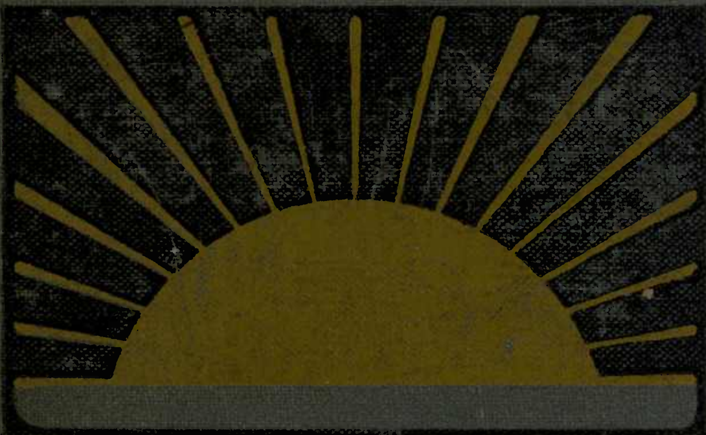
PIONEERS OF PROGRESS



MEN OF SCIENCE

MICHAEL FARADAY

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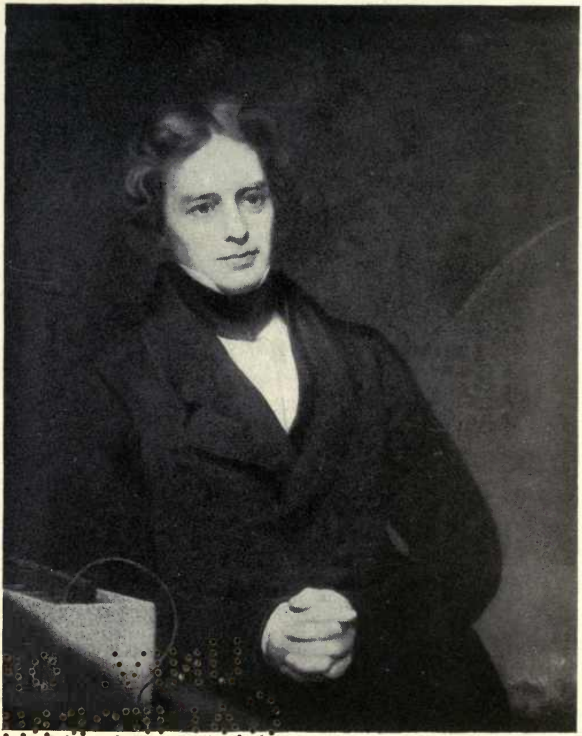

MICHAEL FARADAY

FROM THE PORTRAIT BY T. PHILLIPS IN THE NATIONAL PORTRAIT GALLERY

PIONEERS OF PROGRESS

MEN OF SCIENCE

EDITED BY S. CHAPMAN, M.A., D.Sc.

THE LIFE AND DISCOVERIES

OF

MICHAEL FARADAY

BY

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CONTENTS.

CHAPTER I.

EARLY LIFE.

1791-1813.

THE second quarter of the nineteenth century was a period of unprecedented activity in the world of science. The foundations of mechanics had indeed been laid by Newton and much of the building was complete; the edifice of geometrical optics had been reared, though the companion structure of physical optics was scarce begun. Of the palace of electricity, however, even the site had hardly been surveyed, and the foundation stones were still to be laid. As we contemplate its present grandeur, and consider the comparatively brief space of time in which so much has been accomplished, we pause to pay our tribute to the master builders who have been employed upon it, and exclaim "there were giants in those days". Many stones have been well and truly laid, and will preserve the names upon them to still distant ages. But there is one name which we read more frequently than all the rest, and upon some of the greatest stones of all —the name of MICHAEL FARADAY.

Many of the modern applications of electricity are based upon his discoveries, and had their origin in his fertile brain. The electric currents which light our streets and houses, which propel our electric trams, and drive our electric motors first sprang into existence, evoked by his touch. In the application of electricity to medicine it is mainly Faraday's currents which are employed. The wireless waves which convey our messages across land and sea trace back their origin, if not to his experiments, at least to his ideas. Even the plated ware that glitters in our cabinets and adorns our dining tables owes something to his touch.

And on the purely theoretical side the debt which we owe to him is no less great. One of the difficulties which we now meet with in attempting to appreciate at its true value the genius of Faraday is the almost sheer impossibility of thinking ourselves back into the times before his discoveries were. Only his contemporaries could do that. But in one respect, at least, our view is more complete than theirs. If they could better appreciate the darkness which he faced and made luminous, and the difficulties which he had to overcome, we can grasp more truly the value of the great ideas active in the mind that guided those skilful fingers of his; and can discern not merely in what he did, but perhaps even more clearly in what he attempted and failed to accomplish—what, indeed, he could not with the means at his disposal have brought to a successful issue—how far his searching gaze penetrated into the deep things of nature. With him, indeed, it seemed to be not a matter of induction or deduction, not a slow and painful progress from step to step, but actual vision.

This has been true to a greater or smaller degree of all the great minds which have enriched science. It is the quality which differentiates them from the band of fellow-workers who, following in their footsteps, turn the explorer's track into a broad highway. But of none was it more true than of Faraday. "He smells the truth," one of his contemporaries exclaimed. He was indeed one of the master see-ers or seers of science. As from some Pisgah height he gazed upon the yet unconquered fields of nature, and marked with prophet's vision the paths which should be trod. He placed in the hands of those who should follow him a clue which has led them surely through the devious ways of knowledge, and the greatest of his successors has been proud to call him master.

But when all this has been said, we must pause to realize that it was not so much for what he did as for what he was that those who knew him best revered him most. "Not half his greatness was incorporate in his science," writes a fellow-worker, "for science could not reveal the bravery and delicacy of his heart." At the close of a volume in which Faraday's discoveries are recorded, his friend Tyndall, lingering over the memory of the friend he had just lost, can find no more appropriate epitaph than this—"Just and Faithful Knight of God".

The present volume is an attempt to tell again, as briefly and intelligibly as may be, something of the life and work of Michael Faraday, scientist, seer, and saint.

Michael Faraday was born on 22nd September, 1791, at Newington in Surrey. The Faradays were north-country folk, his grandparents inhabiting one of those little grey stone farm-houses, which, each with its protecting fringe of fir trees, are still to be found dotted here and there among the bleak and desolate moorland pastures which fringe the Pennine peaks. His father, however, a working blacksmith by trade, had found his way south, where he followed his craft first at Newington and later (when Michael had reached the age of 5) in London among the livery stables in the neighbourhood of Jacob's yard, where the family lived in a few rooms above a coach-house.

We picture his father, from the few letters of his which have been preserved, as a hard-working and deeply religious man, a firm adherent to the small and far from influential company of Christian folks—the Sandemanians—to which his forebears had belonged, and of which

Michael himself afterwards became an active and earnest member. He suffered, however, from continual ill-health, which hindered his regular work, and which must have added seriously to the difficulties of the household. At best, those were hard times for working folk. The Napoleonic wars were still impoverishing the nations of Europe. Food was scarce and dear, and with four growing children to be fed it was difficult at times to obtain enough for all. Faraday himself records that once a week a loaf of bread was given to him by his parents, and that he had to make it last for that time.

We know little of his schooling—there could, indeed, be little to know—and in 1804, at the age of 13, he was engaged as an errand boy at a bookseller's shop in Blandford Street. Newspapers in those days were expensive articles and, except by the very wealthy, were hired, and not bought. One part of Faraday's duties was to take out these papers to the different borrowers, and to collect them when the allotted number of hours had expired. To this time belongs his first recorded experiment. While waiting for some little time for an answer to his knock, the question arose in his mind, "If my head were on one side of these railings and my body on the other, which side of the railings should I be on?" With that characteristic energy which marked his subsequent career, and the equally characteristic appeal from speculation to experiment, he proceeded to put the matter to the test, but the door being suddenly opened, the young philosopher, drawing back his head with greater precipitancy than caution, suffered a very unpleasant contusion and the problem remains unsolved to the present day.

Faraday never forgot his early experiences, and ever viewed with a sudden kindling of interest and kindliness the approach of a newsboy. In the same way the childish interests aroused in his father's smithy remained with him in after life. "I love a smith's shop," he writes in his journal in 1841, "and everything relating to smithery. My father was a smith."

His time of probation on this lowest step of the commercial ladder was not of long duration. In the following year (1805) his master, Mr. Riebeau, took him as an apprentice to the trade of bookbinding which he carried on in addition to his profession of bookselling. One sentence in the indentures is worthy of record, "In consideration of his faithful service, no premium is given".

It was from the books which were given out to him to bind that Faraday obtained his earliest acquaintance with the principles of the science which he was destined to adorn. From the numbers of the "Encyclopædia Britannica" he acquired his first notions on the subject of electricity; his earliest knowledge of chemistry from one of those little books of "Conversations" which at that time formed a staple part of the literature of polite learning. Even at that age and under those adverse circumstances he showed that passion for facts, and that distrust of authority (however distinguished), which afterwards characterized his scientific studies. No assertion made by these authors was allowed to pass unchallenged if it was within his capacity to test it. Such experiments as lay within his none too ample means he repeated for himself. What could be spared from his pocket-money at this time he expended on materials for his scientific pursuits, while the pantry was not infrequently laid under requisition to increase these scanty stores. More than once an experiment commenced late at night after the day's work had been well and truly performed, was interrupted and had to be postponed owing to what, under the circumstances, we must almost deem the criminal negligence of his master's housekeeper in failing to replenish the salt-cellar.

His occupation as bookbinder and bookseller not only gave Faraday ready access to the scanty scientific literature of the day; it also brought him into contact with men of culture, through one of whom he was fortunate enough to obtain tickets for a course of lectures on chemistry which were then being given at the Royal Institution by Sir Humphrey Davy. One can imagine the delight of the young enthusiast at finding himself within sight, and within the range of the living tones of the greatest chemist of the day. He took copious notes of the lectures, and at the close copied them out fairly into a large quarto notebook, expanding them where possible, and illustrating them with carefully drawn diagrams of the many experiments by which they had been accompanied—a by no means inconsiderable task at the close of a long working day.

By this time (1812) he had served his term of apprenticeship and was working as a fully qualified journeyman bookbinder for another bookseller, Mr. De la Roche. His new employer seems to have been a man of somewhat uncertain temper, and Faraday was not altogether happy in his new position. In spite of his peculiarities, however, his new master seems to have felt a real affection for his young assistant, or, at the least, a real appreciation of his capacity and worth, and promised him that he should be his successor in the business if he would remain in his employ.

In the meantime, however, Faraday's enthusiasm for science and his distaste for trade had grown by what they fed on, and he was determined, if by any means it could be achieved, to abandon the sure paths of commerce for the uncertain and far from lucrative pursuit of knowledge. With no private means and no influence, he decided, nevertheless, to approach the great Sir Humphrey, at whose feet, though at a very respectful distance, he had already sat. The fair copy of the lecture notes, made with so much toil, served him in lieu of an introduction. He sent it to Sir Humphrey Davy, with a letter asking for employment of a scientific nature. He did not care how humble it might be if only it enabled him to pass from the service of trade, which he thought mean and selfish, to the service of science which, he fondly hoped, made men amiable, liberal, and wise. One can imagine the somewhat bitter smile with which the older chemist would receive these sanguine notions of the young enthusiast. Faraday had yet to learn that it is what a man is, in the inner fibres of him, and not the particular way in which he chances to be employed, which make his true nobility, and that even the glorious pursuit of science can be carried on for ignoble ends, and by ignoble means.

Davy seems to have been frankly puzzled by the unusual request. "What am I to do?" he is said to have asked one of the managers of the Institution. "Do?" the other retorted, "put him to wash bottles. If he is good for anything he will do it directly; if he refuses he is good for nothing." There can be no doubt that Faraday would have washed the bottles, and that he would have washed them well, but his enthusiasm was not to be put to so great a test. Davy, who throughout acted with the greatest kindness, had an interview with Faraday, in which he pointed out (as those who have to deal with young enthusiasm are still constrained to do) that science is a hard mistress, and from a pecuniary point of view rewards but scantily those who devote themselves to her. He told him that comfort and success were assured to him in the trade of which he was now a master, and at the same time very kindly offered to procure for him the whole of the bookbinding of the Institution.

Faraday, however, was not to be turned aside from his course either by fears of hardship, or promises of reward. His love of science was a passion which soared far above all worldly considerations. A few months later a vacancy fortunately occurred in the laboratory of the Royal Institution. The situation was offered to Faraday by Davy, and was immediately accepted. The minute of the meeting at which the appointment was confirmed is worth transcribing.

"Sir Humphrey Davy has the honour to inform the managers that he has found a person who is desirous of occupying the situation lately filled by William Payne. His name is Michael Faraday. He is a youth of 22 years of age. As far as Sir H. Davy has been able to observe or ascertain he appears well fitted for the situation. His habits seem good; his disposition active and cheerful; and his manner intelligent." (March, 1813.)

As a successor to the otherwise unknown William Payne, and at a weekly wage of 25s., Faraday entered the service of the science of which he was destined to become one of the greatest and most shining lights.

But though we may agree with Sir Humphrey that Faraday was well fitted for the situation of laboratory assistant, we may legitimately doubt that the situation was equally well fitted for Faraday. Some of the letters which he wrote at this period have fortunately been preserved, and reflect a mind far above the ordinary, not merely in native vigour and intelligence, but also in what are generally regarded as acquired characteristics, courtliness, culture, and grace. They are distinguished not only for their vitality and correctness of style, but still more by the breadth, the kindliness, and the humility of the thoughts which they convey. The scientific world at the moment was deeply interested in Davy's work on the elementary nature of chlorine, and the battle raged furiously between the supporters of the older notion that that substance was a compound of oxygen, and the followers of Davy who held it to be a simple substance. Faraday's letters are full of the subject, and his exposition of Davy's views in a letter to a sceptical friend shows that grasp of the subject and that power of lucid and orderly exposition which afterwards made Faraday no less distinguished as a lecturer than as a discoverer.

"Be not surprised," he writes, "at the ardour with which I have embraced the new theory. I have seen Davy, himself, support it. I have seen him exhibit experiments, conclusive experiments, explanatory of it, and I have heard him apply those experiments to the theory and explain and enforce them in (to me) an irresistible manner. Conviction, sir, struck me, and I was forced to believe him; and with that belief came admiration."

His friend, however, seems to have felt the exposition of the new views as something of a personal affront (such feelings will arise from time to time even in scientific discussions), and to have addressed to Faraday a somewhat angry letter. Faraday's reply is very characteristic of the man.

"I have received yours of to-day, the perusal of which has raised in my mind a tumult of petty passions, among which are predominant vexation, sorrow, and regret. I write under the influence of them, and shall inform you candidly of my feelings at this moment. You will see by the foregoing part of this letter that I have not acted in unison with your request by dropping the subject of chlorine, and for not having done so I feel very considerable sorrow. I had at various short intervals as time would permit, drawn it up, and felt, I will own, gratified on reading it over; but the reception of yours has made me most heartily regret it. In the first part of this long epistle you will see the reasons I have given for continuing the subject, but I fancy that I can now see the pride and self-complacency which lead me on; and I am fearful that I was influenced by thinking that I had a superior knowledge in this particular subject. Being now aware of this passion I have made a candid confession of it to you, in hopes to lessen it by mortifying it, and humiliating it."

Such was Michael Faraday at the time when he accepted the post of laboratory assistant at the Royal Institution, and such the gifts that he brought to the service of science.

CHAPTER II.

SCIENTIFIC TRAINING.

1813-1831.

THUS following his star with faith and courage, Faraday was now fairly launched upon the career to which he was impelled by the genius within him. Though in the humblest capacity he was already serving his beloved science, but much yet lay before him before he should be fully equipped for the work he was destined to achieve. At the very beginning of this period of preparation a further act of Sir Humphrey Davy afforded him an opportunity which cannot but have been of the greatest service.

At the close of this year (1813) Davy decided to make a grand tour of the universities and laboratories of Europe, visiting the most distinguished of his foreign colleagues, and using the various resources of their different laboratories for the purposes of his research. Davy needed a companion for the tour to assist him in the experimental work, and in the preparation of the scientific memoirs to which he hoped it would give rise. He offered the post to Faraday, to the advantage of both, and they set out for France in October, 1813. The tour was an extensive one, lasting nearly two years. Paris, Genoa, Florence, Rome, Naples, and Geneva were among the many places which they visited, and at some of these they stayed for several months while Davy carried out his experimental work. Faraday thus made the acquaintance of many of the leading natural philosophers of the day, whose names are now household words in science, including Ampère, Gay Lussac, Clement, Desormes, and De la Rive. Some of these, indeed, would pay but little heed to Davy's young assistant, but others with greater penetration saw in him a mind not unworthy to rank with that of his master, and friendships were formed, which, lasting into later years, were a source of encouragement and happiness to the young philosopher. From each, however, friendly or supercilious, Faraday would have the opportunity of acquiring by direct observation something of the methods by which each had won his achievements in science; and something of that unique experimental resource for which Faraday was famous, may perhaps be ascribed to the opportunities afforded him by this early tour.

Faraday kept a journal of the tour, which is still extant, and which shows the wide range of his interests, and his powers of observation and of thought. We hear much of the experiments of Davy, which were obviously a source of great pride to his assistant. Geological observations are also frequent, and two long and detailed accounts of the ascent of Vesuvius occur. But Faraday's passion for science, though intense, was no monomania rendering him blind to other interests and other feelings. Nature in all her moods had for him an irresistible appeal. A thunderstorm, a sunset, a waterfall, a mountain mass, excited in him the highest and most ecstatic feelings, while the myriad-teeming human life around him found in him not only a keenly observant but withal a friendly critic. We hear of the French postillions (their top-boots described with that accuracy and wealth of detail for which Faraday's scientific writings are so justly famous), of the Italian beggars ("Begging is the birthright of modern Italy"), of the Christmas Carnival at Rome of which Faraday was more than a mere spectator, philosophic or otherwise. There was no trace of asceticism in his nature. He did not disdain the milk and honey of life, so that they were honestly come by and did not displace more serious duties, nor did he hold himself aloof from the simple joys of common human friendships. Above his science, and very far above the honours which it brought him, he valued the affection of those around him. In after years, when the great and distinguished crowds which hung upon his lips had gone away and the doors were closed, childish footsteps would steal down from Faraday's quarters up above, and the great lecture theatre of the Institution would ring with laughing voices, that of the great scientist himself being the merriest of them all. This sympathy and sanity of outlook marked the character of Faraday in the earliest as in the latest stages of his life.

Travel sketches, of course, abound in the journal, often not without their touches of humour. "Left Tondi," he writes; "the first two stages rode on a saddle horse. Now, though I am no rider, yet the circumstance must not be attributed to me alone that the horse and I were twice heels over head, but rather it is a wonder that it did not happen oftener in nine miles. A tailor would have said that the horse was religious, and that it only did as other Italians do when they grow old and feeble; but that did not satisfy me, and I would rather have had a beast which would have gone on orderly upon his legs."

The great political events which were shaking Europe at that time, however, seem to have stirred no chord of interest in his mind. The escape of Napoleon from Elba is briefly noted. "I heard for news that Bonaparte was again at liberty. Being no politician, I did not trouble myself much about it." It was, however, not without its effect on the plans of Davy, who, instead of proceeding to Turkey and Asia Minor, as he had intended, returned in haste to England viâ Germany and Holland, arriving in London in April, 1815.

Faraday at once resumed his work as laboratory assistant at the Royal Institution. The years which followed were full of unremitting toil. Davy was at the height of his activity (his researches at this time including that on fire-damp in coal mines, which resulted in the invention of the celebrated safety lamp). The magnitude of the mere mechanical labour involved in a piece of experimental research can hardly be realized save by those who have undergone it, and as Davy's assistant, much of this would fall upon Faraday. In addition he was soon called upon to act as assistant to the various lecturers at the Institution, and the responsibility for the preparation of the numerous lecture experiments with which the lectures were illustrated rested on his shoulders. The energy and ability with which he discharged this part of his work soon became proverbial, and the lecturer who had the good fortune to have Faraday for his assistant was said to be lecturing on velvet, so smoothly and easily did the lectures run. The call upon the assistant's time, however, in producing this enviable result was by no means small, and five or six hours were often spent on the apparatus for a single lecture.

At the same time Faraday was labouring eagerly to extend his knowledge in all directions. Some formal instruction would at first come to him from the lectures which he attended in his capacity as assistant. More would be acquired from the library at his disposal, and still more from the constant intercourse with Davy and other scientists who frequented the laboratory. But his best teachers were the experiments which he was called upon to perform. An experiment has in it something of a living personality,—a personality which a written description utterly fails to convey,—and affects different observers in different ways, and to different degrees. Faraday was peculiarly sensitive, one might almost say "mediumistic" to this subtle influence. Whenever possible he put himself under its control. He never felt satisfied that he had obtained all that could be obtained from a recorded observation unless he had himself repeated it, and, indeed, would hardly trust himself to reason from an experiment unless he had performed it with his own hands. When, a few years later, in 1821, he wrote an account of all that was then known of the science of electromagnetism he could not rest satisfied until he had confirmed by his own observations the great majority of the experiments which he described.

In the meantime his work was not entirely under the direction of others. As he grew in knowledge and confidence, he found time to carry out on his own account original work, some suggested to him by Davy, and some on his own initiative. His first published paper ("An Analysis of Naturally Occurring Caustic Lime") appeared in the "Quarterly Journal of Science" in 1816, at a time, as he writes, "when my fear was greater than my confidence, and both far greater than my knowledge; at a time also when I had no thought of ever writing an original paper on science". The little paper was well received, and other papers on chemical subjects followed in due course. In 1818 he had gained sufficient confidence to publish a paper "On Sounding Flames" in which he was able to demonstrate an error in the theories of no less an authority than Professor De la Rive. It is always a notable event in the progress of a young experimenter when he finds himself able to challenge successfully an accepted theory. In short Faraday was now well on the way to realize his own ideal. "The philosopher should be a man willing to listen to every suggestion, but determined to judge for himself. He should not be biassed by appearances; have no favourite hypothesis; be of no school; in doctrine acknowledge no master. He should not be a respecter of persons, but of things. Truth should be his primary object. If to these qualities be added industry, he may indeed hope to walk within the veil of the temple of nature."

The year 1820 was a memorable one in the history of electrical science. Oersted discovered for the first time a relation between the mysterious electric current and the still more mysterious force of magnetism. He found, almost by accident if tradition be trustworthy, that if a wire carrying an electric current is stretched over a magnetic needle that the latter is deflected from its position and no longer points towards the magnetic north. This relation between phenomena which had hitherto been regarded as distinct created the liveliest interest throughout the scientific world, and every mind was exercised on the new and wonderful effect. The genius of Ampère perceived that every known action between magnets could be imitated by properly arranged electric currents, and the world of science was tense with excitement.

Faraday, also, felt strongly attracted to the subject, and prepared himself to do his part in his usual careful and methodic way. He collected, and repeated, as we have already seen, all the experiments which were then known bearing on these new effects, and his account of the progress of electromagnetism was published in the "Annals of Philosophy," in the following summer (1821).

He followed up the work of others with experimental investigations of his own. The force between a current and a magnetic pole is unlike any force which had then been discovered, being neither an attraction nor a repulsion, and there seems to have been some very pardonable confusion as to what the force could really be. Faraday grasped the fact that the force was indeed a force of rotation, and by an ingenious experimental device he succeeded in making a magnet actually revolve continuously around an electric current, and an electric current around a magnet. The importance of this discovery will be realized when we recall that an electro-motor is but an electric current revolving in a magnetic field, and thus differs only in mechanical details from Faraday's original experiment.

A friend who was present at some of the early experiments records the delight of the philosopher at his success. "I shall never forget," he says, "the enthusiasm expressed in his face, and the sparkling in his eyes." But indeed an experiment was always a source of almost childlike joy to Faraday, whether it originated in his own mind or in that of another, and even in his latest days he would almost dance for joy at being shown a new and ingenious experiment. But these results on electromagnetic rotation had the additional interest to Faraday, that he was able to call his wife into the laboratory to witness the success of his labours. For in the meantime Faraday had married, and had brought his young wife to share with him his rooms in the Royal Institution. An entry made in after years in his own hand, in the book in which he kept record of his numerous diplomas, medals, and honours, thus records the event:—

"Among these records and events I here insert the date of one which, as a source of honour and happiness, far exceeds all the rest. We were married on 12th June, 1821."

Unfortunately, the pressure of other duties prevented Faraday from following up immediately his initial success. As we have seen, he was far from being his own master, and additional calls were now made upon his chemical abilities. At this time the Royal Institution was in financial low water, and apparently fell into the very common, but very fatal, temptation of trying to prove the worth of science by applying it to the improvement of the arts and manufactures. In these technical researches Faraday was naturally called upon to take his share, at a dead loss to the world which it is difficult to estimate. Some day, perhaps, the powers that be will realize that research must be free to be powerful and that there is little to be gained from a servile science; but the day has not yet dawned. In 1821 Faraday commenced a series of attempts to improve the quality of the steel used in surgical instruments by alloying it with other elements; and in 1825 he was called in to assist in a similar piece of work, initiated by the Royal Society, with a view to improving the manufacture of glass for optical instruments, a task which lasted until 1829. Neither of these pieces of technical work, in spite of the wealth of time and thought lavished upon them, led to results of any commercial value; though, in after years, the present of a razor made from one of the alloys discovered was a favourite token of the philosopher's esteem, while a sample of heavy glass produced in the glass-making experiments led Faraday, incidentally, to some of his most profound and illuminating discoveries. Faraday's genius did not, indeed, find its full scope in applied science. His peculiar qualities of mind showed themselves most fully at the confines of knowledge where darkness and light are met together. It was as a discoverer, and not as an inventor, that he excelled. "To perfect a manufacture, not being a manufacturer, is what I am not bold enough to promise," he writes; and in 1829, in a dignified letter to the Royal Society, he claims his freedom to follow the light within him, and to work out his own thoughts on other subjects.

These years, however, were far from being entirely fruitless, and in other directions discoveries were made, upon which a smaller man might well have been content to rest a reputation. In 1823 he showed that the gas chlorine, which had hitherto been regarded as an uncondensible substance, could be liquefied by proper means. He heated in a sealed glass tube some of the solid compound of chlorine and water and found that an oily liquid separated out at the further end of the tube. It is recorded that Dr. Paris, who chanced to be in the laboratory at the time, observing the oil, rallied the young chemist on his carelessness in using dirty apparatus. The next day he received the following communication from Faraday: "The oil you noticed yesterday turns out to be liquid chlorine". The chlorine gas liberated from the solid compound in the tube had generated sufficient pressure to bring about its own liquefaction. Following up this clue Faraday was able to reduce to the liquid state others of the so-called permanent gases. He thus showed that the distinction which had hitherto been drawn between gases and vapours was entirely artificial, and that the so-called permanent gases were but the vapours of liquids of low boiling-point. This discovery went far to put the ideas of the relation between the liquid and gaseous states on a proper footing, and to clear the way for a true dynamical theory of matter. These experiments, from the high pressures produced, and the fragile nature of the vessels employed, were not without their dangers, and on one occasion no less than thirteen pieces of glass found their way into the philosopher's eye, fortunately without any permanent injury to the sight.

Another paper, having the modest title "A New Compound of Carbon and Hydrogen," announced the discovery of, perhaps, the most important chemical substance which has yet been made available by science for the use of mankind—Benzol, which is not only of importance as a fuel, as a cleansing agent, and as a solvent in many commercial processes, but which also forms the basis of the great aniline dye industry.

We are now standing at the threshold of Faraday's great period of discovery. His long apprenticeship is over, and as a fully equipped man of science, or, as he himself always loved to call it, philosopher, who had already proved his skill in many not unimportant fields (he had at this time no less than sixty original papers standing to his credit), he was ready to enter upon the subject with which his name will always be inseparably connected. Before advancing into this new stage let us briefly resume his private history up to the moment which we have now reached.

In 1821 he married Miss Sarah Barnard, the daughter of an elder of the church which Faraday attended. The marriage was a singularly happy one. For his wife Faraday cherished a deep and chivalrous love which only increased with the passing years, and in her society ever found happiness and rest. Mrs. Faraday watched over her husband with tender care, interposing her loving authority to wean him from his laboratory whenever the strain of research was proving too great for his physical powers. There were no children of the marriage, but nephews and nieces, one or other of whom were always with them in their little home above the

Institution, filled the gap, as far as such a gap could be filled. To their instruction and amusement Faraday devoted his scanty leisure hours. His deep love for children gave him an insight into their ways and needs which never failed to evoke an instant response from them. Even the intricacies of a long arithmetical sum became interesting if he were at hand to explain. It was a constant delight to the little ones to sit and watch their uncle at work in his laboratory. From time to time he would stop amid weightier matters to throw a little piece of potassium on water, or perform some other little chemical trick for their delight. These little experiments, unmentioned in any scientific journal, are perhaps not without their record in the pages of another volume. Mrs. Faraday survived her husband. The thought of parting from her, though but for a brief time, was the only dark shadow in Faraday's vision of death.

In 1822 Faraday formally entered into membership with the Sandemanian Church, to which his parents had belonged. This little and almost unknown company of non-conforming Christian folk was an off-shoot of the Presbyterian Church, founded some hundred years before. Though mostly simple and illiterate they were perhaps in some things ahead of their times. They held that it was derogatory to the majesty of Christ that His Church should depend upon the arm of the State; that Christianity never was, and never could be, the "established" religion of any nation without becoming the very opposite of what it was when it was first instituted. They believed that Christ did not come to found an earthly kingdom, in worldly pomp and power, but to give to all who believed on Him the sure hope of an everlasting life beyond the grave. They trusted in the personal power of God over the believer; acknowledging that the faith by which they were saved, nay even the penitence for sin which brought them to His feet was His personal gift to them, a gift which they had neither earned nor deserved.

To this little company Faraday joined himself, on public profession of the faith, and among them he soon became an "elder," preaching to them as occasion served the word of God, "not with enticing words of men's wisdom" (though none knew better how to use them when he chose), but in reverence and humility, and in demonstration of the spirit. The arts and graces which made him the greatest lecturer of his time were all laid aside, together with the knowledge and attainments which raised him above his fellows, when he came to worship Him in whom there is neither wise nor simple, Greek nor Barbarian, bond nor free. Faraday's religion was, indeed, the very core and centre of the man, filling his whole life with power and peace, and embodying itself in all his actions. He would never force it upon others, though he was always ready to speak of it when questioned, not with the air of one improving the occasion, but simply giving the information which was sought.

If his deep religious beliefs but rarely found their way into his scientific discourses it was because he held that they were on a plane far above even that of science, a plane to which no man by mere intellectual processes could hope to rise. "I believe," he writes, "that the truth of the future cannot be brought to man's knowledge by any exertion of his mental powers, however exalted they may be; that it is made known to him by other teaching than his own, and is received through simple belief in the testimony given."

At the same time he held that the invisible things of God from the creation of the world were to be clearly understood from the things that are made. He saw in God's method in nature a hint of His purposes in the spiritual sphere, and he was ever ready to apply the analogy to the needs of himself or his friends. "I have been watching the clouds on these hills for many evenings back," he writes to a friend who was passing through a period of great depression; "they gather when I do not expect them; they dissolve when, to the best of my judgment, they ought to remain; they throw down rain to my mere inconvenience, but doing good to all around; and they break up and present me with delightful and refreshing views when I expect only a dull walk. However strong and certain the appearances are to me, if I venture an internal judgment, I am always wrong in something; and the only conclusion I can come to is, that the end is as beneficial as the means of its attainment are beautiful.

"So it is in life; and though I pretend not to have been much involved in the fogs and mists and clouds of misfortune, yet I have seen enough to know that many things usually designated as troubles are merely so from our own particular view of them, or else ultimately resolve themselves into blessings. The point is this: in all kinds of knowledge I perceive that my views are insufficient and my judgement imperfect. In experiments I come to conclusions which, if partly right, are sure to be in part wrong; if I correct by other experiments, I advance a step, my old error is in part diminished, but is always left with a tinge of humanity, evidenced by its imperfections. The same happens in judging of the motives of others; though in favourable cases I may see a good deal, I never see the whole. In affairs of life 'tis the same thing; my views of a thing at a distance and close at hand never correspond, and the way out of a trouble which I desire is never the one that really opens before me. Now, when in all these, and in all kinds of knowledge and experience, the course is still the same, ever imperfect to us but terminating in good, and when all events are evidently at the disposal of a Power which is conferring benefits continually upon us, may we not be induced to suspend our dull spirits and thoughts when things look cloudy, and, providing as well as we can against the shower, actually cheer our spirits by thoughts of the good things it will bring with it?"

In 1823 Faraday was elected a Fellow of the Royal Society. It is sad, but unfortunately only too true that his election was violently opposed by Sir Humphrey Davy, then President of the Society, who could not forget that Faraday had once been his private assistant. However, after the election, Davy's pride abated, and as Faraday was too great to cherish resentment, the incident led to no permanent breach of the friendly intercourse between them. In the following year Faraday began to lecture in the Royal Institution, and in 1825 he was appointed Director of the laboratory which he had entered as a humble assistant. Faraday's energy, method, and initiative in this position doubtless saved the Institution from financial disaster, and in order that he might devote his energies to the task, he declined the offer of a Professorship at the London University which was then in course of formation. A year later the managers of the Institution relieved him of his duties as lecture assistant "because of his engagement in research," and in 1828 he was given a place at the meetings of the Board of Management of the Institution.

CHAPTER III.

ELECTRICAL RESEARCHES (FIRST PERIOD).

1831-1845.

WE have seen how, kindly but firmly, Faraday disencumbered himself of the labours which the well-meant but mistaken zeal of the Royal Society for "practical" science would have thrust upon him, in order that he might be free to attempt the great ideas which were even then surging in his brain, but there was still more weight to be laid aside before he could feel himself sufficiently free for so great a quest. Though it is not by his work in chemistry that he is now principally remembered, it must not be forgotten that it was by no means slight or unimportant, and his reputation as a chemist stood at this time deservedly very high. His services in this capacity had come to be in great demand in the technical world, and manufacturers were prepared to bid high for his advice and assistance in chemical matters. In 1830 work of this nature, "Professional business" as Faraday called it, brought him over £1000, and, in the considered judgment of one who was conversant with all the circumstances, he had only to will it to realize a professional income from this source of at least £5000 per annum. But the calls which the work made upon his time and energy were equally great; too great to admit of the achievement of the work which he had already planned. As once before, at the beginning of his career, Faraday stood at the parting of the ways. He had to choose whether wealth or his undowered science should be the object of his pursuit; whether he should apply his unrivalled talents for his personal ends, or whether, laying these aside, he should follow the spirit within him, and open for all men another chamber in the secret treasure-house of nature.

That the choice presented itself consciously to his mind we know. His decision is to be learned only from his account books. Without parade of any kind his lucrative commercial work was laid aside. In 1832 his "professional income" fell from over £1000 to less than £200 per annum, and shortly afterwards ceased altogether. "Taking the duration of his life into account," writes Tyndall, to whom we owe these facts, "this son of a blacksmith, and apprentice to a bookbinder had to decide between a fortune of £150,000 on the one side and his undowered science on the other." The world is the richer for his choice—nor do we feel that Faraday was the poorer. The honours which were so freely showered upon him were less to him than to most men; the affectionate esteem of those around him he prized far above all such; and that in the fullest measure he won. But in truth science was to him its own reward; knowledge, more precious than rubies; and he was prepared to pay the price.

On 29th August, 1831, Faraday began the first section of his great work, "Experimental Researches in Electricity," a work which was continued with some intermissions for twenty-three years. The separate papers were published from time to time, as completed, in the Transactions of the Royal Society. But though issued to the world at widely different times, and dealing with many aspects of the subject, they form, as was evidently Faraday's intention from the first, one continuous whole.

The different paragraphs are numbered consecutively from beginning to end, and are firmly welded together by constant cross references. They were subsequently reprinted by Faraday in three volumes. Of them he might well have said with the poet Horace, "Exegi monumentum aere perennius" (I have built a monument more durable than brass), save that Faraday had by far too modest a soul to have said, or even thought anything of the kind. Whether we regard the magnitude and importance of the discoveries which they record, the beauty of the experiments they describe, and their perfect adaptation to the philosophic ends in view, the skill with which they were performed, and the accuracy and clearness with which they are explained, or above all the depth of the philosophic ideas which underlie the work and by which it is animated and inspired, the "Experimental Researches in Electricity" of Michael Faraday forms an achievement unique in the annals of science.

A few words by way of introduction may here be said of the methods of Faraday as a discoverer. One hears a good deal, nowadays, of the scientific method, and in these volumes of researches we have what may be described as a compendium of scientific practice at its highest. For Faraday was not only a master of his craft, but one who was by no means anxious to conceal the processes by which his discoveries were reached.

A good deal of misunderstanding seems still to exist as to the exact nature of the scientific method. It is conceived of, now as a severe system of abstract ratiocination, now as a fortuitous concurrence of haphazard experiments. In reality it is somewhat more complex than either of these popular, but erroneous conceptions. The attention of the scientist is called to some phenomenon which strikes him as being of interest or importance. His first step is to collect all the known facts which seem to bear upon the point. Having thus accumulated the available evidence he proceeds to let his imagination play upon it. It is just in this power of imagination that the great scientist excels his lesser brethren. This process may suggest some theory or generalization which seems to embrace the whole of the facts, and it must first be carefully tested to see that it is not at any rate contradicted by any one of them. If it survives this searching ordeal it becomes a guide to new discoveries. For although the theory arises out of known facts it will almost inevitably, being of the nature of a general proposition, extend beyond them, and suggest the existence of new facts and phenomena hitherto unknown. These phenomena are now to be sought for; and, unless the trained imagination has greatly erred, some at least are sure to be discovered, and thus new realms are added to the domain of science. Not infrequently it happens that, as the quest is pushed further, new facts emerge which are found to be inconsistent with the original hypothesis. These may suggest some modification of the theory which in itself will lead to fresh experiments and new discoveries. On the other hand they may prove to be completely irreconcilable with the theory, in which case it must be abandoned, and the imagination set to work afresh on the now extended mass of evidence. Thus hypothesis is the guide which leads the discoverer on; experiment the touchstone by which he tests his progress.

The method demands a spirit at once independent and humble, that will dare to break away boldly from outworn shibboleths, and yet will recognize at every turn its own fallibility; an imagination so powerful that it can stretch out far into the unknown, and yet so flexible and sensitive that far from being carried away by its own exuberance, it responds to the pressure of the smallest experimental fact, and so keeps itself in the path of true progress. This rare quality of mind Faraday possessed in a very high degree. No scientific writer distinguishes more carefully between what is fact, and what is hypothesis, or emphasizes so repeatedly the distinction between the experimental fact which stands immutable, and the interpretation of the fact which, depending as it does upon other facts known and still to be learned, changes from year to year. In his insistence upon fact it seems sometimes as if he would almost discredit hypothesis altogether; and yet no one ever speculated more habitually and more daringly than he, or followed up his speculations with such persistence, energy, and success. It would hardly be too much to claim that almost every experiment of Faraday's was guided and inspired by hypothesis. He lived in a world of dreams, and the dreams inspired his work.

Of Faraday's theories we shall treat later; they form by no means the least of his contributions to science. Two, however, must be mentioned here, as they will serve as a kind of double clue to lead us through the multitude of his experiments. The first of these was a deep-rooted belief in the simplicity of nature. He felt that underlying the complicated interplay of many and varied forces which mould our universe there was a deep harmony, perhaps even a unity, which it should not be beyond the powers of science to reveal; that heat, light, magnetism, electricity, chemical attraction, were but the names by which we distinguished different manifestations of the same power, and that in consequence there must exist between them relationships of a very intimate kind which, by proper means, might be brought to light. This belief he probably shared to a greater or smaller degree with many of his contemporaries.

The second article of his scientific faith he seems, for a time, to have held alone. This was his rooted and invincible repugnance to the then prevalent idea of the possibility of action at a distance. There are certain forces, such as gravity, magnetism, and electricity, which seem able to exert their powers on bodies far removed from those in which they have their base and origin. Thus the lodestone points to the distant pole, while across spaces too great for the mind to apprehend, the attraction of the sun maintains the planets in their ordered courses. Faraday felt intensely that this appearance of action at a distance was apparent only; that somehow the distant pole and the obedient lodestone were in contact with each other, and that across the seeming void of heaven the sun and the wandering stars were indissolubly linked by real if invisible bonds. He held the dogma that "nothing can act save where it is," and much of his experimental work was directed to making manifest, if not the nature at least the existence of this all-pervading contact.

The first series of experiments with which the volume opens was inspired by the first of these two beliefs. In an early chapter of the suggestion book in which he was wont to note down the ideas and questions which flashed from time to time across his mind he had written "Change magnetism into electricity," and he had already from time to time made unsuccessful attempts to realize this ambition. His faith, however, was undaunted by these repeated failures, and it was now to receive its reward. The second paragraph in the new laboratory notebook records his success. A ring of soft iron was wound round with a coil of many turns of insulated copper wire, the ends of which were connected with a galvanometer. To convert this iron ring into a magnet a second coil of wire was wound upon it, but completely separated from the first, and through this a current could be sent from a voltaic battery. At the moment when the current passed through the second coil the iron ring became a magnet, and at the same instant a current flowed in the first coil, causing the needle of the galvanometer to spin round several times. This "induced current" was indeed but transient. It ceased to flow as soon as the magnetization of the ring was complete. When, however, the magnetism of the ring was destroyed, by stopping the battery current, a current in the first circuit was excited as before, save that this time it flowed in the opposite direction. Thus both the production and the destruction of the magnetic condition in the iron ring were accompanied by a powerful though transient electrical impulse in the insulated wire wound around it.

The discovery was followed up with relentless vigour. A similar experiment was made, this time with a straight bar of iron and again the effect was obtained. There was, however, the possibility of some direct action between the insulated circuit, and the battery current which was used for magnetizing the bar. The magnetizing coil was therefore removed, and the iron bar converted into a magnet by placing it between the poles of a permanent steel magnet; again the "induced current" flowed. The proof of the evolution of electricity from magnetism was complete.

Faraday then found that it was by no means necessary that the coil should be wound upon an iron bar. The mere approach of a magnet to a coil of wire was sufficient to produce a current in the latter, and a similar but oppositely directed current when the magnet was removed. In fact the mere motion of a copper wire between the poles of a strong magnet sufficed to create a current in the wire. These currents, as Faraday noted, only flowed so long as the conductor was in motion. To obtain a continuous current, therefore, it was necessary that the motion also should be continuous. A copper disk was set rotating between the poles of a magnet, and contact was made by conducting wires between the axle and the circumference. As each section of the wheel passed in turn across the magnetic field, the induced currents were excited, and a continuous current flowed round the wire joining the contacts. The first dynamo was at work.

Now Ampère had already seen that every magnetic effect could be imitated by a suitable electric circuit. Thus it should be possible to produce these induced currents without the presence of any material magnet, by the mere action of one electric circuit upon another. Faraday now wound his pair of insulated coils not upon a bar of iron, but on a cylinder of wood. Success again attended his experiments. On passing a current through one of the coils, a momentary induced current could be detected in the other, though the effect was far less than when the iron was present. This phenomenon Faraday called Volta-electric induction; the former, in which magnets were employed, he called magneto-electric induction. Twenty years later Faraday showed that the two were in fact identical. In this later paper he deals with some of the questions of theoretical interest which are raised or solved by this, his greatest discovery. It has indeed thrown a flood of light upon the relations of electricity to magnetism, and of both to light. We shall deal with this point in its place. It may perhaps be permissible to point out here its practical importance.

We have seen that Faraday himself described his experiments as an evolution of electricity from magnetism, and so, in the sense in which he meant it, it was. But it must not be forgotten that the magnetism is not destroyed in the process. The revolving copper disk of Faraday's dynamo does not in any way diminish the strength of the magnet between the poles of which it revolves. Thus while the electricity is set in motion round the circuit under the influence of the magnetic force, the capacity of the current for doing work comes not from the magnet, but from the mechanical force exerted in turning the wheel. The wheel is perceptibly harder to turn when between the poles of the magnet than when the magnet is away. In fact if the magnet is at all strong the sensation produced is exactly like that of churning a sticky substance such as treacle. It is hard to persuade oneself that the wheel is in fact surrounded only by the yielding air. The extra work which has thus to be done in turning the wheel reappears in the energy of the induced currents. Thus, while the currents are generated by magnetic action, the practical importance of Faraday's experiments was this: that he succeeded in converting ordinary mechanical energy, such as that produced by a steam engine, directly into the energy of an electric current. Now mechanical energy can be generated very cheaply by steam, and still more cheaply by water power. On the other hand the electrical energy in the current produced by a battery is purchased at the expense of the consumption of the metals and acids of which it is made. This is vastly more expensive; and had not Faraday succeeded in replacing this costly and messy process by one in which the current could be generated directly by the mere turning of a wheel, electricity, in spite of its many advantages, must from its very expense have remained merely the plaything of the laboratory. These experiments of Faraday are the seed from which all the mighty dynamos which now supply the world with power and light have sprung. In essence each of these is but repeating on its own gigantic scale one or other of Faraday's simple experiments—it is merely moving an electric circuit in a magnetic field.

Other machines of value also find their origin here. The arrangement of the two coils of wire on the iron ring is precisely what is now known as a "transformer," while the two coils upon the straight iron bar are a simple form of induction coil, to the perfecting of which we owe the possibility of wireless telegraphy, X-rays, and many forms of electro-medical treatment.

Faraday had succeeded in producing electricity from magnetism, but the thought seems to have struck him, Is this indeed electricity? Are the varied phenomena of the frictional machine, the voltaic battery, the thermopile, and now this new source really due to one and the same power? It throws a curious light upon the state of electrical science that the question should be asked; but asked it was, and answered too in the negative by many scientists of the age. Davy himself would hazard no definite opinion on the point, contenting himself with generalities which from their vagueness could not be too far wrong whatever the event. Faraday could not tolerate this "doubtful knowledge" as he termed it, nor could he leave such a stumbling-block at the threshold of his work. "It was essential for the further prosecution of my inquiries," he writes, "that no doubt should remain of the identity or distinction of the electricities excited by different means." By a series of beautiful and well-chosen experiments he showed that the same effects could be produced whatever the method employed for exciting the power, and that the apparent differences, which are indeed striking enough, were due solely to differences not in the nature of the electricity but only in its tension and amount.

One of his proofs of the identity of the electricity from different sources was the demonstration that in every case it was able to produce the decomposition of certain chemical compounds into their elements, and his attention was thus directed to the relation between electricity and chemical attraction, that force which binds together the atoms of a compound substance in such close and intimate union. It had long been known that this chemical union could be dissolved by electrical action. Davy had employed the method in the researches which resulted in the discovery of potassium and the alkali metals, but little was known of the laws or mechanism of the action. It was generally assumed that the wires by which the current entered and left the decomposing substance acted like positively and negatively charged conductors, and by their electrical attraction tore the reluctant atoms from the compound molecule.

Faraday saw that this hypothesis would not work. He knew that by suitable arrangements the strongest chemical compounds could be broken up by the feeblest currents. It would follow, therefore, on the old hypothesis that the feeblest current was stronger than a powerful chemical attraction. This seemed to Faraday very improbable, and he proceeded to experiment. The subject was worked out in his usual exhaustive manner. The experiments fill many pages in the volume of researches, and would from their very number and variety be bewildering were they not so closely linked together by the clear and orderly chain of reasoning.

In the first place he showed that the chemical action was connected in the closest way with the passage of an electric current through the substance. If, for example, the wires from the battery were fused into a solid mass of silver nitrate, no current passed and there was no decomposition. If, however, the nitrate was melted, a current began to flow at the moment of fusion, and at the same instant decomposition began, though obviously the electrical force exerted by the two wires was no greater than before. He showed that, providing a current passed, the chemical action would take place as well without as with the metal poles, and that, moreover, when studied quantitatively, the amount of the substance decomposed was quite independent of the size of these conductors or their distance apart; factors which would have the greatest effect on the force which they would exert on the substance. Into whatever forms and varieties the experiment was twisted, the weight of a given substance decomposed depended only on one factor—the absolute quantity of electricity which had passed through it; and to this quantity it was directly proportional. On this newly discovered law, which he called the "law of definite electrochemical action," and which is now known as Faraday's first law of electrolysis, he based his well-known voltameter, the first, and for many years the only method by which quantities of electricity could be accurately measured.

Before pushing his experiments further, Faraday felt the necessity of clearing the ground of the relics of the older theory, by giving new names to the various phenomena. He appreciated to the full the tyranny which mere words can wield over the human intellect; and determined to free at least this branch of science from their baleful influence, by a nomenclature which should imply nothing beyond what had been experimentally confirmed. The wires by which the current entered and left the substance, the "poles" of the older theory, he termed electrodes or "current paths," and the substances which were deposited upon them he christened ions, or "wanderers". He avoided with the utmost caution any assumption as to the direction in which the electricity travelled—he would have avoided the term current itself if it had been possible—by relating his little circuits to the great earth current to which the magnetism of the earth is supposed to be due, and calling one of his electrodes the "sunrise" end or anode, and the other the "sunset" end or cathode. To the decomposition itself he gave the name electrolysis, and the class of substances in which conduction and decomposition go hand in hand he distinguished as electrolytes. These terms have proved so apt that they now form part of the common vocabulary of science.

Faraday now proceeded to investigate the effect of the passage of the same quantity of electricity through different electrolytes using his new voltameter as a measurer of quantity, and soon the second law of electrolysis emerges. Suppose the same quantity of electricity is passed through, let us say, acidulated water and tin chloride, and the products of the action at the different electrodes collected and weighed. They will be hydrogen and oxygen at the electrodes dipping in the water, and metallic tin on the cathode immersed in the tin chloride. Let us suppose for simplicity that the weight of hydrogen evolved is 1 gramme. Then at the same time 8 grammes of oxygen will be given off, while 58 grammes of tin are deposited from the tin chloride. Now 8 grammes is exactly the weight of oxygen which is capable of combining chemically with 1 gramme of hydrogen—the two quantities are, to use the language of chemistry, chemically equivalent. Similarly, 58 grammes is exactly the amount of tin which is capable of combining with 8 grammes of oxygen, or 1 gramme of hydrogen, that is, it is the chemical equivalent of tin. The amount of chemical action produced by the given quantity of electricity is exactly the same in the tin chloride as in the acidulated water. This law Faraday propounded in the form "The chemical power of a current is in direct proportion to the absolute quantity of electricity which passes," or in more modern terms, the weights of different substances deposited by a given quantity of electricity are directly proportional to their chemical equivalents.

This great generalization was not enunciated by Faraday without being tested in the most searching way. Many cases of electrolysis are known in which, owing to complex interactions between the substances liberated, and the materials of the electrodes or the electrolyte, the action is by no means of the simple kind we have described. Faraday would leave no uncertainty behind him. Each case is investigated: he seems indeed almost to take a delight in inventing strange combinations which will strain the theory to the uttermost: but in every instance the law was amply vindicated. Thus, as he concludes with satisfaction, there is the closest relationship, amounting even to identity, between electricity and chemical affinity.

He now turns his attention to the source of current, the voltaic cell. Volta had discovered that if plates of copper and zinc are dipped in acidulated water, a current will flow along a metallic wire joining the two plates, the arrangement forming what is known as a voltaic cell. He had also found that if the two plates were merely placed in contact they became charged with electricities of opposite sign, although no current flowed unless the acid were present. Volta assumed that this difference of potential was the source of the power of the cell to produce a current, and in the absence of clear ideas of the conservation of energy (Mayer's treatise, and Joule's experiments were still in the future), this view was generally though not universally accepted. Faraday now directs his new knowledge upon the problem. He sees that the acidulated water in the battery, without which no current is generated, is merely one of his electrolytes, and should, therefore, be subject to the general laws which he has already enunciated. He quickly obtains experimental proofs of the correctness of this idea. If a voltameter is connected in series with the battery so that the same quantity of electricity passes through both, the chemical action in the battery is exactly equivalent to the chemical action in the voltameter, the sole difference being that whereas in the electrolytic cell the ions are deposited on the electrode, in the case of the battery they are dissolved from it. In the first case a current produces chemical decomposition, in the second chemical combination produces a current; but each is governed by the same law. The source of the power of a voltaic cell lies therefore in the chemical affinity of the acid for the zinc. Thus in Faraday's own words "chemical action is electricity, and electricity is chemical action".

Meanwhile Faraday's imagination had been engaged on the decomposing electrolyte. He sees that the function of the current is not so much destructive as directive, giving order and direction to elements of decomposition already at work in the substance. The sodium atom in a molecule of salt is bound to the chlorine by a bond of chemical affinity, but this bond is not unique; the sodium atom is also attracted by the atoms of chlorine in neighbouring molecules. It is, therefore, already under the influence of forces which tend to separate it from its partner, but normally these forces act indiscriminately in all directions, and hence produce no decomposition in the substance as a whole. The electric current gives direction to these forces, tending to set them along its own direction of flow, or, as Faraday liked to express it, "axis of power". Thus upon the haphazard forces there is superposed a steady pull in one direction, under the influence of which the sodium atom, or "ion" drifts towards the electrode. In other words, the products of the decomposition are not dragged from the electrolyte by the attraction of the electrodes, but are thrown out upon them by the action of the current, as sea drift is cast upon the shore. This theory of Faraday's is substantially in agreement with the modern view.

Faraday's mind next turned from conductors to insulators. He has shown that the decomposition of an electrolyte is not due to the action of poles, but what precisely is the action of a pole, and how does an electrified body affect another across the intervening space? What is the condition of the medium between them, and what part, if any, does it play in the action? Faraday's notebook shows that he had been thinking deeply on these matters. It had long been known that if an electrified body was brought near any unelectrified conductor, the latter became charged by "induction," as it was termed, from the first. It was tacitly assumed that the second charge was produced by a direct action of the first across the intervening space, in which the space itself had no part or function; and a very considerable body of mathematical theory had been built up on this hypothesis. Faraday, as we have seen, was unable to conceive of such action at a distance. He felt that the medium between the bodies must be concerned, that in fact it was the only thing concerned, the two bodies being merely the means by which the action became apparent. As usual he proceeds to experiment. He grasps the fact that if the effect is one of action at a distance it must take place in straight lines radiating from the inducing charge. Only if the medium is brought into play can the effect act in curved lines, or round corners. He shows that there is no electric force inside a closed conducting body, and that, therefore, induction cannot take place through a conductor. On the other hand a charged body will induce a charge upon another body even when a conducting shield is interposed between the two. As the induction cannot take place through the screen, it must have taken place round it. Thus induction can act in curves, and is therefore not due to "action at a distance," but is a property of the medium between the bodies.

The argument is clinched by the proof that the amount of the induction depends on the nature of the substance between the two conducting bodies, and is altered if the medium is changed. He places a charged brass sphere in the middle of a larger hollow brass sphere, and proceeds to investigate how the induction on the concave surface of the larger sphere is affected by substituting other insulators for the air in the space between the spheres. Two such instruments are constructed of exactly the same size, and, by connecting for a moment the two inner spheres, are allowed to share a definite charge between them. If the space between the inner and outer spheres is filled with air in both the instruments, the charge is shared equally between them. If, however, the air in one of the instruments is replaced by sulphur, he finds that the instrument with the solid insulator, or "*dielectric*" as Faraday now calls it, takes considerably more than half the original charge. The sulphur transmits more induction than the air; or in Faraday's words it has a greater *specific inductive capacity.*

Meanwhile Faraday has shown that, just as it is impossible to produce a magnetic pole of either sign without at the same time producing an exactly equal magnetic pole of the opposite sign, so it is impossible to charge a body with, say, positive electricity without at the same time inducing somewhere or other an exactly equal amount of negative electricity. If, as in Faraday's experiments, the attempt is made inside a closed metal conductor, this negative charge appears on the walls of the vessel, and its magnitude can be measured. If, however, there is no such containing vessel, Faraday sees the charge spread over the walls and floor of the laboratory; if these were removed he would look for it upon the sun and stars. This quality of the electrical power, as Faraday terms it, gives him the clue to its nature.

The origin of the electrical effects observed lies not in the charged bodies upon which attention has hitherto been concentrated, but in the dielectric stretching between them. He sees the medium thrown into a state of polarization or strain, filled with curves of induction, or electric force stretching like taut elastic threads from one conducting surface to another. Like stretched cords they tend to contract, while they also exert a lateral repulsion upon each other; the existence of which was seen by Faraday though its real nature was only made clear when many years later the theory was translated into mathematical form by Maxwell. An insulator, or dielectric, is a substance which is able to sustain these electrical strains, while a conductor is one in which the particles, for reasons which at that time were unknown, are unable to withstand the strain upon them, and in yielding to it give rise to an electric current. Hence these lines of electric force, or Faraday tubes as they are now called, end abruptly when they fall upon a conductor.

The electric charges—Faraday protests against the word but finds it too deeply rooted to be eliminated—which appear upon the conductors are thus only the terminations of these lines of force, one end of the line being positive, and the other negative. The whole effect attributed to the charges is due to strain in the dielectric, but the strain only manifests itself at the boundaries of the medium, where it ceases, just as the pull of a stretched cord is only perceptible at the supports to which it is attached.

It is impossible to overestimate the importance of these researches and their accompanying speculations.

They were so far removed from the thought of the times that they seem to have found little acceptance, or even comprehension among contemporary scientists. The difficulties of translating them into mathematical form (a step which the genius of Faraday allowed him to overleap, but which is essential for minds less clairvoyant than his) were considerable, and have not yet been completely overcome. Nevertheless they have produced a revolution in our ideas not only of the electrical field, but of matter and the universe itself, and it can truly be said that the more closely we have been able to make our ideas approximate to those of Faraday, the more fruitful they have proved themselves to be.

The work we have been describing occupied Faraday for ten years. No description can adequately convey the labour involved in carrying out the experiments which have been so briefly summarized. But great as it was, it did not form the whole of Faraday's work at that period. He had, as we have seen, disencumbered himself of his "professional business" in order to devote himself to research, but there was other business of a far less lucrative kind which he would not give up—his work for the Royal Institution. To that body he was bound by affection and gratitude. He did not forget that they had given him his earliest opportunities of scientific work; and for their advantage he was ever ready to exert himself to the uttermost. There is no doubt that for many years the Institution was kept in existence by the fame of Faraday's lectures. No one could handle a scientific theme more simply and more ably than Faraday. His Christmas lectures to children on various more or less popular branches of science were a revelation of how fascinating, how simple, and yet how completely philosophical such expositions may be in the hands of a master. One series, "The Chemical History of a Candle," has been edited and published by Sir William Crookes. These dry bones, so to speak, of the course are full of interest. What they must have been when animated by the genial presence of Faraday himself and illustrated by that wealth of experiment (the experiments sometimes averaged one a minute) which he knew so well how to bring together can be imagined. Nor was his success less with the distinguished, but from a scientific point of view exceedingly mixed and difficult audience, which assembled on Friday evenings (as they still do) to hear of the latest advances in scientific experiment and scientific thought. The least learned felt that they could follow and appreciate, while the most scientific found their knowledge and ideas extended beyond their previous bounds. His style was distinguished by its apparent simplicity and ease; only those who had been intimately acquainted with him in his earlier years knew how earnestly he had studied and practised, and what a wealth of time and thought he had expended to bring his art to its fine perfection. In this, as in everything which he touched, Faraday showed that not invariable accompaniment of genius, an infinite capacity for taking pains. It reveals itself even in the accounts of the Institution, which were at this time in his keeping, and which were a source of wonder to the managing board, while his rough laboratory notebooks are kept with the same care and order displayed in his published works.

The strain of this incessant activity of body and mind was very great, and Faraday had to pay the penalty which Nature not infrequently exacts from great discoverers. He broke down repeatedly in health, the attacks taking the form of headaches, occasional dizziness, and, still worse, loss of memory. From time to time he would find himself unable to draw upon the vast stores of knowledge he had accumulated, and it became necessary for him to retreat from his laboratory to some quiet spot, where he could sit and rest until the healing power of Nature should restore to him his wonted freshness and activity. At the beginning of 1841 the trouble became still more pronounced, and his medical advisers ordered a complete rest from all his scientific duties. For twelve months his work at the Royal Institution was interrupted. His researches were laid aside for an even longer period, and were not fully resumed until the closing months of 1845. The summer of 1841 was spent in Switzerland with his wife and brother-in-law, Mr. George Barnard, the artist. The journal which he kept of this, as of other tours, betrays no failing in his powers either of mind or body. His outlook is as genial, and his interest in all he saw and heard as fresh and buoyant as in his earliest days. His only disease was overwork, the only cure complete rest from the labours with which he had overtaxed his strength.

The journey was made viâ Cologne, where he notes the purchase of some Eau de Cologne (of which he was always exceedingly fond). "Took some trouble to find out the shop, which was the wrong one," he notes in his humorous way. Thence the little party travelled by steamer up the Rhine. Nothing escapes his notice. While his mind and pen are naturally inspired by the grandeur of the scenery, the flowers, the butterflies, and even the frogs are not too small to evoke a kindly reference. We can follow him as he wanders about the churchyard at Oberhofen, where he finds the "little remembrance post set upon the graves very pleasant". "One," he writes, "who had been too poor to put up an engraved brass-plate, or even a painted board, had written with ink on paper the birth and death of the being whose remains were below, and this had been fastened to a board, and mounted on the top of a stick at the head of the grave, the paper being protected by a little edge and roof. Such was the simple remembrance, but Nature had added her pathos, for under the shelter by the writing, a caterpillar had fastened itself, and passed into its deathlike state of chrysalis, and having ultimately assumed its final state, it had winged its way from the spot, and had left the corpse-like relics behind. How old and how beautiful is this figure of the resurrection." The mind of Faraday had ever an upward sweep. From the small experiments of the laboratory his mind soars upwards to the great universe without. So, too, from the things which are seen his spirit rises to the things which are unseen, and eternal. As he stands watching the play of the many coloured rainbows upon the foaming waters of the falls at Brienz, his thoughts again reveal this upward flight. "The sun shone brightly, and the rainbows seen from various points were very beautiful. One at the bottom of a fine but furious fall was very pleasant; there it remained motionless, whilst the gusts and clouds of spray swept furiously across its place and were dashed against the rock. It looked like a spirit strong in faith and steadfast in the midst of a storm of passions sweeping across it, and though it might fade and revive, still it held on to the rock as in hope and giving hope, and the very drops which in the whirlwind of their fury seemed as if they would carry all away were made to revive it and give it greater beauty."

The little party returned to England at the end of September. Faraday's health was much improved by the rest and change, but it is doubtful if his powers of memory were ever completely restored.

The record of Faraday's life during this first period of his Electrical Researches is mainly a record of his experiments; but one or two incidents outside the laboratory demand a passing mention, and help to complete the picture. In 1832 the managers of the Royal Institution (still in financial difficulties) decided that they could not recommend a reduction in Faraday's stipend—the stipend being indeed at an irreducible minimum (£100 per annum, with house, coals, and candles). In the following year, however, Mr. Fuller founded at the Institution the Professorship in Chemistry which is known by his name. The society hastened to show its appreciation of Faraday's work both for them, and for science, and he was elected as the first Fullerian professor for life. It is an interesting mark of the high value which was now set upon his experimental researches that the new professor was given the right of holding his office without lecturing.

We have had occasion to mention Faraday's humility of mind and thought; his habitual gentleness was so marked as to be felt by those who came into contact with him as his most distinguishing quality of soul. But there was nothing servile in his humility, or weak in his gentleness. These qualities were in Faraday (as in their highest expression they always are) the signs not of weakness but of greatness of soul. To whatsoever was worthy of honour he yielded honour with all his heart; but to whatever challenged his independence of mind or the integrity of his manhood he showed an opposition which was none the less firm and decisive from being entirely free from bitterness or rancour. The following incident, which belongs to the year 1835, is worthy of note from the light which it throws on this side of Faraday's character.

Sir Robert Peel, with some idea of rewarding or encouraging science and literature, had instituted a system of royal pensions to be granted to men of mark in the scientific and literary world, as pensions were and still are granted to successful generals and politicians, as a token of appreciation from the nation for services rendered. One of these pensions was intended for Faraday, who, however, was by no means enthusiastic about the matter. While approving of the good intentions of the Government, and in no way reflecting on those who had accepted the pensions, his native independence was touched, and he felt that he would much rather not take pay which was not directly for services performed, while he was able to live by his labours. His reluctance was eventually overcome by the urgent representations of his friends, but before the matter could be completed Peel was out of office, and the business devolved upon his successor, Lord Melbourne, who invited Faraday to an interview. Lord Melbourne seems to have possessed to the full that amazing ignorance of men and affairs, outside the limited sphere of party politics, which is so frequent a characteristic of Ministers of State, and to have considered that he was conferring an undeserved favour, rather than a well-merited honour. He opened the interview pleasantly by remarking that he regarded the whole idea of giving pensions to scientific or literary men as so much humbug, qualifying the epithet with an adjective which Faraday described as "theological". Faraday felt that this was an insult not merely to himself but still more to the honourable profession which he represented. He at once brought the interview to a close, and a few hours later the Prime Minister received a note from him "declining to accept at your Lordship's hands, that which, though it has the form of approbation, is of the character which your Lordship so pithily applied to it".

Lord Melbourne seems at first to have been amused at this ebullition of independence, but on the matter becoming known, he found to his surprise that Faraday, though a mere scientist, by no means ranked so low in the judgment of others as he had imagined. It is said that the King himself lost no opportunity of rallying his Minister upon his unfortunate indiscretion. Lord Melbourne, whether as a result of these remarks, or more probably from real good nature—for ignorance seems to have been at the root of his conduct—was now anxious to carry the matter through. Faraday, though showing no trace of anger or resentment, was firm. He felt that until the words used had been withdrawn and apologized for, it would be degrading both to science and to himself to accept the proffered grant. His firmness brought about the required result. The apology was given, full, frank and honourable, both to the Minister and to the philosopher, and the pension was accepted.

In 1836 Faraday was requested to act as scientific adviser to the Trinity Brethren, that great corporation which has in charge the lighthouses around our coasts. Faraday, now deep in his researches, would not have accepted the position as a matter of business. As a matter of kindness, however, he could not refuse it. He felt the claim of those great beacons which guide the sailors in safety across the seas to the best that was in him. For thirty years he held the appointment, and the services which he rendered were as varied as they were extensive; ranging from investigations of new optical apparatus, and new methods of lighting, to the testing of samples of burning oil, and reporting on the quality of the wicks. Before the close of his life he had the great satisfaction of seeing his own electromagnetic currents employed in lighting the lantern in the lighthouse at Dungeness.

CHAPTER IV.

ELECTRICAL RESEARCHES (SECOND PERIOD).

1845-1855.

THE second period of Faraday's Electrical Researches occupied the years from 1845-1855. The experimental skill expended upon the work is more exquisite than ever, the reasoning as clear, and the insight as perfect, but the results do not as a whole rank in importance with those of the preceding years. Faraday had set a standard which even he himself could not maintain indefinitely, and much time was unfortunately spent on phenomena which proved in the end to be but of secondary importance. It must be confessed that it was not so much his experimental work as his speculative writings that make the ten years on which we are now entering memorable in the history of science.

The series, however, opens brilliantly with the discovery of a direct relation between magnetism and light. We have seen that Faraday believed intensely in what he called the correlation of forces, and this belief had already led him to discover relations between electricity and magnetism, and electricity and chemical affinity. He seems long to have cherished the conviction that light also was an electromagnetic effect, and had on no less than five previous occasions endeavoured by experiment to verify this belief, using for the purpose a beam of polarized light. In ordinary light the vibrations which make up the beam take place in all directions at right angles to that in which the light is travelling. If, however, the light is passed through an instrument known as a polarizing prism only vibrations in one particular direction will be transmitted, and the light is said to be polarized. A second prism placed at right angles to the first will then stop the light completely, unless in the meantime it has been acted upon in some way so as to change the direction in which the vibrations are taking place. Such change can be produced by any kind of one-sidedness in the substance through which the light is passing, and a beam of polarized light is thus a very powerful means of investigating the structure of transparent substances. In this way we can demonstrate the structure in crystals, and in starch grains, and the existence of strains in glass which is subjected to mechanical forces. It is this agent which Faraday applied in his investigations of a possible relation between electricity and magnetism and light. He had tried it, without success, across a decomposing electrolyte, and had also endeavoured in the same way to make manifest the electrical strains which he believed to exist in a charged dielectric. In the latter case the action actually occurs, but the experimental means at Faraday's disposal were not adequate for the task, and thirty-two years elapsed before the effect which Faraday foresaw was demonstrated by Kerr.

Faraday's faith was unshaken by these repeated disappointments, and he returned to the charge, this time substituting magnetic for electric forces. For many weeks he laboured without result. At last, however, he chanced upon a specimen of the heavy glass produced in his early experiments on glass making, and success was immediate. When the glass was placed between the poles of his electromagnet, and the beam of polarized light passed through it in the direction of the magnetic forces, the light was acted upon by the magnetic field, and the direction of its vibrations was rotated through an angle which increased with the strength of the magnetic forces. "Thus," as Faraday writes, "magnetic force and light are proved to have a relation to each other."

This success drives him to further experiment. He is unwilling to believe that his heavy glass is unique in its action on the light. He procures stronger electro-magnets, and with these succeeds in reproducing the effect in the substances, solid and liquid, which had previously given him no result.

Before these results could be published, he had already made another discovery of great interest. Just as in the experiments which we have described he was unwilling to admit that the heavy glass possessed a property which was not shared by other substances, so he had long believed that it was unlikely that the power of setting in a definite direction in a magnetic field should be confined to the very few so-called magnetic metals. He had previously attempted to influence copper and wood by a magnet without success. He at once repeats the experiments with his new and powerful magnet. His first attempt is made with the bar of heavy glass, and is an immediate success. The bar sets itself under the action of the magnet, but whereas a piece of iron would set itself axially, that is from pole to pole, the bar of glass takes up a position at right angles to this direction. Rapidly he tests all the substances within his reach, and finds that all are affected in some degree by the magnetic field. The great majority resemble the heavy glass and set across the lines of force. These he terms *diamagnetic*. Some few, however, set like iron from pole to pole, and these he calls *paramagnetic*. "It is strange," he writes, "to find a piece of wood or beef, or apple, obedient to or repelled by a magnet. If a man could be suspended with sufficient delicacy and placed in a magnetic field he would point equatorially, for all the substances of which he is formed possess this property."

He extends his investigations to gases, and finds that oxygen is strongly magnetic. He sees at once that the presence of this magnetic substance in the atmosphere must affect the earth's magnetic field, and believes that he has here an explanation of the still unexplained daily variations in the earth's magnetic field. This theory, though warmly welcomed at the time, has since been found to be inadequate.

The anomalous behaviour of some crystalline specimens of bismuth, the most diamagnetic of all substances, in the magnetic field now unfortunately led Faraday away on a long series of researches on what he calls magne-crystallic action. He hoped to find some relation between magnetism and the forces at play in building up crystal structure, but the effects, though curious and complex, turned out to be of little importance, and one cannot but regret that so much of Faraday's time should have been spent upon them. One idea of great importance, however, emerges from the experiments, that of magnetic permeability, or as Faraday calls it "the conducting power of a magnetic medium for lines of force". This property of the medium, which corresponds closely to specific inductive capacity in electrical phenomena, is of great importance in practical engineering problems, and its existence was first recognized by Faraday as a result of these otherwise somewhat barren researches.

We are now drawing towards the close of the great series of experimental researches in electricity, begun nearly twenty years before. Through them Faraday had been guided by a great conception, that of lines of force, Where others saw in the mutual attraction of two distant bodies only the result of mysterious fluids affecting each other at a distance, he saw the medium between them filled with tense curves of force linking body to body across the intervening space. The services which this idea had rendered him in his own work had convinced him more and more not only of its value as a hypothesis, but of its close agreement with reality. Little by little he had allowed the idea to escape into his published papers, partly because he found himself more and more unable to think in other terms, partly because no other terms were adequate to express his discoveries. He seems, however, as of set purpose, to have avoided their introduction into his experimental papers as far as possible, not because he was in any way unwilling that others should share his ideas, but from a natural modesty which shrank from appearing to force upon others views which, until supported by experimental proof, were but the private convictions of his own mind. That a scientist should theorize, and theorize boldly, he believed to be a first necessity, but theories were only useful so long as they remained fluid, so long as their author recognized the possibility, even the probability that they might in some respects, perhaps in all, fall far short of the truth. Hypothesis was invaluable as a servant, but unbearable as a master. It was no part of the rights or duties of a philosopher, scientific or otherwise, to impose his own convictions on the minds of others.

But now, as his labours were drawing to a close, Faraday determined to develop in detail the ideas which had led him to so many of his achievements. Like some old explorer, bidding adieu to the scene of his discoveries, he bequeathed to the world the chart by which he had steered, believing that it would still prove a faithful guide to those who should seek to penetrate still further into the unknown land.

The idea of a line of force comes from those curves which are formed when iron filings are sprinkled freely in the neighbourhood of a magnet. The little particles of iron under the influence of the magnet set themselves in chains, sweeping from pole to pole, and marking at each point in their course the direction of the magnetic forces. The experiment is a convenient way of investigating the arrangement of what Faraday was the first to call the magnetic field, and the lines of force, as he termed the curves so obtained, form a very convenient way of representing graphically the actions taking place. This Faraday demonstrates in his paper. But he felt that these lines of force were far more than a convenient convention. They not only represented the magnetic field; in some sense they were the magnetic field, and the magnet itself was merely the girdle which bound the lines together. The lines of force had in fact a quantitative significance; each of them represented a determinate and unchanging amount of force. This he now proceeds to prove by experiment. Returning to his first experiments on the electromagnetic induction of currents he proceeds to make his moving conductors cut the invisible lines of force in various ways and at various distances from the magnet. He shows that if the same number of lines of force are crossed by the conducting wire, then, whether the lines are crowded together as at the poles of the magnet, or spread out over a wide area, as at some more distant region, the quantity of electricity set in motion in the wire is always exactly the same. "Although their forms," he writes, "as they exist between two or more centres of power may vary very greatly, and also the space through which they may be traced, yet the sum of the power contained in any one section of a given portion of the lines is exactly equal to the sum of power in any other section of the same lines, however altered in form they may be."

With his old exuberant vitality he throws his experiments into every conceivable form, but in every case the result is the same. The quantity of electricity set in motion in the induced current is always directly proportional to the number of lines of force intersected by the conductor. The number of lines of force passing through a given area can thus be measured by the quantity of electricity which they can set in motion. The lines of force are, in other words, reduced from a mere speculation to a measurable physical quantity. In this discovery and expression of the law of electromagnetic induction, Faraday's unique experimental skill and his unrivalled physical insight are seen united at their very highest. On the one hand the work completes the great discovery with which the volume of researches had opened and which will, from a practical point of view, ever rank as his greatest achievement. On the other hand it sets upon a firm basis the idea of lines of force, which has been and still is of incalculable value to pure science. Taken only on its lowest grounds, the idea has provided us with a mental picture of the electric and magnetic fields which is at once simple, clear, and adequate, and a method of dealing with them, the power and possibilities of which have not even yet been adequately developed; while on higher grounds we are beginning to find in these lines of force, as Faraday himself perceived, the very woof and warp of our material universe.

We must not conclude our sketch of Faraday as a scientist without a brief summary of his theoretical conceptions. Perhaps at the present moment they form the most fascinating portion of his work. As was to be expected from the character of the man, he left no ordered body of doctrine. Except where his experiments had afforded some sure basis for his theories, his ideas are often only to be gathered from hints thrown off, almost unconsciously in lectures, and in letters. But these hints are so luminous and so consistent that there is little difficulty in tracing the main outlines of the great scheme of things which lay at the back of his mind and directed his energies. At the time of Faraday's researches the physical universe was regarded as being built up of some sixty or seventy different kinds of atoms, which constituted the different chemical elements, and which were pictured as material particles of definite size, shape, and mass. In addition certain mysterious fluids, electrical, magnetic, and the like were invoked to account for the phenomena of electricity and magnetism. Caloric had already gone; light was already recognized as some kind of wave motion, but to account for the propagation of light through a vacuum, all space was regarded as being filled with a mysterious elastic fluid known as the luminiferous ether. Faraday replaces the whole of these numerous hypothetical substances by one bold and simple conception—the line of force. We have already seen how he abolished the electric fluids, by showing that what we still call positive and negative electric charges were but the ends of lines of electric force, Faraday tubes as we now call them, joining the oppositely charged bodies; and that all the phenomena of the electric field must be ascribed to the tension and the mutual repulsion of these entities, in which, and not in the charges, the electric power resided. Similarly magnetic phenomena could be expressed in terms of magnetic lines of force. That gravitational attraction, the only remaining instance of apparent action at a distance, would eventually be found to be transmitted by a similar mechanism he was firmly convinced, though his numerous attempts to obtain experimental evidence for his faith were unsuccessful. Concentrating thus his gaze upon the space between particle and particle he finds no use for the material atom of the older theories. The chemical affinities of the atom, as he has shown, are but an expression of its electrical state, while all the physical forces reside in the medium around it. He sees in the atom only a centre from which the lines of force radiate, a mere point to and from which the forces act. Apart from its lines of force the atom shrinks out of existence; but with them it expands until it fills the universe, for its lines of force pervade all space.

How he conceived of the relationship between the various kinds of lines of force which he had postulated is not clear; possibly he had formed no definite views; but as it was his often expressed conviction that the various forces of nature were at bottom identical, there is no doubt that he regarded it as exceedingly close. From his insistence on the fact that the magnetic lines of force form continuous closed curves, and his frequent use of the analogy between these closed magnetic curves and the flow of a current round a closed circuit, we may perhaps infer that he had some conception that the magnetic curves were of the nature of stream lines, or lines of flow, excited in some way by the motion of the lines of electric force. The idea is implicit in the views which Faraday held; but it cannot be said with certainty that he drew the inference. As we have seen, gravity refused to yield up its secret even to the magic of Faraday, or to return an answer to the many questions he put to it. From the nature of his experiments, as well as from his direct statements, it is evident how strongly he held that gravity was also electrical in origin, or at any rate capable of transformation into electricity.

Having filled space with lines of electric force, he perceives that the luminiferous ether is no longer a necessity. Light is a vibration, but a stretched cord will transmit vibrations quite as well as an elastic solid. If one end of a long cord is shaken from side to side, a series of waves travel out along it with a speed which depends on its mass and tension. In the same way waves may be started in a line of force which will be transmitted along it. Suppose, he says, that two particles are connected by a line of force. If one of these particles is moved sideways the end of the line of force upon it is also moved, and a kind of lateral shake is given to the line which will travel out along it, with a speed which depends upon its tension and its mass. Such vibrations in the lines of electric force, on Faraday's view, constitute the phenomena of light, heat, and other forms of radiant energy. In these simple terms Faraday formulated his electromagnetic theory of light in a short note, entitled "Some Thoughts on Ray Vibrations," which appeared in the "Philosophical Magazine" in 1846. This paper represents the highest point even in Faraday's scientific writings, and affords a most striking proof of the profundity of his amazing scientific insight. That its importance should not have been realized at the time, nor indeed until many years after his death, was perhaps inevitable. The idea was at once too simple, and too profound. Tyndall waves it aside as "one of the most singular speculations which ever emanated from a scientific man," while even Maxwell, Faraday's great interpreter, in developing the electromagnetic theory of light which is known by his name (but which he himself ascribes to Faraday), prefers to found it on another of Faraday's conceptions—that of displacement currents in the dielectric. It is only in recent years, when new discoveries have extended our knowledge of the origin of light, that we have begun to perceive how profoundly true was Faraday's insight, and to revive again, in the simple form in which he stated it, the theory of Faraday.

We cannot conclude this brief account of Faraday's views better than in his own words. "Our philosophy," he writes, "feeble as it is, gives us to see in every particle of matter, a centre of force reaching to an infinite distance, binding worlds and suns together, and unchangeable in its permanency. Around this same particle we see grouped the powers of all the various phenomena of nature: the heat, the cold, the wind, the storm, the awful conflagration, the vivid lightning flash, the stability of the rock and the mountain, the grand mobility of the ocean, with its mighty tidal wave sweeping round the globe in its diurnal journey, the dancing of the stream and the torrent; the glorious cloud, the soft dew, the rain dropping fatness, the harmonious working of all these forces in nature, until at last the molecule rises up in accordance with the mighty purpose ordained for it, and plays its part in the gift of life itself. And therefore our philosophy, whilst it shows us these things, should lead us to think of Him who hath wrought them; for it is said by an authority far above even that which these works present, that 'the invisible things of Him from the creation of the world are clearly seen, being understood by the things that are made, even His eternal power and Godhead'."

CHAPTER V.

OLD AGE.

1855-1867.

THE series of Electrical Researches came to an end in 1855, the last paragraph being numbered 5430. To the last they retain their qualities of freshness, enthusiasm, and brilliance. It is only from Faraday's private letters that we learn that the later series were wrought out by sheer will power, struggling against ever-increasing physical weakness and ill-health. Faraday, in truth, never completely recovered from the breakdown which in 1841 had caused a temporary cessation of his labours. His loss of memory became more and more serious with advancing years. In spite of his elaborate and accurately ordered laboratory notes, he found himself more and more unable to retain in his mind the details even of his own work, and in one instance, at least, after six weeks' continued effort in the laboratory, discovered that he was merely repeating experiments which he had himself performed only a few months before. So serious did this forgetfulness become that, as he himself put it, there was no past for him, only the present. Under such circumstances the continuous effort necessary for scientific discovery became increasingly impossible. With undaunted courage he continued to work, though he knew that he was spending months over tasks for which in his earlier years a brief fortnight would have sufficed.

One by one the fastenings of his earthly tabernacle were removed, but his marvellous insight remained with him to the end. In the last experiment recorded in his laboratory notebook we see it again at its highest stretch. He is investigating the effect of a magnetic field on a source of light. Starting from the comparatively recent discovery of the characteristic emission spectra of the elements, he places a flame containing salt between the poles of his great electro-magnet. He passes the light emitted through his polarizing prism, and seeks to discover the effect of the magnetic field upon the refrangibility (in other words, the wave length) of the light from the flame. The arrangement is, in fact, identical with that with which Zeeman in 1897 dicovered the important phenomenon which is known by his name. The effect lay far beyond the limits of the optical apparatus available in Faraday's time, but it was the means at his disposal, and not the genius of the experimenter that was at fault. Had the experiment been successful it would have ranked with Faraday's greatest discoveries, and would have provided a firm basis for his theory of light. That he should have conceived its possibility shows how profoundly and how accurately he was still thinking along the lines of his theory of ray vibrations.

Faraday's work was done. His last lecture was delivered in 1862, and the same year saw his last experiment. One by one he laid his tasks aside. Acknowledged as he universally was by this time as the very prince of scientists it was inevitable that he should be invited to occupy the Presidency of the Royal Society, the highest honour which English science has to bestow. It was still more inevitable that the Managers of the Royal Institution should feel it fitting that, as his career drew to its close, he should be asked to preside over the Institution which he had entered as a laboratory assistant more than fifty years before. But the duties of these positions, as he conceived them, were beyond his powers. "It was never in his nature to take things easy"; and both offers were declined.

The closing years of his life were mainly spent near Hampton Court, in a house which the Queen had placed at his disposal in 1858. Here he would sit at his window, delighting in the clouds, the trees, and the little knots of holiday makers scattered here and there upon the green. The wild splendours of the lightning, and the gentler glories of the setting sun, still had power to arouse the old enthusiasm. "I shall always connect the sight of the hues of a brilliant sunset with him," writes one who watched over him in his declining years, "and especially will he be present to my mind while I watch the fading of the tints into the sombre grey of night. He loved to have us with him as he stood or sauntered on some open spot and spoke his thoughts, perhaps in the words of Gray's 'Elegy,' which he retained in his memory clearly long after many other things had faded quite away. Then as darkness stole on, his companions would gradually turn indoors, while he was well pleased to be left to solitary communing with his own thoughts."

There is to us something of the sadness of the sunset as we watch the brilliant powers which had so enriched mankind fade one by one into obscurity, but there was no sadness in the heart of Faraday. The querulousness of age never descended upon him; to the last he remained his old sweet, unselfish self. There is no note of complaint in the letter in which he lays down his duties at the Royal Institution. "My life has been a happy one, and all I desired. During its progress I have tried to make a fitting return for it to the Royal Institution, and through it to science. But the progress of years (now amounting in number to threescore and ten) having brought forth first the period of development, and then that of maturity, have ultimately produced for me that of gentle decay. This has taken place in such a manner as to make the evening of life a blessing; for whilst increasing physical weakness occurs, a full share of health free from pain is granted with it; and whilst memory and certain other faculties of the mind diminish, my good spirits and cheerfulness do not diminish with them."

"My worldly faculties are slipping away day by day," he writes in another letter. "Happy it is for all of us that the true good lies not in them. As they ebb, may they leave us as little children trusting in the Father of Mercies, and accepting His unspeakable gift." The past is gone, not to be remembered: the present is but a patient waiting for release: but the future is bright. "Out of the view of death there rises the view of the life beyond," and Faraday's letters are full of what he calls "the glorious hope". How firm that hope was the following incident will show. His assistant, Anderson, who had been first engaged for the glass-making experiments, died in the early part of 1866. Some friends wished to commemorate the long association by some form of memorial tablet, and Faraday was asked for his views on the matter. He expressed himself averse to meddling with sepulchral honours in any case. He had already given instructions that his own funeral should be of the simplest, but, he continues, "I shall mention your goodwill to Anderson". It is not surprising that his niece who was taking the letter down from his dictation hesitated to write the words. But the old philosopher was not to be denied. Standing at the threshold of eternity his vision had already pierced the veil between. He seems to see his old friend waiting for him beyond, and taking the pen in his own cramped and uncertain fingers he sets down the sentence, "I shall mention your goodwill to Anderson".

Peacefully and painlessly he passed away, on 25th August, 1867, seated in his chair in his study. As one of his friends has written, there was a philosopher the less on earth, and a saint the more in heaven. At his own earnest request none but his relatives were present at the funeral in Highgate Cemetery, and a simple stone marks the last resting place of all that was mortal of Michael Faraday.

It has only been possible to summarize the most important of Faraday's many contributions to science. In looking down the list of the 158 original memoirs which stand to his credit in the Royal Society Catalogue, one feels that the researches which have been left unnoticed are enough in themselves on which to base a scientific reputation of no mean order, including, as they do, his work on regelation, on the freezing of solutions, and on the discharge of electricity through gases. In all his philosophy he was peculiarly modern, as compared not merely with his contemporaries, but even with his successors. Tyndall, in his volume on "Faraday as a Discoverer," in which he seeks to give a summary of Faraday's scientific work, seems in comparison to belong to an earlier age. Gradually but surely the ideas of Faraday have permeated physical science, and at no time since their publication have they met with such general acceptance as they do to-day. In one sense Faraday left no successor, founded no school. He was a solitary worker, exploring alone far from the beaten track. But in a wider sense it may fairly be claimed that modern English physics is the school of Faraday, applying his methods, led by his vision, inspired by his faith. Three great Cambridge men, Maxwell, Stokes, and J. J. Thomson, have in turn applied their genius to expound and develop his views; and the honourable position that the Cambridge School of Physics holds in the world of science is due, at least in part, to this continued appreciation of the insight and genius of one who (it is pleasant to recall) received his first public tribute at the hands of the Cambridge Philosophical Society.

We have found no space for mention of the numerous honours which, especially in his later years, were bestowed so freely upon Faraday by learned societies and princes at home and abroad. Their mere enumeration would fill many pages. Perhaps the best summary is that to be found on the envelope of a letter addressed to him by a foreign colleague, "Professor Michael Faraday, Member of all the Academies of Science, London". Faraday valued these tributes to his work, but he prized still more the love and sympathy of his fellows. It was to him by far the sweetest reward of his labours. But his greatness as a scientist was but a secondary cause of the reverence and affection in which he was so widely held. It was the truthfulness, the gentleness, the modesty, and above all the genial kindliness and large-hearted sympathy of his nature which won all hearts. "His work excites admiration, but contact with him warms and elevates the heart," wrote Tyndall, after one of his early meetings with Faraday. The scientist must be admired, but it was the man who was loved. Let the words of his great French contemporary, Dumas, conclude our sketch.

"I do not know if there may be any scientist who would not feel gratified to leave behind him such works as those with which Faraday has delighted his contemporaries, and which he has left as a legacy to posterity, but I am certain that all who have known him would wish to approach that moral perfection which he reached without an effort. In him there appeared to be a natural grace, which made him a teacher full of zeal for the diffusion of the truth, a tireless worker, full of enthusiasm and vivacity in his laboratory, the best and most lovable of men in the bosom of his family, and the most enlightened preacher amongst the humble folk whose faith he followed. The simplicity of his heart, his burning love of the truth, his sympathy in all the successes, and admiration for all the discoveries of others, his natural modesty in regard to what he himself had discovered, his noble soul—independent and bold—all these combined gave an incomparable charm to the character of the illustrious physicist.

"Fidelity to his religious faith was the ruling characteristic of his life. Doubtless his firm belief in that justice on high which weighs all our merits, and in that sovereign goodness which weighs all our sufferings, did not inspire Faraday with his great discoveries, but it gave him the straightforwardness, the self-respect, the self-control, and the spirit of justice, which enabled him to meet evil fortune with boldness, and prosperity without being puffed up."

BIBLIOGRAPHY.

THE standard life of Faraday is that of Dr. Bence Jones, "Life and Letters of Faraday" (2 vols.), 1870, to which I am indebted for the extracts from Faraday's letters and journals included in the present volume. Prof. J. Tyndall's "Faraday as a Discoverer" (1868) gives a very complete account of Faraday's experimental work, and some personal reminiscences. In addition there are lives by Dr. J. H. Gladstone (1872), W. Jerrold (1893); and an excellent estimate of Faraday's life and work (containing some new material) by Prof. Silvanus P. Thompson (1898).

Of books, in the usual sense, Faraday published but one, "Chemical Manipulation" (1827). His "Experimental Researches in Electricity" were reprinted by him from the Transactions of the Royal Society in three volumes (1839), (1845), (1855), and a collection of papers from various journals under the heading "Experimental Researches in Chemistry and Physics" (1859). Two series of lectures, "The Various Forces of Matter" (1860) and "The Chemical History of a Candle" (1861), were published by Sir Wm. Crookes without Faraday's supervision.

A small selection from "Experimental Researches in Electricity" has been republished in the "Everyman" Series (N.D.).

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