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The Story of James Clerk Maxwell

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PREFACE

I have received help from many people, too many to name them all individually, but I would like to thank the following for advice during the writing of the book: C.A. Boardman, Dr Brian Bowers, Sam Callander, Professor T.G. Cowling, Professor Cyril Domb, Dr Nicholas Fisher, Professor R.V. Jones, Professor Brian Pippard, Dr R. Porter, David Standley, Brigadier John Wedderburn-Maxwell. Any misapprehensions under which I laboured, are, of course, my fault. I would also like to thank the library staff of the University of Glasgow, the Syndics of Cambridge University Library, the Royal Society, the National Library of Scotland and the University of St Andrews for access to their collections; my publisher Paul Harris and editor Trevor Royle for their essential initial encouragement of a commission and for the subsequent care and attention they have taken; my mother and brother for their encouragement; my daughter Rebecca for her forebearance and, of course, my wife, Frances, for all these things.

During the writing of this book I have come to appreciate James Clerk Maxwell more and more, both as scientist and man. I hope that a little of his remarkable quality has emerged.

Martin Goldman
Glasgow, April 1983

DEDICATION

For my father Kazimierz Goldman, who introduced me to Maxwell's genius

CHAPTER 1

James Clerk Maxwell is one of the greatest figures in the history of science. Making lists of all-time-greats is an occupation suitable only for schoolboys, selecting teams for epic, imaginary games of cricket on rainy summer afternoons (Stonewall Jackson and the Duke of Wellington would have made a dynamic opening pair). But in physics a clear division does emerge: Archimedes, Newton, Maxwell and Einstein are in a different league from the rest. The other three are all familiar names. Archimedes was the very first streaker, Newton was bruised by falling fruit (he could not catch, was obviously a terrible fielder and so excludes himself from selection among the cricketing superstars), and Einstein had a shock of white hair, a fiddle and no socks. Popular legend, however, has never managed to associate Maxwell with any such quaint trait, to reduce him to common mortality, and so, inevitably, he has been ignored.

Yet his achievements were extraordinary. He completely revolutionised two fields of physics, statistical mechanics and electromagnetism. In statistical mechanics, he took the idea that a gas was made up of molecules, which by bouncing against the walls of their container effectively exerted pressure, and worked out how these molecules would jostle against each other, some fast, some slow. To calculate the motion of each molecule would be impossible, but he was able to show that the gas would settle down to a determinate statistical scatter of velocities—the Maxwell distribution. He thus introduced the idea of probability into physics, and with it was able to calculate many of the properties of gases. For example, he predicted that the viscosity of a gas—how treacly it is, how it resists things slipping through it—should be independent of pressure. This was a startling result, but Maxwell then proceeded himself to perform the experiment that proved it correct.

In electromagnetism, there was a large body of experimental data, and several independent theories to explain its various parts. Maxwell took the unifying notion of 'lines of force' which Faraday had invented, and welded the separate topics of electricity and magnetism into a unified whole, which could be expressed in just four simple mathematical formulae—Maxwell's equations. By combining them he predicted that it should be possible to transmit an electromagnetic wave that would beam off into space. When he worked out its velocity, it transpired that it should be the same as that of light: light was merely one manifestation of his waves. Optics was now no longer a separate branch of physics, but a subdivision of electromagnetism. Though its existence was not proved till after his death, electromagnetic radiation at wavelengths longer than light has made possible radio and television in the present century, and at shorter wavelengths has given us X-rays. The new theoretical technique that Maxwell used in this work: taking 'lines of force' as serious mathematical entities, field theory, has been central to the development of twentieth century physics.

In optics, Maxwell did fundamental work on the physics and physiology of colour vision. He helped prove that the normal eye has three sorts of receptor, one sensitive to red light, another to blue and the third to green. He showed colour blindness to be the result of the absence of one of those receptors, and investigated other defects of vision. A particular effect involving a spot seen by most people when looking at blue light is called the Maxwell spot. Photography was then rapidly becoming a popular Victorian pastime, and Maxwell contributed to it by taking the first ever colour photograph.

In thermodynamics, Maxwell wrote a standard text-book, and almost without being aware of the fact produced a useful set of relations known, confusingly, again as Maxwell's equations. In astronomy, he looked at the structure of the rings around Saturn, and showed it was impossible for them to be either solid or fluid. They had to be made up of lots of solid particles; flights of brickbats, he called them. Maxwell also made important discoveries in the mathematical subject of topology, wrote the founding paper in the field of cybernetics, invented reciprocal diagrams, which are useful in engineering, looked at the theory of optical instruments, the theory of strain-induced double refraction in solids, and, among other things, how a sheet of paper tumbles to the floor.

That is a phenomenal body of work of the very highest quality; Professor C.A. Coulson once said: 'There is scarcely a single topic that he touched upon which he did not change almost beyond recognition'.[1] And yet Maxwell died when he was only forty-eight years old.

As for the man himself, the best description that we have comes from an unnamed source quoted in Lewis Campbell's official biography, someone who is cryptically referred to as having first seen Maxwell in 1866, when he would have been thirty-five:

> A man of middle height, with frame strongly knit, and a certain spring and elasticity in his gait; dressed for comfortable ease rather than elegance; a face expressive at once of sagacity and good humour, but overlaid with a deep shade of thoughtfulness; features boldly but pleasingly marked; eyes dark and glowing; hair and beard perfectly black, and forming a strong contrast to the pallor of his complexion. . . . He might have been taken, by a careless observer, for a country gentleman, or rather, to be more accurate, for a north country laird. A keener eye would have seen, however, that the man must be a student of some sort, and one of more than ordinary intelligence.
>
> The picture of Maxwell, as he appeared in 1866, became afterwards perfectly familiar to residents in Cambridge. They will remember his thoughtful face as he walked in the street, revolving some of the many problems that engaged him, Toby lagging behind, till his master would suddenly turn, as if starting from a

> reverie, and begin calling the dog. . . . He had a strong sense of humour, and a keen relish for witty or jocose repartee, but rarely betrayed enjoyment by outright laughter. The outward sign and conspicuous manifestation of his enjoyment was a peculiar twinkle and brightness of the eyes. There was, indeed, nothing explosive in his mental composition, and as his mirth was never boisterous, so neither was he fretful or irascible. Of a serenely placid temper, genial and temperate in his enjoyments, and infinitely patient when others would have been vexed or annoyed, he at all times opposed a solid calm of nature to the vicissitudes of life.
>
> In performing his private experiments at the laboratory, Maxwell was very neat-handed and expeditious. When working thus, or when thinking out a problem, he had a habit of whistling, not loudly, but in a half-subdued manner, no particular tune discernible, but a sort of running accompaniment to his inward thoughts. . . . He could carry the full strength of his mental faculties rapidly from one subject to another, and could pursue his studies under distractions which most students would find intolerable, such as a loud conversation in the room where he was at work. On these occasions he used, in a manner, to take his dog into his confidence, and would say softly, "Tobi, Tobi," at intervals.
>
> . . . His aquaintance with the literature of his own country, and especially with English poetry, was remarkable alike for its extent, its exactness, and the wide range of his sympathies. His critical taste, founded as it was on his native sagacity, and a keen appreciation of literary beauty, was so true and discriminating that his judgment was, in such matters, quite as valuable as on mathematical writings. . . . As he read with great rapidity, and had a retentive memory, his mind was stored with many a choice fragment which had caught his fancy. He was fond of reading aloud at home from his favourite authors, particularly from Shakespeare, and of repeating such passages as gave him the greatest pleasure.[2]

For the purposes of biography there is another fascinating aspect to Maxwell: he thought deeply about the philosophy and psychology of science, and has left us, albeit mostly unwittingly, a good deal of information about how his particular genius functioned.

There is always a special difficulty in trying to understand genius. Of course, to understand the *detailed* workings of *anyone's* mind is impossible—the brain is too complex—but with 'normal' people, it is at least conceivable that, with enough background information, the major decisions of their lives should be intelligible to another 'normal' person. Not so with genius; there must be something essentially unintelligible about them, the separate segments of their personalities must add to a whole greater than our comprehension—otherwise the recipe for genius would have been analysed, and production lines set up to churn them out like motor cars. Maxwell himself would probably have agreed with this. In a penportrait of his friend Faraday for the journal *Nature* he wrote in 1873:

> Every great man of the first rank is unique. Each has his own office and his own place in the historic procession of the sages. That office did not exist even in the imagination, till he came to fill it, and none can succeed to his place when he has passed away.[3]

Logical thought and imagination are two gifts that any good research scientist must possess, imagination, despite popular belief, being at least as necessary for the scientist as for the artist. Maxwell had them, but probably not in any greater measure than several of his contemporaries. What he did have in addition were flair and tenacity. He would mull over problems for long periods, disgorge his conclusions, but then, far from having finished with the subject, he would continue to mull over the same problems for years more, trying different angles of attack, to add another layer to our knowledge.

Flair is an indefinable but unmistakable quality; it shines through Maxwell's work. Peter Medawar has described science as 'the art of the soluble'.[4] At any given period of history there must always be major scientific questions that are insoluble: experimental techniques have not yet been developed that can provide enough background information and detail properly to begin to understand the problem, let alone solve it. One of the hallmarks of genius is to pick, intuitively, upon those major problems which are just within the bounds of the soluble at that epoch.

There is an element here of what Arthur Koestler prefers to call sleepwalking—of the kind performed by Harold Lloyd: of deciding on incomplete and sometimes actually misleading experimental data, what results are significant and what are, ultimately, irrelevant; of knowing instinctively just how far any theoretical model of phenomena can be pushed before it buckles at the seams.

A good example is Maxwell's problem with the specific heats of gases. The amount of heat required to warm a fixed quantity of gas through one degree centigrade is different if the gas is held at constant pressure or at constant volume. Remarkably, the ratio of those two distinct quantities gives a great deal of information about the internal structure of the gas molecules. Maxwell was able to predict one value of the ratio for monatomic gas molecules, and another value for polyatomic molecules. The experimental results fell neatly between the two: clearly an impossibility. So Maxwell had a theory, his statistical mechanical model of gases, which for the most part was wonderfully successful, but which broke down at this one small point. Trapped in such a dilemma, a scientist can say either that the experiment is wrong, or attempt to fudge his calculations, or he can admit that there is something deep going on that he does not yet understand. The temptation to take the first two options is understandably great. Here, however, Maxwell had the courage to stand by both the experiments and his calculations: he admitted that there was something wrong with the whole matter. The paradox of the specific heats was not, in fact, explained for a further forty years, and then required the revolutionary new theory of quantum mechanics for its resolution.

Being correct always seems easy in hindsight, and Maxwell's prescient quality stands out only in comparison with other scientists of the day. Maxwell exhibited a catlike awareness of which scientific debates to avoid. William Thomson, Lord Kelvin, was a contemporary of Maxwell, and a very great scientist, but much of the work that impressed his peers must now be discarded because it is based on false premises. One of Thomson's major areas of research was the age of the earth. Geologists and evolutionists required the earth to be old, to allow for the slow processes of geological change and evolutionary development. Kelvin leapt into this debate by saying that such long periods were impossible: no known source of energy could keep the sun hot for the boundless aeons envisaged by those scientists.

Thomson calculated that if the sun was powered by gravitational contraction it was probably 10 million years old, and at the outside 100 million years. True enough as far as it went, but Kelvin lived just long enough to have to eat his words, when the process of radioactivity was discovered. At a stroke a vast new source of energy was revealed, and ages of thousands of millions of years for the earth and the sun became possible. Perhaps that is the flaw that separates Kelvin from Maxwell. There is an inspired caution in Maxwell, that has resulted in very little of his work being superceded; very little has dated, and many of Maxwell's papers can still be read today, and profitably, as almost standard texts on their subjects.

For the rest of this book, we will explore, as far as it is possible, the various facets of Maxwell's life and work. We begin by looking at the historical background of science in Scotland, that threw up so many gifted researchers at around this time, and the particular traditions of Maxwell's family. Then we move on to Maxwell's schooldays, and his three years at the University of Edinburgh, both of which played major parts in forming his character. His formal education was completed at Cambridge, as an undergraduate and fellow at Trinity College. After five years, the mature scientist Maxwell left Cambridge to become professor of Natural Philosophy at Marischal College Aberdeen then on to King's College London before retiring to his family estate in Galloway. Aberdeen, London and Glenlair saw the bulk of his major research over a fourteen year period, but he did not tackle things sequentially; he would write a paper on electomagnetism, then do a number of other things, and perhaps return to electromagnetism five years later, to pick up where he had left off, with new ideas. Following the chapters on his life over this period, therefore, there will be separate chapters on his work, where the main themes of his reasearch will be followed through, logically, even though out of chronological sequence. Maxwell was tempted out of retirement, by appeals to his sense of duty, to become the first professor of experimental physics at Cambridge, and it was in Cambridge that he died in 1879. The final chapter is a discussion of Maxwell's impact on, and legacy to, science.

CHAPTER 2

If an undefinable, unquantifiable 'flair' is the hallmark of *genius*, it is nonetheless true that a lot of *very good* science does seem to spring up, almost overnight like mushrooms, in particular places and at particular times. Maxwell was the crowning glory of a 'flowering' of Scottish science, which had also produced Kelvin, Peter Guthrie Tait, Sir James Hall, James Forbes, Sir David Brewster, James Sutton, Charles Lyell, Joseph Black, John Playfair, John Robison, Joseph Lister, William Macquorn Rankine, John James Waterston, James Young Simpson, Balfour Stewart, James Watt. Thomas Young and Charles Darwin were by-blows of it. That background of talent helped Maxwell, sometimes directly—he was taught by Forbes and corresponded with Thomson—but also by creating a suitable scientific ambiance: a volcano towering out of a high plateau has to make less of an effort to get its head in the clouds than one rooted to the ocean floor.

The reason why the capital of Scotland, the Edinburgh of the Enlightenment, deserved the name 'Athens of the North' is much more susceptible to analysis than the individual genius of one man. Fig.1 shows that almost all the great names of nineteenth century British science belong to the North of England, Scotland and the North of Ireland. The names of southerners were not conveniently forgotten when drawing up the map: Faraday, Davy and Rayleigh were born in the South. It is difficult to think of many others. So perhaps the question of why Scottish science was so good should be inverted: why was southern English science so bad? After all, London and Oxbridge in the eighteenth century had housed the extraordinary flowering of talent of Newton, Hooke, Boyle, Wren and their friends.

The root of the trouble goes back farther than that. Oxford (and subsequently Cambridge) University was a religious foundation deliberately located outside the metropolis. In medieval times the church was a democratic institution, rewarding talent rather than birth (for obvious enough reasons). Since it carried out its business in Latin, which was unintelligible to the masses and therefore unlikely to lead to acts of violence in Grosvenor Square[1] its bright young men were allowed great freedom of thought. The result was that fourteenth century Oxford also saw one of those sudden flowerings of science; Heytesbury, Swineshead, Dumbleton and Bradwardine (who was also Archbishop of Canterbury) pushed medieval mechanics as far as was possible in those pre-mathematical days. They discovered the distance law for constant