CLASSIFICATION OF RESEARCH PROBLEMS ON DIELECTRICS WITH SPECIAL REFERENCE TO THE INVESTIGATION OF CABLES AND CONDENSERS

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INTRODUCTION

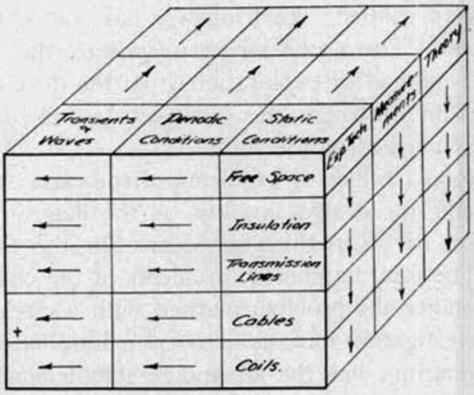
Since autumn, 1926, a cooperative research on cable testing is being carried out at the Engineering Experiment Station of the University of Illinois. In the early stages of the investigation it was realized that in spite of the limitations set by the specific technological character of this research project, the problems involved embrace a vast field of the science of dielectrics. Cables represent special cases of complex forms of condensers whose dielectric is the seat of important processes. Rational methods of cable testing could hardly be developed without a deeper knowledge of the physical and chemical changes which take place in dielectrics under the action of intense electric fields. A review of our knowledge of related phenomena revealed the necessity of extensive research in fundamental properties connected with the deterioration and final breakdown of dielectrics.

DIELECTRICS

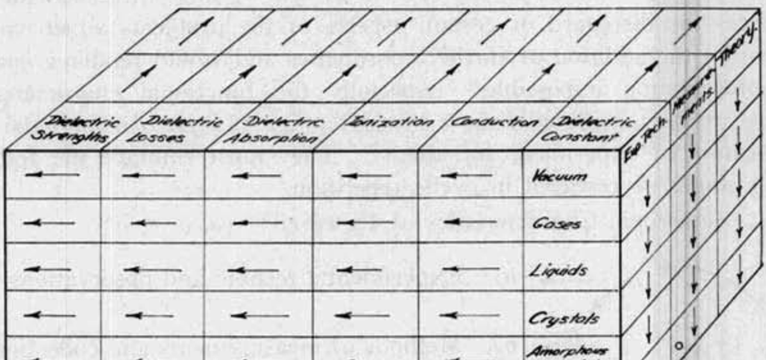
In order to evolve a general plan of research in connection with dielectrics, an attempt was made to unify the multifarious problems in the form of a systematic classification. Specific problems when viewed from the standpoint of an expert may appear disconnected from other problems, yet they may be so interconnected that their solution requires the cooperation of mathematical physicists, experimental physicists, chemists, and research engineers. Cooperation is necessary in most of these investigations in order that a working theory of the dielectric phenomena may be gradually constructed on the basis of the knowledge of correlations to be discovered in all the allied branches of research. Experience has shown that research thus organized often leads to the solution of vital engineering problems.

A simplified diagrammatic picture of the entire field of problems may be obtained by dividing them into two classes. As shown on the accompanying diagram, class A refers to problems of distribution of

Classification of Dielectric Research Problems.



A. Problems of Distribution of Electric Forces.



B. Problems of Insulation and Properties of Dielectrics.

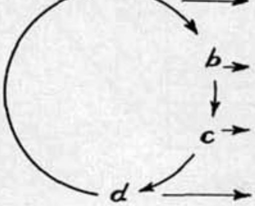
FIG. 1

electric and magnetic forces. Class B refers to problems of insulation which require the investigation of the properties of dielectrics. Each class is represented by a coordinate system in form of an imaginary filing cabinet which contains along its three axes drawers assigned to particular problems. In accordance to the three basic elements, that is, phenomenon, medium, and method, in every investigation, each drawer carries three inscriptions. In the direction of the x-axis follow the inscriptions of the phenomena investigated. Each drawer carries on the top the inscription of one of these phenomena. The y-axis is assigned to inscriptions of the characteristic medium, where the phenomena were studied. Each drawer has one of these media inscribed on the front. The z-axis serves to indicate the sequence of stages in a scientific method of exploration from the development of an experimental technic through measurements to theory. Each drawer is accordingly marked on the right.

The total number of problems of the class A thus obtained is 45. For example, the drawer marked on the diagram by a cross signifies the problem of "Experimental Means for the Study of Waves in a Cable." The total number of problems of the class B amounts to 108. So for instance the problem marked with a circle pertains to "Quantitative Investigation of Conductivity in Laminated Materials."

The diagram has the advantage that a considerable part of the domain of dielectrics may be thus reviewed at a glance. However, such a simplification was arrived at by sacrificing the completeness of the picture. The limitation set by the use of only three coordinates forces the disregard of certain aspects of the problems which would require the addition of further coordinates and would render a spacial representation impossible. Especially the functional characteristics have to be considered from a broader point of view of a periodic application of experiment and theory. They must embrace the following stages of research in cyclic repetition.

Functional Characteristics of Research: (*a*, *b*, *c*, *d*)



(*a*) Experimental technic and observations

(*b*) Methods of measurements and collection of data

(*c*) Theory and interpretation of experimental results

(*d*) General review of the situation and prediction of new phenomena

The functional characteristics are common to every systematic research work and have to be included in all classes of problems. They may be pictured as the consecutive steps along a spiral around which every scientific problem has to progress, moving upwards towards its solution.

For a more complete classification it is suggested to divide the entire field of dielectric research into five classes denoted by I, II, III, IV and V.

I. Problems of distribution of electric potentials and currents.
II. Problems of distribution of temperature and thermal flow.
III. Problems of distributions of mechanical stresses and deformations.
IV. Problems of insulation and physical properties of dielectrics.
V. Problems of chemical transformations and of changes in the properties of dielectrics.

I. Problems of class I relate to the distribution of electric potentials and currents. In this connection the time-space relations of the acting electric and magnetic fields (A, B, C, D), the configuration of the medium (1, 2, 3, 4, 5), the character of the medium (a, b, c) and the functional characteristics of research *(a, b, c, d)* have to be considered.

Time-space relations of the acting electric and magnetic fields:

A. Static conditions
B. Periodic conditions
C. Transient conditions
D. Standing waves

Configuration of the Medium:

1. Pointed or spherical boundaries (spark gaps)
2. Plane-parallel (condensers)
3. Plane-cylindrical (transmission lines and cables)
4. Cylindrical boundaries
5. Spiral boundaries (coils)

Character of medium:

a. Perfect dielectric
b. Imperfect uniform dielectric
c. Laminated dielectric

Using the above five groups of notations

I
A B C D
1 2 3 4 5
a b c
a b c d

we obtain by combination 1x4x5x3x4=240 problems or tasks. So for instance the problem denoted by ID4c*b* refers to "Methods of measuring standing waves in a cable composed of a laminated dielectric." The problem denoted by IB2b*a* refers to "Experimental technic for the study of the distribution of electric potential in a condenser composed of a uniform dielectric."

II. Problems of class II relate to distribution of temperature and to thermal flow. In view of certain analogies problems of this class may be classified similarly to those of class I.

III. Problems of class III are concerned with the distribution of mechanical stresses and deformation, and by analogy are also related with the distribution of electric potentials. They may be also classified similarly to those of class I.

IV. Problems of insulation belong to class IV. They are directly connected with physical properties of dielectrics and aim principally at the discovery of co-relations which may exist between the following three distinct groups of physical factors.

Factors connected with the distribution of different forms of energy in a dielectric:

A. Dielectric constant
B. Conductivity
C. Ionization
D. Electrostriction
E. Dielectric absorbtion
F. Dielectric losses
G. Dielectric strength

Factors determining the structure of a dielectric:

1. Vacuum
2. Gases
3. Liquids
4. Crystals
5. Amorphous materials
6. Laminated materials
7. Textile materials

Agencies which influence the dielectric:

a. Intensity of applied potential
b. Duration of applied potential
c. Wave form of applied potential
d. Frequency of applied potential
e. Action of magnetic flux
f. Action of thermal agitation
g. Action of radiations
h. Mechanical action.

By including the functional characteristics of research *(a, b, c, d)* we may assemble the above groups of notations as follows:

IV.
A B C D E F G
1 2 3 4 5 6 7
a b c d e f g h
a b c d

and obtain by combination 1 x 7 x 7 x 8 x 4 = 1568 problems. For instance, IVE3d*c* denotes a problem on the "Measurement of the influence of frequency on the dielectric absorption of liquids." The problem denoted by IVG2g*d* may serve as another example. It signifies "Theory of the action of ultraviolet radiations on the dielectric strength of gases."

V. Class V of problems refers to transformations which take place in the dielectric under the influence of electric fields and to lasting changes which are produced in the properties of dielectrics by various agencies.

Here again all the factors of Class IV are considered but under conditions which cause a deterioration in the structure of the dielectric.

Furthermore a series of four additional agencies, electro-chemical in origin, are included, *i. e.,*

Q. Bombardment of electrons and ions.
R. Action of impurities.
S. Electrolytic action.
T. Chemical processes.

The entire group of notations for Class V is as follows:

V.
A B C D E F S
1 2 3 4 5 6 7
a b c d e f g h
Q R S T
a b c d

The number of problems is given by the product 1 x 7 x 7 x 8 x 4 = 6272. For instance, the notation IVG5aS*d* signifies "Quantitative determination of deterioration affecting the dielectric strength of amorphous materials subjected to electrolytic action at high potentials."

The problem VB7gT*d* may be described as "A critical study of results of investigations on the chemical processes causing deterioration as observed by increasing conductivity of textile insulating materials subjected to the action of ultraviolet radiation."

The classes as well as the groups in each class may be extended, also sub-groups may be added in order to limit each investigation to specific kind of materials or to specific sets of conditions. In providing these divisions and subdivisions the following principle shall be adhered to: Proceed logically from the simpler to the more complex materials or phenomena respectively, so that by consecutive combinations of the notations, problems may be indicated in the order of their fundamental importance. It should also be kept in mind that the purpose of the classification is three-fold:

1. To give a perspective of the entire field.
2. To show to the investigator lost in details of his labors the channels uniting his work with the greater problems.
3. To facilitate the setting up of a general plan of attack on the problems of dielectrics.

Cables

When we turn our attention to the specific problems of cable investigation we find ourselves confronted with a still greater complexity of materials, forms, and conditions. The simplified conditions we usually attempt to establish for our purely physical investigations appear as mere idealizations when we start experimental or theoretical investigations of cable problems.

The factors enumerated in the foregoing classification must be extended to include technological conditions and processes. Of all factors the following must be considered as the most important:

A. Materials entering into the construction of a cable

B. Phenomena which are involved in the process of manufacture

C. Phenomena which are involved in the installation

D. Phenomena which are involved in the operation of the cable.

A. *Materials Entering into the Construction of Cable and the Properties of Each Material Which May Influence Cable Quality:*

a. Lead—Chemical composition, percentage of alloying elements, etc.
Physical constants such as density, ductility, strength, etc.

b. Paper—Chemical properties.
Physical properties.

c. Compound—Chemical properties.
Physical properties.

d. Copper—Chemical properties.
Physical properties.

B. *Phenomena Which are Involved in the Process of Manufacture and Affect the Properties of Cables:*

a. Mechanical problems.

(1) Influence of tension of the paper.

(2) Effect of overlapping and registration.

(3) Effect of pressure and temperature produced by the lead press.

b. Problems of drying.

How does the rate of drying affect the properties of the paper.

c. Problems of impregnation.

(1) Methods of measurement of the degree of impregnation.

(2) Effects of time, temperature, and pressure on the degree of impregnation.

(3) Detecting and locating places of imperfect impregnation.

d. Problems of testing.

How does the application of over-voltage affect the properties of a cable.

C. *Phenomena which are involved in the installation of cables.*

a. Problems of changes produced by pulling.

b. Problems of changes produced by bending.

c. Problems of changes produced by splicing.

D. *Phenomena which are involved in the operation of a cable:*

a. Thermal.

b. Electrical.

c. Magnetic.

d. Chemical.

a. Thermal problems.

(1) Expansion effects on sheath insulation and conductor, formation of voids, pressure, etc.

(2) Deterioration of cable materials due to heat.

(3) Heat flow from points within cable where heat is produced and the resulting temperature. Heat flow from cable itself into ducts and surrounding region.

(4) Effect of temperature on properties of cable material; relation between temperature and the various losses.

b. Electrical problems.

(1) Why does the dielectric break under voltage stress?

(2) How is the electric stress distributed in impregnated paper insulation?

(3) Discharges in gas-filled spaces; under what conditions do they occur, what circuit effects do they produce? What chemical changes result? What energy losses, etc?

(4) What is the nature of dielectric loss? What is the relation between dielectric loss and the various factors which influence it?

(5) Changes in compound due to ionic bombardment. What is the substance called "X"? Under what conditions is it produced?

(6) Variation of dielectric loss in cable insulation with temperature.

(7) Surges and their effect on the deterioration of cables.

c. Magnetic problems.

(1) Influence of magnetic flux on electrical discharges.

(2) Influence of magnetic flux on dielectric losses.

(3) Influence of magnetic flux on dielectric strength.

(4) Mechanical forces produced between conductor and sheath and between surrounding cables.

(5) Losses in sheath and conductor produced by varying magnetic fields.

d. Chemical problems.

(1) Stability of compound under electric stress, increased temperature, etc.

(2) Relation between chemical properties of compound and ability to withstand voltage stress, the magnitude of dielectric losses, the specific inductive capacity.

(3) The relation between chemical properties of compound and the physical properties such as viscosity, capillarity, etc.

(4) Influence of gases either in solution or in bubbles on compound, oxidation, etc.

(5) Influence of moisture or other impurities on chemical stability and on electrical phenomena, losses, etc.

The growing economic significance of power transmission and the important rôle of cables in the distribution of electric energy makes a thorough research on cables imperative. There is no doubt that the number of publications on dielectric research will steadily increase. Soon it will become necessary to extend the Dewey decimal system of bibliographical notations to the new fields of dielectrics and their applications. It is hoped that the material included in this paper will be helpful also in this connection.