# Electrostatic Phenomena on Planetary Surfaces

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*To my grandson Liam*

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# Preface

Our knowledge of planetary environments has increased considerably as a result of the planetary exploration missions that NASA primarily along with ESA and other space agencies has launched in recent decades. Electrostatic phenomena occurring on the solar system bodies are among the most important ones to consider, as they affect the weather in planets and moons with atmospheres and the physical properties of the surfaces on planets and moons lacking an atmosphere. These phenomena are not completely understood even on Earth. Data on electrostatic phenomena from recent missions are currently being analyzed and results are being published and discussed in scientific journals and at conferences.

My aim with this concise book is to provide an overall understanding of the different aspects of electrostatic phenomena as they occur on planetary atmospheres and surfaces, to show the reader what is known in this important field, what is expected from planned exploration missions, and what the big unknowns are. I have included numerous references at the end of each chapter to guide further research into this field.

# Acknowledgements

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# Author biography

## Carlos I Calle

Carlos I Calle is a senior research scientist at NASA Kennedy Space Center and is founder and head of the Electrostatics and Surface Physics Laboratory. He is currently working on the problem of electrostatic phenomena of granular and bulk material as they apply to planetary surfaces, particularly that of Mars, developing instrumentation for future planetary exploration missions. He has over 150 scientific publications, four books, and several patents.

Dr Calle received the NASA Exceptional Technological Achievement Medal in 2010, the NASA Spaceflight Awareness Award in 2003 for his outstanding contributions to the space program, and the NASA Silver Snoopy Award in 2007 for his exceptional contributions to human spaceflight.

Other books by Carlos I Calle:

*Superstrings and Other Things: A Guide to Physics* 2nd edn (London: CRC Press/Taylor & Francis) 660 pp (2009)
French edition: *Supercordes et Autres Ficelles: A Voyage au Coeur de la Physique* (Paris : Dunod) 608 pp (2004)
*The Universe, Order Without Design* (Amherst, NY: Prometheus Books) (2009)
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# Chapter 1

## Introduction

The diverse planetary environments in the Solar System react in somewhat different ways to the encompassing influence of the Sun. These different interactions define the electrostatic phenomena that take place on and near planetary surfaces. The desire to understand the electrostatic environments of planetary surfaces goes beyond scientific inquiry. These environments have enormous implications for both human and robotic exploration of the Solar System.

In Solar System bodies with an atmosphere, electrostatic phenomena are determined by the physical and chemical properties of those atmospheres. Atmospheric pressure and density, as well as composition, govern the way objects acquire, hold on to, and release electrostatic charge. The transfer of electric charge from an object to another can happen in different ways. If the transfer is fast, as in electrical breakdown, lightning can occur. In addition to Earth, lightning has been detected on Jupiter and Saturn. Recent atmospheric models predict that lightning should also occur on Venus, Mars, and on Saturn's moon Titan. Despite several efforts to detect lightning on these bodies with instrumentation aboard spacecraft, the question remains open. Electrostatic discharges have been detected from Uranus and Neptune, although it is not known if those discharges are caused by lightning.

When the charge transfer is slow, a glow discharge known as a corona can take place. These corona discharges occur on Earth and may also occur on Venus, Mars, Titan, and the three giant planets.

The most extensively studied electrostatic environment is clearly that of the Earth. The Earth's magnetosphere, produced by the interaction of the solar wind with the planet's magnetic field, controls the electrostatic charge content of the atmosphere. The magnetosphere slows down, deflects, and traps many solar wind particles. These trapped particles form the doughnut-shaped regions called Van Allen radiation belts, a nearly impenetrable barrier that prevents the most energetic electrons from reaching the Earth's atmosphere.

Spacecraft and satellites interact with the space plasma environment around the Earth. This interaction generates electrostatic charging on these orbiting craft, a

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complex phenomenon that may interfere with their operation and may disrupt or damage power, navigation, communications, and other instrumentation.

In addition to the Earth, Mercury, Saturn, Jupiter, Neptune, and Uranus, as well as Jupiter's moon Ganymede have magnetic fields. As happens on Earth, these magnetic fields interact with the solar wind, producing magnetospheres which act as semipermeable barriers to the solar wind particles. The magnetic field lines plunge at the planets' magnetic poles, allowing particles from the solar wind to reach lower altitudes. Mass ejections from the Sun's corona, commonly known as solar flares, increase the flux of solar wind particles for several hours. These particles interact with the magnetic fields of the planets, releasing trapped particles which trigger reactions with atmospheric molecules that release photons. In the polar regions, these photons form the auroras, known as the northern and southern lights on Earth. Auroras have been observed on Jupiter, Saturn, and Neptune.

The electrostatic environment of airless bodies, such as the Moon, Mercury, and the major asteroids, is the result of the direct interaction of the surface with the solar wind, cosmic rays, and solar radiation. The surfaces of these Solar System bodies develop a charge that balances the sum of all these current fluxes. The electrostatic interaction between the charged surfaces of these Solar System bodies and the surrounding plasma results in the arrangement of the plasma particles in the form of a shield that surrounds the surface. This shield limits the magnitude of the charge that develops on these surfaces.

The surfaces of Mars, Mercury, the Moon, and a few other Solar System bodies, are covered with a layer of fine dust. Interaction of the surface dust with the unmanned exploration rovers on Mars or with rovers and astronaut boots during the Apollo missions to the Moon generates electrostatic charge on the bodies as they repeatedly make contact and separate, a phenomenon called triboelectric charging. Triboelectric charging is unlikely to be a concern on the day side of airless bodies, but can reach levels that may cause electrostatic discharges on the dark sides due to a stronger electron flux in those regions. Triboelectric charging is also a concern on Mars and NASA took steps to mitigate the issue with all its rovers operating on the planet.

Data from recent and current planetary missions from NASA, the European Space Agency, and the Japanese space agency JAXA has provided unprecedented information on the electrostatic environments of Solar System planets and moons. Some of these data are still being analyzed and new discoveries are frequently being made. But many unknowns remain. Not all planned experiments in planetary missions have been successful. Some missions carrying valuable experiments have failed altogether and at least one important experiment on a successful mission was not carried out.

In the pages that follow I describe in some detail what is known about the electrostatic environment of the Solar System from early and current experiments on Earth, as well as what is being learned from the instrumentation on the space exploration missions of the last few decades. But before embarking in this study, I present a brief review of the basic principles of electrostatics.

# Chapter 2

# Electrostatics principles

## 2.1 Coulomb's law and the principle of superposition

A brief introduction to the fundamental principles of electrostatics should be of use before looking at the electrostatic phenomena on the different bodies of the Solar System.

Electrostatics is a component of electromagnetism, a branch of physics that describes the behavior of the electromagnetic force, one of the four fundamental forces in nature. The fundamental problem of electromagnetism is to understand the force that electric charges exert on one another. Electrostatics restricts itself to answer this question when charges are not in motion. As we shall see, electrostatics does allow for short, slow motions of charges as they interact with each other. Continuous motion of charges generates magnetic fields and that takes us beyond electrostatics to the range of electromagnetism.

The solution to the fundamental problem of electromagnetism was given by Charles Coulomb in the eighteenth century and is known today as Coulomb's law. If two charges $q_1$ and $q_2$, considered to be *point* charges (that is, charges on an ideal object with no physical extension), are separated by a distance $r$, the force that $q_2$ exerts on $q_1$ is

$$\mathbf{F} = k\frac{q_1 q_2}{r^2}\hat{\mathbf{r}} \tag{2.1}$$

where $\hat{\mathbf{r}}$ is a unit vector along the line joining the two charges and pointing away from $q_2$ toward $q_1$. This expression is Coulomb's law. The SI unit of charge is the *coulomb*, C, and the force is given in newtons, N. In SI units, the constant of proportionality $k$ is usually given in terms of the permittivity of free space $\varepsilon_0$, as $1/4\pi\varepsilon_0$, with

$$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}.$$

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The force is repulsive if the charges have equal signs and attractive if they have opposite signs.

The force between these two point charges $q_1$ and $q_2$ is not affected by the presence of any other point charges in the vicinity. The total force on $q_1$ due to all the charges present is calculated by computing the force on $q_1$ due to $q_2$ alone, then calculating the force on $q_1$ due to $q_3$ alone, and so on, and adding all these contributions. This is known as the *principle of superposition*. Coulomb's law and the principle of superposition are the only two physics concepts required for electrostatics. The rest is mathematical manipulation of these concepts [1].

## 2.2 The electric field

How is the force between two charges separated by a distance $r$ transmitted from one charge to the other? The classical solution, introduced by Michael Faraday in the nineteenth century, involves the concept of *field*. According to Faraday, the space around an electric charge is distorted in such a way that any other charge placed in this space accelerates with a force that is given by Coulomb's law.

The electric field around a charge $q$ can be mapped by placing a positive charge $q_0$ at different locations around $q$. The force at each one of these locations is given by Coulomb's law and points away from $q$ (figure 2.1). This force is

$$\mathbf{F} = \frac{q_0}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{\mathbf{r}}$$

or

$$\mathbf{F} = q_0\mathbf{E}$$

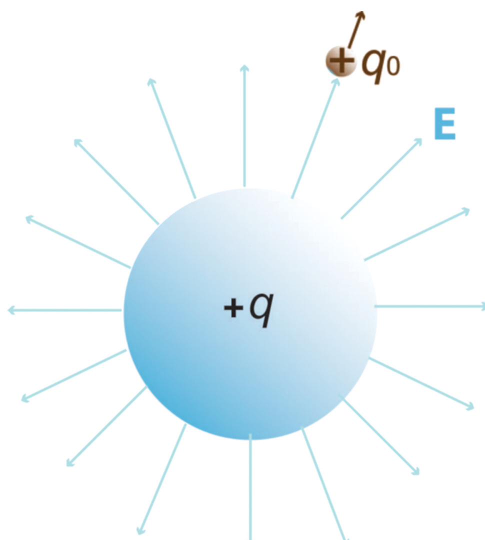


**Figure 2.1.** The electric field in the space around a positive charge $q$ is mapped by placing a positive charge $q_0$ at different points around the charge $q$.