

# F A R A D A Y

This study of the life and work of Michael Faraday is published by the British Electrical and Allied Manufacturers Association (Inc.) during the Centenary year of the discovery of electromagnetic induction

LONDON

THIRTY-SIX KINGSWAY

**FARADAY.**

# F A R A D A Y

*. . . so it must always be; the great experimentalist must ever be the habitual theorist . . . Faraday was more than a philosopher; he was a prophet, and often wrought by an inspiration to be understood by sympathy alone.—TYNDALL.*

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JAMES FARADAY, a blacksmith, came to London in 1787. He was the third son of a large family living near Clapham, in Yorkshire. The family records, however, only went back to the beginning of the century, and there existed a tradition that the family came originally from Ireland. James Faraday settled with his wife and children, a boy called Robert, a girl, Elizabeth, at Newington Butts, where on 22 September 1791, his third child, Michael, was born. They moved some time afterwards to Jacob's Well Mews, near Manchester Square, and then again to 18 Weymouth Street, near Portland Place. His youngest daughter, Margaret, was born in 1802.

The beginning of the nineteenth century was a period of acute distress for the working classes in this country. The long war with Napoleon, begun in 1793, had affected the lives of the whole population. Extreme poverty was on the increase even in 1795, and in that year when George III. was returning in his state coach from opening Parliament, a great and angry mob surrounded his carriage demanding bread. The price of the staple commodities had risen very sharply: in 1760 a bushel of flour cost 3s. 4d., in 1804 it cost 10s., and in 1801 the price of a quartern loaf was 1s. 10½d. In the country, agricultural wages had not risen in anything like the same ratio as the cost of living. Labourers, whose condition had been made worse by the various enclosures of

common land which had been taking place since the middle of the century, flocked to the towns, where there was nothing like enough work for them. The temporary peace of Amiens, and the general disorganization in employment and wages caused by the war, transformed the state of the whole country and made the civil legislation of the time something like that adopted in a besieged town.

As a blacksmith, James Faraday was in no danger of starving, although the earnings even in the skilled trades were greatly reduced. In the general depression at the beginning of the century, the blacksmith would suffer as the garage proprietor of to-day. The price of forage was high; and no doubt a great number of horses were off the streets and parks of London on account of the high price of forage. The Faradays applied for public relief in 1801 and, at the age of nine, Michael had to make one loaf last for a week. The family difficulties were accentuated by James Faraday's ill-health.

However, the lowest ebb of misfortune was reached in the first two or three years of the century. The family were happy and united. Robert, the eldest son, who afterwards became a gasfitter, helped his father in the smithy, Michael was apprenticed to a bookseller in Blandford Street nearby, and went to live, according to the custom of the time, in his master's house. This was in 1804. In 1810 Robert could afford to pay for his brother, Michael, to go to some lectures given by a Mr. Tatum in Dorset Street. This was a material instance of brotherly affection. Michael did very well with Mr. Riebau, the bookseller, and soon had two boys working under him.

During these early years he was, according to a descrip-

tion he gave of himself many years after, 'a lively and imaginative person'. He read the *Arabian Nights* and Mrs. Marcet's *Conversations in Chemistry*. He preferred scientific books to others because, 'facts were important to me. . . . I could trust a fact and always cross-examined an assertion. So when I questioned Mrs. Marcet's book by such little experiments as I could find means to perform and found it true to the facts as I could understand them, I felt I had got hold of an anchor in chemical knowledge and clung fast to it.' Behind the words, 'facts were important to me' can be realized the great necessity of Faraday's mind for something on which to exercise its peculiar and vital powers. Faraday, even as a young man, was not a storer-up of knowledge; quite early in his life, indeed, he began to complain of his lack of memory. It is round a fact, a chemical definition by good Mrs. Marcet, over the article on Electricity in the *Encyclopædia Britannica*, that his mind is stirred, he thinks quickly, his imagination is on fire, he dances about the shop, he writes long enthusiastic letters to his friend, Mr. Benjamin Abbott, who is a Quaker, and has been well educated therefore, and who is a confidential clerk in the City.

The education Faraday received as a child was nothing much more than reading, writing and arithmetic. This was of little importance, the chief quality of his mind being its independence of all knowledge but that which by the attraction of its own nature it drew towards itself. As he grew older, he began to hold certain convictions about the essential unity of the forces governing matter and the manner in which they were exerted. The development of these convictions implied an intellectual independence and



isolation. This independence was shown in other ways. Delighting as he did in the work of other men and in their discoveries, he must always repeat for himself the experiments that have been performed. 'He knew well', wrote Professor Tyndall, 'that from every experiment issues a kind of radiation, luminous in different degrees to different minds, and he hardly trusted himself to reason upon an experiment he had not seen.' Faraday, who had, even in his youth, the right amount of self-knowledge to deal with all his problems, was well aware of this independence of his mind. It was one of the reasons why he would do nothing but what could profit his scientific and imaginative powers, accept no favour that would compromise them.

A very important influence on the whole family and on each of its members individually was their religion. The Faraday family in Yorkshire had joined the community of Sandemanians founded in the middle of the eighteenth century by Robert Sandeman, son-in-law of Richard Glas, a minister deposed by the Presbyterian Church of Scotland. Glas taught that organized religion was bound to become the opposite of Christianity and that the words of Christ in the New Testament were the true and sufficient guides to the conduct of life. His followers met every Sunday for a service consisting mainly of readings from the Bible. The service was directed by elders, and a meal was taken in common by the whole congregation. The characteristics of the Sandemanian community were the recognition of brotherhood and an insistence on the practice of the Christian virtues of humility and charity. This brotherhood, whilst no doubt implying a belief in a general fraternity of human beings, was practised as a natural duty towards

those who met together on Sunday at the chapel. Realizing with true humility that their interpretation of life was conditioned by their own environment, the Sandemanians never attempted to proselytize.

Faraday remained an active member of this community all his life. He did not merely accept the code of the beliefs and habits of the community but he served as an elder and, at the height of his fame as a scientist and as a lecturer, preached in the little chapel at the end of a mews in St. Paul's Alley, and was, by frequent visits and secret charity, in every sense one of the community. This is not to be interpreted as a charming feature in the habits of a great man. Faraday's character and mental outlook are integral.

In a lecture before the Prince Consort on mental education, he says—and when he speaks of himself, of his beliefs and his principles, his words have that air of complete truth which only few men's descriptions of themselves have—'Let no one suppose for a moment that the self-education I am about to commend, in respect of the things of this life, extends to any consideration of the hope set before us, as if by reasoning man could find out God. It would be improper here to enter upon this subject further than to claim an absolute distinction between religious and ordinary belief. I shall be reproached with the weakness of refusing to apply those mental operations which I think good in respect of high things to the very Highest. I am content to bear the reproach.'

He wrote on the same subject to Lady Lovelace in 1844. 'You speak of religion, and here you will be sadly disappointed in me. . . . Your confidence in me claims in return

mine to you, which indeed I have no hesitation in giving on fitting occasions, but these I think are very few, religious conversation is generally in vain. There is no philosophy in my religion. I am of a very small and despised sect of Christians known, if known at all, as Sandemanians, and our hope is founded on the faith that is in Christ. But though the natural works of God can never by any possibility come into contradiction with the higher things that belong to our future existence. . . . I do not think it at all necessary to tie the study of the natural sciences and religion together, and, in my intercourse with my fellow-creatures, that which is religious and that which is philosophical have ever been two distinct things.'

A mental attitude could not be more definitely expressed than in these quotations. In many other ways his religion was to play an important part in his life. Faraday, born in poverty, had all through his life many opportunities of making a great deal of money. Preferring to devote himself to science, the opportunities of applied science had little hold over him. What money he had to spare he gave away. At the end of his life the Queen was to offer him a house at Hampton Court, but he hesitated to accept this offer on account of the expense of repairs. He travelled on the Continent, he went constantly to the sea with his wife, he enjoyed food and wine—but he saved no money. There are two reasons for this which have voices in unison; he was a very generous man and had a small salary, being a worker in pure science, and—his religion forbade saving money, or life assurance or other safeguards against the working of destiny. The Lord shall provide.

The religious community into which he was born

strengthened and protected the strong, delicately balanced powers of his mind. All his life he remained free from any inclination to speculate about the nature of God or the meaning of existence. This freedom was valuable, not because metaphysical speculation is worthless, but because it would have been worthless to him. The concentration of his mind was made possible by the simplicity of his heart. Cardinal Wiseman once asked Faraday if he believed that the doctrine of the Church of Christ, Holy, Catholic and Apostolic was shut up in the little sect of which he was a member. 'Oh, no,' Faraday replied, 'but I do believe in the depth of my soul that Christ is with us.'

The happiness of his family life was one of the natural causes of the happiness of his marriage. He married, when he was twenty-eight, Sarah Barnard, the daughter of a silversmith, who was a Sandemanian. As 'a lively and imaginative person', an enthusiast, a man whose eyes filled with tears of emotion when, middle-aged, he read Byron to his wife and niece, a man such as Faraday might never, without the bond of the strong and constant affection which existed between his wife and himself, have arrived at any full degree of concentration. He was of strong natural powers, but these powers were to be used to the full. Emotional disturbances, whatever effect they may have in broadening the intuition of a man of letters or in quickening the powers of a poet, would have been fatal—not, perhaps, to a few brilliant discoveries, but to the whole sustained and related achievement of Faraday's life. He himself was well aware how the forces of his nature were happily assuaged, and, like the obedient horses in Plato's fable, bore him onwards instead of pulling him this way and that. In 1849 he wrote in one of his

diaries a little note in the third person: 'On 12 June 1821 he married, an event which more than any other contributed to his earthly happiness and healthful state of mind. The union has continued for twenty-eight years, and has in no way changed, except in the depth and strength of its character.'

## II

IN 1813 Michael Faraday wrote, at the request of his mother, a short history of himself to an aunt and uncle. 'I was formerly a Bookseller and binder, but am now turned philosopher, which happened thus: Whilst an apprentice, I, for amusement learnt a little of chemistry and other parts of philosophy, and felt an eager desire to proceed in that way further. After being a journeyman for six months, under a disagreeable master, I gave up my business and, by the interest of Sir H. Davy, filled the situation of Chemical Assistant to the Royal Institution of Great Britain, in which office I now remain, and where I am constantly engaged in observing the works of Nature and tracing the manner in which she directs the arrangement and order of the world. I have lately had proposals made to me by Sir Humphry Davy to accompany him in his travels through Europe and into Asia, as philosophical assistant. If I go at all I expect it will be in October next, about the end, and my absence from home will perhaps be as long as three years. . . .'

The transition from a bookbinder's apprentice to philosopher, the permanent name of the man of science, was easy to Faraday. Mr. Riebau and his wife understood the apprentice who wished to read the insides of books. His love of chemistry and other parts of philosophy did not hinder him in his craft. In 1810 Faraday started going to lectures on

natural science given by a Mr. Tatum at 53 Dorset Street. There he made several friends, Huxtable, Magrath, Phillips and Benjamin Abbott. His correspondence with this latter is extremely interesting. The letters, until some time after his return from abroad with Sir Humphry Davy and his re-engagement at the Royal Institution, are long and frequent. 'A stranger would think you and I a couple of very simple beings, since we find it necessary to write to each other, though we so often personally meet; but the stranger would, in so judging, only fall into that error which envelops all those who decide from the outward appearance of things. He would perceive that we meet and that we write—and he would perceive no more unless he possessed more than common sagacity.'

There is much friendship, disinterested and cheerful, shown in these letters. In the words of Dr. Bence Jones, 'had they been written by a highly educated gentleman, they would have been remarkable for the energy, correctness and fluency of their style, and for the courtesy, kindness, candour, deference and even humility of the thoughts they contain'. At first, one may be a little amused at the young man whose letters express so definitely a desire for self-improvement. Such amusement, however, changes as one reads carefully these first letters, as one realizes the tenacity and strength of this desire for self-improvement, a tenacity which is humble enough to take the improvement effected in handwriting into account, and to acknowledge this as one of the benefits of letter writing, and which, so as not to be diverted from its object, is wise enough to be quite definite about the limits of friendship. With the same care to be exact that he shows in the description in the first letter to Abbott of his

decomposition of sulphate of magnesia, he wishes to explain the nature of his feelings. It is rare to be conscious of the limits of a pleasurable intercourse, it is still rarer to define such limits with words. 'I cannot help but be pleased with the earnest manner in which you enforce the necessity of caution in respect of new acquaintances. . . . I have made use of the term friend several times, and in one place I find the expression commonplace friendship. It will perhaps not be improper at this moment to give you my ideas on true friendship and on eligible companions. In every action of our lives I conceive that reference ought to be had to a Superior Being, and in nothing ought we to oppose or act contrary to His precepts. . . . I would define a friend, a true friend, to be one who will serve his companion next to his God, nor will I admit that an immoral person can fill completely the character of a true friend. Having this idea of friendship it was natural for me to make a self inquiry whether I could fill the character, but I am not satisfied with my conclusions, and I fear I cannot.'

There is no rhetoric in these words. It is true that both Faraday and Abbott thought of their friendship in a perfectly rational perspective, and that Abbott needed no warning against his own impulsiveness. But Faraday is determined, at this stage in his life, to build the mental framework of his life. ['Definitions are valuable things, I like them very much . . .' he writes to Abbott.] At the age of twenty he is intent to make clear to himself how he stands. 'The true friend should have great mental strength and at the same time, complete self-knowledge,' and he continues, with the candour of a mind which denies itself the quality it possesses in greater measure than other minds, 'the above



is my opinion of true friendship, a passion or feeling I have never personally met with'.

In October 1812 Faraday's apprenticeship ended, and he went as a journeyman bookbinder to work for a Mr. De La Roche, a French emigrant. De La Roche took a liking to him and told him that, as he had no son, Faraday might regard himself as his future successor. But this liking was a very different kind of liking to Riebau's. De La Roche had an uncertain, violent temper; he had no sympathy with reading books, and, in a very short time, Faraday was discontented and distressed. He begins to talk of science and trade, the purity and intensity of an imagined life as a scientist, contrasting with his present experiences. In a serious letter to Abbott, he writes: 'I am well aware of my own nature; it is evil and I feel its influence strongly . . .' [Rebellious, angry thoughts.] '. . . I keep regular hours, enter not intentionally into pleasures productive of evil . . . and act up to what the world calls good' [Conscience here of the amenity of his conduct. Proud, and easily upset, he manages to keep control of his temper. He must stay with De La Roche, he must earn his living]. '. . . I appear moral and hope I am so, though at the same time, I consider morality only as a lamentably deficient state.' [Admirable phrase, the most expressive of all he has yet written. He is aware that he could drive his nature into submission. He could go on reading a little less, go to fewer lectures, work harder and become a master bookbinder. But he will not. As he writes to Abbott, he becomes conscious of his destiny. He accepts, seriously and completely, the existence of his discontent. Life as a philosopher is no better morally than life as a bookbinder, but it is the life of his spirit.]

Very fortunately, before he left Riebau, Fate had already given him a chance that he had not neglected. A customer at Riebau's shop had given him tickets to go to the Royal Institution to hear Sir Humphry Davy lecture. In a letter Faraday wrote in 1829 to Dr. Paris, one of Davy's biographers, he gave an account of the circumstances of his subsequent engagement at the Royal Institution.

'You asked me to give you an account of my first introduction to Sir H. Davy, which I am very happy to do, as I think the circumstances will bear testimony to the goodness of his heart. When I was a bookseller's apprentice I was very fond of experiment and very adverse to trade. It happened that a gentleman, a member of the Royal Institution, took me to hear some of Sir H. Davy's last lectures in Albemarle Street. I took notes, and afterwards wrote them out more fairly in a quarto volume. My desire to escape from trade, which I thought vicious and selfish, and to enter into the service of Science, which I imagined made its pursuers amiable and liberal, induced me at last to take the bold and simple step of writing to Sir H. Davy, expressing my wishes, and a hope that if an opportunity came in his way he would favour my views; at the same time I sent the notes I had taken of his lectures. . . .

'You will observe that this took place at the end of the year 1812, and early in 1813 he requested to see me and told me of the situation of assistant in the laboratory of the Royal Institution, then just vacant. At the same time he thus gratified my desires as to scientific employment, he still advised me not to give up the prospects I had before me, telling me that Science was a harsh mistress, and in a pecuniary point of view but poorly rewarding those who devoted them-

selves to her service. He smiled at my notion of the superior moral feelings of philosophic men, and said he would leave me to the experience of a few years to set me right in that matter.

‘Finally, through his good efforts, I went to the Royal Institution, early in March of 1813, as assistant in the laboratory; and in October of the same year went with him abroad as his assistant in experiments and in writing. I returned with him in April 1815, resumed my station in the Royal Institution, and have, as you know, ever since remained there.’

The first wave of good fortune has carried him a long way. Not without reason was the early life of Michael Faraday held up as a moral object lesson to children! How he spared no pains to speak and write correctly! How the blacksmith’s son taught himself to draw in perspective that not a detail might be lacking in his equipment as a philosopher! How he earned the respect and love of his master, Riebau, by his application! How well he set himself to work and how well he was, consequently, rewarded! And it is undeniable that his early life and, indeed, all his life is exemplary. But it bears witness to something much more than the power of hard work and determination. There is something inevitable behind the progress of the young book-binder who became Davy’s assistant. And by inevitable one means that the deep centred enthusiasm, the clarity and precision of his mind and the force of its longings are also behind the successful march of his life. The successful working of a strong character does not of itself explain even his entry into the laboratory of the Royal Institution.

### III

[[ARGELY through the exertions of Humphry Davy, the Royal Institution had just successfully established itself in its position as one of the centres of purely philosophical or scientific research. It was to go through a crisis later on, but a financial crisis only, and the man who was to carry it through for the second time to ensure its continued support and to bring it an even more brilliant reputation than it had gained with Davy as its guiding star, was Faraday himself.

The Royal Institution owes its beginning to Count Rumford, an American whose great ability as an organizer [he had remodelled the army and administration of the Duchy of Bavaria] could not always carry into effect the humanitarian schemes of his mind. Its foundation was decided upon at a meeting held under the aegis of The Society for Bettering the Condition of the Poor, and the private subscriptions to the new institution were for 'diffusing the knowledge and facilitating the general and speedy introduction of new and useful mechanical inventions and improvements, and also for teaching, by regular courses of philosophical lectures and experiments, the applications of the new discoveries in science to the improvement of arts and manufactures, and in facilitating the means of promoting the comforts and conveniences of life'.

It was hardly the time, however, for what amounted to

a kind of technical school, and Rumford's intention of, to use his own expression, making it fashionable to care for the poor and indigent was unrealized. The fact that, at the beginning of the century, the Royal Institution did become fashionable, but fashionable for the sake of pure science, was quite unexpected. Chemistry and natural science had been, until the beginning of the nineteenth century, looked upon by the general public and by Society with complete indifference, for the study of such subjects appeared to have no useful social purpose, and the culture of the period was a long way from taking into account the scientific and mathematical explanations of life. The industrial revolution was based on the discovery of steam power, and progress in adapting steam power to locomotion was long delayed by lack of progress in metallurgy. The cotton mill and coal mine machinery and the first steam engine of Watt in 1804 had no connection whatever with the work of the little bands of natural philosophers in the various capitals of Europe. Nor did the mentality, formed by the study of the natural sciences, play any part in the moulding of the ideas of democracy and nationality which were gaining a sanguinary ascendancy in foreign wars and civil strife.

The position of the physicist was in many ways very fortunate. Though he could expect no degree of widespread interest in his work, he enjoyed complete freedom from the machinations of generals and politicians. Davy, who had just gained one of Napoleon's awards to science, was allowed, during the bitterest years of the Napoleonic war when both England and France had interned French and English civilians respectively, to wander through France and Italy, wherever he would, with a French passport. 'If two coun-

tries or governments are at war', said Davy, 'the men of Science are not. That would indeed be a civil war of the worst description.'

Astronomy alone of the branches of natural philosophy had affected the general mentality of the period. In 1700 Newton's conception of the law of gravitation as the ruling force of the solar system which, at that time, was imagined to comprise the whole universe, was viewed with alarm as impiety, by many of his contemporaries. The discoveries of Herschel, the new conceptions of the solar system by his observation of the planet Uranus, the subsequently discovered enormous vistas of space and the myriads of solar systems which men heard of for the first time, awaked, during the middle and later years of the century, widespread enthusiasm. Society at the end of the century greeted the discovery of the universe with something of the enthusiasm with which it read Rousseau, and the belief, which had the assent of Herschel himself, that the new planets were inhabited, was contemporaneous with the idea that man was born innocent and happy and that his corruption and misery were due to civilization. When Laplace completed his mathematical description of the motion of heavenly bodies, he was asked by Napoleon why there was no mention of God in his work. Laplace replied that he had had no need of that hypothesis. The agnosticism of this reply was, however, more typical of the age of Voltaire than of the nineteenth century.

Although the natural sciences do not appear to have an obvious connection with the intellectual life of the period, around the few years before and after 1800, a series of changes was made in the fundamental definitions of heat,

light, magnetism and electricity, which may, in sympathy with the other activities of the period, be called revolutionary. The work of Rumford and Davy destroyed the idea of heat as a fluid; phlogiston, a wonderful substance which, in combination with the caloric fluid, was supposed to produce flame was to be heard of no more. Young and Fresnel advanced the undulatory theory of light; and the discovery of a means of storing electrical energy [or the galvanic fluid as it was called at that time] coincided with the gradual realization that all electrical effects owed their origin to a single cause. These new definitions, all alike stressing the *immaterial* nature of physical and chemical agents, were to make possible the great generalization of the conservation of energy, fifty years later.

Newton and Boyle held the views on heat which were to be re-stated during the revolutionary epoch. The scientists of the latter period of the eighteenth century were misled by the desire to explain physical agencies in terms of matter. Thus they spoke of heat as a 'subtil fluid' universally distributed in Nature which entered in some degree into the composition of all substances. Contradictions, such as the expansion of most substances when heated and of water when frozen, were explained by ingenious theories of self-repelling particles and chemical agencies which, in their complication, nearly led, by a false track, to the abstract concept of Energy. In his tables of elementary substances, Lavoisier included heat and light along with hydrogen and iron.

Electricity and magnetism were also thought of as fluids, and students of the new science of meteorology were taught that heat, the heaviest imponderable fluid, predominated in

the lower atmosphere and that light, electricity and magnetism prevailed in successively higher strata. A considerable knowledge of the manifestations of static electricity had been gained since the days of Gilbert and Bacon. Besides the inventions of the Leyden jars and the friction machine, Stephen Gray, a fellow of the Royal Society, had discovered the principles of conduction and insulation, had proved that electricity could be excited by the friction of hairs, linen, paper, silk, and had succeeded in 1729 in passing electricity through pack thread supported by silken cords a distance of some seven hundred feet, and through wire an even further distance. Franklin, in his celebrated kite experiment, had demonstrated that lightning and electricity had an identical cause, and that from the 'electric fire' conducted by his kite 'spirits may be kindred, and all the other electric experiments be performed which are usually done by the help of a rubber and glass globe or tube, and thereby the sameness of the electric matter with that of lightning completely demonstrated'. He had also been led to the belief that electricity was not created or produced either by friction or any other process whatsoever, but that it was present everywhere and that every body contained some quantity of this mysterious force. There were indeed many inspired guesses at the theory of electrical action and even of its relation to magnetism, but no coherent knowledge of electrical or magnetic effects, much less any discovery of their inter-relations was possible until very much later.

In 1786, Galvani, a doctor in Bologna, had observed the muscular twitching in the legs of a dead frog when his dissecting knife, touching them, made contact with another metal. This effect he misinterpreted, and in a long contro-



versy with Volta, Professor of Physics at Pavia, maintained his belief that the electricity on the metals was caused by the interactions of the positive electricity in the nerves of the animal and the negative in the muscle. Volta's reply was the construction of the voltaic pile and the first battery, which showed that the rôle played by the frog's legs was simply that of a moist body, a conductor.

This battery was perhaps the most important single invention ever made. For the first time a supply of electricity, separated from the properties of matter, was available for experiment. Through the mediation of Napoleon, who gave Volta the Legion of Honour and who felt a strong personal sympathy for him, Volta's battery was known throughout the scientific world. The vibratory theory of heat had promised great results in chemistry. The new battery at the Royal Institution, which Nicholson and Carlyle used to decompose water in 1801, and with which Davy at once embarked on the series of decomposition experiments culminating in his great generalization in the Bakerian lecture of 1806 that chemical and electrical attraction are produced by the same cause, was the means by which chemistry made an even more important advance.

Attracted by the bright light of the first electric arc, by the even greater miracle of the conversion of potash into a metal which burst into a bright flame on coming into contact with water, Society flocked to the Royal Institution. Nor were the experiments of Davy and the powerful battery the only reasons that the audience hall of the Institution was full. The young experimenter, good-looking and charmingly eloquent, knew how to advocate the cause of Science in a way that stirred them very much more powerfully than the

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monotonous garbling of the brilliant Dr. Young, who had also lectured at the Institution. The qualities that made Davy a success in Society played their part in ensuring the success of his lectures, but it was even more Davy's ardent expression of the aim of science that thrilled the war-excited minds of his listeners. The enthusiasm over Davy's lectures was the first unconscious sign of the recognition of the evolutionary agency of science. Just as the *Critique de la Raison pure* and the transcendental idealism of Hegel freed metaphysics from a cage of mental agility and made its aim the interpretation of life, so, commonplace as they may appear to-day, Davy's eloquent periods foreshadowed the growth of a new, a wiser and a more humane mentality.

'The unequal division of property and labour, the differences of rank and condition amongst mankind are the sources of power in civilized life, its moving causes and even its very soul. In considering and hoping that the human species is capable of becoming more enlightened and more happy, we can only expect that the different parts of the great whole of society should be intimately united together by means of knowledge and the useful arts: that they should act as the children of one great parent, with one determinate end, so that no power may be rendered useless—no exertions thrown away. In this view, we do not look to distant ages or amuse ourselves with brilliant though delusive dreams concerning the infinite improvability of man, the annihilation of labour, disease and even death, but we reason by analogy from simple facts, we consider only a state of human progression arising out of its present condition—we look for a time we may reasonably expect, for a bright day of which we already behold the dawn.'

## IV

*I am a lover of Nature with an ungratified imagination.  
I shall continue to search for untested charms, for hidden  
beauties.*

**H**UMPHRY DAVY was a Cornishman, born at Penzance in 1778, who had shown a remarkable facility for intellectual reasoning on every kind of subject. Apprenticed to a surgeon he had begun to experiment in chemistry and, whilst Assistant Superintendent to the Pneumatic Institution at Bristol, had arrived, although by means of experiments which only convinced ardent but unscientifically trained minds, at the theory of the essential nature of heat which is in accord with our present convictions. In Bristol, at the house of Miss Edgworth, Davy was in an atmosphere that contributed to the vitality and multiplicity of his interests without diverting those interests from the channel in which they flowed most strongly. Coleridge, Wordsworth, Southey, Priestley (the son of the discoverer of oxygen) and the two Wedgwoods were all his friends and admirers. When asked to name, from among the cleverest men he had met, the man who had most impressed him, Coleridge replied, 'Why, Davy can eat them all. There is an energy and elasticity in his mind which enables him to seize on and analyse all questions. . . . Every subject in Davy's mind has the principle of vitality. Living thoughts

spring up like turf under his feet.' Amos Cottle, poet and publisher, said of the young Cornishman soon after his arrival in Bristol from a provincial dispensary, 'I was much struck with the intellectual character of his face. His eye was piercing, and when not engaged in converse was remarkably introverted, amounting to absence, as though his mind had been pursuing some severe train of thought scarcely to be interrupted by external objects: and from the first interview also his ingenuousness impressed me as much as his mental superiority.'

Engaged at the Royal Institution he had performed a very successful and convincing demonstration of his and Rumford's theory of heat by melting two lumps of ice by mutual friction. Where, now, was the caloric fluid? When it was proposed that he should lecture at the Institution, Rumford at first dissented. One of Davy's biographers suggests that he had, at this time, an air of pertness, of smirking, and that this air had displeased Rumford, but that having listened to a rehearsal of Davy's lecture, he had entirely forgotten his first impression.

It is very difficult to arrive at an idea of how Davy personally affected the men he was associated with. He was to have, a few years after his arrival at the Institution, the greatest popular fame of any other man of Science, and he was, indeed, the first scientist to arrive at any degree of popular fame at all. His invention of the safety lamp and his refusal to patent his rights were responsible for this, together with the success of his lectures and the interest aroused by the large battery at the Institution.

He must have been, when Rumford first heard him lecture, a young man of enthusiasm, and enthusiasm hardly

goes with an air of pertness. What Rumford probably noticed in the young Davy was a certain uneasiness—that same uneasiness which in his lectures appeared as a natural awkwardness, strengthening and setting off the impression his eloquence created. Of the source of this uneasiness there can be little doubt. Davy was extremely devoted to his mother and his younger brother, Dr. John Davy. With these natural feelings of affection, not engrafted to them but quite naturally cohabiting with them, there existed the dominant personal desire of Davy's life which was the desire for admiration. It is natural for a mother's love to reply to the demands of a son; Davy was, anyway, worthy of the very highest degree of admiration. The close friendship between the two brothers was a very pleasant part of both their characters; but it cannot be doubted that it was the younger brother's unchanging admiration for the elder that allowed this friendship to remain so close and so unchanging.

His marriage to Mrs. Apreece was not a happy one. For some years after their marriage they were undoubtedly happy; but their felicity was quite remarkable, too remarkable one might almost say, and perhaps Davy, together with genuine feelings, was pleased to present the world with the picture of himself in the rôle of the man who can find complete happiness with a woman. He tells his mother that he is surprised to marry—that he had imagined he would have remained a bachelor all his life. He is, in other words, very surprised to have found a woman he can consider a fit wife for Humphry Davy. It is this excessive need for admiration that spoilt his relations with other men. It was to come out in his relations with almost everyone, Faraday included. It did not interfere with the course of his feelings, but ran

beside them like a distorting shadow. The need for admiration is perfectly normal, only Davy had it to excess.

In its general characteristics Davy's character was one more common to the eighteenth century than to the nineteenth. In the facile and early development of his natural powers, in his many-sidedness without the weakness of superficial ability, which often creates an apparent many-sidedness, he owed, like many other men, Goethe among them as a supreme example, a great deal to the continuous intellectual growth, undisturbed by any revolution in mental and ethical values, of the century into which he was born. Young was only twenty when he made his first communication to the Royal Society, and only twenty-six when he brought forward the undulatory theory of light, and Young had an even more brilliantly adaptable mind than Davy. Fresnel was only twenty-six when he duplicated the discoveries of Young, Arago was famous at twenty. All these three men were remarkable for early development and great versatility.

Davy also seems to unite those qualities which appear exclusive and whose union is also typical of the period of his youth. He was passionately reasonable and he had a sort of devotion to pleasure. He was a humanitarian, a believer in equality and he was devoted to Society, to success in Society. The brilliance and versatility of his mind might have brought him fame in any sphere of activity. He does not seem *inevitably* a physicist and chemist; it seems as though it was in those domains he could best show his genius. And in these sciences the range of his achievement was wide. Apart from the invention of the safety lamp, his name will always be remembered for the brilliant series

of electrochemical experiments at the Royal Institution. His work as a pioneer of the vibratory theory of heat was equally remarkable. He produced, and this of course was only made possible by Volta's battery, the first electric arc light. In 1801, with Thomas Wedgwood, he showed it was possible to secure the imprint of a translucent body upon a chemically prepared plate by exposure to sunlight. He made valuable contributions to geology and mineralogy, as well as to the science and practice of agriculture.

In addition to all this, Davy had the nature of a poet. His verses have little interest to-day, and *Consolations in Travel*, whilst containing many fine antiquarian and pastoral descriptions, is in the main too mannered. But that he had the capacity for the disabling self-identification of a poet is shown very well by a letter he wrote to his brother from Italy.

'I was lying on top of a rock to leeward; the wind was high and everything in motion; the branches of an oak tree were waving and murmuring to the breeze; yellow clouds, deepened by grey at the base, were rapidly floating over the western hills; the whole sky was in motion . . ., everything was alive and myself part of the visible impressions; I should have felt pain in tearing a leaf from one of the trees.' He understands himself with a poetic understanding. 'There are in the nature of all men paramount elements, certain habits and passions that cannot change. I am a lover of nature with an ungratified imagination. I shall continue to search for untested charms, for hidden beauties. My real, my waking existence is amongst the objects of scientific research.'

In his relations with Faraday, the judgment, both of the

men of his time and of posterity, attributes to Davy the responsibility for the two or three regrettable incidents that took place. That Davy generously recognized Faraday's right to a place in the world of science is indisputable. 'Pepys, what am I to do?' asked Davy, 'here is a letter from a young man named Faraday; he has been attending my lectures and wants me to give him employment at the Royal Institution—what can I do?' 'Do?' replied Pepys, 'put him to wash bottles; if he is good for anything he will do it directly; if not, he will refuse.' 'No, no', replied Davy, 'we must try him with something better than that.' That contact with Davy's mind and work was enormously important to Faraday must never be forgotten when Davy's faults are remembered. Davy, the object of Faraday's youthful enthusiasm, remained in Faraday's memory as an object of love and veneration, against whom even implied criticism was painful. Twenty years after Davy's death, Dumas, at lunch with Faraday and his wife at their rooms in the Royal Institution, showed a certain coldness when Faraday mentioned Davy's great experiments. Faraday made no comment. But after lunch he took Dumas down to the library, and stopping before the portrait of Davy said, 'He was a great man, wasn't he?' Then turning round, he added, 'It was here that he spoke to me for the first time'.



FARADAY'S appointment to the Royal Institution was in March 1813. In October of the same year he started on his tour with Sir Humphry and Lady Davy.

Between March and October Faraday wrote several times to Abbott, and in a long letter described experiments on chlorine round which much of the early work of Davy had centred. One of the lectures that Faraday had heard Davy give at the Royal Institution, and which he had carefully copied out, related to Davy's proofs that chlorine contains no oxygen and was an element. Working together, Davy and Faraday afterwards succeeded in obtaining the compound of chlorine and water and later still in liquefying chlorine gas.

In refusing to put Faraday to wash bottles, Davy obviously realized that Faraday had already learned enough to make him a useful assistant. The experiments that Faraday had described in his letters to Abbott were galvanic experiments. With a little battery made of zinc, copper and flannel soaked in hydrochloric acid, he had followed, on a miniature scale, Davy's work with the large battery at the Royal Institution, and had succeeded in decomposing the sulphates of copper and magnesium and the acetate of lead. At that time the number of people who had any knowledge at all of galvanism were few, and those who had any practical knowledge of its effects were rare indeed.

During these months that he spent at the Royal Institution, Faraday had his first experience of the lecture room. He proved himself very soon an excellent assistant to Professor Brande—a rather dull lecturer—and to Powell, who lectured on mechanics. In June he is writing to Abbott about lectures and lecture rooms, writing at great length on this subject. Whilst apprenticed to Riebau, he had taken pains to improve his handwriting and had learned to draw in perspective. Now, not a detail of the lecture room and the lecturers escaped him. It was at this time that he laid the foundation of the mechanics of his future lectures, in which the natural animation of his manner was balanced by the most careful attention to every detail that could serve to concentrate the attention of the audience on the experiments and on the deductions from the experiments.

The new attendant has a pleasing appearance, he is earnest and thoughtful, quiet (Brande lectured on velvet, people say). Davy has really discovered a very good young man indeed. The young attendant in the evening writes to Abbott about the lecturers: 'A lecturer falls beneath the dignity of his character when he descends so low as to angle for claps and asks for commendation. Yet I have seen a lecturer even at this point. I have heard him causelessly condemn his own powers. I have heard him dwell for a long time on the extreme care and niceness that the experiment he makes will require. I have heard him hope for indulgence when no indulgence was wanted, and I have even heard him declare that the experiment now made cannot fail, from its beauty, its correctness and its application, to gain the approbation of all. . . .

'An experimental lecturer should attend very carefully

to the choice he may make of experiments for the illustration of his subject . . . they should rather approach to simplicity and explain the established principles of the subject than be elaborate and apply to minute phenomena only. Let your experiments apply to the subject you elucidate, do not introduce those which are not to the point.'

'It pleases me well to observe', Faraday continues, 'a neat idea enter the head of a lecturer, the which he will immediately illustrate by a few motions of his hand—a card, a lamp, a glass of water, or any other thing that may be by him [once Faraday threw a scuttle of coals, the tongs and the grate at the large magnet in the lecture theatre]; but when he calls your attention in a particular way to a decisive experiment that has entered his mind, clear and important in its application to the subject, and *then* lets fall a card—I turn with disgust from the lecturer and his experiments.'

## VI

**O**N 13 October 1813 Sir Humphry and Lady Davy, a lady's maid and Michael Faraday, Davy's amanuensis and philosophical assistant, left London for Plymouth. They were en route for Paris. They were going to travel for an indefinite period; the objects of the journey were many—to meet Davy's fellow-workers in Paris and to see what they were doing, to make new chemical discoveries [one's mind works very well under the stimulus of new faces, new towns], and to geologize. It is the time when the theories of Hutton, the basis of our conception of the gradual formation and alteration of the earth's crust, were being contested by Werner of Saxony. The Huttonians, of whom Davy was one, held that continents wear away and are replaced by volcanic upheaval. The Neptunists, as the followers of Werner were called, held the theory that all the solids of the earth's crust had been dissolved in the heated waters of a universal sea, that rocks, of whatever character, had been formed by precipitation from this sea as the waters cooled. Mountains, so the Neptunists held, were gigantic crystals, not upheaved masses. The Huttonians, by their gradual accumulation of evidence, in particular from volcanic phenomena, won a slow triumph. Evidence, in part supplied by Davy, enabled Sir Charles Lyell to account for molten areas as lakes in a solid crust heated to melting by electrical or chemical action.

They are also travelling because Davy and his wife like travelling. They are travelling as lovers of nature [in Dr. John Davy's biography of his brother can be found Davy's poem on Fontainebleau and many others]. Michael Faraday has never been twelve miles out of London. Amesbury and Stonehenge, the red lanes of Devonshire, the sea at Plymouth, the luminescence of the sea at night, at dawn—the grey sky and the waves rolling one after the other to the horizon [they sight a French privateer]—Morlaix, the lean Normandy pigs run beside the carriage for a mile or so; in England, fat contented sows, in France those lean, cloven-footed, rope-tailed, pointed-nosed creatures; 'what at a distance I should judge to be a greyhound, I am obliged, on a near approach, to acknowledge a pig'. In the coach on the way to Paris, Faraday holds a glow-worm in his lap; first of all its light disappears then revives a little, at Rennes he finds it to be a small, black worm, not three quarters of an inch in length, and 'having no part particularly distinguished as that which had been luminous'.

They arrived in Paris on Friday 20th—a week's journey from London to Paris. When they go to the Préfecture for their papers Faraday meets an American who would willingly have been inquisitive about Faraday's passport. An Englishman?—a free passport? What are the French doing? The American invasion of Paris has begun. 'There are many things in Paris calculated in an eminent degree to arrest the progress of the traveller', wrote Faraday. These things, however, do not particularly interest him. In after years Faraday is to go frequently to Paris; he is to know Paris much as he knows London. There is to be

his friend Dumas at the Jardin des Plantes [Dumas has a very pleasant family], there is to be Arago at the Observatory [he sees Arago this first time in Paris], there are to be other friends at the Académie des Sciences and at the Sorbonne, and M. Laponte, who makes optical glass for the lighthouses.

A lack of feeling for architecture ['I hardly know why I endeavour to describe the antiquities and works of art that I see in the course of my walks'], for the beauty of cities, their history and monuments, is balanced by a love of nature reflected in all his letters and habits. In later years the sea air at Brighton, the seclusion of Norwood and the mountains of Switzerland were his necessary environments. Natural beauty and peace gave him back, again and again, his health and energy, and he loves nature emotionally and profoundly, particularly storms and mountains, downland and wide stretches of sea.

Sir Humphry Davy was not received by Napoleon. He appeared a little arrogant to the various French savants who came to see him. He walked very rapidly round the Louvre. 'I am glad to have seen it,' he remarked in front of Raphael's 'Transfiguration'—'What a beautiful stalactite!' he said before the 'Antinous'. Dr. John Davy rather indignantly refuted in his biography an accusation that his brother was not a lover of the fine arts. He most certainly was. But probably he did not feel quite sufficiently at home in Paris, quite master enough of the situation, to allow himself to admire. Laplace had an air of protection rather than courtesy, he recorded in some notes made in 1820. 'How different was this same Laplace', Davy went on, 'when I visited him after the fall of his master, Buonaparte,

and when I myself, no longer young in philosophy, had been called to occupy the Chair Newton honoured in his declining years.'

Ampère, Clement, and Desportes come one morning to Davy with a new substance discovered by a M. Courtois, a saltpetre manufacturer. When heated this substance gives off a deep violet vapour. The French chemists are amazed at the variety of experiments with which Davy proceeds to test this substance. It was iodine. Davy made experiments on a prismatic spectrum, and, by the use of air thermometers, found that the rays producing most heat were out of the spectrum and beyond the red rays. Finally, after decomposition tests from a voltaic pile, Davy pronounced it to be a new undecomposed body, an element, as it is held to-day. The French chemists had believed it to be a compound affording hydrochloric acid. Davy has triumphed again. 'We admired Davy', Dumas wrote in later years. He has made one discovery, anyway.

They left Paris by Fontainebleau and Nemours. They rode by the Loire in the early hours of the morning. They went into Auvergne, where Davy geologized; to Lyons, Avignon, Montpellier, to look for iodine, back to Avignon to cross the Rhone. Faraday has seen the Dauphiné Alps, they pass through Aix-en-Provence to Fréjus, to Nice. Travelling is good for Faraday; he wrote to his mother from Rome to say he had thickened.

Lady Davy had, no doubt, a great deal to cause her discomfort in the hazards of the journey, which accentuated the difficulties of living with her husband. Faraday wrote: 'Her temper makes it oftentimes go wrong with me, with herself and with Sir H'. There is little evidence that

Faraday had, at this time, any great degree of tact—and tact was without a doubt necessary with Lady Davy. He was certainly friendly and high-spirited, but he was also quick to be annoyed and mortified.

Some cause for annoyance and mortification he had. In London, Davy had decided to take a valet to make the necessary arrangements about luggage and lodgings for the whole party. At the last moment, however, the valet he had engaged refused to come. Faraday undertook to make those arrangements which were not directly menial until they reached Paris. In Paris they could not find a suitable valet, and they continued throughout the whole tour without one. His duties in this line were limited, however, to seeing after the expenses of the family, the servants, the table and accommodation. If he and Davy had been alone there would have been no trouble whatever; Davy was not at all petty. He appreciated Faraday's worth and enjoyed his company. But Lady Davy, when put out, was fond of emphasizing the difference of position between herself and Faraday. In Geneva, for instance, she was no doubt behind the refusal of the Davys, which greatly astonished M. de la Rive, to dine at the same table as her husband's secretary and *valet*.

Faraday knew quite well that these slights were not really enough to spoil the tour. He was very glad, however, to be pressed by his friend Abbott's question in a long letter to explain why he had said he was sometimes on the point of returning to England, and why he had written at least one very doleful letter. He wrote a very long letter in reply, a letter, however, written in a more cheerful mood. He summed up the situation very well: 'I fancy I have



cause to grumble, and yet I can scarcely tell why. If I approve of the system of etiquette and valuation formed by the world, I can make a thousand complaints; but perhaps if I acted influenced by the pure and unsullied dictates of common sense I should have nothing to complain of. . . .”

From Nice they go to Turin, by way of the Col de Tende. This was in January 1814. After Tende [north-north-east of Nice] there is no road, the carriage is dismantled and placed on sledges which are dragged up to the top of the pass by a gang of men. There is a chaise à porteur for Lady Davy, but Davy and Faraday go on foot, and after a three hours' struggle reach the top. Davy makes barometric observations. Stretching below are immense white plains rising in a curve to the Mediterranean; on either side of them the mountains. A chilly cloud covers them for an instant. The descent is not so tiring, though more dangerous, for the snow is thicker and they are often waist-deep in it. One of the mules missed its step and fell, rolling over and over several yards down the side of the mountain. Some hours afterwards the men with the sledges reach the top of the pass. They stopped only to change the arrangements of the cords and were immediately in motion again, the *traîneaux* sliding rapidly down the mountain-side and over the plain. Evening was coming on, the clouds and mountains were blended together, so that it was impossible to distinguish the earth from the atmosphere. The sledges, running over the snow, catch up with the party. As starlight comes on the sounds of the evening bell of a distant village are faintly heard. Lanterns are lighted and carried before each sledge. They follow the banks of a river, and

arrive at a small village at seven o'clock in the evening and there put up for the night.

Faraday was amused at the difference between the amusements of the poor and those of the rich in Turin. On a large clear piece of ground by a branch of the Po the poor waltz to the music of itinerant musicians. There is plenty of room, and several rival bands of musicians are perched on stones, where they stand, rather precariously, playing loudly and tunefully. As for the rich, 'I found myself in a wide and spacious street of considerable length . . . all the entrances to this street were guarded by soldiers, and no person on horseback or in a carriage could gain admission into it except at the top. A long string of carriages, curricles, saddle-horses etc. filled it, and they continued to move on progressively up and down the street and round the church for several hours. It was presumed that these vehicles carried the principal persons of the town, but nobody pretended to say that the owners were actually in them. One of very goodly aspect and fine appearance was pointed out to me when coming up; the horses were very handsome and the coachman and footman as spruce as could be—and so were the two maids inside. The next was not so dashing, but it was empty; and the third was so shabby that I did not look to see what was inside. There were, however, an immense number of persons who stood on each side of the street looking and gazing with great apparent satisfaction, and who, if they had been conscious of the comparison I was then making between the scene before me and the one I had just left, would have looked down upon me with contempt and derision.'

Generously as they had been treated by the French,

there is no doubt that they felt Italy, as opposed to France, was a friendly country. Napoleon, whom Faraday had seen in Paris 'sitting in one corner of his carriage, covered and almost hidden from sight by an enormous robe of ermine, his face shaded by a plume of feathers descending from a velvet hat', had already made his disastrous retreat from Moscow and was threatened on all sides. Davy's party was in Rome in March 1814, after leaving Turin for Genoa and Florence, and it was then they heard that Paris had been taken by the Allied troops and that Napoleon had been sent to Elba. The part England had played in the long war had impressed the Italians very much. Davy's party were given a triumphal reception at Lucca, and Faraday wrote to his mother that, 'Englishmen are respected here almost to adoration'.

In February they went to Genoa, and here they made experiments on the small fish then called torpedoes or electric skates. It is the vital question of the identity of the electricities that they are tackling, and Davy is attempting to find out whether the electricity of the fish is similar to the electricity of the voltaic battery. Will the electrical power of these animals decompose water? Wires were cemented into tubes and the surfaces of the ends only exposed. The two extreme ends, connected with plates of tin, were placed in contact with the fish. The fish was then irritated, and though it contracted itself, apparently giving the shock, no effect on the water was perceived. However, the smallness and weakness of the fish and the coldness of the season prevented any negative conclusion from being formed.

In Florence, Davy went to the laboratory of the Accademia del Cimento to make further experiments on

iodine. In the Accademia was Galileo's first telescope, with which he discovered Jupiter's satellites. It was a simple tube of paper and wood, three and a half feet long, with a lens at each end. Faraday saw, also, Galileo's first lens set in a frame of brass with a Latin inscription underneath. In an upper room of the museum was placed the Grand Duke's burning-glass, an instrument fixed in the centre of a round table, arranged to admit of raising or lowering, and consisting of two double convex lenses, distant from each other about three and a half feet. The large lens was about fourteen or fifteen inches in diameter, and the lower second lens, by means of which the focus could be reduced, about three inches. One Sunday they started experiments on diamond burning in a glass globe filled with oxygen.

The discovery of oxygen by Priestley in 1774 was one of the last blows struck at phlogiston and the idea of the four primal elements. Priestley himself upheld the phlogiston explanation of fire and heat to the last; but Lavoisier, the year before the French Revolution, in which he perished, had brought a great advance in chemical knowledge to completion by declaring that the elements concerned in combustion are oxygen and heat [the material conception of heat was, it will be remembered, not discarded till some ten years later], that acids are compounds of oxygen with a base, instead of mixtures of earth and water, and that water itself, like air, is a compound of oxygen with another element.

Davy focussed the sun's rays through the window at intervals for three-quarters of an hour, and during that time it was thought that the diamond was slowly diminishing and becoming opaque. Would there be flame? they

wondered. The upper part of the window obstructed the sun's rays, so they sunk the whole apparatus lower in the table. All of a sudden, Davy observed the visible burning, and when removed from the focus it was found to be in a state of active and rapid combustion. It glowed brilliantly with a scarlet light inclining to purple, and when placed in the dark continued to burn for about four minutes. Davy attributed the phenomenon of active and vivid combustion, which had never been observed before, to the free access of air. For several days they continued these experiments on the diamond and they discovered strong signs of electricity, during combustion a few small filaments floating in the oxygen being attracted and repelled. Once again, when the globe was removed, the diamond was seen in a state of vivid and intense combustion. The object of these experiments was to determine whether any peculiar matter separated from the diamond during its combustion and whether the gas formed in the process was precisely the same in its chemical nature as that produced by the combustion of plumbago or charcoal. He found that the only perceptible difference between diamond and the purest charcoal in combustion was that the latter contained a minute proportion of hydrogen, whilst the diamond yielded only pure carbonic acid gas. 'Can a quantity of an element, less in some cases than  $\frac{1}{50,000}$  part of the weight of the substance, occasion so great a difference in physical and chemical characters?' he wondered. This, he concluded, was most unlikely, for even when the minute quantity of hydrogen is expelled by heating the charcoal in chlorine the specific differences remain.

The doctrine at that time current, and which seemed

axiomatic, that bodies can be exactly the same in composition or chemical nature, and yet totally different in all their physical properties, received its first great shock.

In Rome, Davy and Faraday saw Morrichini attempting to give magnetism to a needle by means of solar rays. This experiment, supposedly a repetition of a successful one, was not convincing, but it made, none the less, a great impression on Faraday's mind. So, no doubt, did the experiments on the diamond. No amount of theoretical study ever had the same effect on Faraday's mind as actual experiment, and these experiments on simple physical relations, conducted under circumstances which could not fail to impress the mind and to fire the imagination, went unconsciously to strengthen his central conviction, as yet unformulated, of the unity of all natural forces.

Twice Davy and Faraday climbed Vesuvius. 'Some rain fell as we approached the top, which, being volatilized by the heat, made a much greater appearance of vapour than yesterday, and added to which the fire was certainly stronger and the smoke emitted in far greater quantity. The wind had changed since yesterday, but still was very favourable to our intention, and carried the smoke and vapour in a long black line over the hills to a great distance. It now became dark very quickly, and the flames became more and more awful, at one time enclosed in the smoke and everything hid from our eyes, and then the flames flashing upwards and lighting through the cloud, till by a turn of the wind the orifice was cleared and the dreadful place appeared uncovered and in all its horrors. . . .'

The party lay cloths on the smoking lava. Bread,

chickens, turkey, cheese and wine, and eggs roasted by the heat, are brought forth. Torches are lit; around sit the *lazzeroni*, eating a humbler meal. 'Old England' is toasted, 'God Save the King' and 'Rule Britannia' sung. A Russian who accompanies the party sings two of his country's songs, the music of which is peculiar and very touching.

Faraday visited the beautiful country around Terni, with its orange trees, myrtles and wild geraniums and its cascade of two hundred feet. Geology was their chief interest that day. Some hundred and fifteen years later work was started on the utilization of this cascade for mechanical power to produce Faraday's electricity.

They left Rome in the beginning of June and arrived in Geneva at the beginning of July. This was very rapid travelling. On their way through Milan they saw Volta. 'Saw Mr. Volta, who came to see Sir H. Davy, a hale, elderly man bearing the red ribbon [the Legion d'Honneur] and very free in conversation.' Davy wrote to his brother, 'Volta I saw in Milan in 1814, at that time advanced in years—I think nearly seventy—and in bad health. His conversation was not brilliant; his views rather limited, but marking great ingenuity. His manners were perfectly simple. He had not the air of a courtier nor even of a man who has seen the world.'

In Geneva they were the guests of Professor de La Rive. It was in de La Rive's house that Lady Davy's treatment was most galling to Faraday. De La Rive, with whom Faraday began some years later the first of his many scientific correspondences, showed him a quite particular regard and friendship. It was all the more mortifying, therefore, that the Davys would not allow him to dine at the same

table as themselves. When de La Rive and Davy went out shooting, Faraday accompanied them to load Davy's gun. That was quite all right. But it was just the performance of these quite natural duties that gave Lady Davy the right to treat him as a menial—the right, according to the system of etiquette and valuation formed by the world.

If only Davy had engaged a personal valet! As it was, it was quite impossible to go to Davy and reason with him, to say, If I didn't have to load your gun—a thing I don't mind doing at all, mind you—nobody could insist on my dining alone. [De La Rive had refused to let him dine with the servants.] He was not, after all, sure enough of Davy for that.

They left Geneva late in September, and returned to Rome by way of Vicenza, Venice, Bologna, Florence. They were going to Constantinople, but were dissuaded from that course by rumours of a plague. In Rome the mind of Davy was once again on iodine. He discovered a new solid compound of iodine and oxygen. It had been his insight into the analogy between chlorine and iodine, chlorine being a recognized undecomposed body, or element as we say to-day, that, followed by a series of brilliant experiments, enabled him to make his discovery and to establish it. Natural insight, genius! Yet it is quite according to his character to use this insight and genius to triumph over his enemies, over Gay Lussac in particular, who had intruded into what Davy regarded as his own field of work, the discovery of the alkaline metals. In a letter to his brother, written from Italy in 1814, he was still thinking of this triumph. There is a telling phrase in this letter:



'Iodine is as useful an *ally* to me as I could have found at home'.

Faraday's letters to Abbott, and to his mother, during this second visit to Rome, began to be more and more occupied with home. There was the carnival, horse-racing on the Corso, Davy's work for the King of Naples—but the excitement of the tour was waning.

During his stay in Rome, Faraday wrote also to his sisters, and a letter to Margaret, his younger sister, then aged twelve, is, as may be imagined, very significant of Faraday's character. The letters of young men to their much younger sisters cannot fail to be so. Faraday avoids the rather absurd playfulness adopted by many grown-up people in writing to children; his letter is rather serious and a trifle severe in its demands, but affection has banished any suspicion of condescension.

'DEAR MARGARET—I am very happy to hear that you got my letter, and I am as happy to say that I have received yours. I am greatly obliged to you for the information you give me, and for the kind interest you take in my health and welfare. Give my love with a kiss to Mother the first thing you do on reading the letter and tell her how much I think of her and you. . . . I am also pleased to hear that you go to school, and I hope that you have enough to do there. Your writing is not improved quite so much in one year as I expected it would be when I left home; but, however, it is pretty well. . . . My question about Rome and Naples I did not expect you could answer, but I wished you to look into some books at School, or at Mr. Riebau's or elsewhere, and give me the answers from them, at the

same time fixing them in your memory. I gave them to you as lessons and I still hope you will learn them.

I hope you do not neglect your ciphering and figures; they are almost as necessary as writing, and ought to be learned in preference to French. Of this last you say nothing, but I suppose you still work at it. I will tell you my way of learning the words. When in my grammar or other books I meet with a word [and that happens often enough] that I do not know, I first write it down on a fair sheet of paper, and then look in my dictionary for its meaning; and having found it, I put it down also, but on another part of the same sheet. This I do with every word that I do not know very well, and my sheet of paper becomes a list of them, mixed and mingled together in the greatest confusion—English with French, and one word with another. This is generally a morning's work. In the evening I take my list of words and my dictionary and, beginning at the top, I go regularly down to the bottom. On reading the words, I endeavour to learn their pronunciation, and if I cannot remember the meaning in the other language, I look in the dictionary and, having found it, endeavour to fix it in my memory and then go to the next word. I then go over the list repeatedly, and on coming to a word which I have by previous readings learned I draw a line over it, and thus my list grows little every evening and increases in the morning, and I continually learn new and most useful words from it. If you learn French and pursue this plan at home, you will improve in it very quickly.'

In March 1815 the Romans were in great agitation respecting the intentions of Murat. Napoleon had escaped

from Elba, the Hundred Days had begun, and his star appeared once again in the troubled skies. The party found difficulty in getting post horses for the first stage of their return to England, now decided upon. However, in April they are in Brussels. 'It is with no small pleasure that I write you my last letter from a foreign country,' Faraday wrote to his mother, 'and I hope it will be with as much pleasure that you will hear I am within three days of England. I cannot find it in my heart to say much to B. [Abbott] nor to R. [Faraday's brother] because I want to say it myself, and I feel that I am too glad to write it. . . . I would fain be talking to you, but I must cease.' They arrived in England at the beginning of the last week in April.

## VII

FARADAY was re-engaged at the Royal Institution on 7 May. The very next year, 1816, he published his first original paper in the *Quarterly Journal of Science*, an analysis of caustic lime. In 1821 he succeeded in liquefying chlorine, and his name came before the scientific world in connection with electromagnetic rotation, and in 1823 he became a Fellow of the Royal Society. At the age of thirty he was recognized as an able man of science with some original research to his credit, and likely to undertake more. The Royal Institution, of which he was Director and Superintendent of the laboratory, appreciated him as one of its most valuable servants; but perhaps nobody guessed that at the age of forty he was to begin a series of researches which, in the space of a few years, were to gain for him in the scientific societies of Europe a reputation greater even than Davy's had been.

In 1816 he began to lecture to the City Philosophical Society, which had been founded in 1808 at Mr. Tatum's house in Dorset Street. When Faraday joined in 1813 it consisted, in the words of Dr. Bence Jones, of 'thirty or forty individuals, perhaps all in the humble or moderate rank of life'. Of the many friends Faraday made at Mr. Tatum's house and in the City Philosophical Society, Richard Phillips [afterwards F.R.S., and President of the Chemical Society] was one of the closest and surest. It was

he who obtained the signature to Faraday's candidature for admission to the Royal Society.

He lectured to the City Philosophical Society on chemistry, and in a long series of lectures, lasting until 1819, reviewed the knowledge of matter and of states of matter. These lectures would be invaluable to a detailed history of chemical science in the first two decades of the century, and they show also the nature and extent of Faraday's self education. This is not all, however. The young man with his large nose, untidy hair and bright brown eyes, very neatly dressed, who took such great pains to speak effectively and correctly [he was during all this period taking lessons in elocution, and his notes on this subject cover one hundred and thirty-three pages of quarto manuscript] had a strange sureness of thought if not of delivery. The clarity of his mind made the audience forget that sometimes it was listening not entirely to what it expected—a review of chemical knowledge from Davy's assistant—but to the personal convictions of Michael Faraday. But these convictions were so embedded in the whole tenor of the lecture, which was itself so eminently grave and philosophical, that the audience never had the slightest feeling that the lecturer was exceeding his mandate. Faraday, experimenter that he was, and cautious of hypothesis, even at this time was obliged to relate the knowledge he had gained from books and from practice with his own personal convictions about the states of matter.

The lectures dealt, as Faraday very earnestly pointed out, not with applied chemical knowledge, but with the secret laws and forces of matter. Many of his generaliza-

tions in these lectures are exceedingly bold, in particular his belief that electrical and chemical attraction are the same as gravitational attraction. Yet, whether justified or unjustified by subsequent experiment, all these generalizations lie along the lines of research that posterity has developed.

In one of these lectures there is a passage which shows that the fundamental controversy about the agents of natural science is still continuing. 'There are so many theoretical points connected with states of matter that I might involve you in the discussions of philosophers through many lectures without doing justice to them. In the search after the cause of the changes of state of bodies . . . the old philosophers, and with them many of the highest of the modern, thought it to be occasioned by a change either in the motion of the particles or in their attractive power; whilst others account for it by the introduction of another kind of matter called heat, or caloric, which dissolves all that we see changed. The one set assumes a change in the state of matter already existing, the other creates a new kind for the same end. The nature of heat, electricity, etc., are unsettled points relating to the same subject. Some boldly assert them to be matter; others, more cautious and not willing to admit the existence of matter without that evidence of the senses which applies to it, rank them as qualities. It is almost necessary that, in a lecture on matter and its states, I should give you my own opinion on this point, and it inclines to the immaterial nature of these agencies.'

It is in these years that his correspondence with Benjamin Abbott gradually ended. 'Dear B,' he wrote in June

1815, 'I shall now endeavour to recommence on my side our twopenny post correspondence, though without much hope of success, for I have nothing to write about . . . ' Faraday has only two evenings a week in which he is free. What with lectures to the Society, the Saturday he invariably spends with his family in Weymouth Street, Monday and Thursday devoted to elocution, he has no time to write the long descriptions of his work and speculations which in the past formed the body of his letters. There is some unconscious humour in their mutual attempts to revive this correspondence. 'You hint at a sheet full of observations on lectures and lecturers, and you shall have it some time or another', wrote Faraday. ' . . . In the meantime, as preparatory and introductory to such a course of experiments, I will ask your opinion of and observations on English composition—style, delivery, reading, oratory, grammar, pronunciation, perspicuity, and in general, all the branches into which the *belles-lettres* divide themselves. . . . '

Davy publicly acknowledged the help he had received from Faraday in the construction of his safety lamp. Faraday's zeal in Davy's service was quite natural. Davy's rapidity of thought and sureness of execution aroused his admiration even to the end of his life. Contact with Davy developed also his self-mastery. Davy was a bit of a De La Roche, hasty, bad-tempered. But there was no question of deserting *science* for that! Davy was extremely disorderly. Faraday copied out Davy's scrawled researches in his clear, delicate handwriting, begging, for his pains, to be allowed to keep the originals.

Davy, who went again to Italy in 1819, wrote several

times to Faraday: 'Mr. Hatchett's letter contained praises of you which were very gratifying to me. It gives me great pleasure to hear that you are comfortable at the Royal Institution, and I trust that you will do something good and honourable for yourself and for science. I am, dear Mr. Faraday, always your sincere friend and well-wisher, H. Davy.' After Faraday's marriage it was Davy who succeeded in obtaining the consent of the directors of the Royal Institution that Faraday should be allowed to bring his wife to live there.

During these years Faraday contributed a paper to the *Quarterly Journal of Science* on the flow of gases through capillary tubes. In 1819 he began a long research on steel, and in the same year exposed the claims by an Austrian chemist to have discovered a new element. All this time Faraday continued to make entries in his Commonplace Books. These entries are sometimes directly scientific [some years later he wrote 'Convert magnetism into electricity'], sometimes of general interest.

He had visited a friend in South Devon, and it was there that he found occasion to apply what he had learned from geology during his tour with Davy. There are many references in the Commonplace Book to Shakespeare and Coleridge, and whilst the sufferings of the poor and the increasing social misery of the time do not affect him, the miseries of school children do. 'What precise quantity of misery is thrust into that space of human life which extends from six to sixteen years of age, it is not possible to determine, but it may safely be asserted that it far exceeds that of any other evil that infests the earth; the rod and the cane are in constant requisition, and the cries of infant misery



extend from one end of Europe to the other'; and he proceeds to copy out the misdeeds of a German schoolmaster who had, during his fifty years of superintendence of a large school, given 911,500 canings, 121,000 floggings, 209,000 impositions with detention, 136,000 tips with the ruler, 10,200 boxes on the ear. His Commonplace Books contain also some verses of a humorous nature against love and women, and, it is said, these verses were shown by one of his friends, Mr. Edward Barnard, to his sister, Sarah Barnard.

On 5 July 1820, Faraday was on terms of some intimacy with Miss Barnard, and a letter he wrote to her shows that he took very seriously the affection that had come into his life: 'You know me as well or better than I do myself. You know my former prejudices and my present thoughts—you know my weaknesses, my vanity, my whole mind. You have converted me from one erroneous way, let me hope that you will attempt to correct what others are wrong. . . . Again and again I attempt to say what I feel, but I cannot. Let me, however, claim not to be the selfish being that wishes to bind your affections for his own sake only. In whatever way I can best minister to your happiness either by assiduity or absence it shall be done. Do not injure me by withdrawing your friendship, or punish me for aiming to be more than a friend by making me less; and if you cannot grant me more, leave me what I possess, but hear me.'

Mr. Barnard, a silversmith and an elder of the Sandemanian community very sensibly refused to help his daughter to decide whether to accept or reject Faraday. He contented himself with remarking that love made philo-

sophers into fools. To postpone the necessity of deciding, Sarah Barnard went with her sister, Mrs. Reid, to Ramsgate.

Faraday followed them. He arrived in what he called 'strange spirits'. He could only just manage to keep up a rational appearance and, as so often happens on these occasions, his conversation, from the fact that it was a substitute for things he would have preferred to say, was calculated to displease. He criticized the town and the scenery, and everything around him in a malicious tone, and had assumed a general air of contempt and dislike. Fortunately for him, he was dimly aware of this and managed to retrieve himself by talking of home and friends.

Two days later he wrote in his diary: 'During a walk the conversation gradually became to me of the most pensive cast and my mind was filled with melancholy thoughts. We went into a mill and got the miller to show us the machinery; thus seeking mechanical means of changing the subject which, I fear, weighed heavy on both of us.' Alone in his lodgings that night, Faraday wished 'that memory and sensation would leave me and that I could pass away into nothing. But then pride came to my help and I found that I had at least one independent auxiliary left who promised never to desert me whilst I had existence.'

A day or two afterwards they went to Dover, and Faraday in his diary wrote a long description of the scenery: 'The whole was beautiful or magnificent as the mind received its tone from successive thoughts, and almost became sacred when the eye wandered towards the arch cliff, for there Shakespeare's spirit might be fancied sitting on the very verge absorbed in the contemplation of its grandeur. Then imagination would figure the bark, the

rocks, the buoy, the very lark to whom that immortal has given an existence that will end only with mortality.' Once again in the evening he thought over the day; it had been a success, his memory recalled the happiness he had enjoyed, but then his thoughts saddened and fell, from fear he should never enjoy such happiness again.

The last day was the best, and in the evening they went out for a drive together. 'Not a moment's alloy of this evening's happiness occurred; everything was delightful to the last instant of my stay because she was so.' But the struggle was not yet over. He went to Mr. Barnard's house as soon as he was back and pleased them by accounts of Ramsgate. A week or so later he wrote again: 'Since the week I have passed with you, every moment offers me fresh proof of the power you have over me . . . if your fears return [they have discussed her fears, you see] tell me that I may search out antidotes and doubt not that I shall find them. Read or alter my letters; do anything you please to drive them away. Fly to Mrs. Reid for help and then thank her from me for it. I shall never indeed, as it is, be able to repay her kindness but I will try to acknowledge it in attentions and affection to you, her sister.'

In a few months of delay and doubt both Sarah Barnard and Faraday learnt to know each other and themselves sufficiently to make sure that more than a momentary sympathy connected their lives. They were married in June, the day passing as usual—Faraday working in the laboratory of the Royal Institution in the afternoon. The affection which constantly existed between them and the entire serenity of their married life show that they arrived at the right decision.

## VIII

VERY shortly after his marriage, Faraday, whose thoughts, in common with those of the rest of the scientific world, were beginning to be more and more occupied with electricity and magnetism as a result of Oersted's discovery of the deflection of a magnetic needle by a wire carrying a voltaic current, succeeded in making a wire, carrying electricity, rotate around a magnet, and a magnet round a wire. He at once published this experiment.

Immediately afterwards he heard rumours affecting his honesty, and he was accused of claiming for his own a discovery already made by Dr. Wollaston. He certainly was aware that Wollaston had made experiments similar to his own, and had been present when Wollaston had discussed his work with Davy. But he believed that Wollaston expected the wire and the magnet to rotate on their own axes and not around each other, and there existed no doubt in his mind that he had discovered something new in the rotation around each other of the magnet and the wire.

Contrary to his usual practice, he had published his paper in the *Quarterly Journal of Science* without showing it to Davy who had been away from London. He was extremely upset at the charge of dishonesty and probably overestimated Wollaston's feelings. Anyway, Wollaston behaved very magnanimously, and indeed, was one of the

signatories to Faraday's candidature for membership of the Royal Society in 1823.

In the year of his election, Faraday succeeded in obtaining liquid chlorine as a result of heating chlorine crystals in a closed tube. Watching him at work in the laboratory on this experiment, Dr. Paris had jokingly asked him why he used dirty test tubes. The next day Faraday wrote to Dr. Paris and told him that the oil he had observed in the test tube was liquid chlorine. In point of fact, this liquid chlorine had been already obtained by Northmore in 1806, and, in 1824, when Faraday heard this he at once wrote in the *Quarterly Journal of Science* a historical statement on the liquefaction of gases, acknowledging Northmore's discovery.

Faraday's credit, however, in having repeated an important discovery without being aware that it had already been performed, and in having focussed attention on the whole matter, was disregarded in Dr. John Davy's Life of his brother in which he quoted Davy's diaries. Humphry Davy did not refer at all to Faraday's independent work on chlorine crystals, but simply said that he had 'caused experiments to be made on the condensation of different gaseous bodies by heating them under pressure'. Faraday was indignant about this, and in 1836 wrote a long letter to his friend Phillips in which the facts of the case were accurately stated. Davy had hinted to Faraday that he should heat chlorine crystals in a closed tube: 'How I should have proceeded with the chlorine crystals without the suggestion, I cannot now say; but with the hint of heating the crystals in a closed tube ended for the time Sir H. Davy's instructions to me, and I puzzled out for my-

self in the manner Dr. Paris described that the oil I had obtained was condensed chlorine'.

Davy's attempt to prevent Faraday's admission into the Royal Society is much more discreditable than the chlorine episode. Many years later Faraday gave a friend the following facts, which were immediately written down: 'Sir H. Davy told me I must take down my certificate. I replied that I had not put it up: that I could not take it down as it was put up by my proposers. He then said that I must get my proposers to take it down. I answered that I knew they would not do so. Then, he said, I, as President will take it down. I replied that I was sure Sir H. Davy would do what he thought was good for the Royal Society.' Faraday also said that one of his proposers told him that Davy had walked for an hour round the courtyard of Somerset House, arguing that Faraday ought not to be elected.

Davy certainly wished Faraday well. It is probable, however, that he regarded Faraday as so much his assistant, and, in a sense, his own discovery that he regarded honours paid to Faraday as really due to himself, and an honour such as admission to the Royal Society was one that was for Davy, paid far too directly to Michael Faraday and not enough to the Faraday who was the assistant to Davy. In his excessive need for admiration, Davy could not bear sometimes the equality of other people with himself. A writer in the *Quarterly Journal of Science* suggested in 1868 that Davy was annoyed that the certificate proposing Faraday for election should have originated with Richard Phillips, and that he should have not been consulted before that gentleman was allowed to take the matter in hand.

That Davy, after Faraday's election, realized that it should have been his efforts that brought Faraday into the Society was very likely true. If he attributed his conduct in the affair to annoyance that he had not been allowed to advance Faraday, then one can only say that he was a hypocrite as well.

From 1823 to 1830 Faraday received many honours both at home and abroad. Ampère himself wrote to him: 'Chemistry and physics have both been honoured by your work, and I personally owe you a great deal for your experiments on electromagnetic rotations'. He had carried out important and laborious investigations on alloys of steel and on optical glass; he had discovered two new chlorides of carbon, and from decomposition of oil by heat he had found hydrogen bicarburet or benzol. His notebooks are becoming increasingly full of references to electromagnetism. Whenever he has time, he works with bar magnets, carrying wires, helixes and galvanometers. His thoughts turn again and again to the electric fluids and their identity and to the mysterious cause behind all phenomena. He is far off still from his greatest attempts at the relation between all the forces of matter. He is near, very near, to his great step of synthesis between electricity and magnetism.

## IX

**F**ARADAY'S French passport of 1813 described him as the possessor of a round chin, a brown beard, a large mouth and a great nose. In a portrait of him, painted by Thomas Phillips, R.A., the brown beard has gone, and his face, with its bold features, is exceedingly serene. The appearance of Faraday which is present in our minds to-day is very different from this portrait, however. His face, slightly drawn round the mouth, is deeply lined, his eyes deep set, his whole face speaking of extreme vivacity, quick feelings and mental eagerness. Mr. Phillips' portrait excellently represents Faraday held, as it were, in suspense before he is to do his greatest work. In the later portraits the effort has been made and is stamped about his face—he lives still in the flood of the effort.

Faraday's character was always a combination of extreme seriousness and gaiety. After his evening's work in the laboratory he used to ride round the lecture theatre of the Royal Institution on a bicycle. He was fond of seeing acrobats, tumblers, dwarfs, giants and Punch and Judy shows. He was able to show at this time and always his real nature to children, and this, though most people are fond of children, is very rare. The letter quoted in this biography to his young sister Margaret shows that he did not adopt a 'playful attitude' to children. It shows him stiffer than he was with his young nieces—the stiffness being due to his



youth. In the period of his middle life and old age he plays a great part in the serious side of children's life, and this does not in the least debar him from sharing equally fully in that side of children's nature untouched by the principles of religion and the duties of family and social life.

His niece, Miss Reid, who has left a variety of charming memories of him, was constantly staying with Mrs. Faraday. In 1823 she records how, when her uncle was studying elocution, he took great trouble to teach her—she was then seven—to read with good emphasis. He would go over and over one sentence and make her repeat it with the upward and downward inflections till he was satisfied. 'After I went in 1826 to stay at the Royal Institution, when my aunt was going out [as I was too little to be left alone] she would occasionally take me down to the laboratory and leave me under my uncle's eye while he was busy preparing his lectures. I had, of course, to sit as still as a mouse with my needlework; but he would often stop and give me a kind word or a nod, or sometimes throw a bit of potassium into water to amuse me.

'In all my childish troubles he was my never-failing comforter, and seldom too busy, if I stole into his room, to spare me a few minutes; and when perhaps I was naughty and rebellious, how gently he would win me round, telling me what he used to feel himself when he was young, and advising me to submit to the reproof I was fighting against. . . .

'I have a vivid recollection of a month spent at Walmer with my aunt and uncle. How I rejoiced to go there with him! We went on the outside of the coach, in his favourite seat behind the driver. When we reached Shooter's Hill

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he was full of fun about Falstaff and his men in buckram, and not a sight nor a sound of interest escaped his quick eye and ear. At Walmer we had a cottage in a field, and my uncle was delighted because a window looked directly into a blackbird's nest built in a cherry tree. . . . In those days I was eager to see the sun rise, and my uncle desired always to call him when I was awake. So, as soon as the glow brightened over Pegwell Bay, I stole downstairs and tapped at his door. . . . Once I remember well how we watched the fading light from a hill clothed with wild flowers, and how, as twilight stole on, the sound of bells from Upper Deal broke upon our ears. . . .

'One of the first things to be done when he settled in the country was to set up a standing desk. It was made by putting the travelling boxes on a table. This was placed close to the window, which was generally open, and the telescope was set up. There he wrote, but, however busy, nothing on sea or land escaped his eye. As he had gone to Walmer for rest, I, the young one of the party, had to inveigle him away from his books whenever I could. Sometimes I was allowed to go to read with him, and my grandfather, who was staying with us, used to say, "What sort of reading lessons are those going on upstairs? I hear Ha! Ha! more than any other sound."'

Whilst they were at Walmer, Miss Reid remembers also telling him of a professor, previously of high repute, found abstracting some manuscript from a library. He instantly said, 'What do you mean by abstracting? You should say stealing; use the right word, my dear.'

In the evening he would read aloud. He took great pleasure in Byron and in Coleridge's *Hymn to Mont Blanc*.

‘When anything touched his feelings as he read, he would show it not only in his voice but by tears in his eyes also. . . . When my uncle left his study and came into the sitting room, he would enter into all the nonsense that was going on as heartily as anyone, and as we sat round a fire he would often play some childish game, at which he was usually the best performer, or he would take part in a charade; I well recollect his being dressed up to act the villain, and very fierce he looked. Another time I recollect him as the learned pig.’

One evening, when a thick white sea mist had shrouded the cottage, he called his niece into his room—it was about ten o’clock. ‘He placed a candle behind us as we stood at the window and there, opposite to us, appeared two gigantic shadowy beings who imitated every movement that we made.’

## X

IN 1819 Oersted made the discovery of the effect of an electric current upon a magnetic needle. This, like Volta's invention of the battery, is the second great epochal event in the science of electricity. A graphic account was written many years later by Professor Hansteen<sup>1</sup> to Faraday of how the discovery was made. 'Professor Oersted was a man of genius, but he was a very unhappy experimenter: he could not manipulate instruments. He must always have an assistant who had easy hands to arrange the experiment. . . . Oersted tried to place the wires of his galvanic battery perpendicular [at right angles] over the magnetic needle, but remarked no sensible motion. Once after the end of his lecture, as he had used a strong galvanic battery to other experiments, he said: *Let us now once, as the battery is in activity, try to place the wire parallel with the needle*—as this was made, he was quite struck with perplexity by seeing the needle making a great oscillation [almost at right angles with the magnetic meridian]. Then he said: *Let us now invert the direction of the current*—and the needle deviated in the contrary direction. Thus the great detection was made; and it has been said, not without reason, that he tumbled over it by accident. He had not before any more idea than any other person that the force should be transversal. But as

<sup>1</sup> A compatriot of Oersted—hence the style of the letter.

Lagrange has said of Newton on a similar occasion: *Such accidents only meet persons who deserve them.*'

Very little of importance in the development of the *physical* aspect of electricity had taken place in the twenty years that had elapsed between Volta's invention of the battery and Oersted's demonstration. The galvanic fluid, as this form of electricity was for a long time called, had done such important work in the domain of chemistry that the attention of the scientific world had been devoted to that subject, and on this account electricity was mainly thought of as a decomposing agent. However, the conception that all forms of electricity—whether from animal discharge, from Franklin's kite or from the friction machine or Leyden jar—had a common cause was in the air: it will be remembered that Davy in Genoa had made experiments on the gymnotus to see whether its discharge could decompose water. As early, indeed, as 1807, Dr. Young wrote, 'The identity of the general causes of electrical and galvanic effects is now doubted by few'.

But from the moment that Oersted discovered the deflection of a magnetic needle by a wire carrying the galvanic current, the study of electricity and its physical effects began with intensity. The electromagnetic research immediately carried out by Ampère, Arago and others in Paris, and a little later by Faraday in London, is something more than the beginning of the development of a new form of energy: it is a turning-point in the history of physics.

The eighteenth-century philosopher had hoped to bring the forces of Nature under his sway by the analysis of matter. He had to start with a number of hypotheses in

order to persuade himself that the facts he had observed were really to be explained in terms of matter. But as soon as it was established that there existed a definite relation between magnetism and one of these electrical effects, the attempt to explain changes of state in terms of matter definitely failed. The fact that the earth was a magnet had already linked the study of magnetism with speculation about the æther. The new discoveries to be made in electromagnetism, particularly on the lines which Faraday and Maxwell worked, emphasized the importance of this indefinable æther.

In a letter to Bentley, Newton wrote a passage that Faraday was always quoting: 'That gravity should be innate, inherent and essential to matter so that one body may act upon another at a distance through a vacuum and without the mediation of anything else . . . is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it'. The mathematical interpretation of Oersted's discovery, which Ampère at once undertook, accepted the idea of action at a distance. Ampère ignored whatever might be supposed to happen in the space intervening between the electric current and the needle. From his interpretation, however, arose the extremely important explanation that a magnetic molecule owes its magnetism to an electric current flowing inside it.

The lines on which Faraday and Maxwell worked, however, have proved of far greater significance. In refusing to accept the idea that an electric current and a magnet acted on each other at a distance, in the same way that the force of gravity appears to be exerted, Faraday was

led to envisage the field between the current and the magnet, to a conception of invisible magnetic curves and lines of electric force by which the relations between the current and the magnet could be defined and measured. This visualization and the many other explanations Faraday and Maxwell brought forward of electrical and magnetic action are hypotheses, only they are hypotheses which work. They are the opposite of the *caloric fluid* and the *phlogiston* hypotheses which were introduced to satisfy a preconceived notion about the material nature of physical action.

The necessity of being able to visualize all forms of physical action, and a consequent refusal to accept the idea of action at a distance, is one of the two main ideas of Faraday's life. The other has already been referred to—his innate conviction of the unity of all forms of physical action. He gave this idea its most striking expression in 1854, when he discovered the relationship between magnetism and light. 'I have long held an opinion, almost amounting to conviction . . . that the various forms under which the forces of matter are made manifest have one common origin: in other words, are so directly related and naturally dependent that they are convertible as it were into one another and possess equivalents of power in their action. This strong persuasion . . . extended to the powers of light.' This is the conviction that determined the first line of approach to his electrical researches. Since an electric current has an effect on a magnetic needle, there must be an equivalent effect exerted by magnetism on electricity. In searching for this effect, he discovered the induced electric currents on which is based the modern mechanical produc-

tion of electrical power. We use to-day the same electricity which dazzled the eyes of Davy's audience at the Royal Institution; but the galvanic fluid of Volta's battery depended on chemical action, on a heavy and dangerous apparatus of acid and metals, and it was consequently, and still remains to-day, quantitatively limited in its scope. Faraday's current is produced by the utilization of a force, by the alteration of a tension existing between magnetized iron and copper wire. Its scope as an agent in human affairs is unlimited.

When, in 1819, the news of Oersted's discovery reached London, Davy and Faraday at once set about repeating the experiment. Shortly afterwards they heard that Arago, basing his work on Ampère's generalization of the nature of magnetism, had succeeded in inducing magnetism in iron by an electric current.

In 1825 Faraday experimented with magnets inside a copper wire helix, and observed with a galvanometer whether the current sent through the circuit of the helix from his battery was less when the magnet was absent. The result was negative, though if he had watched the galvanometer when the magnet was being passed through the copper helix, he would have observed the registration of the induced current, and would have made his discovery six years earlier. In November of the same year he tried again with a simpler form of experiment; he passed current through a copper wire lying close to another wire communicating with a galvanometer. But he looked at the galvanometer when the current from his battery was flowing. He did not realize that the induced effect was momentary. No result came from similar attempts in 1825 and in 1828.



In 1831 the first paragraph in the laboratory notebook is 'Experiments on the Production of Electricity from Magnetism'.

The next paragraph describes his apparatus: 'I have had an iron ring made [soft iron], iron round and seven-eighths of an inch thick, and ring six inches in external diameter. Wound many coils of copper round, one half of the coils being separated by twine and calico; there were three lengths of wire, each about twenty-four feet long, and they could be connected as one length, or used as separate lengths. By trails with a trough, each was insulated from the other. Will call this side of the ring *A*. On the other side, but separated by an interval, was wound wire in two pieces, together amounting to about sixty feet in length, the direction being as with the former coils. This side call *B*.

'Charged a battery of ten pairs of plates, four inches square. Made the coil on *B* side one coil and connected its extremities by a copper wire passing to a distance and just over a magnetic needle [three feet from wire ring], then connected the ends of one of the pieces on *A* side with battery: immediately a sensible effect on needle. It oscillated and settled at last in original position. On breaking connection of *A* side with battery again a disturbance of the needle.'

By the very first of the experiments in 1831 he has observed the induced effect on breaking the connection; but once again he expected to see the needle register an effect whilst the current was flowing. This experiment is built on Arago's method of inducing magnetism in the iron bar. 'May not these transient effects be connected with

causes of difference between power of metals at rest and in motion in Arago's experiments?' he wondered.

On 24 September, the day after he had written to Phillips, 'I am busy just now again on electromagnetism, and think I have got hold of a good thing, but can't say,' he prepared fresh apparatus. He began by trying to find the effect of one helix of wire carrying the voltaic current of ten pairs of plates upon another wire connected with a helix. 'No induction sensible.' At last he is satisfied that he has discovered the induced effect. 'An iron cylinder had a helix wound on it. The ends of the wires of the helix were connected with the indicating helix at a distance by copper wire. Then the iron placed between the poles of bar magnets. Every time the magnetic contact of N or S was made or broken, there was magnetic motion at the indicating helix—the effect being not permanent, but a mere momentary push or pull. But if the electric communication [*i.e.* by the copper wire] was broken, then the disjunction and contacts produced no effect whatever.' Here he has made clear to himself that the phenomenon of induction which he had observed really depended on the stresses induced magnetism was subjected to. His next step is the direct production of the induced current. The second experiment he now makes, in which the mechanics satisfied him, has a perfection of detail and simplicity. This is, if the word must be used, the *historic* experiment. 'A cylindrical bar magnet three-quarters of an inch in diameter and eight inches and a half in length, had one end just inserted into the end of the helix cylinder [220 feet long]: then it was quickly thrust in the whole length, and the galvanometer needle moved: then pulled out, and again

the needle moved, but in the opposite direction. [In the same year, 1831, Pixii produced a machine for generating alternating current by the rotation of a permanent magnet in front of bobbin of wire called the armature.] This effect was repeated every time the magnet was put in or out, and therefore a wave of electricity was so produced from *mere approximation of a magnet*, and not from its formation *in situ*.

This group of experiments was undertaken on ten different days. The last experiment described took place on the day of 17 October, and was the fifth day of the experiments. He has satisfied himself that he has made the discovery he was after, the compliment to Oersted's discovery. But he is bound to go on. He is far from at rest, for his mind cannot accept experiment divorced from vision. He has rightly been called the king of experimenters. He was, without a doubt, but he holds his kingship by divine right, and his experiments are responsible to the abstract vision that gives them birth. But what, asks his mind, what has happened in the space between the magnetized iron and the copper?

The ninth day of his experiments was on 28 October, and on this day he made a copper disc turn round beneath the power of the great horseshoe magnet of the Royal Society. The axis and edge of the disc were connected with a galvanometer. The needle moved as the disc turned. The next day that he made experiments, 4 November, he found that a copper wire drawn beneath the poles and conductors of the magnet produced the same effect. The direction of the current was determined by the direction of the motion, the current being reversed when the

rotation was reversed. He is now able to visualize what is happening in the space between. When iron filings are scattered over the magnet the iron particles arrange themselves in lines called magnetic curves. Magnetism is invisible and immaterial, it is a force, and the curve of the filings is due to its operation. It operates everywhere. The turning copper disc is cutting across magnetic curves in the air. It is not the approach, he realized, of the bar towards the magnetized iron that produced the induced current of his former experiment. It is the action of cutting the magnetic field.

Once again this conception of the lines of force of the magnetic field, which he afterwards called tubes of force, is hypothesis. It is hypothesis that has not merely proved an hypothesis rich in practical results, but it is the hypothesis which made possible Maxwell's electromagnetic theory of light, which, in linking together light and magnetism, is the root from which springs the whole theoretical development of modern physics. That physics is to-day the science which questions most closely the reality of scientific values, and in so questioning is likely to effect a change in the human conception of space and time and of the terms of human existence, is due to the power of abstraction and experiment which were so peculiarly united in Faraday.

Having collected these facts into the first series of experimental researches into electricity, Faraday went to Brighton.

**I**N December of the same year [1831] he was back in the laboratory of the Royal Institution. For the next ten years Faraday is to remain consistently at the height of his powers, and during these ten years to work with an intensity that is unprecedented. After these ten years, he is to be afflicted with giddiness and loss of memory in a very definite form, compelling him to rest during four years. Much work of the greatest importance is to be done after this rest, and it is during the latter period of the twenty-five years between 1831 and 1856 that he is to develop his power as a lecturer to its highest. But he is to require longer periods of even more definite repose.

His experiments are still on electromagnetic induction. He attempts now to evolve electricity from the magnetism of the earth itself. He placed a bar of iron in a coil of wire, and lifting the bar in the direction of the dipping magnetic needle, he excited by this action a current in the coil. On reversing the bar a current in the opposite direction rushed through the wire. The same effect was produced when, on holding the coil of wire in the line of dip, a bar of iron was thrust into it. Here, however, the earth acted on the coil through the bar of iron.

His next step was to abandon the bar for the effect of the earth's magnetic field. He set a copper plate spinning in a horizontal plane so as to intersect the earth's lines of

magnetic force. When the plate swung round and intersected these lines, electric currents were induced as he expected and were registered on the galvanometer. He was able to prove the limits of the magnetic field. When the spinning plate was in the magnetic meridian or in any other plane coinciding with the magnetic dip, then its rotation produced no effect upon the galvanometer.

The effect of rotating discs on a magnetic needle had been observed before and, at the suggestion of Sir John Herschel, similar experiments to those of Faraday's had been carried out. But the effect on the magnetic needle had been ascribed to some change in the magnetic quality of the iron disc. Faraday repeated the experiments made by his predecessors, using a hollow brass ball, thus proving that the presumed change in the magnetism of iron had nothing to do with the magnetic deflection. The only necessary characteristic of the rotating body was that it should admit of the formation of currents in its substance, and the higher this characteristic [*i.e.* conducting power] the stronger were the currents. The continuation of these experiments has been vividly described by Professor Tyndall.

'He now passes from his little brass globe to the globe of the earth. He plays like a magician with the earth's magnetism. He sees the invisible lines along which its magnetic action is excited, and sweeping his wand across these lines evokes this new power. Placing a simple loop of wire round a magnetic needle, he bends its upper portion to the west, the north pole of the needle immediately swerves to the east; he bends his loop to the east, and the north pole moves to the west. Suspending a common bar

magnet in a vertical position, he causes it to spin round its own axis. Its pole being connected with one end of a galvanometer wire and its equator with the other end, electricity rushes round the galvanometer from the rotating magnet. He remarks upon the *singular independence* of the magnetism and the body of the magnet which carries it. The steel behaves as if it were isolated from its own magnetism.

‘And then his thoughts suddenly widen and he asks himself whether the rotating earth does not generate induced currents as it turns round its axis from west to east. In his experiment with the twisting magnet, the galvanometer wire remained at rest, one portion of the circuit was in motion relatively to another portion. But in the case of the twisting planet, the galvanometer wire would necessarily be carried along with the earth; there would be no relative motion. What must be the consequence? Take the case of a telegraph wire with its two terminal plates dipped into the earth, and suppose the wire to lie in the magnetic meridian. The ground underneath the wire is influenced like the wire itself by the earth’s rotation; if a current from south to north be generated in the wire, a similar current from south to north would be generated in the earth under the wire, these currents would run against the same terminal plate and thus neutralize each other.

‘This inference appears inevitable, but his profound vision perceived its possible invalidity. He saw that it was at least possible that the difference of conducting power between the earth and the wire might give one an advantage over the other, and that thus a residual or differential

current might be obtained. He combined wires of different materials and caused them to act in opposition to each other, but found the combination ineffectual. The more copious flow in the better conductor was exactly counterbalanced by the resistance of the worse. Still, though experiment was thus emphatic, he would clear his mind of all discomfort by operating on the earth itself. He went to the Round Lake near Kensington Palace and stretched 480 feet of copper wire north and south over the lake, causing plates, soldered to the wire at its ends, to dip into the water. The copper wire was severed at the middle and the severed ends connected with a galvanometer. No effect whatever was observed. But though quiescent water gave no effect, moving water might. He therefore worked at London Bridge for three days during the ebb and flow of the tide, but without any satisfactory results. Still, he urges, theoretically it seems a necessary consequence that where water is flowing, there electric currents should be formed. If a line be imagined passing from Dover to Calais through the sea and returning through the land, beneath the water, to Dover, it traces out a circuit of conducting matter, one part of which, when the water moves up or down the Channel, is cutting the magnetic curves of the earth, whilst the other is relatively at rest. . . .'

The greatest importance of this series of experiments, which have a bearing besides on telephony and on most branches of electrical science, lies in the new relation established between the magnetic poles, the moving wire and the induced current. In 1851 Faraday was able to formulate precisely this relation. He found that the current induced was proportional to the velocity when the con-




ductor [the bar of iron, the brass ball, or any conducting substance] was moving with a uniform motion in a magnetic field of uniform strength; and that the quantity of electricity induced [in the first experiment he set the copper plate rotating in the magnetic field and registered the induced current in the plate by a galvanometer] was directly proportional to the amount of curves intersected.

The consequences of this exploration of the magnetic field and of the magnetic curves have as their result to-day the generalized conception that a magnetic field is a kind of stress, or like a stream of water immobilized at the instant it was about to pour itself down a mountain side, a potential source of energy. Similarly, a wire and a magnet at rest exist in a relation of potential energy towards each other. The definition of the energy that can be produced by means of the falling water, the driving of a mill wheel for instance, has nothing to do with the chemical nature of water nor with its weight; it is concerned solely with the potentiality of water to fall down from a height and expend the energy bestowed on it by gravity as a result of its fall.

Similarly, if at any moment the magnetic strength of the magnet changes, then the wire must adjust itself, and this adjustment is the flow of the electric current. Another part of Faraday's researches probe into the condition of the wire when this adjustment takes place, and here again he is the first to be able to visualize this flow, this adjustment in the nature of a conducting body.

## XII

 ON 25 August 1832, Faraday began another series of experiments. The first object that he had in mind was to place beyond all measure of doubt the identity of his induced electric currents with voltaic current. Quite naturally, his first thoughts are to prove that electromagnetic current can produce electrochemical deposition. Of the identity between the current from a friction machine and the induced electromagnetic current he is assured. His first demonstration was that current from a friction machine can be registered on a galvanometer, and having satisfied himself on this point, using as conducting mediums a wet thread, a copper wire, water and rarefied air, he went on to the question of electrochemical decomposition.

He dipped two silver wires into a solution of copper sulphate, and he found that one of them became copper plated by the current after a specified number of turns from the machine. Following the experiments that Davy had performed with the large voltaic battery, he bleached indigo, turned starch purple with iodine liberated from iodide of potassium and decomposed water. As a result of this series of experiments, he published a paper in 1833 which finally put the identity of the various forms of electrical energy beyond dispute. 'Electricity, whatever may be its source, is identical in its nature.'

This series of experiments have cleared the ground for

him. Faraday's mind is now directed entirely towards an explanation of the phenomena of electrochemical decomposition. From a study of conduction concluded in April 1833 in which he examined the difference in conducting power between substances in solid and liquid states, metals and fatty bodies, and in which he established the relation between conduction and decomposition, he passed at once to the theory of the voltaic pile itself.

His paper on Electrochemical Decomposition, read before the Royal Society in 1834, opened with the proposal of a new terminology. He wishes to abandon the word *poles* as applied to the ends of the battery because it suggests the idea of attraction. He makes use, for the first time, of the word *electrodes*, which, together with *electrolyte* for the decomposing substance and *electrolysis* for the whole process, are the terms in use to-day. A series of brilliant experiments have enabled him to arrive at the first clear conception of the voltaic cell; he has found that the amount of electrochemical decomposition depends not upon the size of the electrodes, nor upon the intensity of the current, nor the strength of the electrolyte, but solely upon the amount of electricity which passes through the cell. The quantity of electricity, he concluded, is proportional to the amount of chemical action.

In the development of this theory he touches directly upon two laws which are to-day among the central conceptions of physics. In 1834 he read a paper on the Electricity of the Voltaic Pole, in which, having seen the quantitative relation between chemical and electrical effects, he proved that chemical decomposition could not take place without the flow of electricity, and that there existed a

complete interdependence of the electrical and chemical effects. It will be remembered that Volta in his invention of the battery, had showed that the rôle played by the frog's legs in Galvani's discovery was nothing but that of a conductor. The theory, however, that was developed to explain the working of Volta's battery was known as the contact theory and explained the decomposing force as due to the disassociation of the molecules of the liquid conductor into their constituent particles, each carrying opposite electrical charges, by the action of the poles. In 1832 the supporters of the Contact Theory are too many and too powerful for Faraday's explanation of the voltaic cell to be accepted. It is not until 1840, when Faraday returned to the attack, that his explanation is listened to. It is at this time that Faraday, pressing home his conclusions, arrives at the idea of the conservation of energy.

It occurs to him as a necessary belief to support his investigation of decomposition. Two or three years later, as a result of the work of Joule and Mayer, it is to be stated as a general principle. The statement of this principle is a landmark in the history of science as important as Newton's theory of gravitation. Here is Faraday's anticipation of this generalization: 'The Contact Theory assumed that a force which is able to overcome powerful resistance as, for instance, that of conductors good or bad through which the current passes, and that again of the electrolytic action when bodies are decomposed by it, can arise out of nothing; that without any change in the acting matter or the consumption of any generating force, a current shall be produced which shall go on for ever against a constant resistance, or

only be stopped, as in the voltaic trough, by the ruins which its exertion has heaped up in its own course. This would indeed be a creation of power, and is like no other force in Nature. We have many processes by which the form of the power may be so changed that an apparent *conversion* of one into the other takes place. So we can change chemical force into the electric current, or the current into chemical force. The beautiful experiments of Seebeck and Peltier show the convertibility of heat and electricity, and others by Oersted and myself show the convertibility of electricity and magnetism. But in no case, not even in those of the gymnotus and torpedo, is there a pure creation of a production of power, without a corresponding exhaustion of something to supply it.'

His proof of the interdependence of current and decomposition was in part devoted to a quantitative analysis of the phenomena. It is then that he arrived at the theory that the equivalent weights of the bodies are simply those quantities of them which contain equal quantities of electricity, it being electricity which determines the equivalent number because it determines the combining force. 'Or if we adopt the atomic theory or phraseology, then the atoms of bodies which are equivalents to each other in their ordinary chemical action have equal quantities of electricity naturally associated with them. But I must confess that I am jealous of the term atom.'

He stated again, 'If the electrical power which holds the elements of a grain of water in combination, or which makes a grain of oxygen or hydrogen in the right proportion unite into water when they are made to combine, could be thrown into the condition of a current, it would

exactly equal the current required for the separation of that grain of water into its elements again'.

Here Faraday has clearly envisaged the landscape, gradually becoming visible throughout the course of the nineteenth century, of the electric structure of matter. Science has to-day reached the horizon of this landscape, and, in the description of the structure of the electrical atom, is before yet another landscape shrouded in the mist of the quantum theory.

Faraday, however, chemist as he is by education, is to turn away from this vista, and if one may stretch a harmless metaphor, to look into the clouds. His conviction of the unity of natural forces is to lead him to the apparently more immaterial speculations on light, on magnetism, on gravity.

'I am jealous of the term atom.' All his life, he is to neglect the work of Dalton, who established the chemical foundation of atomic structure, the exact counterpart of what Faraday had been forced to realize—the unitary electric charge and its inevitable relation to the chemical atom. He turns away from conclusions which, had not his mind been of an inevitable cast, might have directed him in quite another direction.

With the exception of isolated researches and lectures, and his return to the attack on the contact theory in 1840, his mind is to return to electromagnetism, to his lines of force. Before the close of the first ten years of electrical research he is to complete another series of researches on the passage of electricity through space and materials, a series which is as important as its predecessors, for in it is elaborated the basis of the physics of insulating materials.

### XIII

**W**ORK on the last of the four groups of electrical researches which Faraday undertook between 1831 and 1841 was not begun until 1836.

In the first group of electromagnetic induction experiments, the conviction that action at a distance was an absurdity, and the peculiar power of visualization he possessed and was obliged to exercise, had led him to go further than to fix the relationship between magnetism and electricity, and to account for the induced current registered in the spinning plate by the conception of intersected magnetic curves. In this fourth group it is his conception of the flow of electricity through space and through conducting bodies of lines and tubes of force and of streams of electric particles. In 1837 he found that he could induce electricity in an insulated sphere placed completely in the shadow of a body, screening it from direct action. Gravity, or the conception of action at a distance, could be exerted only in straight lines, he realized. He has therefore made it still more impossible to speak of electrical action as action at a distance, and he can visualize his lines of electric force bending round the edges of the screen to induce current in the sphere. He proved that in many cases the augmentation of the distance between his insulated sphere and the inducing body increased the charge on the sphere. This he attributed to the

coalescence of lines of electric force some distance behind the screen.

His next series of experiments in this group of researches was to be concerned with the induction and conduction of electricity by various types of insulators. He placed a metallic sphere in the middle of a large, hollow sphere, leaving a space of something more than half an inch between them. The inside sphere was insulated, the external one uninsulated. To the inside sphere he communicated a definite charge of electricity which acted by induction upon the concave surface of the outside sphere, and he examined how this act of induction was affected by placing insulators of various kinds between the two spheres. In this way he was able to determine the specific inductive capacity of materials.

He visualized the state of his contiguous particles as one after another each succeeding particle is changed by its predecessor. 'Can we not by a gradual chain of association carry up discharge from its occurrence in air through spermaceti and water to solutions, and then on to chlorides, oxides and metals?' Copper, he realized, copper itself, offers a certain resistance to the transmission of electricity. The action of its particles differs only in degree from the action of the particles of rubber.

We are to-day in a position to appreciate fully the beauty of these experiments on materials and the clarity of the principles which seem to have been present in Faraday's mind before the experiments were performed, and yet to have grown from the results of the experiments. Experiment seems to be a materialization of certain mental operations, a part of the whole picture of a conception needing



a special kind of light. Professor Tyndall, in his book *Faraday as a Discoverer*, refers more than once to the metaphysical difficulties of accepting Faraday's views of the flow of electricity through materials. 'Whatever difficulties', he wrote, 'the mind experiences in conceiving action at sensible distances beset it also when it attempts to conceive of action at insensible distances.' Professor Tyndall rightly stresses the fact that by changing a conception of electrical action between masses to electrical action at an insensible, but all the same existing, distance between small particles, Faraday has not succeeded in getting rid of action at a distance. Professor Tyndall does not for a moment discountenance the value of the results of these experiments; he simply states the metaphysical difficulty.

As a result of the practical development of electrical science, the results of the experiments have for us a greater value than they appeared to have in Professor Tyndall's time. The metaphysical difficulty has not been dispersed but it has, like a huge cloud, been blown away from the field of dielectric investigation. The current causing a rapid molecular induction and discharge in copper, which is carried at hundreds of thousands of volts, is envisaged as *energy* whose laws have a relationship as yet unsolved with the atom of matter, which is itself made up of charges of electricity. What we know of the ultimate nature of energy and matter is bound up with the enigma of its emission from the electronic orbits of the atom, and it is the problems of wave-length and frequency in which the enigma is expressed that are to-day under the cloud of the unknown.

THE experimental researches did not interrupt Faraday's very active life as Director of the Laboratory of the Royal Institution; his courses of morning lectures at the Institution were devoted to the treatment of outstanding discoveries and theories in chemistry and physics. In 1835 he was the means by which M. Melloni's work on radiant heat was brought before the scientific public in England; as an old man he bent all his failing energies to present the work on ozone of his friend Schonbein. These are only two instances of the valuable work which Faraday carried out as an interpreter and exponent in all branches of chemistry and physics. His disinterested devotion to science was one of the reasons why in France, Italy and Germany he was not only admired by all the physicists and chemists of the time, but loved. His friends and fellow-workers had never any need to separate the man Faraday from the scientist and lecturer.

One of his first acts when appointed Director in 1825 had been to originate the Friday night meetings which, in his later years, acquired a social importance similar to those of Davy's lectures at the beginning of the century; he also began the Christmas lectures to juveniles. These activities, combined with the renown of his own researches, once again established the Royal Institution. Its reputation had begun to wane after the death of Davy.

In 1830 Faraday's position brought him a vast quantity of professional work which supplemented his income. In that year alone he made £1000 out of professional business, which came to him unsought. Such work, however, he definitely resigned that he might devote himself the better to the Institution and to his own researches. The Royal Institution was poor; Faraday's salary was never more than £200 until 1853 when he became Superintendent of the House as well as Director of the Laboratories. Then his salary was increased to £300. In 1827 he declined the appointment of Professor of Chemistry at London University, giving as his reasons the interests of the Royal Institution. 'I think it a matter of duty and gratitude on my part to do what I can for the good of the Royal Institution in the present attempt to establish it firmly. The Institution has been a source of knowledge and pleasure to me for the last fourteen years, and though it does not pay me in salary what I now strive to do for it, yet I possess the kind feelings and goodwill of its authorities and members and all the privileges it can grant or I require: and, moreover, I remember the protection it has afforded me during the past years of my scientific life.' He kept the accounts of the Institution for a long while, noting down every detail of expenditure, even in farthings.

Whilst he remained a poor man in the worldly sense, he did not remain an unhonoured one. On page 98 of Dr. Bence Jones's biography will be found a full list of all the honours that were conferred on him. In 1832 he received, with Brewster, Brown [the discoverer of the Brownian movement] and Dalton, the degree of D.C.L. from the University of Oxford on the occasion of the second meet-

ing of the British Association. This was the first academic honour he received. Fame was very agreeable to him, but it was not fame that chiefly contributed to the happiness of his life in later years. As he said once to Tyndall: 'The sweetest reward of my work is the sympathy and goodwill which it has caused to flow in upon me from all quarters of the world'.

Two honours which he received deserve special mention. In 1856 he was made a Commander of the Legion of Honour by the Emperor Napoleon III. 'I can only offer a most grateful and unfailing remembrance of that which to me is more than honour. I feel deeply affected by the thought that even *I*, by your Majesty's favour, form one link, though a very small one, in the bands which I hope will ever unite France and England.' Faraday's friends in France were particularly numerous, and in his close relations with Arago, Dumas, de la Rive, Becquerel, to name only a few, he continued the tradition, unmarred by even a hint of nationalistic feeling, of collaboration between English and French men of science, begun by Young and Fresnel, who both arrived independently at the conception of the undulatory theory of light, and who ardently worked together instead of quarrelling for precedence. When Faraday was elected one of the eight foreign members of the Académie des Sciences, his friend Dumas wrote to him immediately, and to make the whole thing more agreeable, Arago addressed the envelope. 'Davy we admired,' wrote Dumas, 'but Faraday we loved.'

The other honour which must be mentioned was the pension he received in 1835 from His Majesty King William IV. during Lord Melbourne's Government. This

was in the middle of Faraday's first period of researches, and the Conservative Government of Sir Robert Peel, in power during the first years of the decade, had been aware of the value of Faraday's work for science and for the Institution and of the small financial return such work brought him. It fell to Melbourne, who came into office in 1835, to carry out the award of a pension. Faraday at first refused on religious grounds to entertain even the idea of a pension. His membership of the Sandemanian Community forbade the accumulation of wealth. He did not mention this in his letter to Sir James South, but while expressing his agreement with the principle of the Government rewarding and sustaining science, he simply wrote, 'but still I may not receive a pay which is not for services performed whilst I am able to live by my labours'. However, his father-in-law persuaded him that acceptance of a pension did not imply the accumulation of wealth. When Faraday went to see Lord Melbourne, however, he was much put about by the latter's declaring that he considered scientific and literary pensions a piece of damned humbug. Immediately after the interview he wrote to Lord Melbourne: 'My Lord—The conversation with which your lordship honoured me this afternoon, including as it did your Lordship's opinion of the general character of the pensions given of late to scientific persons, induces me respectfully to decline the favour which I believe your Lordship intends for me: for I feel that I could not, with satisfaction to myself, 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'.

However, the matter did not end there. Faraday's

friends were determined that he should receive his due, and what was certainly an exaggerated account of the interview with Lord Melbourne appeared in *Fraser's Magazine*. The origin of this article had certainly nothing to do with Faraday, but with great dignity he refused to issue a statement of what had passed between himself and Lord Melbourne and thus pave the way to a kind of public reconciliation, but contented himself with publishing a denial of any communication with the editor of *Fraser's Magazine*. Through the probable intervention of the King, Faraday eventually received a pension. Dr. Bence Jones records that in 1862, in the *Life of Sir Charles Bell*, an account, similar to the account which appeared in *Fraser's Magazine*, of the interview between Faraday and Lord Melbourne was about to be published. The editor asked Faraday if he objected to the publication. He answered: 'Sir—I am very much obliged to you for your kindness in sending me the note regarding Lord Melbourne and my pension. I cannot assent to its publication. Lord Melbourne wrote to me and behaved very handsomely in the matter; and if one part of the affair were published, I think the other part ought to be also. But it was the desire of the Minister and his friends that no notice should be taken of the affair, and therefore I did not consent then, and cannot now, to any partial publication of the circumstances.'

**B**ETWEEN 1831 and 1840 Faraday had suffered from recurrent attacks of giddiness, headache and loss of memory, but these he surmounted by short holidays between the period of his experimental researches. A breakdown, in the form of an unusually violent attack, took place in 1839, and it was this that decided Faraday to take a prolonged rest. During the next four years he abandoned all experimental work and most of his lecturing and other activities.

His trouble was accentuated by a belief that the physicians did not understand the extent of his affliction. 'Whereas, according to the declaration of the true man of the world, Talleyrand,' he wrote on a scrap of paper, to relieve his feelings, 'the use of language is to conceal the thoughts: this is to declare in the present instance, when I say I am not able to bear much talking, it means really and without any mistake or equivocation, or oblique meaning or implication or subterfuge or omission, that I am not able, being at present rather weak in the head and able to work no more.'

Nervous as he was by nature, and made much more so by these attacks, it is unlikely he suspected his physicians of not understanding the quality of his affliction, even if they did not appear to understand how *much* it affected him. He himself [in non-medical language] diagnosed it

as a decay of the physico-mental faculties of his mind. This decay, severe as was its manifestation in 1840, only affected his memory and the nerves of his head. Ten years later or so, its less violent recurrences are to affect the muscles of his arms, legs and throat. The attacks do not at any time alter the quality of his mind. Between 1859 and 1863, at which latter date he was obliged to retire from all forms of activity, whilst constantly unwell, he was able to continue very elaborate researches and to produce results of great value. Only, he complains that he forgets what he has just finished and cannot remember whether or not he has thought out such and such a problem.

In 1840, when he was obliged to rest from all mental work, he felt it a physical strain to write a letter or to try and remember somebody's name, he was quite capable of enjoying travelling and nature to the full. The symptoms accompanying nervous diseases, as severe and definite as Faraday's, are usually dissatisfaction with all kinds of environment and restlessness. Such diseases are rooted in the misuse or frustration of some natural power in the individual. But in Faraday's case there appear none of such symptoms, and there is no reason to suppose that its cause was anything but the continued use of his very peculiar mental faculties. It cannot be said that it was the strain of the first ten years of experimental researches which *caused* this breakdown; they contributed to the severity of its manifestation. The cause cannot be precisely stated, but it is probable that the nervous mechanism of his memory was always put to some strain by the natural development of his mind. The privations he suffered during a short period of his early childhood were, no doubt, a further



contributory cause to the tendency to strain of a part of his nervous system.

He went to Switzerland with his wife and Mr. and Mrs. George Barnard, his brother- and sister-in-law. Barnard was a water-colour painter who had already made a reputation for himself. They went to Thun, travelling by Cologne and the Rhine, Bâle and Berne. They lived for some time in a small house near the Belle Vue Hotel at Thun, where, as he wrote in his journal, they could be as quiet as mice. They breakfasted in their own house, dined at mid-day in the hotel—'tea at seven or thereabouts and propose going to bed at nine o'clock. As for supper, we don't think about it; we do not find the many rolls and loaves too much.'

Faraday slept and walked a great deal. He thought nothing of thirty miles a day, and on one occasion walked forty-five. He had gone with George Barnard to Leuk, where they passed the night sleepless on account of the people who were attending the baths at that place. In the early night they were kept awake by the groans of a Frenchman complaining how ill he was. 'Then at three o'clock, the church struck up a vigorous ringing. I am sure I do not know what for, unless it was prayers for the invalids who go into the baths soon after. . . . At three o'clock there was a particular snapping noise which excited my attention; away I went to the window and found it was the crackling of three great wooden fires, made in different stoves of the baths, opening to the air and intended to warm the buildings. When at the window, the interest of the scene kept me there. As I said before, the principal source of water was just before the house, between it and the baths, and now, in the early morning light, issued out from the various

surrounding houses and hotels the poor creatures cloaked up and coiffed, or dressed otherwise very queerly, each bringing a little basket containing their keys, their handkerchief and a tumbler, with other things. To the spring they ran and began to drink the hot water; some were going, others coming, whilst waiters were washing various articles there quite unknown to me, but I suppose of bathing importance, and such a mixture of men, women, poor, rich [I suppose], at such diversity of occupation I never saw in one spot before. As they drank, when they had taken enough, off they ran to the baths to take their place in the wonderful fluid. And so their days ran on and ran away.'

That morning he decided to walk back to Thun, leaving Barnard at six o'clock . . . 'for here George and I parted, not a pleasant thing to either, though we hoped to meet again in a few days; but he had to go further and sketch and I had to return home, *i.e.* to my dear wife and Emma, by Sabbath day.' He took his way up the Gemmi Pass, and in the early morning sun was well pleased. Sheep, clouds, flowers and glaciers. The weather being cold and dull, he thought of turning back and rejoining George. At Kandersteg he had some tea and a mutton chop. At eleven o'clock he passed the inn where he and Barnard had slept two nights ago. He decided not to stop. The weather broke: the waterfalls at Fruchtigen were beautiful. He dined at Fruchtigen at mid-day and decided to go on through the valley of the Kander. He reached home at Thun twenty minutes after six, felt a little stiff after tea but otherwise well, and with only one small blister on his foot.

It was the time of the discovery of Switzerland by the English upper middle classes. Whole families struggle up

the lower flanks of Rigi with their prayer books. The drawing-rooms of Geneva hotels are hung with pictures of Queen Victoria. However ridiculous the domestic habits and prejudices of one nation invariably appear when transplanted into the country of another, the impulse behind the admiration of Swiss scenery—its mountains, its storms, the *awful peace* of its valleys—is the same as the impulse behind the lyrical expression of nature in the poetry of the Romantics.

This way of loving nature, this particular identification with all in nature that is remote and different from man, is a mode of feeling that is peculiar to the beginning of the nineteenth century, or rather it first found expression at this time. The poets of the Renaissance and of the seventeenth century were lovers of natural beauty, but in its symbolic aspects, as a means of comparison with other objects of their emotions. The sun, flowers, scents, storms and all moods of the weather are compared with human longings, human delight, human despair. Only in Shakespeare does nature exist independently of man, to enhance the horror of murder by sympathy of darkness and gusts of wind, or in smiling calm to isolate man and his struggles. But for Wordsworth and Coleridge a flower, a green wood have a secret of their own, a secret which means something to man but is not connected with his waking and sensuous existence

To me the meanest flower that blows can give  
Thoughts that do often lie too deep for tears.

It is on account of this apprehension of nature that the Romantic movement is something much more than a change in taste, a change in the step of verse. The mean-

ing of these impulses, these sad misgivings and sudden ecstasies, was and remains to-day hidden from consciousness. At the decline of his days in 1867, Faraday's niece, Miss Reid, wrote of Faraday: 'I shall never look at the lightning flashes without recalling his delight in a beautiful storm. How he would stand at the window for hours watching the effects and enjoying the scene; while we knew his mind was full of lofty thoughts—sometimes of the great Creator and sometimes of the laws by which he sees meet to govern the earth.' There is perhaps a direct relation between the impulse to feel nature for herself and the physical study of nature's immaterial agents. Anyway, in the indivisible mind and feelings of Faraday this relation existed.

ALTHOUGH Faraday, previously to 1831, had not been consciously preoccupied with electromagnetism to the exclusion of other branches of natural science, the series of discoveries made in the ten years of the first period of researches was certainly due to a mind which had been fashioned unconsciously for a special purpose. This unconscious fashioning is shown by the two convictions which, neither supported nor contradicted by outside evidence, existed as though from the beginning of his thought—the unity of all manifestations of force, electricity, light, gravity, magnetism, heat, and the impossibility of force being exerted through space or any other medium without a definite physical track. And it is these two convictions that give his mind its peculiar form and which fit it to be the most searching explorer in a new field of scientific knowledge, electromagnetism. To this long and unconscious preparation is due also the stream of energy which for ten years enabled him to live at a height of creative conception. The single discovery of the induced electric current might have been made by any extremely able experimenter who had also a strong speculative tendency; the *series* of discoveries, through which in ten years the principles of a new science were drawn up, could only have been made as the result of an inevitable mode of thought suddenly finding the field in which its

demands could be satisfied. It was not self-confidence, often possessed by men who have no belief at all in the inevitability of their opinions, which enabled Faraday to work on the strength of his opinions about the essential nature of matter and force, opinions which, although admired for the results they yielded through experiment, were neither understood nor accepted by the majority of his contemporaries. It was the dynamism of a mind accustomed to the daily observation of the properties of matter, free from any notion or intellectual hypothesis except its own fundamental convictions.

To the four years of rest, and even to the breakdown which necessitated these four years of rest, is due the un-failing imaginative power of the second period of researches. The decay of his memory and of the subordinate faculties of his mind play an integral and not a fortuitous part in the development of his life work. That without a breakdown he would have continued to do 'good and honourable' work for science is certain: the field in both chemistry and physics in which as able an experimenter as Faraday could have made valuable discoveries was very wide. But the four years' blank of his mind is slowly to be filled with the old conceptions to which he must devote himself, to which he must give evident forms. The second period of his researches is devoted to the relation between magnetism and light, between electricity and gravitation, to the strange vibration of the magnetic field, to the magnetic condition of matter, to the closer investigation and the theoretical elaboration of his tubes of force. During this period he made the acquaintance of Clerk Maxwell, by whom all that seemed most dark in his speculations was understood.

On 30 August 1845 Faraday began to look for experimental evidence on the connection between light and electricity. Earlier in the century the phenomena of polarized light had been examined by Arago and Biot in France and by Brewster in England. It was through the use of polarized light that crystalline substances, which possess the strange property of rotating the plane of polarization, had been studied—quartz crystal solutions of sugar and certain alkaloids. It was Faraday's aim to find out whether electricity—lines of electrostatic tension—would have any effect on varying the plane of polarization of a beam of light. He tried to change the polarization of his beam of light through liquids and through crystalline and non-crystalline dielectrics by means of continuous current, of intermitting current and of rapidly alternating induced current, but without any result. These experiments continued for a fortnight. As soon, however, as he abandoned the electric currents and used magnetic force, success came to him.

A piece of heavy glass, a silico-borate of lead, was experimented with. It gave no effect when the same magnetic power of the contrary poles were on opposite sides [as respects the course of the polarized ray]—nor when the same poles were on the same side either with constant or intermitting current. But when contrary magnetic poles were on the same side there was an effect produced on the polarized ray, and thus magnetic force and light were proved to have relations to each other. His interpretation of this experiment was that when the polarized ray passed parallel to the direction of the magnetic curves, the glass manifested its power of affecting the ray.

In the account of this experiment which he published he further defined the state of the heavy glass when acted upon by magnetic forces and calls it diamagnetic. 'By a diamagnetic I mean a body through which lines of magnetic force are passing and which does not, by their action, assume the usual magnetic state of iron or loadstone.' In the succeeding experiments he proceeded to satisfy himself more definitely about the way in which the magnet had affected the ray of polarized light. He used for this purpose the most powerful electromagnets then obtainable, and with them he was able to state that *the plane of polarization is rotated through a definite angle depending on the strength of the magnet and the direction of the existing current.*

It was inevitable that, with these results, he should at once try to find out experimental evidence for the effects of light. Light should be able to magnetize and to electrify. In Rome, it will be remembered, he had observed some not wholly convincing experiments of the magnetization by sunlight of an iron needle. But his experiments with a spiral of wire along which a beam of sunlight was directed and other similar experiments were unsuccessful.

The evidence he was looking for here was delayed until the latter years of the century when Mayhew discovered the effect of light in altering the electric resistance of selenium. Becquerel, one of Faraday's correspondents, was also to work in this region; it was he who discovered the photoelectric currents and in 1878 succeeded in proving that the magnetism of the earth rotates the plane of polarization of sunlight.

But while engaged on these unsuccessful experiments, he made a discovery which so excited him that he did not



even go to the meeting of the Royal Society at which his paper on the effect of magnetism on light was read. When his very powerful magnets were excited, he observed that the bar of heavy glass which he had used in his former experiments pointed and pointed equatorially or across the lines of magnetic force. His conclusions and his subsequent experiments he recounted to Auguste de La Rive [the son of Davy's friend in Geneva] in a letter from Brighton, where he had gone to rest his head:

'This effect or power [the equatorial pointing] I have worked out through a great number of its forms and strange consequences. . . . It belongs to all matter [not magnetic, as iron] without exception, so that every substance belongs to the one or the other class—magnetic or diamagnetic bodies. The law of action in its simple form is that such matter tends to go from strong to weak points of magnetic force, and in doing this the substance will go in either direction along the magnetic curves or in either direction across them. It is curious that amongst the metals are found bodies possessing this property in as high a degree as perhaps any other substance.'

In his account of his experiments in the *Experimental Researches* he enumerated the many bodies of all sorts—crystals, powders, liquids, acids, oils, organic bodies such as wax, olive oil, wood, beef [fresh and dry], blood, apple and bread—all of which were found to be diamagnetic. 'If a man could be suspended with sufficient delicacy . . . and placed in the magnetic field, he would point equatorially, for all the substances of which he is formed, including the blood, possess this property.'

## XVII

**B**ETWEEN 1840 and 1860 the work of the physicists and chemists of the beginning of the nineteenth century reached its culmination in the doctrine of the Conservation of Energy. The work of Davy and Rumford on heat and of Young and Fresnel on light proved the immaterial nature of these agents. Davy understood heat as a conversion of molar into molecular energy; his work was succeeded by that of Sadi Carnot, who in 1824 demonstrated that a definite quantity of work could be transformed into a definite quantity of heat. The work of Young and Fresnel was followed by that of Fizeau and Leon Foucault who convinced the last sceptics that light was an undulation. In 1837 James David Forbes, a Scotch physicist, showed that radiant heat conformed to the same laws of polarization and double refraction that govern light.

The word *energy*, although used by Young, only gradually creeps into the scientific vocabulary to stand for the common definition of light and heat phenomena. Faraday in his work on electrochemical decomposition had already anticipated the generalization of the inter-convertibility of all forms of energy. The work of Joule and Mayer completed that of Davy and Carnot, and the mechanical equivalent of heat became, as it were, one of the materializations of the abstraction *energy* of which light was

another, and later on Maxwell's electromagnetic theory of light interprets electrical and magnetic phenomena in terms of energy. The use of the conception energy is the characteristic of Science to-day, and with the theory of the electric structure of the chemical atoms we have reached a point which, in certain branches of physics, the formula Energy equals Mass has been found convenient.

It was between 1845 and 1860 that the conceptions on which Faraday's work was based were most discussed by his contemporaries. Faraday's work on electromagnetism had been, from its beginning, the object of the greatest attention to physicists in England and on the Continent. The results of his experiments were admired without qualification, and the letters and honours which he received are the testimony that his work was recognized as contributing to the honour of science in a larger measure perhaps than that of any other man. But it was not until he made the acquaintance of Clerk Maxwell and of the young William Thomson, afterwards Lord Kelvin, that the implications of his refusal to accept action at a distance, with the consequent visualizing of the flow of electricity and the structure of the magnetic field, were realized.

Faraday's own researches, after the discovery of diamagnetism and a long series of experiments on the diamagnetic condition of flame and gases, are devoted more and more to the elucidation of the most typical of his conceptions—the tubes of force, the vibration of rays, the action of magnetism and electricity through the ether. One of the most important series of experiments was that conducted on crystalline structures to find out why, when

suspended in a uniform<sup>1</sup> magnetic field, crystal structures tended to move in a direction perpendicular to their planes of cleavage. 'It appears to me impossible to conceive of the results in any other way than by a mutual reaction of the magnetic force and the force of the particles of the crystal upon each other.' The importance of these experiments lies in a still further realization of the inter-relations of molecular forces and magnetic forces. Such a relationship is, of course, a commonplace to-day when the essential structure of matter is conceived as an arrangement of electric particles—but at that time every relation discovered between molecular force on the one hand and magnetic or electric force on the other was not evidence leading towards an already imagined state. It was only evidence which was gradually forcing acceptance of the darkest and apparently least scientific of the speculations of Faraday.

At the end of his papers on magne-crystallic action he wrote: 'I cannot conclude this series of researches without remarking how rapidly the knowledge of molecular forces grows upon us and how strikingly every investigation tends to develop more and more their importance and their extreme attraction as an object of study. A few years ago, magnetism was to us an occult power, affecting only a few bodies. Now it is found to influence all bodies and to possess the most intimate relations with electricity, heat, chemical action, light, crystallization, and through it with the forces concerned in cohesion. And we may, in the present state of things, well feel urged to continue in our

<sup>1</sup> *I.e.* a magnetic field in which the diamagnetic tendency to move from a strong to a weak point of the field is eliminated.

labours, encouraged by the hope of bringing it into a bond of union with gravity itself.'

As we have mentioned before, Ampère's celebrated definition of magnetism after Oersted's discovery was founded on the idea of action at a distance, an idea accepted by almost all the mathematicians of the time. In a letter written in 1855, Sir George Airy, afterwards Astronomer Royal, very exactly defined and defended his opinion of the mechanical problems raised by Faraday's lines of force. 'I give my opinion without misgiving, as regards the mechanical effects. The effect of a magnet upon another magnet may be represented *perfectly* by supposing that certain parts act just as if they pulled by a string and certain other parts act just as if they pushed with a stick. And the representation is not vague, but is a matter of strict numerical calculation: and when this calculation is made on the simple law of the inverse square of distance, it does [numerically] represent the phenomena with precision. I can answer for this, because we are perpetually making this very calculation . . . I declare that I can hardly imagine anyone who practically and numerically knows this agreement to hesitate an instant in the choice between this simple and precise action on the one hand, and anything so vague and varying as lines of force on the other.'

In a lecture to the Royal Institution in 1852, and in a paper sent to the Royal Society during the same year, Faraday elaborated his conception of lines of force very clearly. In the opening of the twenty-eighth memoir of *Experimental Researches* will be found succinctly his definition and to this memoir the reader is referred. In a letter which he wrote to his friend Matteucci he stated his

views more briefly and generally. 'A physical line of force may be dealt with experimentally without one knowing its intimate physical nature. A ray of light is a physical line of force: it can be proved to be such by experiments made whilst it was thought to be an *emission*<sup>1</sup> and also by other experiments made since it has been thought to be an *undulation*. Its physical character is not proved either by the one view or the other [one of which must be, and both may be, wrong], but it is proved by the *time* it takes in propagation and by its curvatures, inflexions and physical affections. So with other physical lines of force, as the electric current: we know no more of the physical nature of the electric lines of force than we do of the magnetic lines of force: we fancy and we form hypotheses, but unless these hypotheses are considered equally likely to be false as true, we had better not form them; and therefore I go with Newton when he speaks of *the physical lines of gravitating force*. . . . The use of lines of magnetic force as true representations of nature is to me delightful and as yet never failing: and so long as I can read your facts, those of Tyndall, Weber and others by them, I am content to let the erroneous expressions, by which they *seem* to differ, pass unnoticed. It is only when a fact appears that they *cannot* represent that I feel urged to examination, though that has not yet happened.'

The position is admirably summed up in Clerk Maxwell's introduction to his *Treatise on Electricity and Magnetism*, wherein he explained the differences between his work and those published about the same period in

<sup>1</sup> Newton's corpuscular theory of light, abandoned since the work of Young and Fresnel at the beginning of the nineteenth century.

Germany [1870–1875]. ‘ . . . Before I began the study of electricity I resolved to read no mathematics on the subject till I had first read through Faraday’s *Experimental Researches on Electricity*. I was aware that there was supposed to be a difference between Faraday’s way of conceiving phenomena and that of the mathematicians. So that neither he nor they were satisfied with each other’s language. I had also the conviction that this discrepancy did not arise from either party being wrong. I was first convinced of this by Sir William Thomson [Lord Kelvin], to whose advice and assistance, as well as to his published papers, I owe most of what I have learned on this subject.

‘As I proceeded with the study of Faraday, I perceived that this method of conceiving the phenomena was also a mathematical one, though not exhibited in the conventional form of mathematical symbols. I also found that these methods were capable of being expressed in the ordinary mathematical forms, and thus compared with those of the professed mathematicians.

‘For instance, Faraday, in his mind’s eye, saw lines of force traversing all space where the mathematicians saw centres of force attracting at a distance. Faraday saw a medium where they saw nothing but distance. Faraday sought the seat of the phenomena in real actions going on in the medium; they were satisfied that they had found it in a power of action at a distance impressed on electric fluids.

‘When I had translated what I considered to be Faraday’s ideas into a mathematical form, I found that in general the results of the two methods coincided, so that the same phenomena were accounted for and the same laws of action deduced by both methods, but that Fara-

day's methods resembled those in which we begin with the whole and arrive at the parts by analysis, while the ordinary mathematical methods were founded on the principle of beginning with the parts and building up the whole by synthesis.

'I found, also, that several of the most fertile methods of research discovered by the mathematicians could be expressed much better in terms of ideas derived from Faraday than in their original form.

'If by anything I have here written I may assist any student in understanding Faraday's modes of thought and expression, I shall regard it as the accomplishment of one of my principal aims; to communicate to others the same delight which I have found myself in reading Faraday's "Researches".'

Clerk Maxwell's 'Dynamical Theory of the Electromagnetic Field' and his succeeding mathematical developments of the electromagnetic theory of the transmission of light, contains processes of thought which are intuitive and prophetic rather than logical and deductive. The justification for these processes is in their consequences. The dynamical theory of the electromagnetic field is the greatest triumph of Faraday's theoretical speculations. 'The conception of the propagation of transverse magnetic disturbances to the exclusion of normal ones is distinctly set forth by Professor Faraday in his "Thoughts on Ray Vibrations"', and, wrote Maxwell in 1864, 'The electromagnetic theory of light as proposed by him is the same in substance as that which I have begun to develop except that in 1846 there was no data to calculate the velocity of propagation'.



## XVIII

**F**ARADAY was only able to undertake his later experimental work by the very strictest economy and organization of his time and energy. Even immediately after a rest, he had to proceed slowly; he could not always remember from day to day the conclusions he had come to the day before, and everything had to be thought many times over. He was driven to continue working on his experimental researches by the fact that he felt his mind was as clear and as active as ever it had been. The general course of his researches was already developed in his mind—light and magnetism, the magnetic condition of substances, and then, later on, the relations between gravity and electricity; it was a course which followed naturally from the development of his intellectual nature. The last researches on which he was engaged, the search for experimental evidence of a direct relation between gravity and electricity had as their object, like his first electrical experiments on electromagnetic induction, the discovery of the unity of physical forces. Although his nervous energy failed, his mind remained fixed on this object; it often happens otherwise with men of genius, and their failing powers lead them to believe they can attempt something which even in their maturity they would never have attempted, being able to know *then* that it was out of the lines of their natural activity. Only in 1866, the year before

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his death, did his mind show any sign of wandering; one day he fancied that he had made some discovery related to Pasteur's dextro- and lævo-racemic acid, and desired that the traces of it should be carefully preserved, as it might be a 'glorious discovery'.

The contributory cause to his continuing his researches under such great difficulties was the extreme seclusion in which he lived. When not resting at Norwood or at Brighton, or, during the last few years, at the cottage at Hampton Court which the Queen had placed at his disposal, his life was still passed at the Royal Institution, in his rooms at the top of the house, or working in the Laboratory. This seclusion, forced on him in later years by the circumstances of his illness, was, during the first period of his researches, when he definitely abandoned dining out, entirely voluntary. He was by nature extremely sociable, but he would never risk exceeding his powers for fear that in the morning his mind might wander. This seclusion and ordered life preserved the vigour of his mind for many years. Davy, at the age of forty-six, was forced to discontinue his work and died at the age of fifty of paralysis, an extreme form of Faraday's nervous and muscular weakness.

The lectures to the Royal Institution, which he continued to give on Friday nights until 1863, were an additional strain on Faraday's health. The excitement and the success of these lectures stimulated him; he attempted to continue them under the most difficult circumstances. In the Life of Sir Richard Owen there are several memories of Faraday's Friday night lectures. 'Jan. 31 1845. To Faraday's lectures at the Royal Institution. The largest crowd I have ever seen there. Many gentlemen were obliged to

come into the ladies' gallery as they could not get seats elsewhere. After an exceedingly interesting lecture, Faraday said he had a few remarks to make on some new reform laws for the Institution. These remarks were admirably made, and no one could feel offended, although it was a direct attack on those gentlemen who helped to render the ladies very uncomfortable sometimes by filling seats, and often front seats, in the part intended only for ladies. Wearing a hat in the library was one of the delinquencies, likewise sitting in seats reserved for the Directors, who were obliged by their office and duties to be last in. Mr. Faraday also remarked that the formation of two currents caused by certain gentlemen rushing upstairs the instant the lecture was over to fetch their lady friends was not conducive to the comfort of those coming downstairs.' Even in 1849 Faraday's throat was affected by muscular weakness. In this year Sir Richard Owen recorded: '... a crowded audience as usual to hear Faraday's lecture. The poor man entered and attempted to speak, but he was suffering from inflammation or excessive irritation of the larynx, and after some painful efforts to speak, a general cry arose of *Postpone*, and someone apparently in authority made a short speech from the gallery. Mr. Faraday still wished to try and force his voice, saying he was well aware of the difficulty of getting back to the carriages, etc., before the time for the lecture had elapsed, to say nothing of the disappointment to some; but every moment the cry increased, *No, no, you are too valuable to be allowed to injure yourself. Postpone, postpone.*'

In 1870 Lady Pollock contributed to the *St. Paul's Magazine* some memories of Faraday lecturing.

'He would play with his subject now and then, but very delicately; his sport was only just enough to enliven the attention. He never suffered an experiment to allure him away from his theme. Every touch of his hand was a true illustration of his argument. . . . But his meaning was sometimes beyond the conception of those whom he addressed. When, however, he lectured to children he was careful to be perfectly distinct, and never allowed his ideas to outrun their intelligence. He took great delight in talking to them, and easily won their confidence. The vivacity of his manner and of his countenance, and his pleasant laugh, the frankness of his whole bearing, attracted them to him. They felt as if he belonged to them; and indeed he sometimes, in his joyous enthusiasm, appeared like an inspired child. . . . His quick sympathies put him so closely in relation with the child that he saw with the boy's new wonder, and looked, and most likely felt for the moment, as if he had never seen the thing before. Quick feelings, quick movement, quick thought, vividness of expression and of perception, belonged to him. He came across you like a flash of light, and he seemed to leave some of his light with you.'

Faraday had learnt a great deal about how and how not to lecture during his first months at the Royal Institution. He had not wasted time in clarifying his opinions on this subject by means of long letters to Abbott. The principles he expressed in those letters were the mainspring of his success as a lecturer. He always found time to rehearse the experiments he was going to show during the lecture; he chose these experiments very carefully—they were to illustrate the salient points of the deductions he wished to emphasize; they were not to be *tours de force* but were

to be as vivid as possible. It is always better, he thought, to demonstrate a physical fact rather than to describe it in words; this both for adult audiences as well as for children. To a young lecturer he remarked, 'If I said to my audience *This stone will fall to the ground if I open my hand*, I should open my hand and let it fall'. Amongst the rules found in his manuscript note-book were the following: Never to repeat a phrase, never to go back to amend, if at a loss for a word not to *ch-ch-ch* or *eh-eh-eh*, but to stop and wait for it!

In the early days of his lectures he used to have a card in front of him with 'Slow' written upon it in distinct characters. Sometimes he had the word 'Time' on a card brought forward when the hour was nearly expired.

He knew very well that the attention of the audience must be held from the start, and he was aware how easily that attention is lost or strained by anything too difficult. He began simply; he very often got far beyond the understanding of his audience, but not their interest; he never destroyed the sense in the audience that what he was saying was being said for them, that the difficulties would be elucidated. And this always happened, for, at the close of his lectures, it was as necessary to himself as to the audience that the limits of his thoughts should be defined and should be related to other aspects of human truth. 'Nothing can give a notion', wrote his friend de La Rive, 'of the charm which he imparted to these improvised lectures. He exerted an actual fascination upon his auditors, and when, after having initiated them into the mysteries of science, he terminated his lecture, as he was in the habit of doing, by rising into regions far above matter, space and time, the

emotion which he experienced did not fail to communicate itself to those who listened to him, and their enthusiasm had no longer any bounds.'

In 1854 he gave his lecture on Mental Education, from which the expression of the distinction Faraday drew between scientific knowledge and the tenets of his religion has been quoted. In the course of this lecture he dealt at some length with the various forms of *Spirit* manifestation which were then attracting public attention; and he deplored the credulity which accorded serious attention to the mechanism of table-turning and other such tricks of legerdemain. Faraday took some part in the public discussion of such phenomena, because the effect produced by table turners had been referred to electricity, to magnetism and sometimes to some undiscovered physical power. He was probably quite indifferent to the mentality which ascribed such effects to a supernatural agency; but he did not wish that the natural sciences should be connected, however hastily, and by minds however ignorant and assuming, with investigations in which scientific methods were not pursued. He was for a long while afterwards pestered by letters, both from believers in the scientific and in the spiritual origin of table-turning. A letter of his, written in 1864, to a gentleman who had several times importuned him is rather amusing:

'Sir—I beg to acknowledge your letter of the 3rd, but I am weary of the spirits—all hope of any useful result from investigation is gone; but as some persons still believe in them, and I continually receive letters, I must bring these communications to a close. Whenever the spirits can counteract gravity or originate motion, or supply an action

due to natural physical force, or counteract any such action; whenever they can punch or prick me, or affect my sense of feeling or any other sense, or in any other way act on me without my waiting on them; or working in the light can show me a hand, either writing or not, or in any way make themselves visibly manifest to me; whenever these things are done or anything which a conjuror cannot do better; or, rising to higher proofs, whenever the spirits describe their own nature, and like honest spirits say what they can do, or pretending, as their supporters do, that they can act on ordinary matter whenever they initiate action, and so make *themselves* manifest; whenever by such-like signs they come to me, and ask my attention to them, I will give it. But until some of these things be done, I have no more time to spare for them or their believers, or for correspondence about them. . . .'

Between 1846 and the last years of his life Faraday maintained a correspondence with Professor Schonbein, of Bâle. Faraday was very interested in Schonbein's work on ozone, and spared no efforts to present it with success at the Royal Institution. The correspondence has a melancholy interest in that it gives an account of the struggles Faraday had to make against his illness. He had spent some time with Schonbein and his family at Bâle and at the end of a letter written in 1850 he regrets how little he can remember of what has pleased him, '. . . Vaguely I cling to the remembrance of an hour or two out of Bâle at your house, and though I cannot recall the circumstances clearly to my mind, I still endeavour again and again to realize the idea.'

In Brighton during the same year, he wrote, 'It will be

very strange if I do not make your subject interesting. I have gone twice through the MS. and the illustrations. Both are beautiful.' He hangs out of his window the ozonometer strips, and rejoices to see the tint of blue come out from the sea air. He walks on the seashore holding a piece of test paper in his hand for a quarter of an hour, and at the end of that time the blue effect appears again. He cannot resist writing at once to tell Schonbein about this.

In 1853 he began a letter: 'My dear Schonbein—I believe it is a good while since I had your letter, but consider my age and weariness and the rapid manner in which I am becoming more inert, and forgive me'.

He has a great admiration for Schonbein, for his work and for his character. 'Your letters stimulate me by their energy and kindness to write, but they also make me aware of my inability. . . . And so you must accept the manifestation of old affection and feeling in any shape that it may take, however imperfect.' In 1855 he wrote: 'My dear friend—I have brought your letter here that I might answer its great kindness at some time when I could remember quietly all the pleasure I have had since I first knew you. I say remember it all, but that I cannot do, for as a fresh incident creeps into view I lose sight of the old ones, and I cannot tell how many are forgotten altogether. . . . I feel I have pretty well worked out my stock of original matter, and have power to do little more than reconsider old thoughts. A friend of mine will in the course of a month or two put a paper of mine in your way. You will therein perceive I am as strong as ever in the matter of lines of magnetic force and a magnetic medium, and what is more, I think that men are beginning to look



more closely to the matter than they have done heretofore. My own convictions and expectations increase continually; *that* you will say is because I have become more and more familiar with the idea. It may be so and in some manner *must* be so; but I always tried to be very critical on myself before I gave anyone else the opportunity, and even now I think I could say much stronger things against my notions than anybody else has.'

In 1856 he suffered very continuously from headaches, and his letters to Schonbein and to de La Rive are short. He is worried about the lecture he is to give on ozone in 1858. 'Daily and hourly am I thinking about you and yours and with as unsatisfactory result as it is possible for me to have. I think about ozone, about antozone, about the experiments you showed to Dr. Bence Jones, about your peroxide of barium, your antozonised oil of turpentine, and it all ends in a giddiness and confusion of the points that ought to be remembered. I want to tell our audience what your last results are upon this most beautiful investigation, and yet am terrified at the thought of trying to do so, from the difficulty of remembering from the reading of one letter to that of another what the facts in the former were. I have never before felt so seriously the evil of loss of memory and of clearness in the head; and though I expect some day to fail at the lecture table . . . I should not like to fail at ozone or in anything about you.'

In 1860 he wrote a very touching letter to Schonbein—

'MY DEAR SCHONBEIN—It seems to me a long time since we have spoken together, and I know that the blame is mine, but I cannot help it, only regret it, though I can

certainly try to bring the fault to an end. When I want to write to you it seems as if only nonsense would come to mind, and yet it is not nonsense to think of past friendship and dear communions. When I try to write of science, it comes back to me in confusion; I do not remember the order of things, or even the facts themselves. I do not remember what you last told me, though I think I sent it to the *Phil. Mag.* and had it printed; and if I try to remember, it becomes too much, the head gets giddy, and the mental view only the more confused. I know you do not want me to labour in vain, but I do not like to seem forgetful of what you tell me, and the only relief I have at such times is to arrest myself, and believe that you will know the forgetfulness is *involuntary*. After all, though your science is much to me, we are not friends for science only, but for something better in a man, something more important in his nature—affection, kindness, good feeling, moral worth; and so in remembrance of these, I now write to place myself in your presence . . .

‘We are all pretty well here. We get on well enough, in a manner, and are very happy, and I cannot wish you better things; though I have no intention, when I say that, to imagine you without your memory or your science. Long may you be privileged to use them, for the good of human nature.’

In 1865, the following note to Schonbein ended this correspondence: ‘Again and again I tear up my letter, for I write nonsense. I cannot spell or write a line continuously. Whether I shall recover—this confusion—do not know. I will not write any more to you. My love to you.’

## XIX

IN 1861, Faraday had been obliged to give up the Juvenile Lectures, thus relinquishing all duties for the Royal Institution but those of Superintendent of the House. In October of that year he wrote to the Managers of the Royal Institution: 'It is with the deepest regret that I address you. I entered the Royal Institution in March 1813, nearly forty-nine years ago, and, with the exception of a comparatively short period during which I was abroad with Sir H. Davy, have been with you ever since. During that time, I have been most happy in your kindness, and in the fostering care which the Royal Institution has bestowed upon me. Thank God first for all his gifts. I have next to thank you and your predecessors for the unswerving encouragement and support which you have given me during that period. 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 that for me 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

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spirits and cheerfulness do not diminish with them. Still I am not able to do as I have done. . . .’

The Managers requested him to perform only such duties as he felt fitted for, and in 1865, at Faraday’s own request, reiterated their desire that he should continue to make his home at the Royal Institution, and in the words of the Resolution, ‘They beg that he will undertake only so much of the care of the house as may be agreeable to himself: and that whilst relinquishing the duties of Director of the Laboratory, he will retain his home at the Institution’.

During the last years of his life he spent a great deal of his time at Hampton Court. It was there that he wrote, in the Commonplace Book of one of his nieces, the following very characteristic description:

‘This Whit Monday will be long remembered among Hampton Court holiday folk. The wind from the west was very strong, so as to blow down and break trees, displace nests, tear off the mistletoe from the limes, and that whilst the sports were going on. Sunshine and rain alternated, but the rain was only in showers, though some of these were heavy. In the morning, a tree upon the right at the entrance of Bushy Park was blown up by the roots, but clinging at the trunk on one side, it swerved in its fall, and coming against another tree, sheared off all its large branches on one side, and covered the ground with a sad ruin of bright green leaves, fresh horse-chestnut flowers and fragmented stems, the broken ends of which hung very white and fresh, and shone forth like pearls amongst the green and flowery setting. When we saw it about 12 o’clock, multitudes of visitors were climbing into, over, and about it, some were gathering flowers, others a stick, others

wandering in and out and under the branches, hiding themselves amongst the leaves. Some of these people had heard and seen it fall. In the afternoon, we went again to look at the tree, and then to see into what a state the people had brought it. Its glory was low before; but now to see how it was abased! All the flowers gone; such stem parts as had projected into the air had served for horses as long as they could bear the weight added to them, and now were broken down. In the morning, it was a beautiful ruin, and, with the people among it, would have made a fine picture; now it was a degraded and almost formless heap. And behold another tree on the left-hand side of the gate, as large as the former, has been blown down, happily without injury to anyone. The tree snapped off short about eight feet from the ground; in its fall it also treated a neighbouring tree very sadly, and together they made a sad heap of ruins. Besides these trees, great branches were lying about under other trees in all parts. The corner tree on the right of our house on the green had a very large branch torn off; so also had another tree on the green, towards the west and north-west part. . . . I was in and out much. Margery also rambled; altogether it was a day to be remembered.'

In 1864, he wrote from Hampton Court to Tyndall, who, in Faraday's presence, had been sometimes censured for the risks he had taken in various Alpine climbing expeditions. Faraday's constant reply had been, 'Let him alone, he knows how to take care of himself'. In the letter below, anxiety on this score reveals itself for the first time:

'MY DEAR TYNDALL—I do not know whether my letter will catch you, but I will risk it, though feeling very unfit

to communicate with a man whose life is as vivid and active as yours: but the receipt of your kind letter makes me to know that, though I forget, I am not forgotten, and though I am not able to remember at the end of a line what was said at the beginning of it, the imperfect marks will convey to you some sense of what I long to say. We have heard of your illness through Miss Moore, and I was, therefore, very glad to learn that you are now quite well: do not run too many risks or make your happiness depend too much upon dangers, or the hunting of them. Sometimes the very thinking of you wearies me with fears, and then the cogitations pause and change but without giving me rest. I know that much of this depends upon my own worn out nature, and I do not know why I write it. . . . See what a strange desultory epistle I am writing to you, and yet I feel so weary that I long to leave my desk and go to the couch. . . . I forget—but not you my dear Tyndall. . . .’

As he sat in his study looking out of the window at the Green, a visitor asked him how he was. ‘Just waiting’, he replied. He died in the afternoon of the 25 August 1867. Miss Jane Barnard wrote to Dr. Bence Jones: ‘Our cares are over; our beloved one is gone. He passed away from this life quietly and peacefully yesterday afternoon. Almost immediately after you saw him, a little more than a fortnight ago, he became weaker and has said very little to us or taken much more notice of anything from that time; but still we did not expect the change until an hour or two before it happened. He died in his chair, in his study; and we feel we could desire nothing better for him than what has occurred.’

THE writer of this biography has several times referred to Dr. Bence Jones and to Professor Tyndall, and he wishes to acknowledge his indebtedness to the former's *Life of Faraday* and to the latter's *Faraday as a Discoverer*. Professor Tyndall, whose work on radiant heat, on the magnetic condition of gases and on diamagnetism in general, forms one of the most important contributions to physics of the nineteenth century, was peculiarly qualified to make the first general description of Faraday's experimental researches. That Tyndall overlooked certain aspects of Faraday's work, in particular his theory of ray vibrations, about which he contented himself with saying that it was 'one of the most singular speculations that ever emanated from a scientific man', and that he often questioned the value of some of Faraday's hypotheses which have since proved extremely fertile, in no way detracts from the permanent value of his book. *Faraday as a Discoverer*, which first appeared the year after Faraday's death, has the freshness and vigour only possessed by writing done under the direct influence of emotion. Clerk Maxwell was the man who can be truly called the successor to Faraday and whose mind had the clear capacity for visualizing ideas seemingly far from material realization; Tyndall was one of the two or three most intimate friends of Faraday, in close contact with his work and with the processes of his thought and

who knew him as a man. 'His principal researches', wrote Tyndall, 'are all connected by an undercurrent of speculation. Theoretic ideas were the very sap of his intellect—the source from which all his strength as an experimenter was derived. While once sauntering with him through the Crystal Palace at Sydenham I asked him what directed his attention to the magnetization of light. It was his theoretic notions. He had certain views regarding the unity and convertibility of natural forces; certain ideas regarding the vibrations of light and their relations to the lines of magnetic force: these views and ideas drove him to investigation. And so it must always be; the great experimentalist must ever be the habitual theorist, whether or not he gives to his theories formal enunciation. . . . Faraday was more than a philosopher; he was a prophet and often wrought by an inspiration to be understood by sympathy alone. The prophetic element in his character occasionally coloured and even injured the man of science, but subtracting that element, though you might have conferred on him intellectual symmetry, you would have destroyed his motive force.'

The method Dr. Bence Jones pursued was to select from Faraday's letters, notebooks and scientific publications those fragments which in chronological order best presented a complete picture of his life and his work. The result has been a book which is and will remain the guide to the admirers of Faraday.

In the preface to his *Life of Faraday*, Dr. Bence Jones wrote: 'To write a life of Faraday seemed to me at first a hopeless task. Although I had listened to him as a lecturer for thirty years and had been with him frequently for up-



wards of twenty years, and although for more than fifteen years he had known me as one of his most intimate friends, yet my knowledge of him made me feel that he was too good a man for me to estimate rightly, and that he was too great a philosopher for me to understand thoroughly. I thought that his biographer should if possible be one who was his own mental counterpart.'

There are very few men's lives that could adequately be told by selection from their private letters and opinions. We live with our own illusions and rare is the man who is accepted by posterity, whether posterity is a world-wide audience or a generation of private friends and relations, in his own terms. Faraday, however, is such a man. His life and its actions provide no ground for interpretation in terms other than those he employed. His exceedingly simple and unquestioning belief in the tenets of his religion appears strange in a man whose life was passed in the exercise of intellectual discrimination. Yet his religious beliefs were never held as a *conscious* means of simplifying his mental powers; they were a sublimation of that part of his nature which could otherwise have harmed the exercise of those powers.

There is no key to Faraday's life, no isolated grouping of thought and action in the form of a conflict to drive him to work for relief from that conflict. Everything in his life—his birth, his religion, his marriage appear as expressions of a great and simple nature. The reason Faraday as an old man retained the fresh enthusiasm, the simplicity and kindness of his youth was because, in the midst of every kind of intellectual and social triumph, his nature did not change nor acquire qualities or defects alien to it.

And in the crowning expression of his life, the discovery of the fundamental laws of electromagnetism, the experimental philosopher is inseparable from the visionary. He had no need to turn his mind into a passionless instrument; he perceived the human elements of imagination and intuition in the laws and phenomena he investigated.

*This Book was written by E. W. Ashcroft*  
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# FARADAY CENTENARY CELEBRATIONS

SEPTEMBER 1931

IN 1831 Michael Faraday made the discovery of electromagnetic induction in which lies the origin of the dynamo and the starting point of the utilization of electric power. The Celebrations are to be held on the hundredth anniversary of this discovery, and the lead in their arrangement has been taken by the Royal Institution.

It was to the House of the Institution in Albemarle Street that Faraday came in 1813, a youth of twenty-two, to become assistant to Sir Humphry Davy, where later he succeeded Davy, and where he lived and worked and gave his famous lectures throughout his active life. Faraday took up the work begun by Davy, and established in the Institution the tradition of scientific research and exposition of the highest type which has been followed in it down to the present day.

It is no less fitting that the Royal Institution should have, in the arrangements for 1931, the assistance of the Institution of Electrical Engineers, the body representing in this country the profession and industry which owe their existence largely to Faraday's greatest discovery. The two institutions have therefore joined forces in making the plans, and they are indebted to a number of other societies and organisations for their courtesy and cooperation. The Royal Society will entertain the delegates to the Celebrations; the British Association for the Advancement of Science has arranged the dates for its Centenary meeting in London, also in 1931, in consultation with the Joint Committee for the Faraday Celebrations; the Federal Council for Chemistry will participate in the arrangement of the Faraday Exhibition, for Faraday's chemical researches, his isolation of benzene and his establishment of the laws of electrochemistry, are hardly less remarkable than his purely electrical discoveries. Government, university, and scientific interests have joined in offering their cooperation and assistance to make the celebrations worthy of the occasion.

The principal responsibility for the arrangement of the Faraday Exhibition has been undertaken by the Institution of Electrical Engineers. The central feature of the Exhibition, which will be held at the Royal Albert Hall, will be reproductions and illustrations of Faraday's actual experiments, prepared by the Royal Institution, and including a display of some of the historic apparatus.