CHAPTER I

Origins

The whole of Electrical Engineering is based on magnetic and electrical phenomena and no history of the subject can ignore the origins of these two groups, remote and sometimes uncertain as these origins may be. For many centuries man has observed magnetic effects in natural minerals found in the ground and electrical effects in lightning, the aurora borealis, St. Elmo's fire, the electric eel and the attraction of light objects by natural resins when rubbed.

Some of these observations have been put to practical use from the very earliest recorded times—the lodestone for navigation, the electric eel for medicinal purposes—so that, if electrical engineering is the practical application of electrical and magnetic science, there is a sense in which it has not only its roots in the remote past but actually existed as a human activity even in those far-off days. The two sides, magnetism and electricity, however, remained quite apart until the beginning of the nineteenth century when the discovery of the close relationship between them brought the two streams of thought together and opened the way to the establishment of their interrelation. The great surge forward on the foundation of electromagnetism made modern electrical engineering.

The records of magnetic effects date back to remotest antiquity. Mottelay opens his comprehensive and fascinating history of electricity and magnetism[1] with a statement that in the year 2637 B.C. the Chinese Emperor Hoang-ti constructed a chariot carrying a prominent female figure which always pointed to the south no matter in whatever direction the chariot was moving.

Sixteen centuries later we hear again of these 'south-seeking carts', Tcheou-Koung, a Chinese Minister of State, is said to have taught the use of the magnetic needle compass to ambassadors sent from Cochin China and to have given them an instrument called *tchi-nan*, meaning 'Chariot of the South'. On one side it turned towards the

north and on the other side to the south, the better to direct them on their homeward voyage.

Several writers have supported the view that, in the ninth century B.C., navigation on land and sea was carried out with the aid of a floating needle, one of the most authentic accounts being written in the second century B.C. by Szu-ma-thsian, a great Chinese historian. King Solomon, son of David, is said to have employed the compass and indeed to have invented it, while certain verses in Homer's *Odyssey* are interpreted as evidence that the properties of the lodestone were understood and applied in his time. On the authority of Socrates we understand that Euripides referred to the natural magnetic ore as Magnesian stone or the Herculean, while many have considered the word magnet to have derived from its origin in Magnesia, a part of Asia Minor.

Attempts to account for the working of the elementary phenomena of magnetism, again, go back a long way. Lucretius (55 B.C.), for example, considered that the lodestone had hooks on its surface which engaged with rings on the surface of the attracted iron. This same poet, in his *De Rerum Natura*, vividly describes magnetic induction in iron by the lodestone in the following lines:

When without aid of hinges, links or springs,
A pendant chain we hold of steely rings,
Dropt from the stone; the stone the binding source,
Ring cleaves to ring, and owns magnetic force;
Those held superior those below maintain
Circle neath circle downward draws in vain.

Attraction of iron at a distance was also well known as is evident from the further lines:

The steel will move to seek the Stone's embrace
Or up or down or t'any other place.

Three centuries later the Chinese writer Koupho, referring to the attraction of iron by the lodestone, speaks of the 'breath of wind that promptly and mysteriously penetrates both bodies, uniting them imperceptibly with the rapidity of an arrow. It is incomprehensible.'

In A.D. 428 Saint Augustine, the early Christian writer, describes the attraction of a piece of iron lying on a silver dish by the lodestone underneath. In his *De Civitate Dei* he speaks of being thunderstruck by magnetic experiments which he witnessed. Speaking of his brother

in the episcopate, Severus, Bishop of Milevis, he says (Dod's translation):

'He told me that Bathanarius, once Count of Africa, when the Bishop was dining with him, produced a magnet and held it under a silver plate on which he placed a bit of iron; then as he moved his hand with the magnet underneath the plate, the iron upon the plate moved about accordingly. The intervening silver was not affected at all, but precisely as the magnet was moved backward and forward below it, no matter how quickly, so was the iron attracted above. I have related what I have myself witnessed; I have related what I was told by one whom I trust as I trust my own eyes.'

In a Chinese dictionary completed in A.D. 121 there appears to be the first reference to the communication of magnetic polarity to an iron needle by rubbing with the lodestone and by striking it in a methodical manner.

During the Sung dynasty in China about A.D. 1000, the magnetization of iron by rubbing was certainly known for, we are told, fortune-tellers rubbed the needle with the lodestone to make it indicate the south. During the following two centuries, French sailors were rubbing needles upon the ugly brown stone called *mariniere* to produce the element for navigational compasses.

From the earliest times the outstanding practical application of magnetic effects has been of course in the field of navigation. Allowing for some uncertainty in the first references, it is possible that about 1000 B.C. the Chinese were finding their way across the boundless plains of Tartary with the aid of the compass.

There is nothing really authentic however to indicate sea navigation by the magnetic compass until the third century A.D. In a Chinese work Mung-khi-py-than soothsayers are recorded as using the needle floating on water and pointing to the south. They also suspended the needle on a thread in a place free from draughts and, although they were unaware of the fact that one end of the needle was attracted to the south, and one to the north—they thought that the difference was between needles—they did discover magnetic deviation.

During the next few hundred years this deviation was more and more observed and by the twelfth century, the knowledge of the compass and its application had spread, due to various travellers, to many countries. The famous letter of Peter Peregrinus, written in 1269, provides a remarkable account of the knowledge of the subject up to that time and gives a detailed specification for the construction

of a mariner's compass enclosed in a case and complete with a 360-degree scale marked North, South, East and West.

Christopher Columbus naturally employed the magnetic compass on his famous voyage and was well aware of the deviation of the magnetic from the geographic pole. He was surprised to find, however, that the deviation changed as he sailed west. Washington Irving has left a striking account of the episode. He says:

'On the 13 of September (1492) in the evening being about two hundred leagues from the Island of Ferro (the smallest of the Canaries) Columbus, for the first time, noticed the variation of the needle.—He perceived about nightfall, that the needle, instead of pointing to the North Star, varied about half a point, or between five and six degrees to the north west, and still more on the following morning. Struck with this circumstance he observed it attentively for three days and found that the variation increased as he advanced. He at first made no mention of the phenomenon, knowing how ready his people were to take alarm, but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the laws of nature were changing as they advanced and that they were entering into another world subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues; and without that guide what was to become of them in a vast and trackless ocean.'

To allay their terrors Columbus told them that the direction of the needle was really towards some remote point beyond the Pole Star. The deviation was not due to any failure of the compass but to the movement of the Pole Star! With this explanation and his great reputation as an astronomer their alarm subsided.

The practical and rapidly extending use of the mariner's compass by many navigators, including Vasco da Gama and Sebastian Cabot, led to an intensive study of terrestrial magnetism and in 1544, a Nuremburg clergyman named Hartmann discovered the phenomenon of 'dip' or inclination. By 1576 Robert Norman, 'a good seaman and ingenious artificer', had established a factory at Wapping for the manufacture of compass needles and, ignorant of Hartmann's priority, announced the discovery of 'dip' in his instrument. It was a serious problem for him because having constructed his instruments before magnetizing the needle he found it necessary to add a small weight to bring back the needle into a horizontal position. Norman provided an early example of the electrical engineer adding to fundamental knowledge. As the result of his practical manufac-

turing difficulty he made a 'dip circle' and determined the value of the magnetic inclination in London to be 71 degrees 50 minutes.

In the year A.D. 1600 William Gilbert of Colchester, who was Physician to Queen Elizabeth I, published a book *De Magnete*, the appearance of which was an epoch-making event in electrical progress. As its title suggests, the work dealt largely with the phenomena of magnetism but it also covered the complete range of electrical effects as known at that time, as well as adding much new knowledge through Gilbert's own experiments. To appreciate the significance of *De Magnete* as a factor in the foundations of electrical engineering, therefore, it is necessary to glance back over the years and see to what extent electrical phenomena had been observed alongside the magnetic development already described.

It is safe to assume that the first electrical effects to be noticed by man were the lightning flash and the aurora borealis. Their existence called for no deliberate act on his part and they occurred long before he had produced electrical charges himself, either fortuitously or by design. At first they and their effects were completely out of man's control, though several thousand years ago damage to buildings by lightning strokes was prevented by the nature of their construction. Several famous historic buildings, including the Temple of Juno and Solomon's Temple, had their roofs covered with metallic points—sword blades or sharp ornamental objects—with resulting immunity to damage by lightning, and there is no record that Solomon's Temple was ever struck by lightning during a period of a thousand years. The pipes which are known to have carried the roof water into caverns under the hill no doubt contributed to this result. There seems to be no evidence that protection of buildings was understood or deliberately adopted, although Pliny in his famous *Naturalis Historia* written during the first half of the first century A.D. asserts that the Etruscans had a secret method of drawing lightning from the clouds five centuries earlier and turning it aside in any desired direction.

It was not until the great Benjamin Franklin, American writer, philosopher and statesman, became interested in electrical phenomena that the idea of deliberate protection of buildings emerged. After his famous and extremely dangerous experiments of collecting electric charges by sending kites up into thunderclouds, Franklin, in 1750, conceived the idea of a lightning conductor and in his *Poor Richards Almanac* for 1753 he puts forward the proposal for the protection of buildings 'from mischief by thunder and lightning'.

St. Paul's Cathedral, which had been partially destroyed by lightning in 1561,[2] was first provided with lightning conductors in 1769. A few years later a futile dispute arose over the relative merits of pointed and blunt conductors. The majority of the members of the Royal Society accepted Franklin's view that points were the more effective, but owing to his participation in the American Revolution he was regarded as an enemy of England and his scientific views were the subject of disparagement. King George III, the patron of the Society, was persuaded to have the pointed conductors on Buckingham Palace replaced by ball-ended ones and suggested to Sir John Pringle, the President, that he should use his influence in favour of this preference. The result was the resignation of the President, an episode recalling more than one attempt, even in recent times, to put science in strings for political purposes.

Closely allied with lightning, two other atmospheric electrical effects have been observed for some centuries past, the polar lights—those in the north named aurora borealis by Pierre Gassendi in 1621 and those in the south named aurora australis by Ulloa, a Spanish mathematician in 1752—and St. Elmo's Fire observed by Italian sailors in the Mediterranean as early as the third century A.D. They noticed that light was emitted at night from the mastheads and rigging of their ships during dry stormy weather. In his record of his second voyage in 1493 Columbus wrote 'St. Elmo appeared on the top gallant masts with seven lighted tapers.'

Through these early years the electrical effects displayed by certain fishes were frequently described. Greek philosophers, including Aristotle and Plutarch, two thousand years ago, knew that the electric torpedo was capable of stunning its prey by an electric charge and over the next few centuries there were many references to the phenomenon. Pliny reported that a man could receive a shock by touching such a fish with a spear and the electrical properties of the *torpedo* and *gymnotus* were frequently proposed for the cure of human ailments, including gout and rheumatism.

The development of frictional or static electricity grew up over the centuries alongside that of magnetism and originated in the observation of the tiny crackling sparks produced by combing the hair in dry weather. For many centuries the fossil resin, amber, has been known to acquire the property of attracting light objects when heated and rubbed, but it was only in the year 1600 that any systematic study was made of such controllable electrical effects. In the second book of Gilbert's *De Magnete* he recorded a careful study of amber and

distinguished between 'electrics' and 'non-electrics'. He spoke of electric force for the first time, electric attraction and the absence of poles in an electric such as were recognized in a magnet.

Other philosophers became interested and in an English translation of a work by the Belgian scientist Van Helmont, published in 1650, the following reference to static electricity appeared:
'the phansy of amber delights to allect strawes, chaffe, and other festucous bodies; by an attraction, we confesse, observe obscure and weake enough, yet sufficiently manifest and strong to attest an *Electricity* or attractive signature.'

Ten years later, that is in 1660, following a number of sporadic experiments, the first frictional electrical machine was constructed by Otto von Guericke of Magdeburg. He made a sulphur globe mounted on an axis which, when rotated against a cloth rubber pressed to its surface, emitted crackling sparks and evinced the well-known phenomenon of attracting light pieces of straw.

The first one to observe the electric light *in vacuo* appears to have been Jean Picard, French astronomer, who noticed a light inside the tube of a mercury barometer which he was carrying. Sir Isaac Newton in 1675 communicated to the Royal Society an observation that rubbed glass would also attract light bodies and moreover, that the glass showed a second kind of electricity on the side opposite to that on which it had been rubbed. He also noted the similarity between the electric spark and the flash of lightning.

The first half of the eighteenth century saw many discoveries and applications of electricity. Outstanding among these was the principle of conduction and insulation enunciated by Stephen Grey in 1720. By suspending a hempen line on silken threads he transmitted electric charges hundreds of feet. When metallic wire was substituted for the hempen cord, circuits up to several miles were made to carry the charge.

The French scientist Dufay seems to have been the first to have established the idea that electricity appeared in two distinct forms, *vitreous* and *resinous*, the former produced on glass, and certain other materials, and the latter on amber, silk, paper, etc. He also observed that each repels its own kind and attracts the other.

Frictional machines were developed to produce powerful charges and in 1745 the great step forward of storing the charge in a Leyden jar was taken. Several different experimenters are claimed as the discoverers of the Leyden jar and it does appear that the ability to store a charge in a bottle—or jar-shaped container—was noticed at the end

of 1745 and the beginning of 1746 by more than one independent observer. Popular opinion gives the credit definitely to Cunaeus working with Musschenbroek at Leyden. Musschenbroek, the more readily to prevent the escape of electricity from a conductor, employed a glass jar containing water with the conductor inserted through the neck. Cunaeus, attempting to remove the conductor which had been charged by a powerful friction machine, unexpectedly received through his body the full discharge from the inner conductor to the outside of the jar which he was holding in his hand.

The English scientist, Dr. Watson, made many experiments with the Leyden jar, established the idea of two coatings separated by the dielectric and spoke of 'plus' and 'minus' electricity. With others he also made up long circuits up to several miles and discharged the Leyden jar through them.

The tempo of investigation into static electrical phenomena increased rapidly towards the end of the eighteenth century when it dramatically resulted in the discovery of the steady electric current. Over a period of twenty-five years two names stand out prominently, Galvani and Volta, the former in connection with his observations on the contraction of the muscles in legs of dead frogs and the latter in the developing of the Voltaic Pile, the first device to produce a steady controllable current of electricity.

As early as 1678 Swammerdam, a celebrated Dutch scientist, carried out the first known experiment in the influence of electricity on animal nerve and muscle. Drawing a dissected muscle with a protruding nerve from a glass tube by means of a silver wire attached to the nerve and bringing the nerve into contact with a copper ring, the muscle was seen to contract. The report of the experiment appears in the account of his experiment published at Leipzig in 1752.

In 1762 another flood of light was thrown on the phenomenon by Sulzer, a Swiss philosopher. Using the words of Sabini from his *Nouvelle Theorie des Plaisirs* published in 1767: 'On taking two pieces of different metals—silver and zinc—and placing one of them above and the other underneath his tongue, he found that, so long as the metals did not make contact with each other, he felt nothing; but when the edges were brought together over the tip of his tongue, the moment contact took place, and as long as it lasted, he experienced an itching sensation and a taste resembling that of sulphate of iron.'

The significance of Sulzer's discovery was not appreciated by him and remained unrecognized until twenty-four years later when, in 1786, Galvani, a young Italian scientist, made his now famous dis-

covery. Galvani, studying the effects of lightning discharges and discharges from electrical machines, found that they produced similar convulsions in the limbs of dead frogs. He also found that the effect could be produced without any other external agency than a pair of dissimilar metals. First of all a frog's leg hung on a copper hook fastened to an iron railing and blown into contact with the railing produced the twitching phenomenon. The result was also obtained from the two extremities of a bimetallic strip. He found copper and zinc very effective.

In the light of our present knowledge it seems strange that Galvani should have formulated and persisted in the idea that the source of the electricity lay in the nerves and muscles of the frog but his views were not shared by all his contemporaries. A great rivalry sprang up between him and the other Italian scientist Volta. Born in Como in 1745 and later in life a professor in the University of Pavia, Volta made many valuable contributions to the understanding and development of electrical phenomena. In 1775 he had invented the electrophorus by which a small charge of static electricity can be multiplied many times by the manipulation of mechanical apparatus. A dish of solid resin being electrified by rubbing or striking with warm flannel or a silk handkerchief has a metal disc provided with an insulating handle placed over it. The surface of the disc is discharged by touch while resting on the resin and it is then removed, bringing with it a charge which is held captive up to that point.

Between the rival Universities of Bologna and Pavia the ideas of Volta and Galvani were made the basis of serious factions and the dispute spread to other European countries where it raged for several years, as absurd a display of unscientific intransigence as that of the lightning conductors a little earlier.

This story of Galvani and the physiological effects of electrical discharge takes us into a curious chapter of history of electrical engineering in which the bodies of executed murderers were made to perform gruesome contortions by the application of electricity, but rather away from the origins. In this direction and more appropriate to the present introduction, it was Volta's reasoning arising from his observations of Galvani's experiments that led to the epoch-making discovery of the steady electric current.

There had already been some anticipation of the electric current and conduction in certain of the experiments made with static electricity and in observations on the effects of lightning. Lightning rods had been found to be heated by the discharge. In 1761 Ebenezer

Kinnersley, for instance, a friend of Benjamin Franklin and an English master in the College of Philadelphia, came very near to the conception of an electric current when he wrote: 'No heat is produced by passing shocks through a large wire but a small wire is heated red hot, expanded and melted.' Again in 1796, John Cuthbertson, an English instrument maker, showed that the discharge from a battery of fifteen Leyden jars containing 17 square feet of coated glass fused a 6-foot length of iron wire 1/150 of an inch in diameter.

Henry Cavendish, the famous English scientist who later gave his name to the well-known Cavendish Laboratory at Cambridge, found in 1772 that 'a saturated solution of sea-salt conducts seven hundred and twenty times better than fresh water, also that electricity experiences as much resistance in passing through a column of water one inch long as it does in passing through an iron wire of the same diameter four hundred million inches long'.

By the year 1780 Volta was deeply engaged in a wide range of electrical experiments and was particularly interested in Galvani's use of the lively muscular contraction of the frog's leg as a sensitive electroscope. Galvani had found that it was sufficient to touch the lumbar nerve and the muscles of the thigh with the ends of a wire to produce the contraction, a phenomenon which he attributed to 'animal electricity'.

Volta, after experimenting for many years, succumbed to the same explanation and in a published account of his work stated 'the evidence of many experiments well combined and accurately described (shows) that there exists a true and real animal electricity, that is to say, electricity excited by the living organs themselves.' He soon concluded, however, that the action of a circuit of two dissimilar metals was greatly superior to that of a homogeneous circuit in its effect on the muscle and in the course of these experiments he rediscovered the phenomenon observed by Sulzer twenty-five years before, whereby the contact of two dissimilar metals applied to the tongue produced a curious effect of taste. While making mental reservations on the existence of the effects produced he was soon convinced that they were not due to animal electricity but were produced in some way by the contact of dissimilar metals.

About this time Volta observed that this new electricity differed from the flow from a Leyden jar, it was a continuous phenomenon and he began to use the term 'current of electricity'. The world-wide controversy which was waged with ardour—though with courtesy—

between the views of Galvani and those of Volta began to wane when once it had been established that an electromotive force exists between two wet conductors in contact.

Volta found that adding a second pair of metals in series, separated by a moistened fibrous diaphragm, increased the effect and then, adding more and more, was led to the 'Voltaic Pile', a discovery which astonished the world. In a centenary lecture delivered in Como on 18 September 1899, Professor Auguste Righi said 'Alessandro Volta's noble intellect shone nowhere so brightly as in his researches on contact electricity. A lively imagination, controlled at all times by the coolest judgment, a serene spirit in the face of difficulties, which compelled him to modify his ideas; a penetrating sagacity in contriving experiments, and unequalled skill in their execution, sane reasoning power in the interpretation and collation of facts, and in drawing conclusions from them—these were the salient characteristics of his lofty mind.' In the same address Professor Righi referred to Volta's Pile as producing with extremely simple means many of the effects of the discharge of electrical bodies and obtaining entirely new and unexpected results. Anticipating a famous dictum of Kelvin, Righi referred to Volta's stern adhesion to strict scientific method and his condemnation of fanciful, speculative, or merely sensational experiments. 'What possible good', Volta wrote, 'can come out of all this, unless the observations are reduced to scale and measure. . . . What is the use of ascertaining a cause unless the quantity and intensity of the effect is determined, as well as its character or quality.'

Volta was a Fellow of the Royal Society and made his formal announcement of this newly established electric current in a letter to Sir Joseph Banks, the President, which was read on 26 June 1800.

After explaining how he was led to the construction of an apparatus which bore a great resemblance to the Leyden phial but had the singular property of recharging itself continually, he described the arrangement in the following words:[3]

'It consists of a long series of an alternate succession of three conducting substances, either copper, tin and water; or what is much preferable, silver, zinc and a solution of any neutral or alkaline salt. The mode of combining these substances consists in placing horizontally, first, a plate or disc of silver (half-a-crown, for instance) next a plate of zinc of the same dimensions; and, lastly, a similar piece of spongy matter, such as pasteboard or leather, fully impregnated with the saline solution. This set of three-fold layers is to be repeated thirty or forty times, forming thus what the author calls his

'columnar machine'. It is to be observed, that the metals must always be in the same order. That is, if the silver is the lowermost in the first pair of metallic plates, it is to be so in all the successive ones, but that the effects will be the same if this order be inverted in all the pairs. As the fluid, either water or the saline solution, and not the spongy layer impregnated with it, is the substance that contributes to the effect, it follows that as soon as these layers are dry, no effect will be produced.'

The pile when consisting of twenty pairs of plates or more would give shocks and produce a spark and he referred to a pile with sixty plates giving shocks 'as high as the shoulder'. And again, in announcing what is now so well known as his *Couronne de Tasses*, he described 'an apparatus in which the fluid is interposed between the metals without being absorbed in a spongy substance. This consists of a number of cups or goblets, of any substance except metals, placed in a row either straight or circular, about half filled with a saline solution, and communicating with each other so as to form a kind of chain, by means of a sufficient number of metallic arcs or bows, one arm of which is of silver, or copper plated with silver, and the other of zinc. The ends of these bows are plunged into the liquid in the same successive order, namely, the silver ends being all on one side, and those of zinc on the other,—a condition absolutely necessary to the success of the experiments.'

The Abstracts in *Philosophical Transactions* for 1800[3] say: 'at the close of the paper the author points out the striking analogy there is between this apparatus and the electric organs of the torpedo and electric eel, which are known to consist of membranaceous columns filled from one end to the other with a great number of laminae or pellicles, floating in some liquid which flows into and fills the cavity. These laminae cannot be supposed to be excited by friction, nor are they likely to be of an insulating nature; and hence these organs cannot be compared either to the Leyden phial, the electrophore, the condenser, or any other machine capable of being excited by friction. As yet, therefore, they can only be said to bear a resemblance to the apparatus described in this paper. The effects hitherto known of this apparatus, and those which there is every reason to expect will be discovered hereafter, are likely it is thought, to open a vast field for reflections and inquiries, not only curious but also interesting, particularly to the anatomist, the physiologist, and the physician.' Today we may add 'and to the Electrical Engineer'.

It is interesting to note in Volta's description of his observations

and experiments the mental process by which he detached electricity from the static form which had held sway in man's attention for many centuries. Hesitatingly he clung to the Leyden jar, the electrophorus and the frictional machine. Shocks and sparks were the means of recognition and yet he found something remarkable in the laminated structure of the electric eel and the rebuilding up of its charge from within after a shock had been given. Suspecting that he was launching out on to a vast new world of electrical knowledge, he yet could not fully realize the extent to which his discovery had given mankind one of its greatest boons, the electric current.

REFERENCES

1. Paul F. Mottelay, *Bibliographical History of Electricity and Magnetism*, Griffin, London, 1922.
2. Ibid., p. 210.
3. *Phil. Trans.*, Part II, 1800, p. 408.