50. Reference 20, p. 480.
51. Reference 17.
52. D. Layton, "The Educational Exhibition of 1854", *J. Royal Soc. Arts*, **1972**, *120*, 183-7 & 253-6.
53. This world is explored in reference 24.

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THE MILITARY CONTEXT OF CHEMISTRY: THE CASE OF MICHAEL FARADAY

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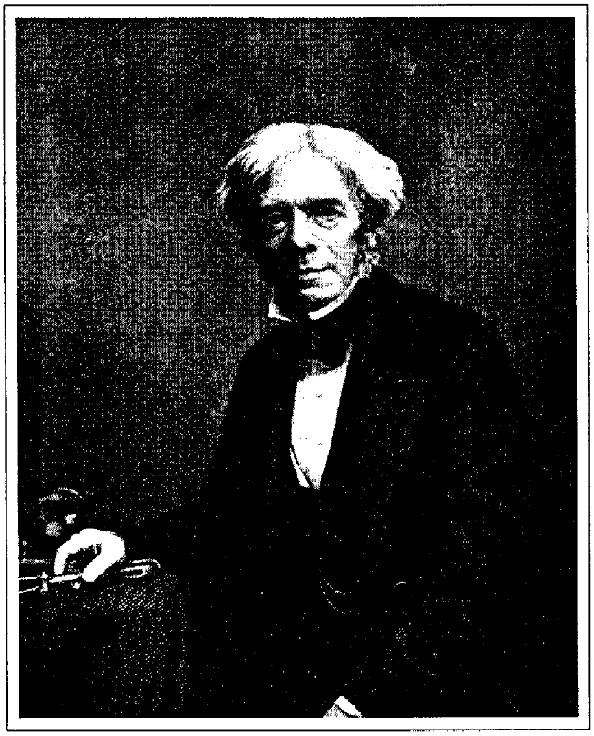
There are many essential requirements for a person to become a successful scientist. One of them is the availability of sufficient time to perform research. Michael Faraday (1791-1867) was perfectly well aware of this and frequently commented that, lacking property, time was his "only estate" (1). However, as I shall show, for various institutional and personal reasons time for research was in short supply during the latter part of the 1820s.

Faraday's opportunity to do original research, while he was still Laboratory Assistant in the Royal Institution, occurred following the discovery in 1820 of electromagnetism by the Danish natural philosopher Hans Christian Oersted (2). Men of science all over Europe conducted many further experiments in the subsequent months and advanced theories to understand this phenomenon. In the summer of 1821 Richard Phillips (3), a close friend of Faraday's, asked him to survey this activity for the *Annals of Philosophy* which Phillips edited. This Faraday did, writing up his conclusions in his only anonymous paper, "Historical Sketch of Electro-magnetism" (4). During this process he discovered electro-magnetic rotation - the principle behind the electric motor (5). He quickly published this discovery and promptly got into a priority dispute involving William Hyde Wollaston (6), the interregnum President of the Royal Society for a few months in 1820 between the death of Joseph Banks (7) and the election of Humphry Davy (8), Faraday's patron at the Royal Institution. It was claimed that Wollaston had predicted the existence of such a phenomenon, that Faraday had known this, but had not acknowledged it. However, Wollaston did not press the claim and the dispute was short lived, not at that time reaching the press (9).



Faraday in his later years.

However, it resurfaced over a more serious priority dispute in 1823 after Faraday had liquefied chlorine. He had been conducting an experiment suggested by Davy, the unexpected result of which led to the liquefaction of chlorine under pressure (10). When Davy demanded a share of the credit, Faraday demurred. A published report claimed that Davy, speaking from the Presidential Chair of the Royal Society, had stated that Faraday had been following Wollaston's suggestion when he discovered electro-magnetic rotation (11). Although Davy quickly said he had been misreported (12), the damage was done and Faraday was forced to declare his authorship of the "Historical Sketch" so as to defend his priority in public (13).

Worse was to follow. Faraday was nominated, without Davy's prior knowledge, to be a Fellow of the Royal Society (14). Davy opposed Faraday's election, since otherwise, because of their close association, it might be assumed, by members of various factions within the Royal Society, that he had prompted it. He did not want to be seen as continuing the Banksian tradition of supporting his friends and opposing his enemies irrespective of their scientific merit (15). The reason why Davy wanted to distance himself from the Banksian tradition was his hope that a firmer relationship would develop between the Society and Government, particularly the Admiralty. He wanted to encourage the state to ask for scientific advice from the Society and also to provide support for science. Davy was firmly committed to this policy and thus it was essential that it was seen that the misuse of patronage had ceased to flourish in the Society. Davy, now past his prime as a researcher, also seems to have been unable to accept the success of his protégé. As Faraday commented in 1835: "I was by no means in the same relation as to scientific communication with Sir Humphry Davy after I became a Fellow of the Royal Society [in January 1824] as before that period" (16). This did not mean that their relationship had completely ended. It is noticeable that Davy was now prepared to use Faraday's undoubted abilities for his own purposes without worrying about the effect these demands might have on Faraday's career.

An example of this occurred when very shortly after Faraday's election to the Royal Society, Davy secured his services as unpaid secretary to help form a new club which Davy and John Wilson Croker had decided to found (17). This club, which shortly became the Athenaeum, involved Faraday in a large amount of correspondence and administration between March and June 1824 to the almost complete neglect of his research (18). When the club was able to offer a salary to its secretary, Faraday passed the position on to his friend Edward Magrath (19).

By the mid-1820s he was responsible for more Royal Institution activities, particularly after he was appointed Director of the Laboratory in February 1825 (on Davy's recommendation) (20). For example he initiated the Friday Evening Discourses, the Christmas Lectures for young people, and generally strove to help the Royal Institution out of the difficult financial position it then found itself in. Nevertheless, his duties at the Royal Institution should in theory have allowed him sufficient time to do research.

That there was not time for research in the latter 1820s was almost entirely due to the time-consuming project to improve optical glass. This began in April 1824 while Davy was enjoying considerable success with the Admiralty after apparently solving the problem of preventing the corrosion of the copper sheeting of ships' bottoms by in effect inventing what we now call sacrificial cathodic protection (21). At the meeting of the Board of Longitude on 1 April 1824 it was proposed, at Davy's suggestion, that a Joint Committee of the Royal Society and Board of Longitude be established to try to improve optical glass (22). It was argued that this would be valuable for improving the accuracy of navigation. Although this was the explicit rationale, the foundation of this committee should be understood as a defensive move to preserve the very existence of the Board of Longitude. The Board had been founded in 1714 with the aim of improving methods of finding longitude at sea. This problem had been largely solved by the 1770s by the use of Tobias Mayer's method of lunar distances (23). By the 1820s the Board, which drew its membership from the scientific community, Parliament and the Admiralty, was increasingly coming under threat during the government's retrenchment program. Its major task, in the early 1820s, that of preparing the *Nautical Almanac*, could be quite easily transferred elsewhere (24). As one of the few established institutions to receive government funding for science through the Admiralty, it would be embarrassing for its abolition to occur during the term of a President committed to increase state support of science.

Members of The Joint Committee included Davy, Wollaston, the optician George Dollond (25), Davies Gilbert (26) (one of Davy's early patrons) and later John Herschel (27) (son of the discoverer of Uranus and a distinguished man of science in his own right). The Joint Committee first met on 20 May 1824 (28). They appointed the glass-making firm of Pellatt and Green to build a furnace for the project and asked Faraday to analyze chemically the glass produced - the kind of work that Faraday would normally do in the course of his Royal Institution chemical consultancy work.

At its fourth meeting on 5 May 1825 the Joint Committee appointed Faraday as a member and also appointed an experimental sub-committee comprising Herschel, Dollond and Faraday (29). Faraday was to supervise making the glass at Pellatts, Dollond was to grind it and Herschel was to determine its optical properties. Faraday's activities on this sub-committee entailed far more than his normal Royal Institution consultancy. Faraday's task was to prove difficult since Pellatts was some three miles distant from the Royal Institution. Thus there was a lack of proper supervision and the results were disappointing during the ensuing year (30).

Davy's health began to give way during this period; the last time he chaired the Joint Committee was on 25 May 1826 (31). The next two meetings were chaired by Wollaston, before Gilbert took over (32). On 8 May 1827 the Joint Committee met to discuss the continuingly disappointing results (33). Because of the financial difficulties of the Royal Institution, on which he was economically completely dependent, Faraday was not in a position at that meeting of the Joint Committee to refuse to take part in extending the project if it entailed support for the Royal Institution (34). Thus he actively supported the decision made at that meeting to approach the Royal Institution for permission to build a glass furnace there and for Faraday to take over personally the making of the glass. The negotiations were duly completed by the end of May. When the furnace was installed, in the back yard of the Royal Institution, Faraday began what turned out to be two years of arduous work.

The story is told through the highly detailed notebooks that Faraday kept of the project and which are now in the archives of the Royal Society (35). Of the 731 days between 3 December 1827, when the work began in earnest, and 2 December 1829, by which time it had effectively ceased, Faraday worked on glass on 337 days (46.1%). If one excludes the 104 Sundays (for Faraday was a deeply religious man (36)) and at least 104 days spent outside London (for he suffered badly from headaches very possibly brought about by close work with the furnace), then the number of available working days was 507. In other words, on 66.4% of available working days Faraday spent some time working on glass. Of course he did not spend every minute of these days working on glass, but what time he did spend was taken from time he could have devoted to research. Nor did he work unaided. He had the help of Charles Anderson (37) (formerly a Sergeant in the Royal Artillery), but he was little more than a pair of hands. It was Faraday who decided where the crucibles should be placed in the furnace, what temperature the furnace should be heated to, for how long, what the chemical composition of the glass should be and so on (38).

The institutional and personal contexts which had brought this about were beginning to dissolve but had been replaced by others. In 1827 Davy's health and thus position had been further weakened by a stroke. He went abroad after resigning the Presidency of the Royal Society on 6 November 1827 (to be succeeded by Gilbert). In July 1828 the Board of Longitude was finally abolished (39), the *Nautical Almanac* ultimately being transferred to the Royal Astronomical Society in the early 1830s (40). Instead the Admiralty appointed a resident committee of three scientists at a salary of £100 a year each (41). The first committee comprised Faraday, Thomas Young (42) (former Secretary of the Board of Longitude) and Edward Sabine (43) (a Royal Artillery Captain and a Secretary of the Royal Society). The committee took over the supervision of the glass project with funding directly from the Admiralty. Evidently they still believed that improved navigational instruments would emerge from the project.

On 29 May 1829 Davy died in Geneva but his death was not reported in the *Times* until 9 June (44). By the end of 1829 Faraday had effectively stopped doing any glass work. He made his views of the project plain in a letter to Gilbert written in May 1830 (45):

> I further wish you most distinctly to understand that I regret I ever allowed myself to be named as one of the committee. I have had in consequence several years of hard work; all the time that I could spare from necessary duties (and which I wished to devote to original research) [has] been consumed in the experiments.

Since by this time the finances of the Royal Institution were on a much better footing than in the middle of the 1820s (mainly due to the success of the Friday Evening Discourses initiated by Faraday), there were no financial worries for the Royal Institution occasioned by Faraday's withdrawal from the glass work (46).

This did not mean that Faraday refused to continue providing advice to the Admiralty. In his capacity as resident scientific adviser, Faraday helped the Admiralty with many analytical chemical problems. For example, following the failure of Davy's method of copper protection to be uniformly applicable, Faraday analysed copper sheets for ships' bottoms. In 1830 nine companies sent samples of copper sheets to the Navy to be analysed - the company that produced the best sheet would be awarded a large contract to supply 45 tons of copper sheeting. Faraday's report has not survived, but from correspondence it is clear that he did not believe that analyzing the small impurities contained in the copper sheets was sufficient to determine whether sacrificial cathodes would protect them. In the end the order for the copper was divided equally between the nine companies. Faraday, unlike Davy, had a good grasp of the limitations of science (47).

Faraday was thus happy to work for the Admiralty provided it was on his own terms and did not take up much of the time he could otherwise devote to research. What he wanted was to ensure that in future he would be able to avoid burdensome tasks such as the glass work. Before he knew of Davy's death, Faraday was contemplating leaving the Royal Institution and thus the glass work, while continuing to give lectures there (48). Now that Davy was no longer alive, Faraday decided to remain at the Royal Institution. The only way he could be sure of having the necessary time for research in the future was by obtaining some economic freedom from the Royal Institution in case it again fell on hard financial times. Within a month of Davy's death, Faraday was actively negotiating with the Royal Military Academy in Woolwich for a position there (49). The Academy had been founded in 1741 to train cadets for the Army, particularly the Royal Artillery and Royal Engineers. Its courses had a strong scientific and technical component to allow cadets to learn how to take advantage of the new industrial processes for warfare. Faraday negotiated the professorship of chemistry there whilst retaining his position at the Royal Institution.

To secure sufficient economic freedom, Faraday drove a hard bargain with the Academy. His work for the subcommittee had been done gratis and he seems never to have drawn his salary from the Admiralty (no doubt to avoid being under an obligation to undertake all their requests). At the end of June 1829 the Commandant of the Academy, Colonel Percy Drummond, visited Faraday by prior appointment, following which Faraday wrote to him giving his terms (50). He said that he received the equivalent of £8-15s per lecture at the Royal Institution and for 20 lectures - the minimum he believed necessary for a course of chemistry - that came to £175, but as he would be willing to give a lecture or two extra he thought a fee of £200 a year would be sufficient (51). It seems that it was taken for granted, or else the documentation has not survived, that he would have an assistant, James Marsh (52), and expenses for chemicals and apparatus. On the slightly modified terms of giving 25 lectures a year, Faraday was appointed Professor of Chemistry at the Royal Military Academy in mid-December 1829 (53).

From the point of view of the Academy, what is particularly interesting is that they accepted Faraday with very little alteration to his terms. That these were very favourable can be seen when compared with the appointment of the Professor of

French at exactly the same time. Mr. Tasche was appointed in September at a salary of £150 per year and with the requirement that he reside in Woolwich (54). This reflects the belief by the military establishment (both in the army and the navy) that science had a vital role to play in the future of the armed services and that it was pointless to employ, or continue to employ, second-rate men. As a contemporary commented in a letter to Drummond, "Faraday ... is not only one of the best chemists of the day, but certainly the best lecturer, qualities not always combined" (55). One has to pay for the best and Tasche was not noted for anything distinguished.

In practice what happened was that from 1830 until 1851, when he retired, Faraday spent two days a week at Woolwich during their terms. To many creative scientists this might have been an onerous burden. But for Faraday, who had suffered for two years doing glass work two out of every three days, it must have seemed a happy release; his time devoted to utilitarian ends had been drastically reduced, potentially to one day in six.

Faraday had now achieved the economic security and the time, albeit still under several constraints, to pursue his own researches. As it turned out, the Royal Institution remained in a reasonable financial position for the remainder of his career and no project, like the glass making, ever got beyond the proposal stage. He never seems to have contemplated leaving the Royal Institution again.

To conclude, it is not a coincidence that Faraday made his discovery of electromagnetic induction shortly after he dropped the glass work. As David Gooding and his students have shown, it took considerable time to build the induction ring (56). Such investment of time was impossible for Faraday while he was working on glass. This is a social contingent argument. We cannot explain from this analysis what prompted Faraday to undertake this 1831 work. But it does tell us how Faraday negotiated the time to undertake this work.

References and Notes

Acknowledgements: I wish to thank the Royal Society (RS), the Royal Greenwich Observatory (RGO) and the General Register Office (GRO) for permission to work on Manuscripts in their possession. I would also like to thank Dr. Geoffrey Cantor for many useful comments on this paper. Additional abbreviations used in the notes include: DSB = C. Gillespie, ed., *Dictionary of Scientific Biography*, 14 Vols., Scribners, NY, 1970 - 1975 and DNB = *Dictionary of National Biography*, 63 Vols.

1. For example, see Faraday to Drummond, 29 June 1829, in Frank A. J. L. James, ed., *The Correspondence of Michael Faraday*, Vol. 1, Peregrinus, London, 1991, letter 404 and Faraday to Thompson, 3 July 1832, in L. P. Williams, R. Fitzgerald and O. Stallybrass, eds., *The Selected Correspondence of Michael Faraday*, 2 Vols., Cambridge, 1971, letter 142. It is surely not a coincidence that both of these were written in a military context.

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3. Richard Phillips (1788-1851, DNB).

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5. M. Faraday, "On Some New Electro-Magnetical Motions, and on the Theory of Magnetism", *Quart. J. Sci.*, **1821**, *12*, 74-96. For discussions of this see D. Gooding "'In Nature's School': Faraday as an Experimentalist", in D. Gooding and F. A. J. L. James, eds., *Faraday Rediscovered: Essays on the Life and Work of Michael Faraday 1791-1867*, Macmillan, London, 1985, pp. 105-35, esp. 110-23; D. Gooding, "History in the Laboratory: Can We Tell What Really Went On?" in F. A. J. L. James, ed., *The Development of the Laboratory: Essays on the Place of Experiment in Industrial Civilization*, Macmillan, London, 1989, pp. 63-82, esp. 71-9; and D. Gooding, *Experiment and the Making of Meaning*, Kluwer, Dordrecht, 1990.

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7. Joseph Banks (1743-1820, DSB). President of the Royal Society, 1778-1820.

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12. *Ibid.*, p. 391.

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23. Johann Tobias Mayer (1723-1762, DSB).

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26. Davies Gilbert (1767-1839, DNB). Treasurer of the Royal Society, 1819-27 and President 1827-30.

27. John Frederick William Herschel (1792-1871, DSB). Secretary of the Royal Society, 1824-7.

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30. M. Faraday, "On the Manufacture of Glass for Optical Purposes", *Phil. Trans.*, **1830**, *120*, 1-57, p. 3.

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33. *Ibid.*, 153-7.

34. M. Berman, *Social Change and Scientific Organization: The Royal Institution, 1799-1844*, Cornell University Press, London, 1978, p. 165 and reference 30, p. 3.

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37. Charles Anderson (d. 1866, age 75, GRO Death Certificate). Joined Faraday on the glass project on 3 December 1827 (reference 16, Vol. 1, p. 398).

38. For a discussion of the technical aspects of this work see M. Cable and J. W. Smedley, "Michael Faraday - Glassmaker", *Glass Tech.*, **1989**, *30*, 39-46.

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41. James, reference 1, letter 384.

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43. Edward Sabine (1788-1883, DSB). Secretary of the Royal Society, 1827-1830.

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49. *Ibid.*, Faraday to Pasley, 26 June 1829, letter 402.

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MICHAEL FARADAY'S BIBLES AS MIRRORS OF HIS FAITH

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A devout Christian's Bible is a cherished and very personal possession. Although after long usage its spine hinges crack, its covers loosen and its pages become dog-eared, the owner will not lightly put it aside for a newer one because it has become a familiar old friend. Part of its attraction is likely to be the markings, underlinings, and notes that have accumulated around passages which strike a familiar chord, support a cherished belief, note a fact to be recalled, or that are simply inspirational. I believe that to a great extent such marginalia mirror what the Bible owner holds relevant to his faith.

Two well-worn Bibles that belonged to Michael Faraday (1791-1867) are now in the archives of the Royal Institution in London. Both are heavily marked in pencil. Both are the King James version of 1611. One was published in 1776 and the other in 1817, but there are no handwritten dates or other direct clues to indicate when the bibles were used, or whether they were used consecutively or simultaneously. Although they were subsequently presented by Mrs. Faraday to relatives, there is nothing to indicate they were ever used by anyone other than Faraday (1).

In July 1990, I copied all of the markings in these Bibles into two new Bibles so as to duplicate, as nearly as possible, every mark, word change, underscore, marginal note, etc., given in the originals. Study of these copies provided the foundation for this paper, the purpose of which is to determine if the markings shed any light on what religious beliefs Faraday held near and dear.

In July 1821, Faraday, at age 30, made a profession of faith in the Church of Christ, popularly known as the Sandemanians and fully committed his life to the cause of Jesus Christ, a