Chapter III
History of Electricity and Magnetism

The history of Electric and Magnetic phenomena is complex; its origin goes back to Greek Antiquity, and over the years many philosophers and scientists have formulated their opinions about it.[1] Yet it would take a very long time before our contemporary view would become commonly accepted. *For us today* electromagnetic waves are waves of electric and magnetic forces. To define this notion more carefully, one could begin by stating that the universe consists of numerous small particles; among them some are charged positively and some negatively. The particles with the same charge repel each other, those of opposite charge attract each other. Moving particles are surrounded by electric and magnetic fields. If a particle with a charge is surrounded by other charged particles, it will be acted upon by a force by virtue of its electrification. The part of the total force which depends only on the charge of the particle and not on its velocity, is called *the electrical force*. The remaining part which depends on the velocity of the particle as well as its charge, is called *the magnetic force*. The ratio of the electric force to the charge of the particle is *the electric intensity* or the *electric field strength* at the point occupied by the particle. The ratio of the magnetic force to the product of the velocity of the particle and the charge is *the measure of magnetic induction* at the point occupied by the particle. To detect the existence of an electric and magnetic force and, thus of *electric and magnetic waves*, a supply of electric particles is needed as well as a means of detecting their motion in response to electric and magnetic forces. Metallic wires and elaborate structures of them (*antennas*) are ideally suited for this purpose, because they contain numerous negatively charged particles, which are easily detachable from the atoms and easily movable (*electrons*).

When an electric charge is suddenly displaced, a ripple of electric and magnetic force is generated in much the same manner in which a water ripple is produced by dropping a pebble in a pond. If one studies the water ripple more carefully, one will discover that two movements are involved, the up and down movement of the water particles and the propagation of the disturbance of the water on the surface in all directions with a certain velocity. These two movements are the essential features common to all waves. Yet electromagnetic waves will move also through a vacuum and thus do not seem to require a

[1] Cf. Whittaker, vol. 1, pp. 33–334.

material medium for their existence and propagation. But let us return to the history of electricity and magnetism.[2]

Although the Greeks (Thales, Lucretius) were already familiar with *some* magnetic and electric phenomena, they do not seem to have had any sophisticated knowledge and understanding of electromagnetic action and to have assumed that both are *examples of action-at-a-distance.* Yet the idea that action-at-a-distance could be accepted in a *science* of nature was rejected by most philosophers and scientists since the time of Aristotle, but for many centuries this rejection entailed that electro-magnetic phenomena remained without a satisfactory, *scientific* explanation. The first scientist to attempt to deduce the fundamental law of electromagnetic action in terms of an electric field propagated at a finite velocity was Gauss (1830).

In order to overcome some of the obstacles, Descartes had introduced the idea that to explain a number of wave phenomena one had to assume the existence of a substance that occupied all space, which consists of moving particles which do not affect our senses, and yet can transmit forces by contact and collision (*ether*). Euler had tried to apply this notion in his study of magnetism, as well. Maxwell, too, would make use of the same idea. This development explains why for a long time the history of the study of electromagnetic waves ran parallel to the history of modern, ether theories.

Originally and for a long time one had assumed that electric and magnetic effects materialize instantaneously. Eventually this view was to be abandoned on the basis of experiments. The notion of action-at-a-distance was then gradually given up, also. Measurement of the velocity of electric waves, including that of visible light, in the 19th Century, eventually showed that the velocity of electromagnetic waves definitely also is finite.

Euler, who with Descartes did not believe in action-at-a-distance nor in instantaneous propagation, had expressed the idea that magnetism consisted of *vortices* in the omnipresent ether. He suggested in 1752 that light as well as gravitational phenomena might be considered as derangements in the ether, propagated at the same velocity. Similar ideas we find later in the work of Faraday, who considered all space to be in a state of stress when electrified or magnetized and suggested that the fields of stress could be portrayed by *lines of*

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[2] Cf. J.L. Heilbron, *Electricity in the 17th and 18th Centuries: A Study of Modern Physics* (Berkeley: University of California Press, 1979); G.N. Cantor, *Optics After Newton. Theories of Light in Britain and Ireland, 1704-1840* (Manchester: Manchester University Press, 1983); G.N. Cantor and M.J.S. Hodge, eds., *Conceptions of Ether: Studies in the History of Ether Theories, 1740-1900* (Cambridge: Cambridge University Press, 1981); M. Hesse, *Forces and Fields: The Concept of Action at a Distance in the History of Physics* (London: Nelson, 1961); J. Larmor, *Aether and Matter* (Cambridge: Cambridge University Press, 1900). See also: *Encyclopedia Britannica* (1967 edition), vol. 8, 128ff.

force. Like Euler, Faraday also believed that one single ether could account for both electrical and optical effects, rather than a separate ether for each of them. According to Faraday, electric lines of force originate at positive charges of electricity, whereas magnetic lines of force form closed curves, and all lines of force are both in a state of tension, and repel each other. He further postulated that *light* consists of electric and magnetic lines of force in motion, but later suggested that both light and radiant heat may consist of transverse vibrations of the stresses portrayed by the lines of force. Yet, Faraday did not succeed in measuring the velocity of the propagation of electric and magnetic effects, but he did discover a possible connection between light and magnetism by observing that when a strong magnetic field is set up parallel to a beam of polarized light passing through glass, it produces a rotation of the plane of polarization (Faraday effect, 1845). A similar result was noted one year later by Wartmann in connection with the passage of radiant heat through rock salt.

Maxwell was inspired both by Faraday's portrayal of electric and magnetic forces by means of lines of force and Thomson's observation on the analogy between the flow of heat and the conduction of currents over submarine telegraph cables. Thus, for some time, Maxwell too considered all electric and magnetic phenomena as states of stress in an ether which had mechanical properties and believed that these phenomena are propagated in the form of waves of stress. In his theoretical research concerning these phenomena, he started with the fundamental laws of electricity and magnetism, which had already been definitely established at the time, and then applied the mathematical procedures developed by Lagrange in his *Mécanique analytique* to the immediate vicinity of a point where the fields of electric and magnetic force were assumed to be present; in this way he developed the famous *Maxwell field equations*, which tied the various effects together in their mathematical relationships. (*"On Faraday's Lines of Force,"* 1855) In that paper Faraday's views on the nature of fields were put into a form suitable for mathematical treatment by introducing the idea of a *tube of force*, a tubular surface, whose elements were the lines of force passing through a small closed curve in the field such that the tubes would originate on the surface of positively charged bodies and terminate on corresponding negatively charged ones, the magnitudes of the two charges included within one single tube being the same. In a series of three articles, written in 1861, he also worked out a special theory for magnetic fields, by looking upon a tube of magnetic force as a vortex in the ether, whose axis of rotation coincided with the direction of the force. The final form of his theory was stated in 1865, in a paper *"A Dynamical Theory of the Electromagnetic*

Field."[3] In this paper he also introduced the notion of a displacement current, which can set up a magnetic field in addition to that set up by charges moving through wires.

For the present purposes it suffices to follow the history of the scientific study of electric and magnetic phenomena in greater detail from about 1820, i.e., about thirty years, or one generation before Maxwell entered the scene. But as we have seen, by that time the phenomena of electricity and magnetism had already been studied scientifically for several hundred years.

In about 1820, just before Oersted had undertaken his by now famous experiments on the mutual influence of electricity and magnetism, there had been three separate branches of natural science of electromagnetic phenomena, *electrostatics*, *magnetism*, and *galvanism*.[4]

1. The most advanced was the science of *electrostatics*, the widely accepted and dominating theory of which was due to the work of Coulomb, Laplace and Poisson. Following the pioneering work of Franklin in the middle of the 18th century, Charles Augustin Coulomb (1736-1806) had in 1780 established the inverse square law for the repulsion between like electric charges and the attraction between opposing ones. Then in 1812 Siméon Denis Poisson (1781-1840), who was an ardent supporter of the mechanical approach to physics, had published his by now classical memoir on the distribution of electricity on the surface of conductors; it is a *mathematical* treatment of electrostatics based on Laplace's mechanico-molecular principles. By 1820 Poisson's theory had become widely accepted as the standard treatment of the subject and it was still considered so some thirty years later, both in France and Britain.

Yet the opinions about *the physical nature* of electricity differed between English- and French-speaking scientists. The English followed Cavendish (1731-1810) and tended to treat electricity as a single imponderable fluid, but most French physicists followed Coulomb and held that there are two such fluids, corresponding to the two types of electricity, positive and negative. If these two fluids could be assumed to be mechanically incompressible, one could develop a theory using only attractive forces, and this tied in well with the so-called Newtonianism of the theory of Laplace (1749-1827). In view of the fact that the relationship between mechanism and mathematics was complex, it is therefore not shocking to find that Poisson's theory of electrostatics was built, as was Laplace's own version, upon the concept of *a potential*, introduced (though not yet named) by the dynamistically oriented mathematician Lagrange

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[3] Cf. *The Scientific Papers of J. Clerk Maxwell*, ed. Niven, 2 vols. (Cambridge: Cambridge University Press, 1890), vol. I, pp. 526–97.

[4] Cf. Hendry, pp. 52–55.

(1736-1813). Laplace had already introduced such a *gravitational potential.* In order to establish a corresponding theory of electrostatics, Poisson had introduced an analogous *electrostatic potential*; this expression was not yet used by Laplace, nor by Poisson; it was introduced later by Green (1793-1841). At any rate, the experimental results discovered by Coulomb about the electrical behavior of variously shaped bodies could now be derived by Poisson from a hypothetical structure of material and electrical molecules with attractive forces acting at a distance between them. The success of the theory in reproducing the observed results was then taken as confirmation of the physical hypotheses. Another disciple of Laplace, namely Jean Baptiste Biot (1774-1862), wrote in 1816 in his textbook that Poisson's theory gives us the highest degree of probability, not to say a complete certainty, as to the real existence of the two fluids.[5]

2. The theory of *Magnetism*, on the other hand, was at that time still less well developed, and there was far less certainty about the empirical behavior of magnets, than about that of electrical conductors. But the inverse square law had again been established by Coulomb, and in 1824 Poisson completed a *theory of magnetism* parallel to that which he had provided of electrostatics. Even though it had been impossible to draw the physical conclusion as to the existence of imponderable magnetic fluids with certainty, the approach to magnetic phenomena was fundamentally the same, and Poisson, Biot and other followers of Laplace, adopted a two-fluid theory of magnetism (*austral* and *boreal*), analogous to their theory of electricity.

3. Finally, the third area of electromagnetic theory, that of *galvanism*, presented a rather different picture. At first it was known by the name 'animal electricity' and had been demonstrated by Luigi Galvani (1737-1798) in 1791; it had been brought into the realm of the physical sciences through the work of Alessandro Volta (1745-1827) who had demonstrated the electric action of the so-called '*Voltaic pile*' in the 1790s and in the publication of his experiments in 1800. The electric properties of the pile or *battery* had quickly been identified with those demonstrated by Galvani; experimental work using these batteries had been developed rapidly. Yet in 1820 galvanic electricity was still something of a mystery. Volta had argued that the electricity produced by the pile was substantially the same as that manifested in electrostatic phenomena. This view was soon generally accepted. Yet behind all the similarities there were also some marked differences which could not be ignored. Whereas electrostatic discharge was a discrete phenomenon, galvanic discharge was continuous.

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[5]J.B. Biot, *Traité de physique expérimentale et mathématique* (Paris, 1816), vol. II, p. 312. Quoted by Hendry, 53.

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