THE HISTORY OF ELECTROMAGNETIC THEORY

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by

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Introduction

The object of the author's paper is to summarize the history of electromagnetic theory from an engineering point of view preparatory to the investigation of some specific problem. The following definition of an engineer has been published by the Engineers' Council for Professional Development:

> "The engineer may be regarded, therefore, as an interpreter of science in terms of human needs and a manager of men, money and materials in satisfying these needs."

The mention of "human needs" raises many questions outside of the mathematical and physical aspects of the subject.

Perspective

The procedure of concentrating upon a narrow portion of a particular field is necessary for the discovery of new knowledge, but society has suffered because of the ignorance of some specialists concerning the relationships between their work and the general problems of mankind. To counteract this difficulty we should examine the relationship of progress in our knowledge of electromagnetic theory to human progress in general. An historical perspective must consider the approximate lines of occurrence of events of the universe important to mankind, the geological eras of the earth, the development of man, and the evolution of man's thinking. In such a perspective the elementary phenomena of nature can be arranged in order of increasing dependency upon the preceding types as follows:

Physical
Chemical
Biological
Psychological
Social

Electromagnetic phenomena are basic physical phenomena, and within certain limits are basic to all natural phenomena.

Outline of History of Electricity and Magnetism

The history of electricity and magnetism can be broken down into the following periods:

Static Period, 1600-1799
Current Period, 1799-1831

Electrotechnical Period, 1831-1865
Systematic Period, 1865-1895
Atomic Period, 1895-1915
Quantum Period, 1915-1926
Wave Mechanics Period, 1926-1931
Nuclear Period, 1931 -

Basic History of Electromagnetic Theory

Action-at-a-distance theories derived from gravitation theory characterized the early advances in the study of electromagnetic phenomena. Coulomb's laws of attraction for electric charges and magnetic poles have the same form as the inverse-square law for gravitational attraction. Poisson showed that many mathematical concepts developed by Laplace and Lagrange in gravitation theory could be used in electrostatics.

In 1831, Faraday discovered that electric currents are induced in conductors moving with respect to a magnetic field. Maxwell undertook the job of putting Faraday's discoveries into mathematical form. Maxwell then commented as follows:

> "When I had translated what I considered to be Faraday's ideas into a mathematical form, I found that in general the results of the two methods coincided so that the same pheonomena were accounted for, and the same laws of action deduced by both methods, but that Faraday's methods resembled those in which we begin with the whole and arrive at the parts by analysis while the ordinary mathematical methods were founded on the principle of beginning with the parts and building up the whole by synthesis.

Maxwell extended Faraday's ideas by mathematical formulation and by the concept of displacement current. In 1865, he predicted the existence of electromagnetic waves travelling with the velocity of light. Maxwell's equations in Gaussian units are as follows:

$$\text{curl}\ \overline{H} = \frac{4\pi}{c}\ \overline{i} + \frac{1}{c}\ \frac{\partial \overline{D}}{\partial t}$$

$$\text{curl}\ \overline{E} = -\frac{1}{c}\ \frac{\partial \overline{B}}{\partial t}$$

$$\text{div}\ \overline{D} = 4\pi\rho$$

$$\text{div}\ \overline{B} = 0$$

The Faraday-Maxwell theory of electromagnetic phenomena was only partially accepted until Hertz experimentally demonstrated the existence of electromagnetic waves in a series of experiments in 1886-1888. Using a spark gap as a source, he demonstrated reflection, refraction, and polarization of electromagnetic waves and showed that the velocity of propagation was close to that of light. He also showed that the electromagnetic field can be represented by a single vector function when the electric field is symmetrical about an axis.

The fundamental content of Maxwell's equations was examined and applied by Hertz, Poincaire, Lorentz, Abraham, Sommerfeld, and others. At the close of the nineteenth century it was thought that Maxwell's equations would lead to an explanation of the whole universe. The verification of the quantum theory indicated that Maxwell's equations were limited to large-scale electromagnetic phenomena. Stratton stated that the statistical average of quantum electrodynamics over large numbers of atoms must lead to Maxwell's equations. Maxwell's equations can be derived from the relativity geometry of Weyl and from the emission theory of Page and Adams in which the theory of relativity is applied to lines of force consisting of elements moving with the velocity of light.

Application of Electromagnetic Theory

By 1850 infra-red and ultra-violet radiation had been found to have properties in common with light. By 1888 the verification of electromagnetic waves generated by electric circuits established the existence of the electromagnetic spectrum. By 1914 x-rays and gamma rays had been shown to be part of the spectrum.

In this paper a sample slice of the spectrum is considered. The more significant communications applications and implementing inventions are listed. As the communications industry developed, many problems arose as to how these new instruments could best serve human needs. The policy of the Royal Society of London to avoid investigation of social phenomena because of opposition from church and state appears to have increased the lag between the physical and social sciences, so that we are not well prepared to deal with social problems. There are potential relationships between the status of our knowledge of physical phenomena and social philosophy which are not well understood at present.

Application to Microwave Wave Guide Transmission

The transmission of electromagnetic waves in a wave guide is examined as a more specific part of the application to communications. In 1897 Lord Rayleigh obtained the general solutions for the passage of electric waves through perfectly conducting metal tubes. In 1936 both Barrow and Southworth independently investigated the case for finite conductivity of the metal conductor. In the period 1936-1941 there was extensive research in various shapes of wave guide, horns, and resonant cavities. Extensive practical applications of wave guides occurred during World War II in the development of microwave radar.

Future Perspective

The development and application of electromagnetic theory has resulted in the accentuation of maladjustments in our society. Although it is reasonable to expect the social sciences to lag behind the physical sciences, the lag has been made more acute through the existence of positive incentives in the physical sciences and negative incentives in the social sciences.

If we wish to continue the trend of progress in the physical sciences in our particular civilization, we must concieve a future policy based upon our historical perspective, through which people working in the different branches of science can cooperate to assist the democratic processes of the people of the world. The expansion of our knowledge requires still greater specialization in the basic sciences. One possible working hypothesis for a future policy is to extend engineering science to bridge the gaps between basic science and social phenomena which now receive only slight engineering attention in comparison to physical and chemical phenomena.

Supplementary Discussion:

Since the preparation of the author's paper, three independent University of California proposals have come to the author's attention which may make it easier for engineers to concentrate upon physical problems and at the same time fulfil their obligations in respect to human needs. Dean Boelter* of the UCLA College of Engineering has proposed the inclusion of biotechnology in the engineering curriculum. A new undergraduate curriculum in social science has been proposed by a committee under the chairmanship of Professor Brady. A graduate seminar on atomic energy control is being conducted on an experimental basis under the direction of Professor Condliffe in w ich graduate students in economics, sociology, political science, history, chemistry, physics, and electrical engineering are participating.

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* Craig L. Taylor and L. M. K. Boelter, "Biotechnology: A New Fundamental in the Training of Engineers," Science, pp. 217-219, Feb. 28, 1947.

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