Understanding Lightning and Lightning Protection

A Multimedia Teaching Guide

Tibor Horváth
Budapest University of Technology and Economics, Hungary

John Wiley & Sons, Ltd
Research Studies Press Limited

Understanding Lightning and Lightning Protection

RSP SERIES IN ELECTROSTATICS AND ELECTROSTATIC APPLICATIONS

Series Editor: **Professor J F Hughes**

Electrostatic Hazards in Powder Handling
Martin Glor

Electrostatic Spraying of Liquids
Adrian Bailey

Industrial Electrostatics: Fundamentals and Measurements
David Taylor and **Peter Secker**

Electrostatic Particle Charging: Industrial and Health Care Applications
John Hughes

Understanding Lightning and Lightning Protection: A Multimedia Teaching Guide
Tibor Horváth

Understanding Lightning and Lightning Protection

A Multimedia Teaching Guide

Tibor Horváth
Budapest University of Technology and Economics, Hungary

John Wiley & Sons, Ltd **Research Studies Press Limited**

Published by John Wiley & Sons, Ltd., The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England
Telephone (+44) 1243 779777

Email (for orders and customer service enquiries): cs-books@wiley.co.uk
Visit our Home Page on www.wiley.com

This Work is a co-publication between Research Studies Press Limited and John Wiley & Sons, Ltd.

This book cannot be used without running the multimedia teaching guide (the PC program?), which can be found (ordered?) in cs-books@wiley.co.uk.

Other Wiley Editorial Offices

John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030, USA

Jossey-Bass, 989 Market Street, San Francisco, CA 94103-1741, USA

Wiley-VCH Verlag GmbH, Boschstr. 12, D-69469 Weinheim, Germany

John Wiley & Sons Australia Ltd, 42 McDougall Street, Milton, Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01, Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 22 Worcester Road, Etobicoke, Ontario, Canada M9W 1L1

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Library of Congress Cataloging-in-Publication Data

Horváth, Tibor, 1928-

Understanding Lightning and Lightning Protection: A Multimedia Teaching Guide / Tibor Horváth.
p. cm.

"This work is a co-publication between Research Studies Press Limited and John Wiley & Sons, Ltd."

Includes bibliographical references and index.

ISBN-13 978-0-470-03018-9 (paper/cd : alk. paper)

ISBN-10 470-03018-6 (paper/cd : alk. paper)

1. Lightning protection. I. Title: A Multimedia Teaching Guide.

TH9058.H67 2006

693.8'98--dc22

2006005569

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN-13 978-0-470-03018-9 (PB)
ISBN-10 0-470-03018-6 (PB)

Typeset in 10/12pt Times New Roman by Laserwords Private Limited, Chennai, India
Printed and bound in Great Britain by TJ International, Padstow, Cornwall
This book is printed on acid-free paper responsibly manufactured from sustainable forestry
in which at least two trees are planted for each one used for paper production.

Contents

Preface

This book is attached to a computer program, and it gives textual commentaries to each picture displayed on the screen. The computer program can be used without this book, because the same commentary can be also displayed and read on the screen. It depends on the decision of the user, whether the printed or the displayed text will be preferred. The book cannot be properly used without the computer program.

The author developed this program for illustration of the special course LIGHTNING PROTECTION at the Budapest University of Technology and Economics. The series of this course began about 20 years ago and now more than 100 students choose it in each semester. Projecting this program, the lecturers almost never found it necessary to use blackboard and crayon. The examinations verified that many students learned, with good results, from this program. The success encouraged me to develop this version, which also contains on-screen comments and their printed form. Therefore, it can be an excellent medium for individual study at home. To understand some special subjects, fundamental knowledge of mathematics and physics is necessary, although most topics do not need them. It has been demonstrated by the great success of the presentation of the Chapter 'The mankind in the thunderstorm' for little children at a nursery in Budapest and for the students at Stanford University in USA.

Lightning was the first electrical phenomenon seen by prehistoric man, although over 1000 years passed until scientists discovered its processes and properties. In spite of our knowledge today lightning is still a mysterious phenomenon. This program tries to give a fundamental knowledge about lightning from the meteorological phenomena to the proper behaviour in open terrain during the thunderstorm. The development of a lightning flash involves many interesting processes, which are usually unknown. The computer animation can spectacularly illustrate them, and shows how complex a phenomenon lightning is. However, the investigations have discovered many details of the lightning process, though many secrets remain unexplored. One of them is ball lightning, for which the final solution is unknown in spite of several theories. Nevertheless, the most important aim of investigations is the protection against danger and damage due to lightning.

Concerning this aim, the first question is: Where will be the point of strike? According to our theory, it would be on the air termination system, avoiding the structure to be protected. Since the time of Benjamin Franklin up to now, a protected space has been presumed into which the air termination excludes the penetration of lightning stroke. Several lightning strokes demonstrated that no completely protected space exists and our knowledge about the striking process initiated a probabilistic approach to this problem. The PC program deals with this topic on the base of a new theory and calculation method to estimate the efficiency of lightning interception and to evaluate the risk of damage. It was described in the book ‘Computation of Lightning Protection’ by the author published by Research Studies Press in 1991. Nevertheless, with high efficiency, we can protect the human being and his property against damage caused by lightning. Our knowledge on the processes of lightning strokes helps to understand the operation of lightning air terminal systems. The practical application of some theoretical conclusions is illustrated with the Hungarian Standard for Lightning Protection of Structures. However, the program does not intend to replace a handbook, referring the standard aims only to show the practical application. The protection of low voltage equipment and electronic equipment against over-voltage due to lightning is an actual problem of lightning protection. This topic is dealt with on the basis of the recent international recommendations. The operation of surge protection devices can be demonstratively followed on the screen. The measurement methods and the lightning localisation systems have made great developments in the last 10 years. These are also demonstrated on screen. The author has participated over 20 times in the International Conference on Lightning Protection, since 1963, which compiles current information about lightning.

Study lightning from your computer at home! Enjoy and use this program with good success!

Tibor Horváth
Professor Emeritus

INTRODUCTION

Guide to using the program

This book is a manual to the educational program ‘Understanding Lightning and Lightning Protection’, which can run on a personal computer. Using this program, pictures and animations of the topics can be studied. A textual commentary accompanies each screen, which can be either read in this book or displayed on the screen. These commentaries are principally the same and independent of the form, but the screen highlights some words with different colours, which are printed with different character types in the book. This commentary can be displayed only when there is no motion on the screen. In this case, two numbers appear on the upper right. The upper figure shows the serial number of the chapter and the lower one the serial number of the text. The same numbers are above the right side of each commentary and are separated by a hyphen (e.g. 1-23). A special commentary is displayed when the list of topics is on the screen and the serial number of the topic is zero, such as 1-0. In this case, the text gives information on the menu items when a group of topics is selected. Because all commentaries can be read either on the screen or in the book, the user can choose the most convenient method.

When the program starts, the main title appears on the screen. While this is displayed, the following instruction will be shown when the key **[Read me]** is pressed**.** Different words and objects are marked with colours on the screen and by different types of characters in the book, as follows:

Highlighted words:	Red colour on screen.
[Key]:	White letters on black background.
LIST OF CHAPTERS:	Blue colour on screen.
***List of topics*:**	Green colour on screen.

This program has **two menu lists** from which the topic of study can be chosen. When the key **[Start]** is pressed, the **LIST OF CHAPTERS** appears on a blue background. A chapter can be selected by double-clicking on its name in the menu list. Then the background of the screen changes to dark green and the submenu of the selected chapter is shown on a light green background. This menu contains a ***list of topics***, which can be selected by double-clicking as before. While the ***green menu*** is on the screen, key **[Chapters]** appears on top. When this is pressed, the program goes back to the **BLUE MENU**. After a topic is selected, the screen shows the first picture of the topic under study. On the top of the screen a key **[Topics]** can be seen while the selected subject is running. On the keys **[Chapters]** and **[Topics],** small blue and green symbols show the menus, which will be displayed after pressing. The key **[Exit]** terminates the program and returns to Windows. After a topic is selected from the ***green menu,*** the first picture appears, sometimes after a short delay. Inside a topic the picture progresses after the screen is clicked on or **[Enter] is pressed**. These are disabled while the picture moves on the screen. One needs to wait until the motion is completed. At the end of the topic, the program returns to the first step and the subject can be studied again. After some topics are selected from the ***green menu,*** the program runs over several topics or even over an entire list. A **textual commentary** can be similarly displayed as with the key **[Read me]**. A press of the key again will cancel the text. When a picture is present on the screen the appropriate commentary can be displayed by pressing the key **[F1]**.

The commentary often refers to other topics dealing with similar subjects. In this case, the **subject** is highlighted in the book and marked red on the screen. The appropriate chapter is printed in the book with normal characters but marked blue on the screen. The referred topic is printed in the book with italic letters and marked green on the screen. To find the given subject, the referred item is to be selected in the displayed list of topics. The subtitles of this book are not the same as the items to be selected, but the small differences should not cause a problem.

This program has been developed under Microsoft Windows 98 and experience shows that it runs correctly under Win 95, Win 98 and Win 2000 environments. Windows NT and XP systems reserve some data after closing the program, which prevents running of the program again. Therefore, these have to be deleted or the computer should be restarted before the program is run again. The program creates pictures of 800 × 600 pixels; therefore, it cannot be used with a screen of lower resolution. With the use of a higher display (e.g. 1024 × 786), the pictures cover only a part of the screen. For the best view, it is advised to set the display on 800 × 600 pixels.

CHAPTER 1

Cloud, cyclone and fronts

1-0

Each item of this menu can be selected by double-clicking on it. The program displays several topics when the following items are selected:
All items: from *Development of a cloud* to *Distribution of thunderstorms*.
Development of a cloud: to *Growing of a thunderstorm cloud*
Cyclones and fronts: from *Development of a cyclone* to *Warm and cold fronts*.
Types of thunderstorms: *Thermal thunderstorm* + *Orographic thunderstorm* + *Warm and cold fronts*.

Development of a cloud

1-1

The development of clouds always starts with the elevation of a warm and wet air mass. In this picture, the vertical line shows the altitude above the ground and the horizontal line, the temperature in centigrade. At the bottom of this picture, a white band represents the warm and wet air mass, whose temperature is assumed to be 26°C. Moving upwards, the potential energy of this air mass increases, while it loses the same quantity of its thermal energy. Therefore, its temperature continuously decreases. In the next picture, a band of red lines shows the temperature in such a way that its right edge indicates the ascending air and the left one the surrounding temperature.

1-2

At the bottom, an equation shows the balance of the potential and the thermal energies.

m (kg): the mass of the ascending air;
g (m/s^2): the gravitational acceleration;
h (m): the altitude;
c (J/kg °C): the specific heat of the air;
t_o (°C): the temperature at the ground and t: in the altitude h.

Understanding Lightning and Lightning Protection T. Horváth

The temperature of the ascending air decreases 1°C per every 100-m elevation. The red lines show the change of temperature in such a way that the right edge indicates the ascending air and the left one the surrounding temperature. The temperature of the air reaches its dew point (assumed to be 9°C) and condensation of water drops begins to occur.

1-3

The heat of evaporation of the water is released during the condensation process, and this can be expressed by mQ in the equation of energy balance. In this case, Q (J/kg) is the evaporation heat, which decreases the temperature drop to 0.6°C per every 100-m elevation.

The precipitation of water drops produces a cloud whose base usually forms a horizontal interface.

1-4

In the upper region of the cloud, the temperature falls below 0°C and freezing begins. The released melting heat reduces the temperature drop still more, which falls below 0.6°C per 100-m elevation. In the equation of the energy balance, the value Q will be greater than in lower heights.

In the picture, the red band becomes wider, illustrating that the temperature difference increases between the ascending air and its surroundings. This produces a growing lift force; therefore, the air mass is elevating faster until it will be without water and the lift force will eventually disappear.

Growth of a thunderstorm cloud

1-5

Thunderstorm clouds usually grow up to heights of 7000–8000 m, but 20 000-m high thunderstorm clouds have also been observed. However, if warm air streams into the high atmosphere, the growth of the cloud stops, and no thunderstorm develops.

The lower part of the cloud forms the well-known cauliflower shape, which expands on top and produces an anvil-shaped top. This type of cloud is called cumuli-nimbus. Under the freezing level, the cloud consists of water drops, but ice crystals and needles are formed above.

1-6

Before the development of a thunderstorm, cumulus clouds appear in the sky. In this period, the sky remains mainly blue with bright white clouds. The sun is usually visible and the wind movement is slight.

1-7

When the development of a thunderstorm begins, the clouds become grey and cover almost the entire sky. The sunshine becomes broken, appearing in breaks between the clouds and the wind increases.

1-8

This picture has been composed from three photos showing a thunderstorm cloud from a distance of about 10 km. The anvil top is about 7000—8000-m high and extends horizontally to 10–15 km. The sun was obscured by clouds. In some places, rainfall can also be observed below the clouds.

1-9

This picture shows two thunderstorm clouds viewed from a distance of about 20–30 km. The anvil top is completely developed to the left, while it is at the middle of the development to the right.
The photograph was taken in the evening near Uppsala in Sweden at the end of June.

1-10

The sun heats up the earth's surface depending on the heat absorption of the soil. Especially in springtime, there will be a difference between a dark ploughed field and a forest or a water surface. The locally heated air mass produces a labile stratification above the ground and therefore the air begins to move upwards. Because this ascending air is always warmer than its surroundings, there is a continuous lift force, which elevates this warm and wet air mass.

The temperature of the ascending air decreases and as it reaches its dew point the **development of a cloud** begins. When suitable conditions are present in the atmosphere, the lift force exists up to the high troposphere and a **thunderstorm cloud** grows. Around the cloud, a descending stream evolves, which has a drying effect and hence no condensation occurs. This is the mechanism of a thermal storm, which usually produces isolated thunderstorm cells.
development of a cloud: See: Idem *Development of a cloud.*
thunderstorm cloud: See: Idem *Growth of the thunderstorm cloud.*

1-11

When a warm and wet airstream meets a mountain slope, it is forced to ascend. As it cools down during its ascent, the conditions become suitable for the **development of clouds**. If the mountain is high enough, a thunderstorm cloud may develop. This is called topographic or orographic thunderstorm, which is a typical phenomenon on the southern sides of the Alps and the Himalayas.
development of cloud: See: Idem *Development of a cloud.*

1-12

Flowing over the mountain the air mass descends on the other side and its temperature rises. Because the absorbed water will be mostly lost, the relative humidity decreases with the rising temperature. The descending wind becomes warmer and dryer. This phenomenon is called foehn, which often occurs on the northern sides of Alps and has contributed to the development of the Gobi desert in the Himalayas.

Development of a cyclone

1-13

There are two typical configurations of the isobar lines of the atmosphere: the low and the high. In the first case, the air pressure falls towards the centre of the low formation. In the other case, the barometric pressure is the highest in the centre and decreases outwards. It is evident that the air tries to move to the centre of the low configuration and to expand from the high configuration. In the northern hemisphere, cool air moves usually from north to south and warm from south to north, but in the southern hemisphere these movements are reversed.

1-14

During the rotation of the earth, the peripheral speed depends on the geographical latitude, which means that the air moves with different speeds towards east. This speed is added to the speed of each individual moving air mass.

1-15

In this figure, the red and blue vectors represent the speeds of warm and cool air masses respectively. The yellow lines illustrate the peripheral speed produced by the rotation of the earth.

1-16

Taking the speed at the center of each configuration as the reference speed, the horizontal red and blue vectors represent the peripheral speeds of the air masses, which are added to their own speeds at the points shown in the picture.

1-17

The resulting vectors of the components shown represent the starting speeds of the air masses. They do not move radially, but deviate from these directions. This phenomenon can also be explained by the effect of the Coriolis force.

1-18

Because of the peripheral speed, the paths of the airstreams deviate from the straight path and all of them have tangential components. Therefore, this motion has also a moment of rotation.

1-19

At the low pressure, the configuration develops into a vortex, which is known as a *cyclone*. Its rotation is anticlockwise in the northern hemisphere and clockwise in the southern hemisphere. In the temperate zones, it has a lateral extent of several hundred to thousand kilometres. It is associated with intensive ascending air motion, usually leading to heavy thunderstorms. At the high pressure, the rotation is clockwise in the north and anticlockwise in the southern hemisphere. This phenomenon is known as an *anticyclone*, and has less intensive rotation and descending air motion, which destroys the clouds. Therefore, no thunderstorms develop in an anticyclone.

1-20
In the photos of the earth, the vortices of clouds can be seen. This picture shows cyclones in the southern hemisphere, which are rotating clockwise.

Warm and cold fronts

1-21
During the rotation of a cyclone, warm and cold air masses follow each other. Ahead of the progressing air mass, the meteorological conditions change considerably. At these lines weather fronts form, which turn around such that the warm front is forwarding front and the cold front follows it. The cold front usually moves faster and will often catch up with the warm front. In this case, an occlusion of fronts comes into being. In the mean time, the cyclone shifts towards the east in both hemispheres.

1-22
This is a typical picture of the meteorological data and phenomena in Europe. The black lines indicate the isobar levels; L and H show the centres of low and high configurations. The red lines with rounded markers represent the warm front and the blue lines with pointed markers the cold front. Hatching marks the regions of rain. Arrows show the directions of the wind.

1-23
A warm front brings warmer and lighter air than that that is in front of it. The oncoming warm air slips up over the cold air and it is cooled. Condensation first produces the high cirrus, and then the fleecy clouds, which slowly come together to form stratus clouds. This usually results in light rain, but thunderstorms usually never occur.

1-24
In a cold front, an air mass rushes in, which is colder and heavier than the existing mass. This warm air is pushed up and its fast elevation produces the conditions conducive to the development of thunderstorm clouds. Along the front, many **thunderstorm cells** may exist, but may be in different states of development. During propagation of the front, new cells grow, and it appears as if the thunderstorm clouds float forwards. Cold fronts are responsible for most thunderstorms throughout the world.
thunderstorm cells: See: Idem *Growth of a thunderstorm cloud.*

Distribution of thunderstorms

1-25
This map indicates the isokeraunic levels, which represent the annual number of days when at least one thunder was heard. The highest thunderstorm activity is in the tropical regions of Africa, South America and Indonesia, where more than 100 thunderstorm days per year occur.

1-26

The isokeraunic levels are considerably lower in the temperate zones, as shown in the map of Hungary. It slightly increases in some regions where there are small mountains 500–1000-m high. Some empirical relations are available to estimate the ground-flash density from the thunderstorm days per year. Such a formula was used in this map. The new **lightning localisation** systems can record the ground-flash density but this takes a long time to compile.

lightning localisation: See: Lightning measurement and localisation + *Localising the lightning*.

1-27

Because the **cold fronts** produce most of the thunderstorms, they occur with the highest frequency during the monsoons or at the beginning of the rainy season. In the moderate zones, the monsoon is not so intensive as in the tropics, and fewer thunderstorms occur. This diagram plots the monthly distribution of thunderstorms in Hungary, where the Atlantic monsoon arrives late springtime, if at all. In winter, thunderstorms rarely occur, but its occurrence cannot be ruled out.

cold fronts: See: Idem *Warm and cold fronts*.

1-28

The heat radiation of the sun intensifies the activity of a **cold front** by a similar effect as that of creating **thermal thunderstorm.** Therefore, thunderstorms are created with the highest frequency in the early afternoons. The diagram shows their daily distribution in Hungary.

cold front: See: Idem *Warm and cold fronts*.

thermal thunderstorm: See: Idem *Thermal thunderstorm*.

1-29

The duration of the activity of a thunderstorm in Hungary, and probably in Europe, rarely exceeds 2 hours. In the morning or before noon, it is even shorter. When a thunderstorm begins in the evening, it is probably produced by an intensive **cold front** and therefore lasts longer. May be that it is thundering during the whole night.

cold front: See: Idem *Warm and cold fronts*.

CHAPTER 2

Electric charges in clouds

2-0

Each item of this menu can be selected by double-clicking on it. The program displays several topics when the following items are selected:

All items: from *Processes of charge separation* to *Relation to the ionosphere*.

Processes of charge separation: from *Charging process in the liquid phase* to *Final distribution of charges.*

Charging theorises: from *Charging process in the liquid phase* to *Charging process during freezing.*

Processes of charge separation

Charging process in the liquid phase

2-1

At the base of a thunderstorm cloud, the temperature is above the freezing point and therefore it consists of water drops. Above the altitude of 0°C, supercooled water drops or ice particles exist. These different physical conditions lead to several processes of charge separation. Wind blows under the cloud and then turns upwards. Inside the cloud, a **cold front** can produce intensive wind, which is often upward directed.

cold front: See: Cloud, cyclone and fronts *Warm and cold fronts*.

2-2

It was observed about hundred years ago that the spray in front of waterfalls always consists of negatively charged drops. This phenomenon is called waterfall electrification.

2-3

F. Lenard explained the mechanism of waterfall electrification using the droplet fragmentation theory. Later *G. Simpson* applied this theory to describe the electrification in the liquid zone of thunderstorm clouds.

Understanding Lightning and Lightning Protection T. Horváth