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EDITORIAL

Maxwell and Faraday: The Anniversary of a Unification

Colloquia, where accomplished researchers present an overview of their work to an audience of colleagues from other disciplines, are presumably a device to promote a broad understanding of diverse activities in academic institutions. At a recent event in my own institution, a distinguished and cheerful mathematician presented a talk with a deceptively simple title: 'Differentiation?(!)'. Despite an intrinsic fear of mathematics (and sometimes, mathematicians) I tried to concentrate on the talk. Formidable terms like Mobius groups, Hilbert space and the Weyl commutation quickly made me realize that I was witnessing a trip into an academic space that required a background that I quite simply did not possess. Mathematics in all forms, but especially so in its pure form, seems austere and remote, with the promise of forbidding beauty, that only its most devoted practitioners are privileged to behold. As is customary, there was a time for questions and answers. In seminars, this is a session that is often both enlivening and enlightening. I was struck that among the animated discussants was a young theoretical physicist, a string theorist, confirming a suspicion that many distant observers must share, that the frontiers of theoretical physics merge seamlessly into esoteric mathematics. In thinking about subjects that I know very little about, I could not help recalling a metric often used by a thoughtful colleague of mine (a physicist, of course) in judging prospective applicants for academic positions in physics: 'Can the candidate teach Maxwell's equations to students?' In these days of interdisciplinary research, faculty are often recruited on the basis of lists of publications acquired during doctoral and post-doctoral years, together with their ability to present their past work and also envision their future research. The most glamorous publications are often the result of group effort in well organized laboratories, with considerable depth of expertise. Judgements about an individual researcher's potential and promise are often hard to make. Was my colleague's metric in assessing a fundamental background in physics robust and reliable? Why did my colleague seem so convinced that an understanding of Maxwell's equations provides an assurance of a firm grounding in the foundations of physics? When did mathematics and physics become so inextricably linked? Was there a time when physics advanced without the support of a firm mathematical underpinning, driven only by experiments and observation? Did it not appear that Newton's invention of the calculus, driven as it seemed to be by his insights into natural phenomena, was really a means of codifying and extending a domain of human endeavour that seemed rooted in observation? An anniversary came to my rescue in providing answers to some of these questions. Almost exactly 150 years ago, James Clerk Maxwell (1831–1879) published a paper in the *Philosophical Magazine* with a title, 'On Physical Lines of Force', that seems both cryptic and understated by modern standards. Between 1861 and 1862 Maxwell effected a profound transformation of science by unifying electricity, magnetism and light; subjects that even a century and a half later are sometimes still introduced as distinct and unrelated topics. A recent editorial in *Nature* (2011, **471**, 265) celebrates the anniversary by asking a question: 'What is it that makes physicists proud to be physicists?' The answer, most certainly 'one answer', must lie 'in James Clerk Maxwell's equations. Physicists can rejoice in a historical moment of great insight, can share in the expressions of that insight that only they can understand in any depth . . . and, above all, can roam freely in deploying the power thus provided for understanding the world and, on occasion, changing it'.

Public perception about scientists and their impact can be dramatically different from those of scientists themselves. In 1985, *New Scientist* reported the results of a poll where people were asked to name 'three famous scientists, living or dead'. The clear winner was 'Don't know', polling 47% of the vote. Trailing far behind were Einstein (28%), Newton (13%) and Fleming (11%). Faraday polled only 4%, while Darwin (2%) was even further behind (*New Scientist*, 1985, February 21, p. 16). Maxwell was not on the list, an omission, I suspect, which would undoubtedly be repeated today. I was fortunate to lay my hands on a marvellously written, engaging biography, *The Man Who Changed Everything: The Life of James Clerk Maxwell* (Mahon, B., Wiley, 2003). The author, Basil Mahon, an engineer, paints a warm and affectionate portrait of a man, who by all accounts was a genius, but also 'the warmest and most inspiring of companions'. Biographies can often be heavy and dull. Mahon's book on Maxwell is fast paced and fascinating in its description of one who was 'to physicists, easily the most magical figure of the nineteenth century'. Maxwell was, clearly, a precocious child publishing his first paper, 'On Rolling Curves' in 1848, at the age of 14. Mahon's account is captivating; the young Maxwell employing both experiment (drawing curves with pins, pencil and string) and mathematical insight to draw curves with multiple focal points. Professors at the University of Edinburgh then discovered that the only prior work in the area was by Rene Descartes; as a forerunner of things to come, Maxwell's construction was simpler and more general and the bi-focal curves had a 'practical application in optics'. More remarkably, early success did not influence his personality, ensuring that he constantly learnt from the work of his predecessors and contemporaries. In thinking about the role of experiments and theory in science, I found in Mahon's book an account of Maxwell's experience in Edinburgh as a student: 'James was not at all impressed by Professor Wilson's lectures in moral philosophy which, to his mind, served only to demonstrate that wooly thinking leads to wooly conclusions. He enjoyed chemistry but thought it odd that lectures from Professor Gregory were given separately from practical chemistry sessions under Mr Kemp, particularly as "Kemp the practical" was apt to describe procedures taught by Gregory as "useless and detrimental processes invented by chemists who want something to do". This experience helped to form Maxwell's conviction that practical work is not only essential to a proper scientific education, but should be part and parcel of the lecture course, not tacked on as an afterthought.' This appreciation of the importance of experimentation was to serve Maxwell well in later life, when he went on to establish the Cavendish laboratory at Cambridge, which in the 20th century was to be at the centre of two scientific revolutions, the first in atomic physics and the second in structural molecular biology. In a remarkable experiment, designed as a demonstration for a lecture at the Royal Institution in London, in 1861 Maxwell produced 'the world's first colour photograph'. This experiment could never be repeated; Mahon notes that 'the mystery was solved about 100 years later by a team at Kodak Research Laboratories'. The experiment had worked for the wrong reasons. Maxwell believed that one should 'never . . . dissuade a man from trying an experiment no matter how slim the prospect of success, because he might find something entirely unexpected'.

No retrospective of Maxwell's unification of electricity, magnetism and light can fail to be dazzled by the path illuminated by Michael Faraday, arguably the greatest experimental scientist of the modern era. His experiments demonstrated the magnetic 'lines of force' and he also postulated 'electric lines of force'. Reading Faraday's writings, Maxwell was struck by the description of 'his unsuccessful as well as his successful experiments and his crude ideas as well as his developed ones, and the reader however inferior to him in inductive power, feels sympathy even more than admiration and is tempted to believe that, if he had the opportunity, he too would be a discoverer' (Mahon, p. 59). This view of Faraday must be contrasted with Maxwell's reported characterization of Ampere's descriptions of his work: 'If you have built a perfect edifice, do not remove all traces of the scaffolding by which you have raised it'. The concept of 'fields' emerges from Maxwell's analysis of Faraday's classic experiments; 'a new and mathematically impeccable concept'. Maxwell's first paper in the area 'On Faraday's Lines of Force' used the analogy of fluid flow 'and did not offer even a semblance of a theory as to the nature of electricity or magnetism'. Faraday's reaction was 'charming': 'I was at first almost frightened when I saw such mathematical force made to bear upon the subject and then wondered to see that the subject stood it so well.' In *Michael Faraday and the Royal Institution* (1991, Adam Hilger, Bristol), J. M. Thomas notes that 'such was the prodigality of his [Faraday's] output and the diversity of his skills that modern chemists, no less than physicists, engineers and materials scientists regard him as one of the founders of their subjects: some sciences and technologies owe their very existence to his work'. Thomas goes on to add that 'in none of his four hundred and fifty publications is there a single differential equation, for he knew no mathematics'. He also notes Maxwell's view of Faraday: 'in reality a mathematician of a very high order – one from whom the mathematicians of the future may derive valuable and fertile methods'. But it is Maxwell who finally produced the four equations that Mahon describes as 'majestic mathematical statements, deep and subtle yet startlingly simple. So eloquent are they that one can get a sense of their beauty and power even without advanced mathematical training'. Maxwell's synthesis 'not only explained all known electromagnetic phenomena, it explained light and pointed to the existence of kinds of radiation not then dreamt of'.

Maxwell died young, even by the standards of the 19th century. His contemporaries and successors were unstinting in their admiration. Mahon quotes Oliver Heaviside (an 'acerbic and cynical man') who noted that men like Shakespeare and Newton 'live the best part of their lives after they are dead. Maxwell is one of those men'. Mahon's introduction borrows from Feynmann who said that 'the most significant event of the nineteenth century will be judged as Maxwell's discovery of the laws of electrodynamics'. Einstein, as always, is quotable: 'One scientific epoch ended and another began with James Clerk Maxwell'. To his admirers Maxwell's physics was poetry.

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