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BOOK REVIEW

The history of electromagnetic theory through the lives of its founders

Nancy Forbes and Basil Mahon: Faraday, Maxwell, and the electromagnetic field: How two men revolutionized physics. Amherst, NY: Prometheus Books, 2014, 320pp, US $25.95 HB

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This engaging book presents the history of the development of the science of electromagnetism through the lives of two of its founders. The first seven chapters of this seventeen-chapter book belong to Michael Faraday, the story of whose rise to scientific prominence from an unprivileged background (his father was a blacksmith) is eternally appealing. Chapters eight through fifteen belong to James Clerk Maxwell, a truly great scientist whose name should be better known than it is. The book's penultimate chapter introduces the "Maxwellians"—the Britons Oliver Heaviside, Oliver Lodge, and George Francis Fitzgerald and their German colleague, Heinrich Hertz—and describes their achievements building on Maxwell's and Faraday's contributions. The final chapter takes us from Michelson and Morley's 1887 experiment disproving the existence of the aether to Einstein's *annus mirabilis* of 1905, in which, among other achievements, he explained the photoelectric effect, predicted the photon, and published his special theory of relativity. The book also contains a useful chronology of the main scientific breakthroughs covered in the book, as well as an eight-page insert of black-and-white illustrations of not only the book's two heroes at different times in their careers and of some of Faraday's apparatus and laboratory, but also of William Thomson, who played a role in the life of each, and of other members of the tale's *dramatis personae,* including André Marie Ampère, perhaps the most collegial of Faraday's French colleagues; Faraday's scientific hero and mentor Humphry Davy (though their relationship was ultimately damaged); Katherine Maxwell (who some considered his "awful wife"); and the "Maxwellians" Heaviside and Hertz.

In their acknowledgments, the authors share the book's back story. As a graduate student in physics, one of the authors heard Nobel laureate C. N. Yang talk about the history of field theory, which led to major breakthroughs in modern physics and underlies the Standard Model. Yang traced field theory back to simple instruments

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in Michael Faraday's laboratory in the Royal Institution, explaining, however, that without Maxwell's translation of Faraday's ideas into the language of mathematics—an area in which the autodidact Faraday was deficient—Faraday's work "could not have had the monumental effect on physics it had." Excellent storytellers, Forbes and Mahon had this reader hooked by the final sentence of the acknowledgments: "It was a story that was begging to be told," and I was all ears.

Forbes and Mahon carefully explain Faraday's experiments culminating in his principal discoveries—of the principles of the electric motor and dynamo, electromagnetic induction, the concept of lines of magnetic force, the basic laws of electrolysis, the fact that all substances have magnetic properties—and his perseverance in carrying them out despite the problems he encountered. Yet my main takeaway from the Faraday chapters is of his personal traits, as a man whose curiosity and self-determination enabled him, though lacking both social standing and formal education, to think outside the box, to challenge the scientific establishment's accepted views. His sense of self-worth and personal dignity helped him overcome humiliation when, in order to travel to France with Humphry Davy's entourage to meet the who's who of French science, he had to double as Davy's valet. These same traits enabled him to overcome unjustified charges of plagiarism twice in his career, the second time introduced by Davy himself.

My main takeaway from the chapters on Maxwell is of his staggering brilliance. Maxwell returned three times, over a period of a decade, to his electromagnetic theory, each time raising "it to new heights by taking a completely fresh approach." In 1855–1856, Maxwell "used the analogy of an incompressible fluid to give mathematical expression to Faraday's concept of lines of force." Five years later, a totally different analogy—"spinning cells and idle wheels"—enabled him to account for all known electromagnetic effects and to predict the existence not only of displacement currents (time-varying electric fields) but also of electromagnetic waves that traveled at the speed of light. Two years later, in a seven-part paper, "A Dynamical Theory of the Electromagnetic Field," Maxwell adopted an entirely new approach. Instead of building a model from analogy, he applied the mathematical laws of dynamics—hitherto thought to apply only to material objects like levers, pulleys, gears, and springs—to the electromagnetic field, thus deriving the theory of the electromagnetic field directly from the laws of dynamics.

But Maxwell's work on electromagnetic field theory was hardly the only feather in his cap. As the authors say, "Had he done nothing else, he would now be known as Maxwell, one of the great founders of the science of color vision," for figuring out that mixing colors in light differs entirely from mixing colors in pigment. Maxwell, we learn, was also the first, in 1861, to take a color photograph, a feat not replicated for many years. In another first, Maxwell, in working out the distribution of molecular speeds, calculated "the first ever statistical law in physics"; his work on the statistical properties of matter was taken up by Ludwig Boltzmann and Josiah Willard Gibbs. In addition to these and other breakthroughs in physics, Maxwell had earlier made a significant contribution to astrophysics, which only began to separate itself from astronomy in the mid-nineteenth century. In 1856, responding to a problem set by the Adams Prize committee of St. John's College, Cambridge, Maxwell proved that Saturn's rings could be neither solid nor fluid but must consist of many independently orbiting bodies. Maxwell thus predicted not only the existence of electromagnetic waves but also “exactly the structure we have now seen on flyby pictures from the Voyager and Cassini space probes.” As a successor to Maxwell in his academic perch as professor of natural philosophy at King’s College London said, “There is scarcely a single topic that [Maxwell] touched upon which he did not change beyond recognition.”

Although Forbes and Mahon do not underline this comparison, I was struck by how much overlap there was, despite their differences in background, in the professional lives of Faraday and Maxwell—as contributors to scientific language and to nationally important projects, and as institution builders and educators.

Regarding their contributions to scientific language, Faraday, lacking knowledge of classical Greek, sought guidance from better educated acquaintances and scholars. Physician Whitlock Nicholl suggested the words *electrode, electrolysis,* and *electrolyte*. Cambridge polymath William Whewell suggested *anode* for the positive electrode, *cathode* for the negative one, as well as *ion, anion, and cation*. The authors note that terms used today in electrolysis are primarily those that Faraday introduced in the 1830s, relying on “the shield of … authority” of his more learned friends. Like Faraday’s, Maxwell’s thoughts about electromagnetism were “often visual,” and his mental pictures led him to coin “three expressions that eventually became universal currency—*curl, divergence, and gradient,* the last two usually being abbreviated to *div* and *grad*.” All three terms “have stood the test of time. Once grasped, these images brought everything to life…. They were concepts essential to the magnetic field.”

Despite their primary commitment to basic research, both men answered the patriotic call to undertake nationally important projects. Early in his career, Faraday spearheaded the effort of the Committee for the Improvement of Glass for Optical Purposes to make Britain competitive in lens making with France and Germany. Later in life, he led government investigations into explosions in gunpowder factories and coal mines and for many years advised Trinity House (a corporation dedicated to the safety of shipping and the well-being of seafarers) on lighthouse operation. Maxwell, for his part, played an important role in solving the problem of how to lay a workable telegraph cable beneath the Atlantic Ocean, contributing to the experiment that established the first standard of electrical resistance and made possible transoceanic telegraph communication.

Both men were consummate institution builders. Although the Royal Institution came into existence 13 years before Faraday joined it in 1812 as “fag and scrub” (entrusted with bottle washing, fireplace cleaning, and floor sweeping), as director for 40 years from 1825, he began the enduring traditions of Friday Evening Discourses and children’s Christmas lectures. Over the years, fifteen scientists affiliated with the Royal Institution have been awarded Nobel Prizes. Similarly, although Maxwell was the University of Cambridge’s third choice to be the inaugural director of its new Cavendish Laboratory, he made it into a major center of experimental physics, the eventual venue of the discovery of the electron and the structure of DNA.

Both men felt strongly about combating pseudoscience through improved science education. In 1862, Faraday wrote the commissioners of public schools that they were turning out students who “talk to me… about mesmerism, table turning, flying through the air… and I say again there must be something wrong in the system of education which leaves minds, the highest taught, in such a state.” Maxwell, who served on the faculties of universities in Aberdeen, London, and Cambridge, stressed his belief in the importance of scientific education in his inaugural lecture at each institution. In a death notice in *Nature,* physicist P. G. Tait lamented the “extent of the loss which [Maxwell’s] early death [just days before his 48th birthday] has inflicted…on the cause of common sense, of true science, and of religion itself, in these days of much vain babbling, pseudoscience, and materialism.”

The world is unlikely to note that 2015 marks several anniversaries in the history of electromagnetism: the 170th of Faraday’s introduction of the term *magnetic field*; the 160th of the publication of the final volume of Faraday’s *Experimental Researches in Electricity* and of Maxwell’s “On Faraday’s Lines of Force”; the 155th of Maxwell’s “On Physical Lines of Force”; and the 150th of his “A Dynamical Theory of the Electromagnetic Field.” Reading Forbes and Mahan’s history would be a fine way to pay homage to the founding fathers of electromagnetic theory in this shared anniversary year.