The book was found

Electrostatic Phenomena on Planetary Surfaces (IOP Concise Physics)

by

Carlos I Calle

[Image of book cover]

[Download button]
Synopsis

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. This book describes 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 (NASA, European Space Agency, and the Japanese Space Agency) of the last few decades. It begins with a brief review of the basic principles of electrostatics.
Look inside the book
Electrostatic Phenomena on Planetary Surfaces
Carlos I Calle
Senior Research Scientist
NASA Kennedy Space Center, USA
Morgan & Claypool Publishers

Copyright © 2017 Morgan & Claypool Publishers
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publisher, or as expressly permitted by law or under terms agreed with the appropriate rights organization. Multiple copying is permitted in accordance with the terms of licences issued by the Copyright Licensing Agency, the Copyright Clearance Centre and other reproduction rights organisations.

Rights & Permissions
To obtain permission to re-use copyrighted material from Morgan & Claypool Publishers, please contact info@morganclaypool.com.

DOI 10.1088/978-1-6817-4477-3
Version: 20170201
IOP Concise Physics
ISSN 2053-2571 (online)
ISSN 2054-7307 (print)
A Morgan & Claypool publication as part of IOP Concise Physics
Published by Morgan & Claypool Publishers, 40 Oak Drive, San Rafael, CA, 94903 USA
IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK

To my grandson Liam

Contents
Preface
Acknowledgements
Author biography
1 Introduction
2 Electrostatics principles
   2.1 Coulomb's law and the principle of superposition
   2.2 The electric field
   2.3 Gauss's law
   2.4 Electric potential
   2.5 Conductors in electrostatic fields
   2.6 Capacitance
   2.7 Electrostatic breakdown
   2.8 Dielectrics in electric fields
   2.9 Plasmas
References
3 Electrical breakdown and charge decay in planetary atmospheres
   3.1 Electrical breakdown in planetary atmospheres
   3.2 Glow discharges and ion wind
   3.3 Charge mobility
   3.4 Charge decay in planetary atmospheres
References
4 The terrestrial electrostatic environment
   4.1 The Earth’s atmosphere
   4.2 Electrical breakdown in the terrestrial atmosphere
   4.3 Radiation from the Sun: the solar wind
   4.4 Radiation belts
   4.5 Auroras
References
5 Spacecraft and satellites in the electrostatic environment of the Earth
   5.1 Spacecraft and satellite orbits
   5.2 Spacecraft charging
   5.3 Spacecraft charging in LEO
   5.4 Charging of the ISS
   5.5 Spacecraft charging in MEO
   5.6 Spacecraft charging in GEO
   5.7 Mitigation techniques
References
6 The electrostatic environment of the Moon
   6.1 The lunar surface environment
   6.2 The lunar electrostatic environment
   6.3 Electrostatic charging of the lunar regolith
   6.4 Triboelectric charging on the lunar surface
References
7 The electrostatic environment of asteroids
   7.1 The asteroid electrostatic environment
   7.2 Electrostatic dust transport
   7.3 Cohesive forces in asteroids
References
8 The Martian electrostatic environment
   8.1 The Martian atmosphere
   8.2 Electrical breakdown in the Martian atmosphere
   8.3 Electrostatic charge and size of Martian atmospheric dust particles
References
9 The electrostatic environments of Venus and Mercury
   9.1 Electrical phenomena in the Venusian atmosphere
   9.2 The electrostatic environment of Mercury
References
10 The electrostatic environments of the giant planets
   10.1 The electrostatic and magnetic environments of Jupiter
   10.2 Lightning on Jupiter
   10.3 The electrostatic environment of Saturn
   10.4 The electrostatic environments of Uranus and Neptune
   10.5 The electrostatic environment of Saturn’s moon Titan
References

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

The idea for this concise book on electrostatic phenomena on planetary surfaces came from Nicki Dennis at Morgan & Claypool and Institute of Physics joint publishing. I am indebted to her. I would also like to thank Dr José Nuñez at NASA Kennedy Space Center for his support of this work. I would like to acknowledge the valuable contributions to our work on electrostatic phenomena on the Moon and Mars by the research team at the NASA Kennedy Space Center Electrostatics and Surface Physics Laboratory. Their work has led to the development of several electrostatics-based technologies for NASA's planetary exploration missions. I would like to acknowledge in particular Dr Charles Buhler, Dr Sid Clements, Paul Mackey, Dr Michael Hogue, Dr James Mantovani, Michael Johansen, Ellen Arens, James Phillips III, and Rachel Cox. Finally, I would like to thank Dr Luz Marina Calle, my wife and fellow NASA scientist. She has always been a wonderful sounding board during my research and writing endeavors.

Author biography


IOP Concise Physics

Electrostatic Phenomena on Planetary Surfaces

Carlos I Calle

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 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.

IOP Concise Physics Electrostatic Phenomena on Planetary Surfaces Carlos I Calle

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 q1 and q2, 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 q2 exerts on q1 is

\[ F = \frac{k q_1 q_2 r^2}{r^2} \]  

(2.1)

where \( \hat{r} \) is a unit vector along the line joining the two charges and pointing away from q2 toward q1. 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 \( \varepsilon_0 \), with 

\[ \varepsilon_0 = \frac{1}{4\pi}\varepsilon_0 \]

force is repulsive if the charges have equal signs and attractive if they have opposite signs. The force between these two point charges q1 and q2 is not affected by the presence of any other point charges in the vicinity. The total force on q1 due to all the charges present is calculated by computing the force on q1 due to q2 alone, then calculating the force on q1 due to q3 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 q0 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 \( F = q_04\mu_0qr^2r \) or \( F = q_0E \) where \( E \) is the electric field of the charge \( q \): \( E = 14\mu_0qr^2r \).

(2.2)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 \( q \). 2.3 Gauss’s law The electric field lines around a charge \( q \) are the graphical representation of the electric field vectors \( E \) at different locations around the charge. From (2.2), we can see that the field lines around a positive charge point radially outward from the charge and those around a negative charge point radially toward the charge. If we assume that the number of field lines is proportional to the magnitude of the charge \( q \), we can see that if we place this charge inside a closed surface, all the field lines coming out (for a positive charge) or going in (for a negative charge) cross this closed surface. We can define the flux of \( E \), \( \Phi = \int \mathbf{E} \cdot d\mathbf{A} \) through any surface as the net number of field lines crossing this surface. Since the number of field lines is proportional to the magnitude of the charge, the flux is \( \Phi = \oint \mathbf{E} \cdot d\mathbf{A} \). Equation (2.3) is known as Gauss’s law.

2.4 Electric potential If a charge \( q_0 \) moves from point 1 to point 2 in an electric field \( E \), the work done by the field is \( W = q_0 + 12E \cdot dl \) where \( dl \) is an element of length along a path from 1 to 2. The work done by the field is independent of that path from point 1 to point 2 and depends only on these two points. The electric field is said to be a conservative field. The difference in the potential energy between the final point 2 and the initial point 1, as the electric field moves the charge \( q_0 \) from 1 to 2 is \( 9EC\Phi = 9CE \cdot dl \). The negative sign indicates that, as the electric field does work on the charge to move it between those two points, the potential energy of the point charge decreases, being less at point 2 than at point 1. The potential energy of \( q_0 \) depends on the nature of the electric field \( E \) and on the magnitude of the charge. It is then convenient to define the potential energy per unit charge, \( V \), which depends only on the nature of the field, as follows, \( 9EC\Phi = 9CE \cdot dl \). The quantity \( V \) is called the electric potential.

If we chose point 1 to be the standard reference point which we can arbitrarily locate at infinity, and assign to the potential energy of \( q_0 \) when located at this point a value of zero, then \( V_1 \) is clearly zero and we can set \( V_2 \) to \( V \). The potential at a point in an electric field is then, \( V = -E \cdot dl \). (2.4)

2.5 Conductors in electrostatic fields Conductors are a particular class of matter in which electric charges are free to move about in the material. In the case of solid metallic conductors, one or two electrons per atom are the charges that move about. In the case of liquid conductors, such as salty water, it is ions that are free to move in the liquid. Gases at extremely high pressures, such as hydrogen deep in the atmospheres of Saturn and Jupiter, are also liquid conductors. In this case, it is electrons freed from their hydrogen nuclei that are free to move. Although conductors have free charges that can move about, an isolated conductor is still neutral. If an additional charge were to be placed inside an isolated conductor, the repulsive forces of the charges inside the conductor would push this additional charge out to the surface, where this mutual repulsion is balanced by surface forces. The time for this process to take place would be of the order of 10^14 s [2]. Thus, the net charge inside an isolated conductor is zero. In electrostatics, there are no continuous sources of energy in a conductor and the electrons arrange themselves until the electric field everywhere inside the conductor is zero. This is true even if the conductor is placed in an external electric field. In this case, the external field exerts a force on the free electrons, moving them inside the conductor in an opposite direction to the field, leaving the positive ions in the metal unpaired. However, the conductor is still neutral. This separation of charges caused by the external field generates an internal electric field that opposes and cancels the external applied field, so that the net field inside remains at zero. For the case of a charged spherical conductor, the charges are distributed uniformly over the surface of the sphere. The electric potential at the surface of a sphere of radius \( r \) holding a charge \( q \) is

Download to continue reading...
The book by Carlos I Calle has a rating of 5 out of 4.0. 1 people have provided feedback.