Faraday and his fields

N. Kumar

From the fundamental concept of a physical field induced by a magnet to his enormously successful lectures for popularizing science, Faraday's achievement sprang from his deep faith in simple facts of observation.

Immortalized by his life-long 'experimental researches in electricity' and magnetism, Michael Faraday (1791–1867) was undoubtedly the greatest experimental physicist of the nineteenth century, perhaps of all time. He preferred, however, to be known and remembered as a natural philosopher, and not as a physicist (which he could not abide) or a chemist.

Some idea of the magnitude of his scientific greatness can be had from a mere listing of the discoveries he made, often in quick succession. Faraday discovered the continuous 'electro-magnetical rotation' of a current-carrying wire in the transverse field of a magnetic pole (the principle of an electric motor). One should hasten to add that this went far beyond the mere deflection of a magnetic needle due to an electric current, as had indeed been reported earlier by his Danish contemporary Hans Christian Oersted, both in terms of the experiment and the underlying idea. The announcement of this discovery in the October 1821 issue of *Quarterly Journal of Science* thrust Faraday into the first rank of the European physicists, and thereby changed the course of his life. Then came, after ten years of intense concentration, the greatest discovery of his life — his celebrated 'ring experiment' demonstrating the principle of 'electromagnetic induction' (the principle of an electric generator, or dynamo), which changed the course of history. There is an entry in his diary dated 29 August 1831 recording in minute detail the transient deflection of a galvanometer connected in the secondary coil of his ring transformer during the make or break of the current in the primary. Shortly thereafter, Faraday demonstrated the same inductive effect with a coil and a permanent bar magnet in relative motion. He then constructed the world's first continuous generator of electricity, a homopolar machine. Underlying these two obviously momentous discoveries, there was a third, much deeper discovery that possessed Faraday — he had discovered and demonstrated the concept of the magnetic (and the electric) 'lines of force' as a physical 'condition' of the space itself, and not merely as a convenient graphical representation or mathematical construct for visualizing or calculating the resultant effect of the sources. This unfolded gradually into a revolutionary and profound concept in physics — the concept of (electromagnetic) field acting locally, and replacing thus the Newtonian 'action at a distance'. The elucidation of this idea of a field as a reified, physical entity became his life-long preoccupation. I shall return to this point later.

Then there were his extensive investigations of magnetism in materials (paramagnets, ferromagnets) and of the deeper problem of diamagnetism of gases and the magne-crystalline effect in crystals. He discovered the magneto-optical effect (the 'Faraday rotation' of the plane of polarized light in a glass in the presence of a magnetic field). To this we must add his researches in electrochemistry — he practically started it with his two laws of electrolysis (1832, 1833). Then there was Faraday the synthetic chemist. He synthesized benzene (1825); he was also the condenser of permanent gases. The list is mind-boggling. Little wonder that Faraday had to coin a whole terminology to express his novel findings and ideas properly — electrode, cathode, anode, ion, anion, ionization, electrolyte, paramagnet, diamagnet.

But to see the absolute genius of Michael Faraday truly, we must correct our impression for the conditions of his time and for the circumstances peculiar to his life. The physics of nineteenth-century Europe was a confusion of imponderables — the 'hidden variables' of the then science! Thus there were the two fluids of electricity, the various effluvia of magnetism, the caloric fluid of heat, and, of course, the luminiferous aether for light. The two fluids of electricity could, for instance, combine chemically with other matter, and act at a distance subject only to Newton's laws of motion, but with the proviso that they shall not be observed. Clever models were contrived using these fluids to explain various phenomena, in much the same way as the epicycles of Ptolemy were used to describe the planetary motions before Newton. The only way out of the morass of these imponderable fluids was exhaustive experimentation. But the English school of experimental physics in the nineteenth century was surviving on 'beeswax and string'. Added to this was Faraday's personal disadvantage (or was it!) — his formal education was limited to rudiments of reading and writing and his mathematics to mere ciphering. And so it was that, when Faraday was called upon to defend his physicalized magnetic fields against the mathematically sophisticated construct of André Marie Ampère (the Newton of electricity!) based on the two-fluid electricity acting-at-a-distance, he simply had to admit that he could not possibly follow Ampère's mathematics. But Faraday felt fully secure in the robustness of his *simple facts* of observation against the other's *facts deduced* from observation. He agreed to disagree with Ampère, but, of course, was proven right in the end. This point is sufficiently fundamental to Faraday's electromagnetism and illustrative of his experimental approach to all questions to bear repeating.

Ampère had proposed a theory of attraction (repulsion) between two long parallel wires carrying currents in the