*Nayana H et al./ SDC Journal of Theoretical and Experimental Research (SDCJTER) 01(02), 2023, 18–24*

# Dust dynamic theory and levitation mechanism of charged dust grains in lunar plasma field environment

Nayana. H [a,b], Nandana. H [a,b] , Josna Joseph [a,b], Sibi K S [a] , Rakesh Chandran S. B [b*]

[a] *University of Kerala, Kariavattom Campus, Thiruvananthapuram, Kerala India,695007*

[b] *PG Department of Physics, Sanatana Dharma College, Alappuzha, Kerala India, 688001*

---

## Abstract

Dust particles are electrostatically levitated and carried across the lunar surface by the ambient solar wind plasma, which charges the surface. Since the height of the dust particle is determined by the electric field and plasma sheath near the lunar surface, this process is strongly associated with surface charging. Because it enables the linking of fields and the environment of the particles to the dynamics of the dust grains, the study of the charging of microscopic dust particles is of fundamental interest. Due to the possibility of increased charge and radiation dosage during Solar Experiments (SEPs), dust levitation is a phenomenon of great scientific interest. The knowledge gathered from these investigations will be helpful in reducing the negative impacts of dust on human exploration. Given that increased charge and radiation dosage during Solar Experiments (SEPs) could make dust levitation dangerous, the phenomena is of great scientific interest. The knowledge acquired through these investigations will be helpful in reducing the negative impacts of dust on human exploration.

*Keywords- Solar wind, Lunar Plasma environment*

---

## 1. Introduction

The study of electrical discharges in gases gave rise to the area of plasma physics about a century ago. The component atoms may break into separate, mobile electrons and ions as a result of the high temperature. Being in a quasi-neutral condition wherein the almost equal quantities of ions and electrons in the plasma result in nearly electrical neutrality. Due to the fact that the majority of the particles in plasma are charged, they react in a very interesting and complex fashion to strong electrostatic and electromagnetic field forces. There are

---

[*] Corresponding author: rakwin@gmail.com

many uses for plasma research in the domains of geophysics, space physics, and astrophysics because over 99 percent of matter in the universe is in the plasma state.

The Interplanetary Magnetic Field (IMF) is the name given to the magnetic field carried by the solar wind. The whole magnetic field of the Sun is the source. Because of the Sun's rotation, the IMF carried by the solar wind takes on a spiral form.

Humans are protected from these powerful particles by the magnetosphere, which is created around the planet by the interaction of the solar wind and the magnetic field. During the day, the Earth's magnetic field is compressed by the pressure of the solar wind, and at night, it is stretched into a long tail. Although the Earth's night side magnetic field extends to hundreds of Earth radii (R E), a considerable distance beyond the Moon's orbit at 60RE (1RE = 6731km), it is only present in a small region of around 10 Earth radii from planet's core on Earth's dayside.

Since the coronal holes are magnetically open structures rather than the closed or arched field lines found elsewhere on the Sun, they are the primary source of the solar wind. As a result, the coronal holes allow electrically charged particles in the heated solar atmosphere to escape the Sun. Their distinctive form is derived from their trapping in closed magnetic field lines in other locations within the structured corona. Because it has too much energy to be contained by solar gravity, the volatile, hot solar coronal plasma extends out from the Sun.

The Moon travels approximately 384000 km around the Earth. With a mean density of only 3 $gcm^{-3}$, it has a diameter of 3476 km. The Moon has no inherent magnetic field since it does not have a large core of molten iron as our Earth does. However, there are weak, localised, dispersed magnetic anomalies in it. The Moon has no atmosphere and its gravitational pull is only one-sixth that of Earth. The Moon experiences temperature extremes because it lacks an atmosphere. The night side of the moon experiences bone-chilling cold, while the side that receives sunlight gets scorching hot, reaching $130^0$C (-180). (Luhmann, 1998; Sternovsky et al., 2002).

The regolith on the lunar surface becomes electrically charged due to solar UV and the surrounding plasma environment (Manka, 1973; Stubbs et al., 2006). According to McCoy (1976), Zook and McCoy (1991), Rakesh Chandran et al. (2013), and others, this can lead to the electrostatic transport of charged dust (<10μm}) in the lunar exosphere, which has been recorded to reach heights >100 and speeds of up to 1 kms−1 (Berg et al., 1976).

## 2. Data and method

The Lunar Prospector spacecraft carried five science instruments (SIs): a gamma ray spectrometer (GRS), an electron reflectometer (ER), a magnetometer (MAG), an alpha particle spectrometer (APS), and a neutron spectrometer (NS). These SIs were mounted on three deployable poles that were positioned externally to the SC module (Figure 1.16). In addition to the five SIs, the LP mission also conducted a Doppler Gravity Experiment (DGE) that measured gravity using S-Band transponder tracking data.

It was noted that sunlight was dispersed at the terminators during the Apollo era of lunar exploration, resulting in "horizon glow" and "streamers" above the lunar surface. Between dusk and dawn, this was seen on the Moon's dark side. These findings were surprising since it was previously believed that the Moon's exosphere, or atmosphere, was quite thin. Subsequent studies have revealed that dust grains with an electrical charge that originated from the surface were responsible for scattering sunlight. Furthermore, mathematical modelling was created that uses sub-micron dust grains, whose spatial density fluctuates with height above the Moon, to optimally drive the light.

In addition to reacting to all other forces operating on uncharged grains, dust particles submerged in plasma also accumulate electrostatic charges. This section covered the theory of charging isolated grains in plasma and developed equations for charging lunar dust in two different plasma conditions: average solar wind and during solar wind pulses. The primary sources of charging current in the lunar wake region are secondary electrons, plasma ions, and plasma electrons, respectively. emerges mostly as a result of intense electron bombardment. The dust grain submerged in the plasma has a total current of

$$dQ/dt = I = I_e + I_i + I_s = \sum_k I_k \tag{1}$$

The charging currents in lunar dust grains depend on plasma parameters and dust grain properties. The probe theory was used to find these currents, but for spherical dust grains, the probe radius is smaller than the Debye length. Current density equations were derived from charged particle flux to study charging processes. The plasma environment was assumed to be quasi-neutral, with electrons and ions having the same temperature and density. The grains were assumed to be isolated and at rest, with grain motion essentially unchanged by charging currents. As was previously mentioned, it was assumed for the study that the grains were isolated and at rest in relation to the surrounding plasma. In fact, dust grain flow velocity is far slower than electron thermal velocity. Consequently, grain motion has little effect on the charging currents (Whipple, 1981).

The flow of ions and electrons travelling at a speed of light in the z direction, saturating a solitary dust grain with a radius of a, a<<λ

$$\Gamma_\alpha = \int v_z f_\alpha(v) d^3v \qquad .(2)$$

Here is the distribution function, which is given by, and is the Debye screening length for ions and electrons, respectively.

$$f_\alpha(v) = n_\alpha \left(\frac{m_\alpha}{2\pi k T_\alpha}\right)^{3/2} \exp\left(\frac{-E}{kT_\alpha}\right) \qquad (3)$$

$$\Gamma_\alpha = \int_{v=0}^{\infty} \int_{\theta=0}^{\pi/2} \int_{\psi=0}^{2\pi} v\cos\theta f_\alpha(v) v^2 \sin\theta d\theta d\psi dv$$

$$= \pi \int_0^\infty v^3 f_\alpha(v) dv \qquad (4)$$

and equation for current density

$$J_\alpha = ne \int_0^\infty \pi v^2 f_\alpha(v) dv \qquad (5)$$

Electron current density,

$$J_e = -ne\left(\frac{m}{2\Pi KT}\right)^{\frac{3}{2}} 2\Pi/m^2 A(\phi_d) \qquad (6)$$

Net current incident on a dust particle is zero

$$J_e + J_i = 0 \qquad (7)$$

$$1 + J_i/J_e = 0 \qquad (8)$$

Assume $n_i \sim n_e$, $T_I \sim T_e$

$$\sqrt{\frac{m_i}{m_e}} = 40 \qquad (9)$$

Equation (8) and (9) gives

$$\frac{1}{40\, e^{\left(\frac{e\phi}{KT}\right)}} + \frac{1}{40e\phi}/KTe^{\left(\frac{e\phi}{KT}\right)} = 1$$

$$e^{\left(\frac{e\phi}{KT}\right)} + \frac{e\phi}{KTe^{\left(\frac{e\phi}{KT}\right)}} = 40$$

$$e^{x} + xe^{x} = 40 \qquad (10)$$

Put $\frac{e\phi}{KT} = x$

Equation becomes

$$e^{x(1+x)} = 40 \qquad (11)$$

This equation is numerically solved by bisection method using MATLAB programming.

## 3. Results and discussion

The Moon's interaction with the nearby plasma environment and electron photoemission charge the dust grains similarly to the lunar surface. Both the grain size and the plasma environment affect the equilibrium grain potential. It is difficult to estimate grain potential precisely in the lunar wake area. This paper examines the dust charging processes under typical solar wind conditions ($T_e < 100$ eV) and studies the dust grain potential at various plasma temperatures.

The study studied the lunar dust potential under typical solar wind conditions by utilising electron data received from the Electron Reflectometer instrument of the Lunar Prospector spacecraft, together with theoretical calculations.

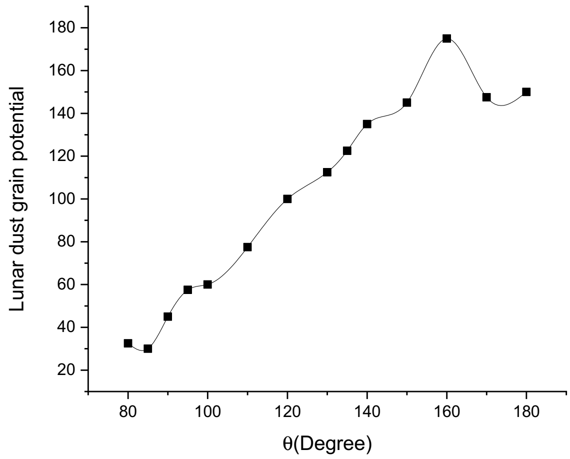

Figure 1 Plot of Lunar dust potential versus θ in lunar wake region on 23 March 1998

Equation (11) was numerically solved to determine the dust grain potential as a function of θ and solar wind electron temperature (eV) in the lunar wake area. The result is displayed in Figure 1. Angle from sub solar point is indicated by the θ value. Since the lunar wake area is our main target, we choose values between $80^0$ and $180^0$. After two days of study, the fluctuation of dust grain potential with electron temperature and is presented here.

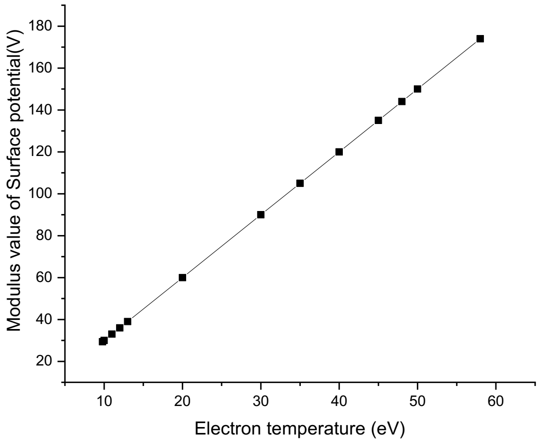

Figure 2 Plot of Lunar dust potential versus electron temperature in lunar wake region on 14 April 1998.

Figure 2 shows Potential – Current characteristics of a dust grain. On the graph showing the variation of dust grain potential with θ, the grain potential values peak at lunar wake region from $\theta=130^0$ to $\theta=180^0$.This large value of potential is due to the presence of highly energetic electrons in the wake region. The trend is confirmed from the data measured by Lunar Prospector spacecraft as given in Figure 2

Using the data values measured by the spacecraft on 23 March 1998 and 14 April 1998, we calculated electrostatic acceleration experienced by dust grains of 0.1 µm and 0.5 µm. The results are shown here.

.

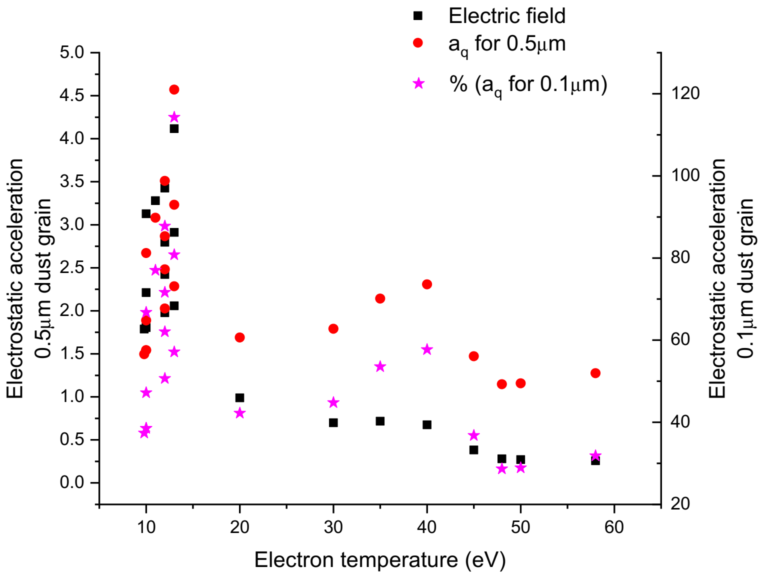

Figure 3 Plot of electrostatic acceleration experienced on dust grains of different radii (0.1 µm and 0.5 µm).

Electric field repels like charged dust grains from the lunar surface causing it to levitate above the lunar surface. Since the electric field is not uniform over the lunar surface, the electrostatic force experienced by the dust grains is also different. The variation in potential and electric field causes the variation in Maximum radius of the lofted dust grain ($R_{max}$) and maximum levitation height ($Z_{max}$) values. Using the equations of surface charging and dust dynamics, we calculated $R_{max}$ and $Z_{max}$ as a function of electron temperature.

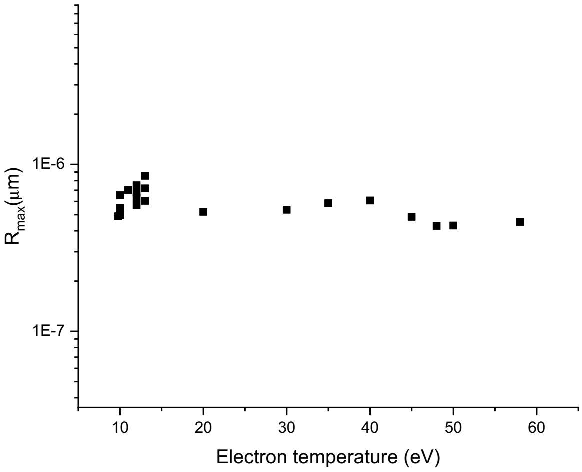

Figure 4 Variation of $R_{max}$ as a function of electron temperature

Figure 4 shows the variation of $R_{max}$ as a function of electron temperature. The radius of maximum sized grain that can be lofted peaks at 0.85 μm when the electric field value is high. This peak is also due to the effect of combination of large lunar and dust grain potential. When the electric field decreases and the electrostatic force acting on the dust grains also decreases. Thus, $R_{max}$ decreases.

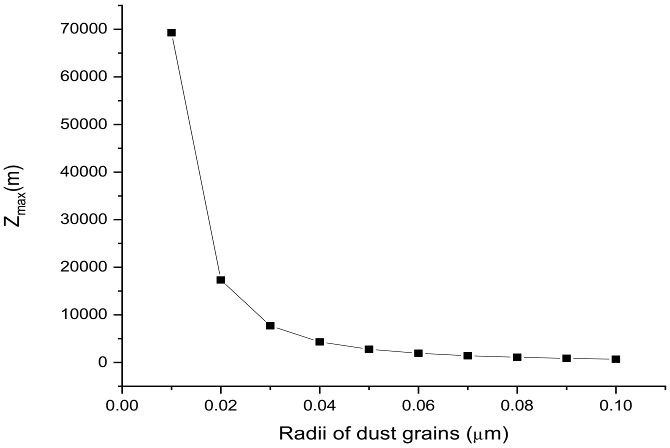

Figure 5 shows the variation of $Z_{max}$ with electron temperature during SEPs.

Figure 5 depicts $Z_{max}$ for various dust grains of radii ranging from 0.01μm to 0.1 μm. The dust grains having radius 0.1 μm is seen to levitate on the night side region above 500 m. Most of the exploration activities are focused on this height and the charged dust grains are a significant threat to the exploration activities.
The maximum height reached above the lunar surface ($Z_{max}$) varies with lunar surface potential. During solar energetic particle events, surface potential is very large and this reflects in $Z_{max}$ values also. Figure 5 shows the variation of $Z_{max}$ with electron temperature during SEPs. During SEPs even 10 μm radius dust grain is seen at an altitude of 200 m and it cause serious threat to exploration activities.

## 4. Conclusions

In the lunar wake region, dust potential varies in accordance with electron temperature. Under average condition, the dust grain potential reaches to a maximum value of -175V, when the electron temperature is 70eV. The dust charging process is more violent during SEPs. The equilibrium grain potential is independent on secondary current for average solar wind condition because of low plasma temperature.

Dust particles are continuously adjusting their surface potential towards the local equilibrium value as influenced by the charging plasma conditions. To discuss the dynamical behavior of lofted dust grains above the lunar surface, dust levitation theory was developed and analyzed. The calculation strongly reflects the dependence of grain radius and electron temperature on levitation height. At average SW condition 0.1 μm dust grain shows a levitation height of 600 m at the nightside region. We also proved $R_{max}$ and $Z_{max}$ have a strong dependency on surface electric field. The radius of maximum sized grain that can be lofted peaks at the terminator region. This is due to the effect of intense electric field experienced at that region.

## Acknowledgments

The authors are thankful to the Department of Physics, Kariavattom Campus and Sanatana Dharma College, Department of Physics, Alappuzha.

## References

1) **Luhmann JG**, Plasma interactions with unmagnetized modies, in *Introduction to Space Physics*, Kivelson MG and Russell CT (Ed), Cambridge Uni. Press, New York, **1998**, 203-225.
2) **Manka RH**, Plasma and Potential at the lunar surface, in *Photon and Particle Interactions with Surfaces in Space*, RJL Grard (Ed), D. Reidel Publishing Co., Dordrecht, Holland, **1973**, 347-361.
3) **McCoy JE**, Photometric studies of light scattering above the lunar terminator from Apollo solar corona photography, Proc. Lunar Sc. Conf., 7th, **1976**, 1087-1112.
4) **Rakesh Chandran SB**, Renuka G, Venugopal C, Plasma electron temperature variability in lunar surface potential and in electric field under average solar wind conditions, Adv. Space Res., 51, **2013**, 1622-1626.
5) **Whipple EC**, Potentials of surfaces in space, Rep. Prog. Phys., 44, **1981**, 1197-1250.