REPORT of CONFERENCE on ELECTRICITY and MAGNETISM in ENGINEERING EDUCATION

By J. G. Potter and L. O. Olsen

THIRTY-FOUR electrical engineers and physicists met at Lehigh University February 7–9, 1955, to discuss desiderata in instruction by electrical engineering and physics departments for undergraduates in electrical engineering and other engineering in view of the changing demands on engineering education. Appropriate prerequisite and concurrent mathematical instruction was also considered. The deliberations of the conference led to the assignment of various committees to formulate the collective attitudes of the conference in reports which were then revised and adopted by the conference. The following reports were adopted without dissent, with the single exception that one dissenter wished to go on record on one of the reports.

Objectives of Teaching Electricity and Magnetism in Engineering Education. The objectives of teaching electricity and magnetism in engineering education are:

(1) to teach fundamental principles from an overall scientific point of view, including their relationships to other types of physical phenomena, and

(2) to teach the application of these principles to the solution of engineering problems, including their relationships to other types of engineering.

Conceivably this might be done in a single department, but (1) is primarily in the province of physics and (2) is primarily in the province of engineering: hence complementary courses in these areas are highly desirable. In any case, it is evident that close and continued cooperation between the local physics and engineering departments is necessary for the successful attainment of these objectives.

Mathematics in the Basic Physics Courses. It is believed by this Conference that it is both possible and desirable for the fundamental concepts of the calculus —the derivative and the integral—to be introduced at an early stage in the curricula of engineering students. This introduction can be made simultaneously in physics and mathematics, thus re-enforcing the learning process. In this way the student should gain a deeper understanding of both mathematical and physical concepts. Calculus methods should then be used in increasing measure in succeeding portions of the basic physics courses.

If local conditions make it impossible for the department of mathematics to introduce the calculus concurrently with, or before, the first course in physics, it is recommended that certain concepts of the calculus be introduced in this physics course. It is suggested that this introduction be limited to conceptual matters, that is that it not be extended to include the derivation of a formal table of derivatives or integrals as this should be left for the appropriate course in mathematics.

The Conference further recommends that at least part of the basic physics courses, preferably electricity and magnetism, be taught with the calculus as a firm prerequisite.

As much of the mathematics as possible should be left in the hands of the professional mathematics teachers. In any event the first two years of the mathematics courses should be so taught.

It is recognized that a major cause of difficulty and failure on the part of students in the beginning physics courses is the inadequate preparation which many of them have in high school mathematics. It is recommended that prerequisites in mathematics for engineering students be strengthened so that a minimum basis for admission into the freshman year will be adequate mathematical preparation through trigonometry.

Electricity and Magnetism in Elementary Physics for Engineers. It is recognized that the practice of engineering has come to require more and more complete knowledge of the basic laws and discoveries of pure science. Obviously then the importance of the basic training in the elements of the field of physics as a prerequisite to the professional training of engineers has increased likewise.

It is also recognized that many of today's methods in the technological application of the fundamental laws and facts may soon be obsolete. In other words, the specific nature of the engineering devices changes rapidly whereas the fundamental laws on the basis of which such devices were designed are timeless.

In recognition of this situation with respect to the enduring value of an understanding of basic principles, as distinguished from the temporary value of knowing the technical details of today's application, it is recommended that the general course in elementary physics for all engineering students be so given as to instill (1) a thorough understanding of the basic laws and principles, (2) the viewpoints found most useful in analyzing representative physical situations and (3) the application of the mathematical skills including integral calculus and elementary linear differential equations.

The authors served as Co-Secretaries of the Conference. L. O. Olsen is Professor of Physics at Case Institute of Technology. J. G. Potter is Professor and Head of the Department of Physics at the Agricultural and Mechanical College of Texas.

To this end the following outline suggests highpoints of the portion of a general course in physics that should be devoted to the study of electricity and magnetism. This course is visualized at approximately the sophomore level.

The outline is neither to specify the details nor the extent of the content, but *is for the purpose of illustrating the viewpoint* that is recommended in emphasizing the fundamental laws and illustrating their implications by examples, in such a way, and of such a sort, as to develop the student's ability to think clearly about these laws and to make effective use of the mathematical skills that are available to him for aid in such thinking. In this viewpoint, except for the laws and some of the basic characteristics of matter, *the facts are of secondary importance in relation to the ability to reason effectively concerning the implications of such facts.*

Outline of Highlights in Electricity:

A brief resumé with respect to our current model of the electrical structure of matter.

Coulomb's Law, the concept of an electric field and the use of Faraday's electric flux concept particularly as expressed by the integral form of Gauss' Law. These expressions to be used in vector form along with the evaluation of the magnitudes in illustrative problems.

Illustrative problems, in general restricted to points, planes, spheres, and infinite cylinders.

The concept of a scaler potential, the conservative field, and the relation of the potential gradient to the previously defined electric field vector. In the introduction of the idea of potential and its relation to energy, it is believed feasible to introduce the utility of the vector dot-product in connection with the line-integral that expresses the potential difference between two points in an electric field. The elementary properties of idealized isotropic dielectrics and their effect on the potential difference between charged conductors in the simple arrangements represented by parallel plate, concentric spherical and concentric cylindrical capacitors.

The concept of an electric current, "free" electrons and the conductivity of metals, with the introduction of the concept of conductivity in connection with current density and electric field intensity, as well as the resistance of wires and other simple conductors, and the assumption of Ohm's Law.

Joule's Law, the concept of emf, and the idea of the transformation of energy from some other form into electrical in a source of emf. Then consideration of the energy stored in a capacitor, not only in terms of its charge and potential difference, but also in terms of energy per unit volume of its electric field.

Kirchhoff's rules, as basic concepts, rather than as techniques for the solution of networks. Such circuits as the potentiometer and the Wheatstone bridge as illustrations for the application of the ideas represented by Kirchhoff's rules.

The magnetic field, as a consequence or manifestation of the motion of electric charges in general. Ampere's Law as the basic statement (preferably in the form of the vector cross-product) of the magnitude and direction of the magnetic field related to moving charges as individual entities and as an electric current.

The magnetic field, in terms of the force on a charge moving therein (the Lorentz force) and likewise in terms of the force on a current carrying conductor in the magnetic field. Illustrative examples and problems from a variety of devices with the emphasis always on the fundamental laws rather than the utility or detailed operating characteristics of the devices.

Induced emf, "motional" from the standpoint of the Lorentz force, as well as the more general situation expressed by Faraday's Law. The property of inductance as a consequence of Faraday's Law.

The general properties of idealized magnetic materials and some of the qualitative aspects of ferromagnetism, mostly as illustrated by the hysteresis loop. Ampere's circuital relation as a line integral embracing the magnetizing current in such simple cases as the toroid with and without an air-gap. In this connection, once again the concept of stored energy, this time in the magnetic field.

Simple circuits with inductance, capacitance, and resistance, and the simplest relationships in alternating currents.

Essential Points Concerning Upper-Division Courses. Upper-Division courses should be based on, emphasize, and re-emphasize the physical principles of electricity and magnetism introduced in lower division work. Additively, the perimeter of mathematical knowledge and the appreciation of its value in electrical engineering should be expanded as demanded by: (i) those portions of the developing domain of physical science, which must be incorporated into a viable engineering curriculum, and (ii) the engineering applications thereof.

This desired expansion of mathematical knowledge could be given in a single systematic mathematical course or by inclusion in engineering courses as dictated by local conditions. Thus, Fourier series could be developed as needed for solution of periodic nonsinusoidal circuit problems, Laplace and Fourier transforms as needed for the solution of transient problems, conformal mapping as needed for static electric and magnetic field problems, vector analysis as needed for electromagnetic field theory; etc.

Work in upper-division electromagnetic theory ought to be expanded to include study of phenomena associated with other than strictly linear isotropic media to which current instruction is generally limited. In such connection it is desirable to include in the engineering curriculum a core content of the physics of matter from the modern point of view. This gives rise to the requirement for a book on solid-state physics specifically directed to the needs and professional interests of the engineer.

Modern Physics and Properties of Matter. Physics seeks to understand nature; engineering seeks to utilize nature. However, in order to properly utilize nature one must also understand nature. Prior to about 1900, the electrical engineer was limited in his efforts to understand and control nature by the fact that the treatment of electric and magnetic phenomena had not advanced beyond the stage of the macroscopic methods of Maxwell. Since 1900 the development of modern physics, including quantum theory, the theory of the solid state, nuclear physics and high-energy physics, has provided a much broader base for the consideration of these phenomena. This new knowledge, in combination with the classical principles of electromagnetic theory, has permitted the engineer to create the new devices and components which have made possible recent developments in communication and automation. Thus the engineering student today must have an understanding of this new knowledge on the properties of matter, in order that he may contribute creatively to the technology of tomorrow and in order that he may improve the operation of present day devices by extending their frequency of operation, increasing their reliability, and providing for further miniaturization.

It is recommended, therefore, that in order to meet a real need brought about by developments of the last 50 years and to anticipate the developments of the next 50 years, the salient points of modern physics should be presented in a course to electrical engineering students as early as possible in their curriculum. It is believed by the committee that this course can be the same for all engineers and should be offered in addition to a course in general physics. The course content recommended in the report of the closed conference on nuclear physics in engineering education meets with the approval of this committee. This is as follows:

a. Atomic structure of matter; kinetic theory
b. Fundamental particles
c. Quantum theory of light
d. Atomic structure: (1) Energy levels; (2) Spectroscopy; (3) Periodic system
e. X-rays
f. Wave nature of matter; one dimensional wave equation
g. Atomic nucleus
h. Molecular structure; valence bonds
i. Nuclear structure; elements, isotopes, elementary particles
j. Binding forces
k. Binding energy curve: (1) Mass-energy curve; (2) Radioactivity; (3) Nuclear reactions; (4) Fission, fusion
l. Neutron chain reaction: (1) Heat—power; (2) Radiation interaction with matter, radioisotopes, breeding; (3) Fission products

It is further recommended that a course in the physical properties of matter should be available for election by electrical engineering students and that this course should present a phenomenological basis for understanding the characteristics of materials used in electrical engineering. Such a course might include the topics suggested by the Allerton Conference on Solid-State Physics in Engineering, namely: crystal structure; binding forces and crystal types; mechanical and thermal properties; electrical conductivity, (a) metals, (b) semiconductors, (c) salts; dielectric properties; magnetic properties; surface effects; and phosphors and photoconductivity.

Modern Applications in Traditional Engineering Courses. In addition to strengthening the scientific foundation of engineering by the inclusion of "modern" physics courses, it is important to point out applications in modern physics by illustrative material and problems introduced into pertinent existing courses in each of the conventional branches of engineering. This would include problems posed by the newer industries within the conventional engineering disciplines and the newer techniques which can now be applied in older industries.

As an illustration of the applications of nuclear physics in the field of electrical engineering, instrumentation studies may be considered. These should include the detection of the various nuclear radiations over a wide range of intensities, and as a part of the control system of a nuclear power reactor. This becomes a good example of a servomechanism. The radioactive thickness gauge is a corresponding example of how a new technique can be applied as a process control in the older paper industry.

Need for Experimentation in Curricula. This conference, recognizing the many pressures for change in Electrical Engineering curricula, makes explicit its wish that no action taken by it shall be interpreted as discouraging experimentation by the universities in altering the content of courses, or in changing the location of courses within departments.

Cooperation to Meet Local Situations. The conference recognizes that the jurisdictions for the various functions implied in its recommendations must vary from one institution to another as indicated by local conditions. It strongly urges sustained contacts between the departments of physics and electrical engineering in each institution by such means as frequent conferences and exchanges of teachers and personnel on research projects. The understanding gained by such contacts should make it possible for faculties to develop optimum engineering programs with their local facilities.

Conference Members

L. V. Bewley (Dean of Engineering) Lehigh University
W. B. Boast (Electrical Engineering) Iowa State College
J. C. Boyce (Associate Laboratory Director) Argonne National Laboratory
J. G. Brainerd (Electrical Engineering) University of Pennsylvania
T. B. Brown (Physics) George Washington University
H. E. Hartig (Electrical Engineering) University of Minnesota
V. P. Hessler (Electrical Engineering) University of Illinois
G. H. Hickox (Engineering Sciences) National Science Foundation
T. J. Higgins (Electrical Engineering) University of Wisconsin
C. L. Hogan (Applied Science) Harvard University
J. H. Howey (Physics) Georgia Institute of Technology
V. A. Johnson (Physics) Purdue University
E. C. Jordan (Electrical Engineering) University of Illinois
J. J. Karakash (Electrical Engineering) Lehigh University
J. H. Lampe (Dean of Engineering) North Carolina State College
W. A. Lewis (Dean of Graduate School) Illinois Institute of Technology
D. P. Mitchell (Physics) Columbia University
F. E. Myers (Physics) Lehigh University
A. O. Nier (Physics) University of Minnesota
L. O. Olsen (Physics) Case Institute of Technology
H. A. Peterson (Electrical Engineering) University of Wisconsin
J. G. Potter (Physics) Agricultural and Mechanical College of Texas
E. Rogers (Physics) University of Alabama
E. R. Schatz (Electrical Engineering) Carnegie Institute of Technology
W. M. Schwarz (Physics) Union College
R. J. Seeger (Chairman, Physics Division of ASEE) National Science Foundation
H. Semat (Physics) City College of New York
J. N. Thurston (Electrical Engineering) Clemson Agricultural College
J. H. Van Vleck (Dean, Division of Applied Science) Harvard University
H. W. Welch, Jr. (Electrical Engineering) University of Michigan
M. W. White (Physics) Pennsylvania State University
D. Williams (Physics) Ohio State University
J. Zaborszky (Electrical Engineering) Missouri School of Mines and Metallurgy