PREFACE

Materials that do not normally conduct electricity and have the ability to store electrical charge are known as dielectrics. The behavior of dielectrics in electric fields continues to be an area of study that has fascinated physicists, chemists, material scientists, electrical engineers, and, more recently biologists. Ideas that explain aspects of dielectric behavior in high voltage electrical cables are also applicable to the insulating barrier in metal oxide semiconductors or interlayer insulation of integrated circuits. Microwave drying of milk, dielectric properties of agricultural products such as flour and vegetable oils to determine their moisture content, and the study of curing of cement etc., are some nontraditional applications of dielectric studies that show potential promise. Deeper insight into the interaction between electric fields and molecules has resulted in many new applications. Power engineers are interested in the study of insulating materials to prolong the life of insulation and determine the degree of deterioration in service to plan for future replacements or service maintenance.

Polymer scientists are interested in understanding the role of long chain molecules in varied applications ranging from heat resistant dielectrics to selfrepairing plastics. The intensity of research in this area, after a brief respite, has resumed at a furious pace, the published literature expanding at a rate faster than ever. Advances in instrumentation and theoretical models have also contributed to this renewed interest.

Organic polymers are considered to be stable materials at high temperatures and have the ability to withstand radiation, chemical attacks, and high electrical and mechanical stresses, making them suitable for extreme operating environments as in a nuclear power plant or in outer space. Polymer materials have the ability to store electrical charges. Like a diamond-studded sword, this property is wholly undesirable in applications such as electrical equipment and the petrochemical industry; yet it is a sought-after property in applications such as photocopying and telephones.

This book explains the behavior of dielectrics in electric fields in a fundamentally unifying approach that is based on well-established principles of physics and engineering. Though excellent monographs exist on specialized topics dealing with a relatively narrow area of interest, there is a need for a broader approach to understand dielectrics. It has evolved out of graduate lectures for nearly thirty-five years at the Indian Institute of Science, Bangalore (1966-1980) and the University of Windsor, Windsor, Ontario, Canada (1980-2002). The probing questions of students has helped the author to understand the topics better and to a certain extent dictated the choice of topics.

The book begins with an introductory chapter that explains the ideas that are developed subsequently. The calculation of forces in electric fields in combinations of dielectric media is included because it yields analytical results that are used in the study of the dielectric constant (Ch. 2). The band theory of solids is included because it is required to understand the energy levels of a dielectric, as in the conduction and formation of space charge (Ch. 6-11). The energy distribution function is dealt with because it is a fundamental property that determines the swarm parameters in gaseous breakdown and partial discharges (Ch. 8-9).

Chapter 2 deals with the mechanisms of electrical polarization and their role in determining the value of the dielectric constant under direct voltages. Expressions for the dielectric constant are given in terms of the permanent dipole moment of the molecule and temperature. Several theories of dielectric constant are explained in detail and practical applications are demonstrated. Methods of calculating the dielectric constant of two different media and mixtures of liquids are also demonstrated.

Chapter 3 begins with the definitions of the complex dielectric constant in an alternating electric field. The Debye equations for the complex dielectric constant are explained and the influence of frequency and temperature in determining the relaxation is examined. Functions for representing the complex dielectric constant in the complex plane are given and their interpretation in terms of relaxation is provided. Several examples are taken from the published literature to bring out the salient points.

Chapter 4 continues the discussion of dielectric relaxation from chapter 3. The concept of equivalent circuits is introduced and utilized to derive the set of equations for both Debye relaxation and interfacial polarization. The absorption and dispersion phenomena for electronic polarization are considered, both for damped and undamped situations. These ideas have become very relevant due to developments in fiber optics technology.

Chapter 5 deals with the application of these ideas to understand the experimental results in the frequency domain and with temperature as the main parameter in selected polymers. A brief introduction to polymer science is included to help the reader understand what follows. The terminology used to designate relaxation peaks is explained and methods for interpreting observed results in terms of physics and morphology are presented.

Chapter 6 deals with the measurement of absorption and desorption currents in the time domain in polymers. Though external parameters influence these measurements our concern is to understand the mechanisms of charge generation and drift. Time domain currents may be transformed into the frequency domain complex dielectric constant and the necessary theories are explained. The low frequency, high temperature relaxations observed in several polymers are explained as complementary to the topics in Chapter 5.

The magnitude of electric fields that are employed to study the behavior in dielectrics outlined in Chapters 1–6 is low to moderate. However, the response of a polymer to high electric fields is important from the practical point of view. The deleterious effects of high electric fields and/or high temperatures occur in the form of conduction currents and the complex mechanism of conduction is explained in terms of the band picture of the dielectric. Several examples are selected from the published literature to demonstrate the methods of deciphering the often overlapping mechanisms. Factors that influence the conduction currents in experiments are outlined in Chapter 7.

Chapters 8 deals with the fundamental processes in gaseous electronics mainly in uniform electric fields and again, due to limitation of space, physical principles are selected for discussion in preference to experimental techniques for measuring the cross sections and swarm properties. A set of formulas for representing the relevant properties of several gases, such as the swarm coefficients are provided, from recent published literature.

Chapter 9 is devoted to studies on nonuniform electric field in general and corona phenomenon in particular. These aspects of gaseous breakdown are relevant from practical points of view, for providing better design or to understand the partial discharge phenomena. Both experimental and theoretical aspects are considered utilizing the literature published since 1980, as far as possible. Several computational methods, such as the Boltzmann equation, solutions of continuity equations, and Monte Carlo methods are included. The results obtained from these studies are presented and discussed.

Chapter 10 deals with thermally stimulated processes, mainly in polymers. The theory of thermally stimulated discharge currents and techniques employed to identify the source of charge generation are described to assist in carrying out these experiments

Chapter 11 deals with measurement of the space charges in solids and the different experimental techniques are explained in detail. These nondestructive techniques have largely replaced the earlier techniques of charging a dielectric and slicing it for charge measurements. The Theory necessary to analyze the results of space charge experiments and results obtained is included with each method presented. The author is not aware of any book that systematically describes the experimental techniques and the associated theories in a comprehensive manner.

The book uses the SI units entirely and published literature since 1980 is cited, wherever possible, except while discussing the theoretical aspects. The topics chosen for inclusion has my personal bias, though it includes chapters that interest students and established researchers in a wide range of disciplines, as noted earlier. Partial discharges, breakdown mechanisms, liquid dielectrics, Outdoor insulation and nanodielectrics are not covered mainly due to limitation of space.

I am grateful to a number of graduate students who contributed substantially for a clearer understanding of the topics covered in this volume, by their probing questions. Drs. Raja Rao, G. R. Gurumurthy, S. R. Rajapandiyan, A. D. Mokashi, M. S. Dincer, Jane Liu, M. A. Sussi have contributed in different ways. I am also grateful to Dr. Bhoraskar for reading the entire manuscript and making helpful suggestions. It is a pleasure to acknowledge my association with Drs. R. Gorur, S. Jayaram, Ed Churney, S. Boggs, V. Agarwal, V. Lakdawala, T. Sudarshan and S. Bamji over a number of years. Dr. R. Hackam has been an associate since my graduate student years and it is appropriate to recall the many discussions I have held on various aspects of dielectric phenomena considered in this book. The personal encouragement of Professor Neil Gold, University of Windsor has contributed in no small measure to complete the present book.

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Gorur G. Raju