Plasma-dust system in near-surface layer of the Moon

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A renaissance is currently being observed in investigations of the Moon. The Russian missions "Luna-Glob" and "Luna-Resource" (the latter jointly with India) will include investigations of dust near the surface of the Moon. Measurements of dust characteristics are planned in the daytime to ensure the power supply of instruments at lunar stations owing to solar energy. The Moon landing of the Luna-Glob and Luna-Resource will be performed near the polar regions of the Moon.

The surface of the Moon is charged under the action of the electromagnetic radiation of the Sun, solar-wind plasma, and plasma of the Earth's magnetotail. The surface of the Moon and dusts levitating over the lunar surface interact with solar radiation. They emit electrons owing to the photoelectric effect, which leads to the formation of the photoelectron layer over the surface. Dusts located on or near the surface of the Moon absorb photoelectrons, photons of solar radiation, electrons and ions of the solar wind, and, if the Moon is in the Earth's magnetotail, electrons and ions of the magnetospheric plasma. All these processes lead to the charging of dust particles, their interaction with the charged surface of the Moon, and rise and motion of dust. Thus, dust over the Moon is a component of the dusty plasma system; investigations of this system in the surface layer of the illuminated part of the surface of the Moon are of significant interest, including technological interest, for instruments mounted on lunar stations, choice of a Moon landing site, *etc.*

Recent detections [1] of neutron fluxes passing through regions of the surface of the Moon in the Southern Hemisphere of the Moon on the Lunar Reconnaissance Orbiter show the existence of hydrogen-enriched regions in the surface layer of the Moon at lunar latitudes exceeding 70$^{\text{o}}$. The investigation reported in [1] possibly indicates the existence of ice in surface regions of the Moon, and the existence of surface regions of hydrogen is possibly due to electrons and protons of the solar wind, which collide with the Moon and are absorbed by its surface, where they form neutral hydrogen atoms. This hydrogen can rise on the surface of the Moon in the form of atomic or molecular hydrogen or water vapor [2]. In this case, the sensitivity of the hydrogen-enriched regions of the surface of the Moon to photoemission is much higher than that of surrounding regions; this finally affects the charging of dust particles and their dynamics.

Data on the near-surface density of dust on the Moon are almost nonexistent. The existing works describe the dust density using either the model disregarding photoelectrons [3] that is certainly inapplicable for the surface dusty plasma layer or analysis of the scattering of light by dust on Apollo 15 [4]. The dust density was estimated in [4] at altitudes of several kilometers.

In this work we study the dusty plasma system in the surface layer of the illuminated part of the Moon. The situations where dust particles are formed over lunar regolith regions and hydrogen-enriched regions of the surface of the Moon are analyzed. The dust and electron number densities, dust particle charges, and some other dusty plasma characteristics over the surface of the Moon are calculated.

To describe the dusty plasma system in the surface layer of the Moon, we use a modified model [5] in which the charging of dust particles over the surface of the Moon is calculated taking into account the effect of photoelectrons, electrons and ions of the solar wind, and solar radiation. The interaction of dust particles with the plasma of the Earth's magnetotail is neglected, because this interaction is significant only for the dark side of the Moon. The modification of the model [5] is that here we take into account the photoelectrons from both the lunar surface and the surfaces of dust particles, while in [5] only the photoelectrons from the lunar surface are taken into account. The consideration of the photoelectrons from the dust particle surfaces modifies the model strongly and requires a self-consistent investigation because the photoelectrons influence dust particle distributions while the dust particle distributions determine the number of the photoelectrons.

The angle between the Moon's axis and the ecliptic plane is only 1.5424$^{\text{o}}$, which determines the small difference of the lunar latitude from the angle θ between the local normal and direction to the Sun. For this reason, calculations are performed in terms of the angle θ. Furthermore, we use two photoemission working functions $W = W_R = 9$ eV for regolith regions and $W = W_H = 4$ eV for hydrogen-enriched regions of the surface of the Moon.

Here, we present the photoelectron and dust distributions obtained as a result of our calculations. The photoelectron density $n_{e,\text{ph}}$ as a function of the height h within the range of the angles θ from 0$^{\text{o}}$ to 89$^{\text{o}}$ is described with a good accuracy by the formula

$$n_{e,\text{ph}} \approx N_0 \frac{\cos\theta}{[1 + \sqrt{\cos\theta/2}(h/\lambda_D)]^2} + N_e (h/h_1)^{\alpha}, \tag{1}$$

where $N_0 \approx 2 \times 10^5$ cm^{-3} for regolith regions and $N_0 \approx 2 \times 10^8$ cm^{-3} for hydrogen-enriched regions, λ_D is the Debye length for photoelectrons with the temperature $T_{e,\text{ph}} \approx 0.1$ eV and the number density N_0, $h_1 = 1$ cm, the constants α and N_e are given in Fig. 1 for regolith and hydrogen-enriched regions of the surface of the Moon.
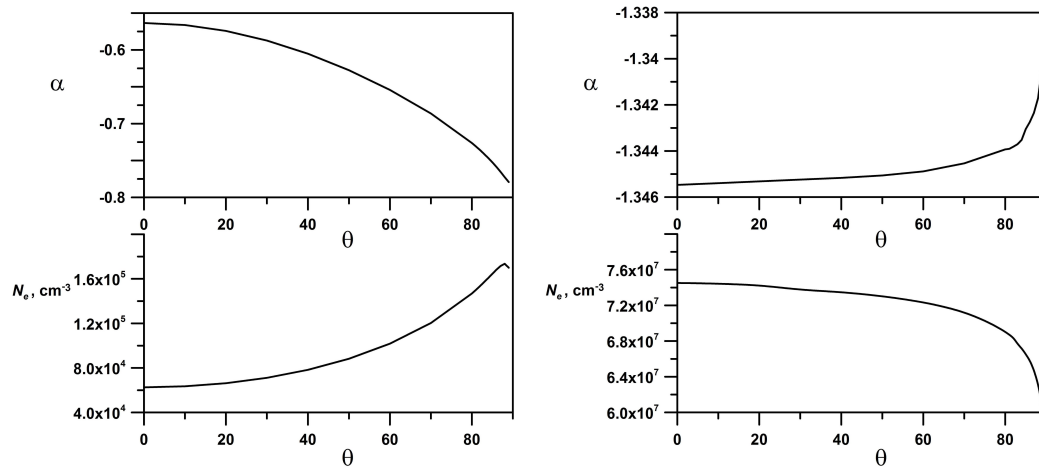
Figure 1: The constants α and N_e vs θ for regolith regions (left panel) and hydrogen-enriched regions (right panel) of the surface of the Moon
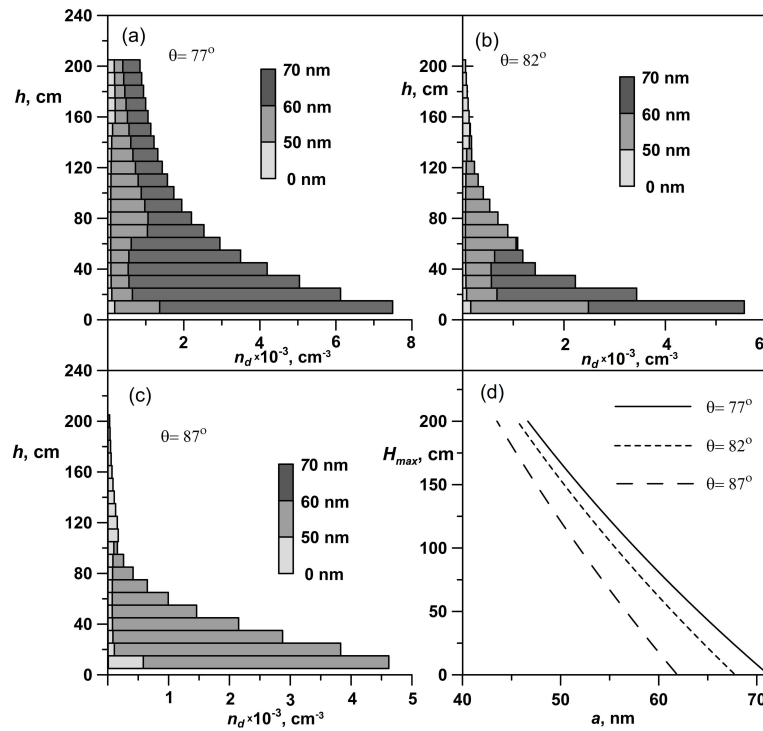

Figure 2: Distributions of dust particles over the surface of the Moon for $\theta = 77^o$ (a), 82° (b), and 87° (c) as well as dependencies of maximum possible rise heights H_{max} (d) of dust particles on their sizes a under the conditions corresponding to the lunar regolith regions

Data characterizing the dust distributions under the conditions corresponding to the lunar regolith are plotted in Figs. 2 and 3. Histograms given in Figs. 2(a)–(c) present the results of calculations of the number densities n_d of dust particles over the surface of the Moon for $\theta = 77, 82^o$, and 87°. The length of a single-color horizontal segment in each of the plots shown in Fig. 2 characterizes the density of particles (in cm^{-3}) with sizes in the corresponding interval (indicated on the right scale) at the corresponding heights. The total length of the horizontal segment in the plot corresponds to the total dens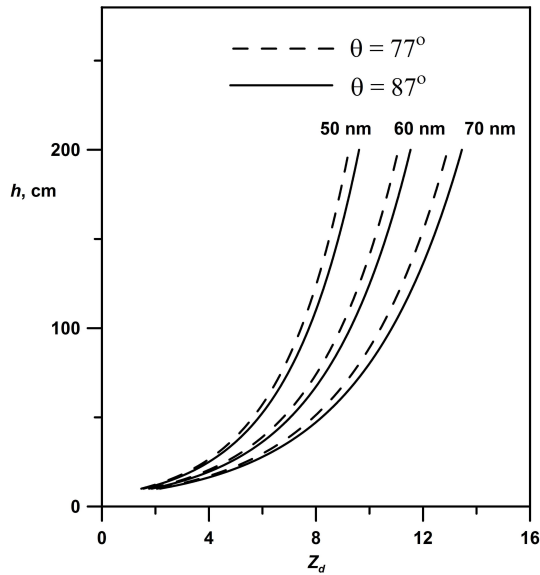ity of the particles with the sizes presented in this plot. Figs. 2(d) and 3 show, respectively, maximum possible rise heights of dust particles of various sizes and the height distributions of dust charge numbers Z_d for different θ.

Figure 3: Height distributions of dust particle charge numbers Z_d over regolith regions of the surface of the Moon for $\theta = 77^o$ (a), 82° (b), and 87° (c) and dust particle sizes of 50 nm, 60 nm, and 70 nm

For hydrogen-enriched lunar regions the height distributions of electrons and dusts are qualitatively the same as in the case of regolith surface. But the characteristics of dust rising over the lunar regolith and hydrogen-enriched regions of the lunar surface are different. The difference is that the dust levitating over the hydrogen-enriched regions has larger sizes (up to ≈ 250 nm), larger charges, rises to larger heights, *etc.* than in the case when the dust levitates over the lunar regolith region.

Thus, the dusty plasma system in the surface layer of the illuminated part of the Moon includes positively charged dust, photoelectrons, and electrons and ions of the solar wind. There are no significant constraints [5] on the Moon landing sites for future lunar missions that will study dust in the surface layer of the Moon.

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