Insulation and design of electrical windings

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INSULATION AND DESIGN OF ELECTRICAL WINDINGS
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WITH DIAGRAMS

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PREFACE

It is generally recognised that insulation constitutes the most vulnerable part of electrical machinery, and manufacturers and users alike are confronted with the problem of how to ensure the maintenance of electrical service while dependent on materials known to be of an unreliable character.

The extremely unmechanical nature and general unsuitability of the commercial insulating materials for withstanding the high temperatures and stresses occurring in service, has discouraged any wide-spread scientific investigations of directly practical application. As a result, therefore, insulation problems have in the past been solved largely by process of trial and error.

The necessity for greater attention to these problems has been forced upon engineers by the advent of high voltages and larger and more costly units.

Modern scientific research has thrown much light on the electrical behaviour of dielectrics, and much scattered data has been published dealing with the properties of insulating materials. This information, however, has not been available heretofore in a co-related form whereby it can be used as a fundamental basis for the practical insulation of electrical apparatus.

In this treatise the authors have endeavoured to set forth the underlying principles and methods whereby the design of insulation can be carried out with precision, and have embodied the results of many years of practical experience in connection with insulating problems.
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CHAPTER I

PHYSICAL CHARACTERISTICS OF DIELECTRICS

Introduction.—In considering the physical characteristics of insulating materials it is important to appreciate that all matter to some extent possesses the property of electrical conductivity, and that in this respect the difference between "conductors" and "insulators" is not so much one of kind as of degree.

The exhaustive investigations of Sir J. J. Thompson and others show that the conductivity of gases is explained by the presence and motion of infinitely small electrically charged particles termed "ions," which may be considered to consist of atoms or groups of atoms, or of very much smaller negatively charged particles known as "electrons." Largely as a result of these investigations the "electron theory" has been developed, which has served to throw much light on the electrical behaviour of matter.

In applying this theory to the study of electrical conductivity it is assumed that every atom has associated with it one or more detachable electrons whose aggregate negative charge is balanced by an equivalent positive charge on the atom, and that an ion possessing a definite positive or negative charge is formed by the addition of an electron to, or its removal from, one of these neutral atoms or combinations of atoms.

If the cohesion between atoms and their electrons is overcome, the ions thus formed are free to move under the influence of an electric force, and when in motion in a definite direction constitute what is ordinarily termed an electric current, the magnitude of which is determined by the number of the ions and the velocity with which they move.

The theory thus presents a mental picture of the conducting
process which, in so far as it is at present understood, is the same for all matter, whether in a solid, liquid, or gaseous form.

The relatively high conductivity of so-called conductors may be explained by assuming that the cohesive force between their atoms and electrons is very weak, and consequently there are always a large number of ions free, whereas in dielectrics comparatively few ions are normally free and considerable force is required to liberate the electrons.

When a difference of potential exists between two electrodes separated by a dielectric, a stress is set up in the latter the intensity of which is dependent on the size and shape of the electrodes and the distance separating them. The effect of this stress is to distort the molecular structure of the dielectric and tend to liberate some of the electrons, and these, together with any ions already existing in the medium, are propelled—as in the case of all charged moveable bodies when placed in an electrostatic field—in the direction of the lines of force, and thread their way through the interatomic space with a velocity depending on their mass, charge, and strength of the field. The transference of ions in this way constitutes a flow of electricity from one electrode to the other, and the magnitude of the operation represents the conductivity of the medium.

In materials, such as metals, having a high conductivity, the current at a given temperature increases directly as the applied voltage, that is to say, the “resistance” to the motion of the ions is constant. In dielectrics, however, the resistance is constant probably only as long as conduction is due solely to the initially free ions, and when the field is intense enough to liberate electrons, the resistance rapidly decreases, and ultimately the disruption of the molecular structure occurs, and the dielectric is then said to have “broken down.”

The property possessed by a material whereby it is able to resist this disruption of its molecular structure is known as its dielectric strength.

The distortion of the structure prior to actual disruption, whatever its precise nature may be, accounts for the charging or displacement current familiar in condenser work, the magnitude of which for a given area of electrodes and thickness of dielectric