had completed by 1826.

With the exception of *Chemical Manipulation*, all of Faraday's books had previously appeared in the periodical literature or else were transcriptions of public lectures. Like many another text, it arose out of a course, this one given at the Royal Institution as William Jensen describes in his "Michael Faraday and the Art and Science of Chemical Manipulation". Faraday had plans for a new edition of *Chemical Manipulation* and as a former bookbinder he prepared an interleaved copy that he annotated with new material. This copy is now the proud possession of Sydney Ross who describes his treasure in "The Chemical Manipulator". Ross is also the author of "Unpublished Letters of Faraday and Others to Edward Daniel Clarke", interesting examples of the minutiae, then as now, of scientific life. For chemists Faraday's crowning achievement was the enunciation of the law(s) of electrolysis, as described in John Stock's "The Pathway to the Laws of Electrolysis". The final paper, "From Electrochemical Equivalency to a Mole of Electrons: The Evolution of the Faraday" by Marcy Hamby Towns and Derek Davenport, was first presented at a Workshop for Teachers held during the Great Lakes Regional Meeting of the American Chemical Society in Indianapolis in late May. It is directed more at teachers of chemistry than at historians of chemistry but it may serve to illustrate a firmly held belief that history is too important to be left entirely to the historians.

Acknowledgements: Several years ago The Camille and Henry Dreyfus Foundation, Inc., was one of the principal donors when Faraday's basement laboratory at the Royal Institution was converted into the wonderfully elaborative Faraday Museum. Their fealty to Faraday was again manifested with the award in 1990 of a special grant in the chemical sciences that helped to underwrite this symposium and to make possible the production of this bumper issue of the *Bulletin*. Thanks are also due to the Petroleum Research Foundation of the American Chemical Society for providing travel support for two of our visitors from England.

Derek A. Davenport, Purdue University

THE ROYAL INSTITUTION & MICHAEL FARADAY: A PERSONAL VIEW

John Meurig Thomas, Royal Institution of Great Britain

Having lived and worked for five years in Michael Faraday's home and laboratory, my initial interest in, and curiosity about, the great scientist has developed into a passionate admiration for all that he stood for and achieved (1). His scientific and spiritual presence at the Royal Institution confers a unique aura that pervades the whole place. One cannot escape it. Whenever I stand at the lecturer's desk, where Faraday stood on more than a 1000 occasions, and where Davy, Dewar, Young, Rayleigh, Rutherford, Arrhenius, Cannizarro, Mendeleev, Hoffmann, Bridgman, Lawrence and William Bragg, and Pauling have also stood, Wordsworth's reference to "the spiritual presence of absent friends" comes to mind.

Young Michael Faraday

No chemist (organic, physical, analytical, surface or electro-), no physicist, no engineer or materials scientist is unaware of Faraday's towering contributions to their subject. No experimentalist has ever bequeathed to posterity a greater body of pure scientific achievement than Faraday and the practical consequences of his discoveries have profoundly influenced the very nature of civilized life. Yet he was self-taught: he left school at the age of 12, and started his career as an errand boy, then as a bookbinder. He rose to be one of the greatest scientists of the age. At the same time, he remained morally incorruptible and throughout his life retained his boyish sense of awe and humility. In reading his work, just as in contemplating his astonishing range of accomplishments, we are conscious of the presence of a unique human being (2):

> Nothing is too wonderful to be true, if it be consistent with the laws of nature and, in such things as these, experiment is the best test of such consistency.

In none of his 450 publications is there a single differential equation, for he knew no mathematics. But, according to Albert Einstein, Faraday was responsible, along with Clerk

Maxwell, for the greatest change in the theoretical basis of physics since Newton.

The story of Faraday's life speaks to us across the years, and its romance bears repetition to every generation. Who was this man? What were his precise contributions? And why is it that no name stands higher in the general esteem of scientists the world over than that of Faraday? In the definitive biography of Faraday by L. Pearce Williams these questionsand others are answered in great detail (3). In a more recent, less comprehensive analysis, I have endeavoured to weave the genius of Faraday the man with that of the place where he lived for nearly 50 years and where he worked for a somewhat longer period - the Royal Institution (4). Fresh light on the private, public and religious life, as well as the scientific work, of Faraday continues to be shed (5, 6). These complement a number of classic, earlier studies, dating from the fascinating and elegant survey of *Faraday as a Discoverer* (7) by his contemporary and successor, John Tyndall, and the *Life and Letters of Michael Faraday* (8) by his friend, the eminent contemporary physician, H. Bence Jones, who was Secretary of the Royal Institution from 1860 to 1873.

It is convenient to enumerate Faraday's contributions under two somewhat arbitrary headings: chemistry on the one hand, and electricity and magnetism on the other (see Tables 1 and 2). These enumerations reflect the vast extent of Faraday's canvas and cogently exemplify the interdisciplinary nature of his pursuits. Little wonder that the Faraday Society (now the Faraday Division of the Royal Society of Chemistry) was set up to explore the territory between well-established divisions of natural philosophy. No one has more brilliantly investigated the interfacial regions separating existing disciplines than did Michael Faraday.

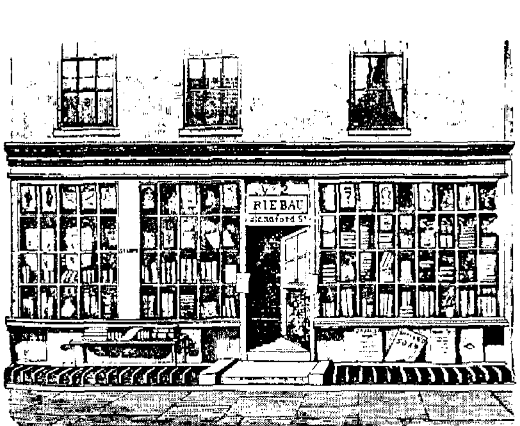
Vast as the subject matter encompassed by Tables 1 and 2 is, it is somewhat paradoxical that the enumerations therein tend to conceal the really major breakthroughs that Faraday made. It has often been said that, had there been Nobel prizes in Faraday's day, he would have won at least six! The citations could well have been for the:

* Discovery of electromagnetic induction which, along with his earlier related work on the relationship between electricity and magnetism, brought forth the first transformer, dynamo and electric motor.

* Laws of electrolysis, which rank among the most accurate generalizations in science. (These led, through the subsequent work of Johnstone Stoney, Helmholtz and J. J. Thomson, to the realization that matter is electrical in nature. They also led to the idea of ions, electrodes, electrolytes - all terms that Faraday, along with his polymathic Cambridge friend, Whewell, coined - and to electrodeposition, electroplating, coulometry and electrochemical analysis).

* Discovery of the magnetic properties of matter and the foundation of magnetochemistry (the terms paramagnetism and diamagnetism; paramagnetism of oxygen gas).

* Discovery of benzene and his analysis of its composition. (Faraday was as much the founder of the chemical - certainly the dyestuffs and explosives - industry as of the electrical power generation and electroplating industries. Table 3 summarizes the set of compounds intimately associated with



Riebau's book store where Faraday worked as an apprentice.

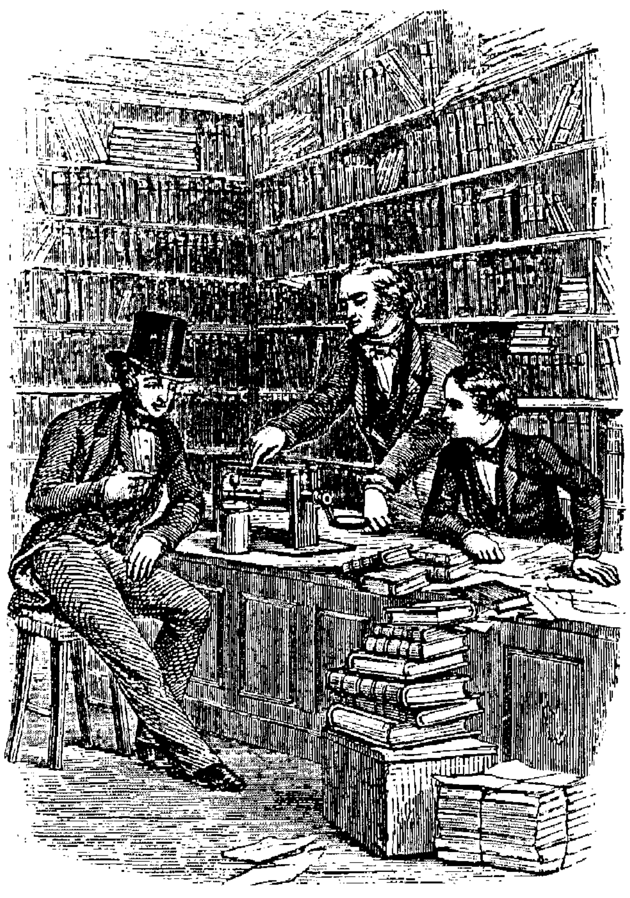
Table 1. Faraday's principal contributions to chemical science.

1816	(With Davy) Evolution of miners' safety lamp.
1818-24	Preparation and properties of alloy steels (study of Indian Wootz). Metallography.
1812-30	Analytical chemistry. Determination of purity and composition of clays, native lime, water, gunpowder, rust, dried fish, various gases, liquids and solids.
1820-26	Organic chemistry. Discovery of benzene, isobutene, tetrachloroethene, hexachlorobenzene, isomers of alkenes and of α and β napthalenesulphonic acids, vulcanization of rubber. Photochemical preparations.
1825-31	Improvements in the production of optical grade glass.
1823& 1845	Liquefaction of gases (H_2S, SO_2 and six other gases). Recognized existence of critical temperature and established reality of continuity of state.
1833-36	Electrochemistry and the electrical properties of matter. Laws of electrolysis. Equivalence of voltaic, static, thermal and animal electricity. First example of thermistor action. Fused salt electrolytes, superionic conductors.
1834	Heterogeneous catalysis. Poisoning and inhibition of surface reactions. Selective adsorption. Wettability of solids.
1835	"Plasma" chemistry and the magnetic properties of matter. Magneto-optics. Faraday effect. Diamagnetism. Para-magnetism. Anisotropy.
1857	Colloidal metals. Scattering of light. Sols and hydrogels.

Faraday's work as an organic chemist).

* Discovery of the Faraday effect (the rotation of the plane of polarization of light by a magnetic field) and for laying the foundations of magneto-optics.

* Introduction of the notion of a field. (Unlike his contemporary scientists, Faraday refused to be guided solely by the mathematical precision of Coulomb's law in interpreting the forces between charges. He reflected deeply upon what occurred in the intervening space. This led him, in turn, to discover induction, inductive capacity and permittivity. He also convinced himself that the energy of a magnet could extend beyond the perimeter of the magnet itself).



An imaginative 19th-century reconstruction of Faraday's first experiments with electricity while still a bookbinder's apprentice.

Einstein is said to have kept a portrait of Faraday on the wall of his study. How appropriate, for it was Faraday who served as the pioneer and prophet of the grand revision that made Einstein's work possible. Many chemists - fewer physicists! - are unaware of the major theoretical impetus provided by Faraday. They tend to think of him largely as the experimental genius that he undoubtedly was, a man for whom the primacy of experiment always took precedence over speculation. Chemists are also unaware of the role that Faraday played in laying the foundation of the technology of the modern world.

Table 2. Faraday's principal contributions to physical science.

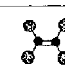
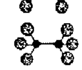
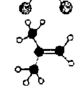
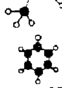
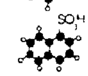
1821	Electromagnetic rotations.
1831	Electromagnetic induction. Acoustic vibrations.
1832	Identity of electricities from various sources.
1833	Electrolytic decompositions.
1835	Discharge of electricity through evacuated gases. (Plasma physics and chemistry.)
1836	Electrostatics. Faraday cage.
1845	Relationship between light, electricity and magnetism; diamagnetism; paramagnetism.
1846	"Thoughts on ray vibrations".
1849	Gravity and electricity.
1857	Time and magnetism.
1862	Influence of a magnetic field on the spectral lines of sodium. Lines of force and the concept of a field. The energy of a magnet lies outside its perimeter. The notion that light, magnetism and electricity are interconnected.

To his numerous gifts as an experimentalist and theorist, Faraday possessed two other talents that set him apart from most other scientists (9). First, his published papers are masterpieces of lucidity, self-criticism and insight, and conjure up a sense of perspective that is rather rare in the writings of chemists and physicists. Second, he believed passionately in the importance of conveying the essence of science to lay audiences and to young children. A few examples will suffice.

Faraday begins his classic paper "On the Magnetization of Light and the Illumination of Magnetic Lines of Force", which he wrote on 5 November 1845, thus (10):

> I have long held an opinion, almost amounting to conviction, in common I believe with many other lovers of natural knowledge, that

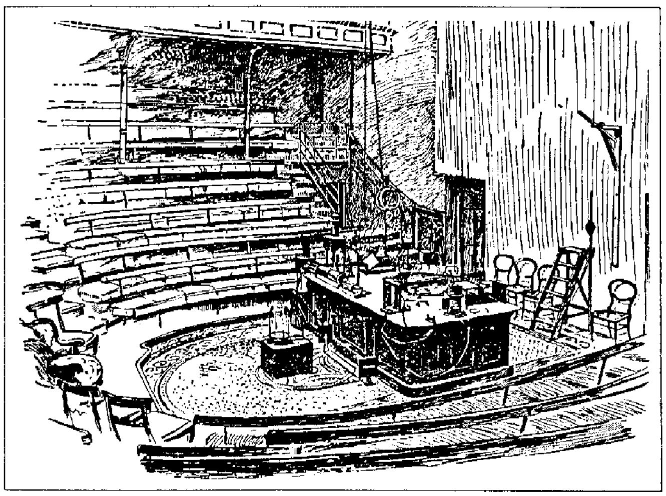
Table 3. The compositional and structural formulas of substances discovered by Faraday.

Substance	Chemical Formula	Structural Formula
C_2Cl_4	Tetrachloroethylene (Tetrachloroethene)	
C_2Cl_6	Hexachloroethane	
$(CH_2)_4$	Isobutylene (Isobutene)	
C_6H_6	Bicarburet of Hydrogen (Benzene)	
$C_{10}H_7SO_3H$	Naphthalene Sulphonic Acid	

the various forms under which the forces of matter are made manifest have one common origin; or, in other words, are so directly related and mutually dependent, that they are convertible, as it were, one into another, and possess equivalents of power in their action. In modern times the proofs of their convertibility have been accumulated to a very considerable extent, and a commencement made of the determination of their equivalent forces.

Faraday expressed the view that evening lectures, of the kind introduced by him at the Royal Institution in 1826 - the famous Friday Evening Discourses - should amuse and entertain as well as educate, edify and, above all, inspire. This is the principle that continues to inspire the Royal Institution's numerous educational activities, especially the Christmas Lectures, which were also introduced by Faraday in 1826, and given by him on 19 occasions.

The most famous series of Christmas Lectures remains those given by Michael Faraday on *The Chemical History of a Candle*. (Japanese translations of this book have run to over 70 editions.) In his opening remarks in the first of his six lectures, Faraday spoke to the multitude of children assembled in the theatre of the Royal Institution in December, 1860 thus (11):

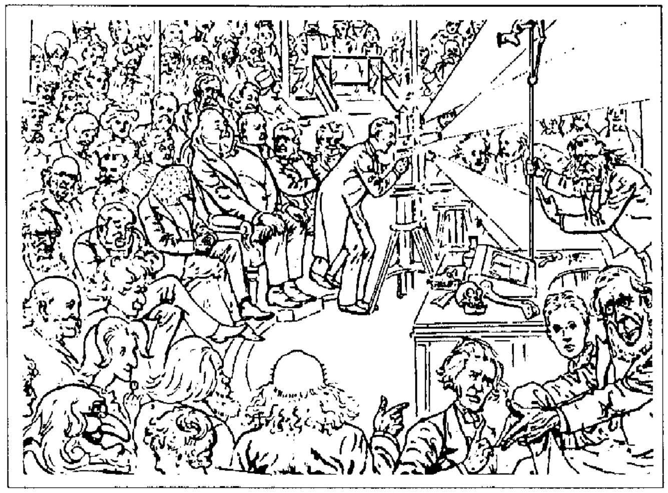


A late 19th-century etching of the main lecture hall at the Royal Institution.

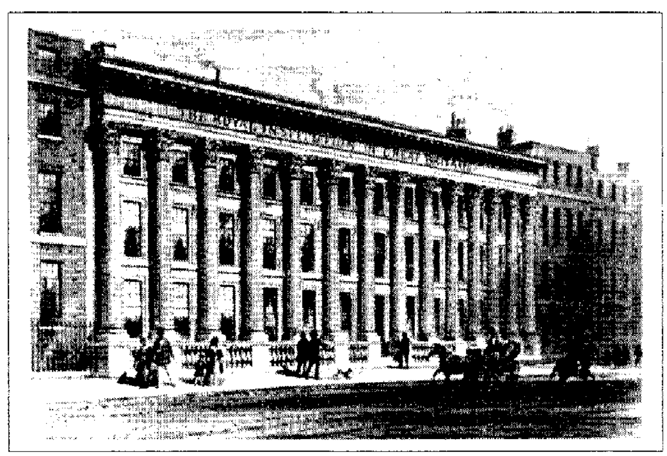
I have taken this subject on a former occasion; and were it left to my own will, I should prefer to repeat it almost every year - so abundant is the interest that attaches itself to the subject, so wonderful are the varieties of outlet which it offers into the various departments of philosophy. There is not a law under which any part of this universe is governed which does not come into play, and is touched upon in the phenomena. There is no better, there is no more open door by which you can enter into the study of natural philosophy, than by considering the physical phenomena of a candle. I trust, therefore, I shall not disappoint you in choosing this for my subject rather than any newer topic, which could not be better, were it even so good.

And before proceeding, let me say this also - that though our subject be so great, and our intention that of treating it honestly, seriously, and philosophically, yet I mean to pass away from all those who are seniors amongst us. I claim the privilege of speaking to juveniles as a juvenile myself. I have done so on former occasions - and, if you please, I shall do so again. And though I stand here with the knowledge of having the words I utter given to the world, yet that shall not deter me from speaking in the same familiar way to those whom I esteem nearest to me on this occasion.

And now, my boys and girls, I must first tell you of what candles are made. Some are great curiosities. I have here some bits of timber,



A cartoon by Harry Furniss depicting some of the famous scientists who have lectured at the Royal Institution. Faraday and John Tyndall are in the immediate foreground while Thomas Huxley holds forth at the lecture desk.



Exterior of the Royal Institution in 1838.
(From an etching by Thomas S. Sheppard)

branches of trees particularly famous for their burning. And here you see a piece of that very curious substance taken out of some of the bogs in Ireland, called candle-wood, - a hard, strong, excellent wood, evidently fitted for good work as a resister of force, and yet withal burning so well that where it is found they make splinters of it, and torches, since it burns like a candle, and gives a very good light indeed. And in this wood we have one of the most beautiful illustrations of the general nature of a candle that I can possibly give. The fuel provided, the means of bringing that fuel to the place of chemical action, the regular and gradual supply of air to that place of action - heat and light - all produced by a little piece of wood of this kind, forming, in fact, a natural candle.

At the end of his sixth and last lecture he said (12):

All I can say to you at the end of these lectures (for we must come to an end at one time or other) is to express a wish that you may, in your generation, be fit to compare to a candle; that you may, like it, shine as lights to those about you; that in all your actions, you may justify the beauty of the taper by making your deeds honourable and effectual in the discharge of your duty to your fellow men.

These words, and those that follow them, along with the elegant sequence of simple experiments described by Faraday in the written version of his Christmas Lectures have made *The Chemical History of a Candle* a classic in the annals of science. The Preface, composed with much felicity for a later edition by William Crookes (1832-1919), a prominent member and active participant in the affairs of the Institution (and President of the Chemical Society), adds to the charm (13):

From the primitive pine-torch to the paraffin candle, how wide an interval! Between them how vast a contrast! The means adopted by man to illuminate his home at night, stamp at once his position in the scale of civilisation. The fluid bitumen of the far East, blazing in rude vessels of baked earth; the Etruscan lamp, exquisite in form, yet ill adapted to its office; the whale, seal, or bear fat, filling the hut of the Esquimaux or Lap with odour rather than light; the huge wax candle on the glittering altar, the range of gas lamps in our streets, - all have their stories to tell. All, if they could speak (and, after their own manner, they can), might warm our hearts in telling, how they have ministered to man's comfort, love of home, toil, and devotion.

Apart from his astonishing range of discoveries, at least four other factors have helped to make Faraday immortal. First, he wrote and spoke about his work in memorable ways. Second, he recorded everything that he observed experimentally at the time of the observation. (His diaries (14) reveal that he invariably recorded the key points of each experiment; he also had the habit of writing up his work promptly for publication. 'Work, finish, publish' was one of his mottos!) Third, almost all the successful experiments that he carried out he proceeded to refine, with a view to demonstrating them publicly at Discourses in the Royal Institution. They were intended to leave an indelible impression and in this he succeeded triumphantly. Last, he had the good fortune to have as one of his interpreters one of the greatest physicists since Newton - J. Clerk Maxwell. Maxwell selected "Faraday's Lines of Force" as the title of his brilliant paper delivered to the Cambridge Philosophical Society in December 1855 and February 1856, when he was a 24-year old Fellow of Trinity College, Cambridge (15). With that monumental work, mathematical precision and quantitative prediction were added to Faraday's qualitative views on field theory in general and to electromagnetism in particular. With this event a new era dawned.

References and Notes

1. This paper is an abbreviated version of a lecture given at the American Chemical Society "Faraday Symposium", April 1991. An extended version of the author's views on this theme has recently been published as reference 4. Copies may be obtained in North America from The American Institute of Physics, c/o AIDC, 64 Depot Road, Colchester, VT 05445, USA.

2. T. Martin, ed., *Faraday's Diary, (1820-1862)*, 7 Vols., Bell, London 1931-1936, Entry for 19 March 1849, Vol. 5, p. 152.

3. L. P. Williams, *Michael Faraday, A Biography*, Chapman and Hall, London, 1965.

4. J. M. Thomas, *Michael Faraday and The Royal Institution: The Genius of Man and Place*, Adam Hilger, Bristol, 1991.

5. G. A. Cantor, *Michael Faraday: Sandemanian and Scientist*, Macmillan, London, 1991.

6. B. Bowers, *Michael Faraday and the Modern World*, EPA Press, Saffron Walden, England, 1991.

7. J. Tyndall, *Faraday as a Discoverer*, Longman, Green and Co., London, 1868.

8. H. Bence Jones, *The Life and Letters of Faraday*, Longmans, Green & Co., London, 1870.

9. Though Faraday knew no mathematics, he was, according to J. Clerk Maxwell, "in reality a mathematician of a very high order - one from whom the mathematicians of the future may derive valuable and fertile methods".

10. M. Faraday, "On Magnetization of Light and the Illumination of Magnetic Lines of Force", *Phil. Trans. Roy. Soc.*, **1846**, *136*, 1-62.

11. M. Faraday, *The Chemical History of a Candle*, Harper, New York, NY, 1861, pp. 9-11.

12. *Ibid.*, p. 183.

13. *Ibid.*, p. v. At various times, William Crookes was President of the Chemical Society, the Institution of Electrical Engineers, the Society of Chemical Industry, the British Association and the Royal Society. He discovered the element thallium, and invented the radiometer and the evacuated tubes named after him.

14. Reference 2. Faraday did not commence numbering his paragraphs until 29 August 1831, the date he discovered electromagnetic induction. From that date to his last entry, on 12 March 1862, there

are some 17,000 paragraphs.

15. J. Clerk Maxwell, "Faraday's Lines of Force", *Proc. Camb. Phil. Soc.*, **1856**, *10(1)*, 1-76.

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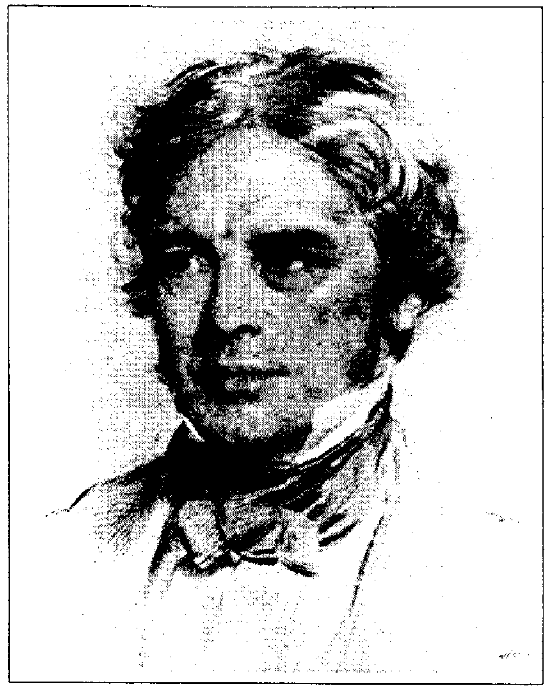
FARADAY AND HIS BIOGRAPHERS

L. Pearce Williams, Cornell University

Before examining the biographers of Faraday, it is worth raising the question of the value of biography where scientists are concerned. For artists and writers, movers and shakers in the political and military spheres, the answer is obvious. Biography permits us to understand the motives and the influences that shaped these people and this gives us real insight into their works. The case with scientists would seem to be quite different. The same nature is there for everyone and differences of education, religion, private thoughts or what have you cannot change it. Biographies of scientists, it would appear, therefore, are useful only in the sense that they permit a person's life work to be easily summarized and presented.

This was the view that prevailed until quite recently. Biographies of scientists tended to be eulogies and, with the truly great ones such as Isaac Newton or Charles Darwin, hagiographies detailing and celebrating their achievements. No one claimed that biographies of scientists could tell us much about science and how it works, except insofar as they focused on persistence, experimental expertise and theoretical insights. All that has now changed. Ever since the publication of Thomas S. Kuhn's *The Structure of Scientific Revolutions*, the whole picture of the nature of science has been dramatically altered. As is well known, Kuhn's major point was that scientists do not "discover" nature; they "construct" it. The raw materials are, of course, the phenomena of the natural world but the selection of which materials to use and the arrangement of these materials into coherent theories are the product of the scientists, not of nature. Furthermore, which theories survive and which die aborning is not determined, according to Kuhn, by their "fit" with observed phenomena but



Michael Faraday
(Drawing by George Richmond)

is the result of extremely complex social negotiations that lead to a consensus. Science, then, is as much a social product of human beings as it is a description of some posited objective nature. Indeed, for some of the more extreme social constructionists, nature itself places no constraints upon the construction of scientific theories. This position is occupied by very few, yet it does serve to illustrate just how far from the old views we (meaning historians, philosophers and sociologists of science) have come. I would not expect that these views will be greeted with wild enthusiasm by practicing chemists, but you should be aware of them and, perhaps, even invest some time in studying them.

In this new world of social construction, biography moves to a central position. The source of original ideas and hypotheses is to be sought in the rich internal lives of creative scientists. Or, to put it another way, new ideas can come from anywhere - they are not, necessarily, the product of the study of nature. So, for example, it has been demonstrated rather clearly that Isaac Newton drew some of his most important scientific hypotheses from his concept of the nature of God, not from the study of the world. And, as will become evident here, the same is true of Faraday. The only way to discover these sources is to examine closely the lives of these innovators upon whom the life of science depends. Furthermore, the fate of what starts out as hypotheses, if it depends upon social negotiation, can only be understood if these negotiations are examined in detail. Once again, the essential fulcrum for prying into historical reality is the life of individuals. This is a very complicated