no upstream bowshock but a cavity downstream. The solar-wind oxygen ionic species induce and undergo a complex set of reactions with the elements of the lunar minerals and the solar-wind derived trapped gases. The oxygen concentration indigenous to the lunar surface material is about 60 at.%. Some of these oxygen are displaced from their crystal lattice locations by interactions of the solar-wind corpuscles. A small fraction of these displaced oxygen is in active state. The solar-wind oxygen species flux is about \(6 \times 10^4\) \(\text{cm}^{-2}\) \(\text{s}^{-1}\). Besides inducing and undergoing various reactions these species become trapped as oxygen atoms in the lunar grains. Only a portion of these trapped oxygen atoms is in active state. For the contribution of oxygen atoms and molecules from the lunar surface grains to the atmosphere and their reactions with other species, the diffusion coefficients of oxygen atom and molecule should be known. However their values in the highly radiation-damaged lunar surface material are not known. The coefficients are calculated by using the apparent lifetimes of atomic and molecular oxygen in the lunar material. The atmospheric concentration of oxygen atoms and molecules near the lunar surface are found to be about 20 and 3 \(\text{cm}^{-3}\), respectively. These values appear to be very reasonable in comparison with the experimental data. The Apollo 17 lunar orbital UV spectrometer data indicate the atomic oxygen concentration is \(< 8 \times 10^1\) \(\text{cm}^{-3}\). The Apollo 17 lunar surface mass spectrometer (sensitivity: 1 count = \(2 \times 10^2\) molecules \(\text{cm}^{-3}\)) did not detect any oxygen molecules on the dayside of the Moon, but the sunrise concentration was reported to be \(1 \pm 10^3\) \(\text{cm}^{-3}\). At the time of the sample collection on the Moon the oxygen content in the trapped gas layer was partly as oxygen atoms and partly as oxygen molecules. At the time of sample analysis on the Earth the concentrations of these two species did not change appreciably.

1. Introduction

The lunar atmosphere is very tenuous and the lunar magnetic field is small. The solar wind, therefore, interacts directly with the lunar surface material and the dominant nature of interaction is essentially complete absorption of solar-wind particles by the surface material resulting in no upstream bowshock, and a cavity downstream. On a long-term basis the interaction products are the main source of the species in the lunar atmosphere (Mukherjee and Siscoe, 1973; Mukherjee, 1974, 1975, 1976a, b), although the species concentration, on a short term basis, may be higher than that due to solar wind because there are a few evidences for sporadic increase in concentration of atmospheric species. This increase is considered to be related to lunar degassing (cf. Mukherjee, 1975). In this paper we discuss the long-term concentration and the role of oxygen derived from the solar-wind.

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2. Mechanism of Interactions of Solar-Wind Oxygen Ions with Lunar Surface Material

The oxygen ions, $O^{n+}$ in the solar wind are highly positively charged, the value of $n$ being closer to 6 rather than 1, although the possible maximum is 8. The flux of these ions at about 1 AU is about $6 \times 10^4 \text{ cm}^{-2} \text{s}^{-1}$ (cf. Bame et al., 1970). These ions are energetic with energies probably in the range of 10–20 keV. They penetrate the lunar surface material to a depth of 0.06 to 0.12 μm. While penetrating, they ionize, dissociatively ionize, and dissociate the lattice elements and trapped gases in the top 250 to 300 atomic layers of the material, and at further depths they may react with lattice atoms and trapped gases or themselves become atoms. The reactive atomic species generally diffuse at a slow rate in highly radiation-damaged material (Ducati et al., 1973), and form radicals or molecules upon encounter with other reactive atoms. These molecules, while diffusing in the material or while in residence at locations, encounter oncoming solar-wind particles and/or their degradation products, energetic neutrals. These encounters result in a complex set of reactions involving the diffusing species, such as ionizations, dissociative ionizations, dissociations and exchange reactions. Some typical examples are given in the next section.

2.1. Possible Reactions Resulting from Oxygen Ions

As indicated earlier, the reactions are quite complex. For simplicity, some of the possible reactions are given below using augite, $\text{Ca(Mg, Fe, Al)(Al, Si)_2O}_6$, a mineral of pyroxene group present quite extensively at the lunar surface. Besides conventional chemical symbols the other symbols used in the following illustrative reactions are defined as: $O(E)$ = energetic oxygen atom derived from the neutralization of a solar-wind $O^{n+}$, $(D)$ shown after any species = displaced species, such as $\text{Al(D)}$ meaning displaced Al species from its lattice site, $s$ = solid material, $(T)$ shown after any species = species derived from the solar-wind and trapped in the lunar material,

$$\text{Ca(Mg, Fe, Al)(Al, Si)_2O}_6 + O^{n+} \rightarrow \begin{cases} \text{Ca(Mg, Fe, Al)(Al, Si)}_2O_6^+ + O^{n+} + e, \\ \text{Ca(Mg, Fe, Al)(Al, Si)}_2O_6 + O^+ + \text{Ca(Mg, Fe, Al)(Al, Si)}_2O_6^+ + O^{n+} + e, \end{cases}$$

In Reactions (2) and (3) we have shown dissociative ionization of O and Al, but similar reactions may occur for other elements of augite. At greater depths, say > 250 atomic layers, dissociative reaction and dissociation may occur in accordance with

$$\text{Ca(Mg, Fe, Al)(Al, Si)}_2O_6 + O^{n+} \rightarrow \begin{cases} \text{Ca(Mg, Fe, Al)(Al, Si)}_2O_6^{(n+1)+} + O^2_+, \\ \text{Ca(Mg, Fe, Al)(Al, Si)}_2O_6 + O(D) + O^{n+}, \end{cases}$$

The displaced ions on the right side of Reactions (2) and (3), and $O^2_+$ on the right side of Reaction (4) may rapidly become neutrals by picking up the solar-wind electrons impinging on the surface prior to their encounter with the solar-wind ions.

The solar-wind oxygen ions, upon neutralization at depths in the lunar grains, may