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The Genius and Faith of Faraday and Maxwell

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The religious commitments of the great scientists of history are today often dismissed as mere idiosyncrasies. Their beliefs are considered regrettable if understandable blemishes, the incidental flaws of great minds who helped advance civilization out of primitivism yet could not fully escape it. After all, is not science supposed to aspire to an understanding of the universe that is independent of the beliefs and opinions of scientists, whether religious, political, social, or aesthetic?

Yet, science does not exist in a vacuum, and studies in the sociology, history, and philosophy of science often emphasize how scientists' broader beliefs and practices influence their work, and thus the way that science develops. Some scholars even argue (if not entirely convincingly) that scientists' beliefs influence science's settled content.

The strict separation we commonly observe between a researcher's scientific ideas and his or her "personal beliefs" is a modern, and even recent, norm. From antiquity through the Scientific Revolution, science was viewed as a form of philosophy, and many of the thinkers we have retroactively dubbed "scientists" freely intermingled their speculation about the natural world with theological, philosophical, and mathematical writings, often expending a great deal of their scholarly time and energy on religious study. Kepler's seventeenth-century laws of planetary motion, for example, seem to his modern readers like needles of scientific inspiration buried in a haystack of theological speculation. Newton and Boyle likewise intermingled physics and philosophical theology without apparent hesitation.

By the nineteenth century, however, natural philosophy had become more natural and less philosophy. Theology and natural science were substantially separated. Apologetic natural theology—arguing that God can be deduced from nature—was now mostly for the theologians. The language of physics had become measurement and mathematics, and the

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objective of science had become a description of the world of nature in its own terms, rather than through the purposes of a Creator. As a result, it is tempting to read the science of that era as if it were completely independent of the religious commitments of its practitioners. But it wasn't.

Because Victorian scientists are of interest to us mostly owing to their scientific contributions, their religious beliefs tend to be treated as incidental conformities to the conventions of the day—as if these figures were proto-rationalists and proto-materialists who, without the benefit of our full present enlightenment, had not completely shaken off the superstitions of an earlier age. This caricature is demeaning and mistaken, as can be illustrated by the lives and ideas of two men who were arguably the greatest physical scientists of their time, and among the greatest of all time: Michael Faraday (1791–1867) and James Clerk Maxwell (1831–1879).

The two men had very different backgrounds. Faraday was English; Maxwell Scottish. Faraday was the son of a blacksmith of limited means; Maxwell's father had inherited a substantial estate and hardly needed to practice the law in which he had been trained. Faraday had only a basic, grade-school education; Maxwell had the finest education available. Faraday was one of the most popular scientific lecturers of his day; Maxwell gained a poor reputation in the classroom. Faraday knew practically no formal mathematics; Maxwell was one of the finest mathematicians of his time. Faraday's research became dominant for experimentation in electricity and magnetism; Maxwell's for electromagnetic theory. One experience they had in common: both were committed Christians. Yet even here fascinating contrasts existed between the religious traditions to which they belonged and the ways their spiritual commitments influenced and strengthened their science.

The Great Electrical Experimenter

Michael Faraday's immense contribution to science is in part indicated by the dozen or so laws, phenomena, and experimental instruments that bear his name: the Faraday cage, the Faraday constant, Faraday's law of induction, the Faraday (rotation) effect, the farad (a unit of electrical capacitance), and on and on. In 1823, he became the first person to liquefy chlorine, and in 1825, he first isolated benzene. His first significant independent discovery, in 1821, was an elegant experiment demonstrating that a magnetic field affects an electric current by causing it to move perpendicular to both the current and the field, and it is his research into electricity for which he is best known. Foremost was his 1831 discovery of electromagnetic induction: that varying magnetic fields induce currents to flow in electric circuits.

The close relationship between electricity and chemistry in his research—and in all the science of his day—is best exemplified by Faraday's laws of electrolysis, which relate the rates at which substances electrolyze to their molar weights. His studies of the passage of electricity through ionized gases led him to identify in 1838 the particular phenomenon of glow discharges known as the "Faraday dark space,"(of particular interest to me, since I work in plasma physics). But the breakthrough that shows most clearly both his complete command of experimental technique and his dogged persistence is his discovery in 1845 of Faraday rotation, in which a magnetic field causes rotation of the polarization of light. This effect, which Faraday pursued over a twenty-year period, driven mostly by philosophical conviction, was a critical demonstration of the link between light and electromagnetism.

Finally, there is Faraday's extremely influential, and initially unconventional, championing of the significance of fields. Faraday's theoretical and philosophical intuition, growing over decades of experimentation and culminating in his 1852 paper "On the Physical Character of the Lines of Magnetic Force," was, in hindsight, perhaps his most enduring legacy. A young James Clerk Maxwell certainly took him seriously, and turned the ideas into what we now call Maxwell's equations of electromagnetism. Physics today sees the field of force, not material substance, as the most fundamental natural reality.

Faraday's forebears were from Yorkshire, but he grew up in London, the son of an impoverished blacksmith. Almost all we know about his first thirteen years was what he said about them later: "My education was of the most ordinary description, consisting of little more than the rudiments of reading, writing, and arithmetic at a common day school. My hours out of school were passed at home and in the streets." In 1804, he became errand boy, and later apprentice, to a local bookseller. His real education had begun. "Whilst an apprentice I loved to read the scientific books which were under my hands," he said, and "made such simple experiments in chemistry as could be defrayed in their expense by a few pence per week, and also constructed an electrical machine...."

At the age of twenty-one, Faraday managed a transition from journeyman bookseller to amanuensis for the most famous London scientist of the day, Sir Humphry Davy. The story has been well told many times, and though it has a fairy-tale atmosphere, it speaks also of Faraday's persistence and attention. His meticulous notes of some of Davy's public lectures first brought him to the attention of Davy, then the Honorary Professor of Chemistry and Director of the Laboratory of London's Royal Institution. Chemical explosions, injuries, and the firing of a predecessor opened the opportunity for Faraday. Then, barely seven months into his appointment, Faraday left England as Davy's "philosophical assistant" on an eighteen-month scientific trip to the continent—a remarkable scientific apprenticeship. By the 1820s, Faraday's place at the Royal Institution was secure, and he had gained admittance to the Royal Society and acceptance in the scientific circles of the day.

In 1821, just shy of his thirtieth birthday, Faraday entered into a marriage with Sarah Barnard that would endure to his life's end. The following month he entered into an equally enduring commitment, making his Confession of Faith before the Sandemanian Church, and thereby became a full member of the congregation.

The Sandemanian Church arose from the experience of Scotsman John Glas (1695–1773). A popular minister of the Presbyterian Church of Scotland near Dundee, Glas was unable to reconcile his understanding of the scriptures with the state's role in the established church. In 1730, Glas and nearly a hundred members of his congregation joined together to found an independent church committed to the Bible alone, rejecting the political covenant. Robert Sandeman (1717–1771), attracted to the independent congregation that Glas subsequently founded in Edinburgh, married one of Glas's daughters, and in 1744 became an Elder of the Glasite Church in Perth. Sandeman spent a great deal of time working for the church, and became its most influential spokesman in England and the North American colonies.

Sandemanianism is usually portrayed as an unorthodox and peculiar Christian sect. This impression is enhanced by a much-quoted remark by Faraday himself that he belonged to "a very small and despised sect of Christians." There is no doubt that the sect was small: Only 252 Confessions of Faith were recorded in London during the nineteenth century. But despite their radical nonconformity, the theology of the Sandemanians was essentially orthodox Christianity. What was unorthodox, by the standards of the day, was their ecclesiology—the church organization, practices, and polity. They tried to live out a New Testament pattern for the church as closely as possible. The New Testament knows no formally established ordination or clergy; neither did Sandemanians. There are just two recognized offices in the New Testament, elders and deacons; these were the pattern of the Sandemanians' leadership. The New Testament Christians were an intimate fellowship, characterized by separation from many of the practices of the surrounding cultures; Sandemanians too observed a close-knit fellowship separated from society's religious conventions, expecting in return, as one early member put it, "the hatred of that part of the world which shall take the lead in popular and pharisaical devotion."

The unity of the brethren was of critical importance to the Sandemanian congregation. They took with the utmost seriousness Paul's plea: "I appeal to you, brothers and sisters, by the name of our Lord Jesus Christ, that all of you be in agreement and that there be no divisions among you, but that you be united in the same mind and the same purpose" (1 Cor. 1:10). In the name of this unity, Biblical moral standards and discipline were to be enforced by the elders, while avoiding any strife, division, or ill-feeling. If any division did arise, the only remaining recourse was to exclude the adversaries from participation in the Lord's Supper and the full spiritual benefits of the congregation. And this happened quite frequently, both with individuals and between and among Sandemanian congregations as a whole. Thus, paradoxically, the most distinctive feature of Sandemanian church practice—their emphasis on complete unity—was the primary cause of repeated splits and splinters in the church.

Faraday grew up within the orbit of such a congregation. His father was a devoted Sandemanian, who made his Confession of Faith the year of Faraday's birth, and though his mother never entered into full membership, she regularly attended the services. Faraday's own Confession then was, so far as we know, not a conversion but a formal acceptance of the responsibilities of membership in a demanding spiritual fellowship—which he well understood.

Science and Spiritual Authority

There was another aspect of Sandemanianism that was peculiar—and ultimately fatal to the sect: a lack of evangelical effort. Sandemanians placed no emphasis on proselytizing. This trait relieved Faraday of any commission to argue religion with those outside the fellowship—such as his colleagues—and it helps to explain why he was perfectly comfortable maintaining an official separation of his faith from his profession.

Sandemanianism's hands-off approach to religion in public life can also help explain why many of Faraday's biographers have brushed aside his religious commitments. Consider John Tyndall, Faraday's earliest and perhaps most admiring biographer, whose appointment to the Royal Institution in 1853 undoubtedly owed much to Faraday's influence. Tyndall (1820–1893), like Faraday, was an upwardly mobile son of a modest family, and had pursued his early career—in Tyndall's case, as a surveyor—without the benefit of a university education. Tyndall became Faraday's close colleague at the Royal Institution, and eventually his successor. He carried on Faraday's tradition of practical research and popular lectures.

In his 1868 volume *Faraday as a Discoverer*, Tyndall portrayed Faraday as the greatest experimentalist ever, a scientific prophet of sorts. This was despite the fact that Tyndall's own religious opinions were far different from Faraday's. His biography made no mention of Faraday's Sandemanianism, and was critical of his theoretical speculations. Tyndall was a skeptic, a materialist, a friend of T. H. Huxley (the biologist known as "Darwin's Bulldog"), and a member of the nine-person X Club—which for nearly thirty years acted almost as an advocacy group for scientific naturalism and liberalism, "untrammelled by religious dogmas," as one member put it. But the separation that Faraday maintained between his faith and his profession permitted him the most cordial and constructive personal and professional relationship with Tyndall, despite their differences. Tyndall remarked that, in all their acquaintanceship, he and Faraday never discussed religion except once, when Tyndall raised it.

It would be wrong, however, to suppose that the intellectual separation that Faraday practiced meant his faith had no influence on his science. He believed that in his scientific researches he was reading "the book of nature…written by the finger of God," as he put it in his 1854 lecture "Observations on Mental Education." Faraday's preoccupation with nature's laws was colored by theological beliefs. "God has been pleased to work in his material creation by laws," he remarked, and "the Creator governs his material works by definite laws resulting from the forces impressed on matter."

Science historian Geoffrey Cantor, in his 1991 biography of Faraday, argues that Faraday's understanding of the consistency and simplicity of nature was not only the *result* of his scientific work but also a premise of it: it was intrinsic to the metaphysical presuppositions that directed his research. He sought the unifying laws relating the forces of the world, and was highly successful in finding these laws for electricity, magnetism, and light. Faraday's metaphysical principles sometimes functioned as necessary truths, and other times as guiding principles.

One of these guiding principles was Faraday's conception of creation as a divinely planned economy. In Faraday's theoretical musings, he referred to the "stability of creation" and God's perfectly productive use of "power." In his scientific work, he spoke of the "conservation of force," hinting at the conservation of energy—before Joule's demonstrations of the mechanical equivalence of heat, and Kelvin's formulation of the laws of thermodynamics—and the divergenceless character of lines of force. The concepts of consistency and conservation, derived from his theological views of the economy of nature, were driving ideals behind his championing of lines of force, and hence of the foundations of field theory.

In keeping with his era's understanding of the disciplines, Faraday always referred to himself as a philosopher, not a scientist. But he took pains to draw a distinction between his scientific philosophizing and his Christian commitment. In Faraday's time, the latest approach to theology was rationalistic—exemplified by the liberal Anglicans, who tended to base their religion not on revelation or history, on which they felt higher criticism had cast doubt, but on intellectual theorizing, particularly the argument from design. Faraday disavowed their approach, as he stated explicitly in "Observations on Mental Education":

> Let no one suppose for a moment that the self-education I am about to commend, in respect of the things of this life, extends to any considerations of the hope set before us, as if man by reasoning could find out God. It would be improper here to enter upon this subject further than to claim an absolute distinction between religious and ordinary belief. I shall be reproached with the weakness of refusing to apply those mental operations which I think good in respect of high things to the very highest. I am content to bear this reproach.... I have never seen anything incompatible between those things of man which can be known by the spirit of man which is within him, and those higher things concerning his future, which he cannot know by that spirit.

For Faraday, intellectual authority could never reside in the products of pure reason, or ungrounded human imagination. In an 1858 letter, he remarked that he was a very "imaginative person, and could believe in the 'Arabian Nights' as easily as in the 'Encyclopædia.'" He kept this imagination in check by turning to facts: "facts were important to me, and saved me." A "fundamental fact," he wrote elsewhere, "like an elementary particle, never fails us, its evidence is always true." And in science, fundamental facts mostly came from experiments. "Without experiment I am nothing," he said. He saw all of science as founded on carefully observed facts, distinguished from opinion or conjecture. As his own publications show, this did not mean that science excluded imaginative insights or interpretations—but what remained essential was that the distinction between the experimental facts and the theoretical interpretations should always be scrupulously maintained.

Modern philosophers of science, in the main, regard Faraday's conception of experimental facts as naïve. They insist that all observations are theory-laden and that there is no such thing as a bare fact. But they are not in Faraday's privileged position. He was able almost immediately to verify for himself in the laboratory essentially all the scientific reports he read. "I was never able to make a fact my own without seeing it," he wrote. If experimental verification were as immediate today as it was in Faraday's time and field, the philosophical skepticism toward "facts" would perhaps receive less emphasis. (And as an experimentalist myself, I sympathize with Faraday's attitude. Many a modern scientific paper would be greatly improved by maintaining a clearer distinction between experimental observations and their interpretation.)

In parallel with this reliance on a direct reading of the book of nature, Faraday, along with his fellow Sandemanians, saw spiritual authority as flowing from a direct reading of God's other book, the Bible. He saw reliance on the Bible as an anchor against the influence of emotion, superstition, and spiritual or political domination. The Christian "looks for no assurance beyond what the Word can give him," he wrote in an 1859 letter. "The Christian religion is a revelation, and that revelation is the Word of God. According to the promise of God, that Word is sent into all the world." Just as in science, for Faraday, the direct access to experimental observations is what guarantees trustworthiness, so in matters of faith direct access to God's word in the scriptures is his spiritual foundation.

The difficulty with Faraday's reliance on a direct reading of God's book, whether nature or scripture, is the question of *whose* reading. Faraday was not oblivious to the factional interests that so often govern the practice of religion and science alike. His solution in the realm of science again paralleled his religious views: he chose to avoid factionalism altogether, along with patronage and politics. His vision of the pursuit of science was one in which scientists were to be members of a true fraternity, and if differences of scientific opinion should arise, they were to be resolved in a spirit of brotherhood. In a letter about a controversy between two eminent scientists he says:

> These polemics of the scientific world are very unfortunate things; they form the great stain to which the beautiful edifice of scientific truth is subject. *Are they inevitable?* They surely cannot belong to science itself, but to something in our fallen natures. How earnestly I wish, in all such cases, that the two champions were friends.

Faraday sought to pursue his research in conformity to this idealistic vision of science, but recognized that his ideals, which were based on his spiritual commitments, were out of step with the practice of science in his day. He limited his political involvements, and felt ill-equipped to undertake positions of worldly leadership. After turning down the presidency of the Royal Society in 1857, he said to Tyndall, "I must remain plain Michael Faraday to the end." And he stuck to this conviction: Despite the urgings of his wife to accept a nomination for the presidency of the Royal Institution in 1864, he refused.

The scientific brotherhood that Faraday envisioned was not a closed communion. He was no elitist, whether socially or intellectually. Instead, he committed himself to bringing the results of science to the public, most notably through public lectures and scientific demonstrations. His position at the Royal Institution demanded this commitment. The Royal Institution had been founded in 1799 by Ben Thompson (Count Rumford) and Humphrey Davy for the dissemination of practical knowledge to the artisan class. But financial difficulties, along with Davy's genius and charisma, had turned it into a center for chemical research and popular scientific lectures. The Institution's famous Friday Evening Discourses were stimulating evening entertainment, and the primary means for the interested public of the day to learn of scientific matters—as well as a vital source of revenue for the Institution. For nearly four decades, from 1825 to 1862, Faraday delivered about a fifth of these evening discourses, bringing in considerably higher than average attendance. He introduced the Institution's annual Christmas Lectures for teenagers, which continue to this day. Faraday himself presented the Christmas Lecture nineteen times. His final in the series, entitled *The Chemical History of a Candle*, was published as a book in 1860, and has been translated into many languages and never been out of print in English.

Faraday was also concerned to disseminate the results of science in practical ways that brought material benefits to his fellow man. He saw the powers of nature as intended "always for our good," and the understanding of nature thus as an opportunity for material improvement. Although his primary motivation was to display the structure of Creation and thereby glorify the Creator, he nevertheless saw the practical application of science as a worthy undertaking, on par perhaps with his frequent ministrations to the sick and needy of his congregation. Faraday spent considerable effort in consultations on the development of improved light sources for light-houses, and was often called on by the British government for his scientific expertise. In Faraday's view, science, applied practically, "conveys the gifts of God to Man."

By the time Michael Faraday died in 1867 at the age of 75, he was revered as one of the grandest figures in British science. One might speculate that his lifelong religious nonconformity lent a certain color to his psychological makeup that enabled him to comfortably champion unorthodox scientific positions. His theoretical views—particularly his highly influential ideas about the physical reality of lines of force—were at best tolerated by the scientific establishment of the day, and that only because of the reputation that his experimental research had won. But his personal conviction, backed by what he saw as the basic authorities for knowledge—experimentally verifiable fact and Biblical scripture—was enough for him. At least in scientific matters, the judgment of history is decidedly in his favor.

The Theorist and His Faith

James Clerk Maxwell's scientific achievements are the work of a genius of physical theory. He contributed to optics, color vision, elasticity, and the dynamical theory of a spinning body. The work that established him as a foremost natural scientist was his analysis of Saturn's rings, in which he showed that they could not be rigid but must be made up of swarms of particles in a stable configuration. Maxwell was also the first person to apply the methods of probability to the analysis of the properties of gases. He invented the idea of representing the range of different velocities of the molecules of a gas by a mathematical function, and worked out the expression for its equilibrium form, known as the Maxwell–Boltzmann distribution. Maxwell went on to work out a variety of concrete predictions that could be obtained from this kinetic theory of gases, and, with the help of his wife, he carried out experiments to confirm the predictions.

The work for which Maxwell is most remembered, though, is his formulation of the set of equations that govern classical electromagnetism: Maxwell's equations. These led immediately to the prediction of electromagnetic waves and the consequent unification of electromagnetism and light. His formulation of electromagnetic theory in the form of differential equations, and his championing of the fundamental nature of the field to explain electromagnetic phenomena, in contrast to the action-at-a-distance theories of his day, are the basis of essentially all of modern physics. "One scientific epoch ended and another began with James Clerk Maxwell," wrote Albert Einstein. In addition to his personal contributions, Maxwell founded and supervised the building of the Cavendish Laboratory of experimental physics at Cambridge University, which became arguably the world's preeminent physics department for the next fifty years.

For the early years of his life, spent at his family's estate Glenlair in Galloway—a day's journey from the nearest city, Glasgow—Maxwell's education was entirely in the hands of his mother. He exhibited an astonishing memory. At the age of eight, he could recite long passages of Milton and the whole of Psalm 119—one hundred and seventy-six verses. Indeed, his knowledge of scripture was already very detailed; he could give chapter and verse for almost any quotation from the psalms. From an early age, devout Christian practice and demanding mental discipline were for Maxwell part of the same experience. He also showed great interest in the practical aspects of tending to and improving the family estate, under his father's patient, informal tutoring.

James's mother died when he was eight. He and the private tutor hired to continue his education were utterly incompatible, and after two years he was sent to Edinburgh Academy, lodging with his aunt. The Academy was one of the most successful Scottish schools of its day, with a strong emphasis on classics. The science teaching, however, was weak. The star pupils seemed to know more than their teachers, perhaps in part as a result of the "Philosophical Society" they formed to educate themselves. After a slow start, Maxwell settled in, and made some lifelong friends among the fellow students. Lewis Campbell, later Professor of Classics at St. Andrews University and a Maxwell biographer, moved in a few doors away. Peter Guthrie Tait, who would later best Maxwell for the Professor of Natural Philosophy position at Edinburgh University in 1859, became his classmate, and the two worked together on mathematical problems they called "props" (short for propositions). One of Maxwell's geometrical propositions was published when he was just fourteen; it was seen to be an improvement on René Descartes's equations for bi-focal curves. At age sixteen, Maxwell entered Edinburgh University, where he studied physics, along with the dominant theme of Edinburgh's courses: philosophy.

By all accounts, students at Edinburgh had substantial liberty for leisure and private study. From his letters to Campbell, we can tell that Maxwell took advantage of both. He writes:

> So I get up and see what kind of day it is, and what field works are to be done; then I catch the pony and bring up the water barrel....Then I take the dogs out, and then look round the garden for fruit and seeds, and paddle about till breakfast time; after that take up Cicero and see if I can understand him. If so, I read till I stick; if not, I set to Xen. or

> Herodt. Then I do props, chiefly on rolling curves.... After props come optics, and principally polarized light.
>
> Do you remember our visit to Mr. Nicol? I have got plenty of unannealed glass of different shapes....

This industry and breadth of education were a critical part of Maxwell's greatness, especially his philosophical sophistication. Maxwell was by no means a narrow scientific technician. Nor was he a shallow generalist—when he read Cicero and Xenophon, it was in the original languages.

Maxwell stayed three years at Edinburgh, longer than some of his contemporaries, perhaps because it took that long for his father to reconcile himself to James's desire for a scientific rather than a legal career. But in 1850, Maxwell departed Scotland for the foremost British institution of scientific education: Cambridge University.

The chief objective of ambitious Cambridge undergraduates was to become a "wrangler," that is, to obtain first-class honors in the mathematical examination series. It is remarkable how dominant mathematics was in the educational system of the time, but it should be remembered that Isaac Newton was Lucasian Professor of Mathematics in his own day, just as was Stephen Hawking until 2009. Mathematics at Cambridge encompassed all of physics as well. Maxwell settled to mathematical training and exercises with some restlessness, yearning to move forward faster than Cambridge tradition permitted to uncovering new discoveries about nature.

Maxwell's study and understanding of his Christian faith also grew rapidly during his Cambridge undergraduate years. A year into his residence at Trinity College, he writes to Campbell:

> Man requires more. He finds x and y innutritious, Greek and Latin indigestible, and undergrads. nauseous. He starves while being crammed. He wants man's meat, not college pudding. Is truth nowhere but in Mathematics? Is Beauty developed only in men's elegant words, or Right in Whewell's Morality? Must Nature as well as Revelation be examined through canonical spectacles by the dark-lantern of Tradition, and measured out by the learned to the unlearned, all second-hand.

When Maxwell arrived at Trinity, William Whewell was Master of the College. An ordained Anglican priest with an evangelical outlook, Whewell had made significant direct contributions to science as Professor of Mineralogy, and through mathematical textbooks and studies of the tides. But Whewell's enormous range of expertise was what he was best known for: He published on architecture, economics, and philosophy (for a time as Cambridge Professor of Moral Philosophy). He authored one of the *Bridgewater Treatises* (1833), and twenty years later, *Of the Plurality of Worlds*, both concerned in part with the relation between science and Christianity. And it was he who coined the very word *scientist.* One satirist said of him: "science is his forte and omniscience his foible."

Whewell's most important influence on Maxwell was not technical education—which was not the College Master's job—but his 1840 book *The Philosophy of the Inductive Sciences: Founded Upon Their History.* Whewell's philosophy of science lays out a "fundamental antithesis" of knowledge, almost Kantian in its content, that science depends not only upon empirical observations and induction from them, but equally upon fundamental ideas that arise unexplained from the mind itself, whose deductive consequences are tested against the experimental facts. Based on his historical research into how science had actually been practiced, Whewell contradicted many of the theories of the inductivist orthodoxy of his day—and it would be a century before philosophers of science came around to views like his. But we can be certain, from a letter Maxwell wrote in 1855—shortly before he became a Fellow of Trinity and published his first paper on electricity—that he knew and sought to practice Whewell's approach:

> It is hard work grinding out "appropriate ideas," as Whewell calls them. However, I think they are coming out at last, and by dint of knocking them against all the facts and half-digested theories afloat, I hope to bring them to shape, after which I hope to understand something more about inductive philosophy than I do at present.

Maxwell viewed religious faith itself as something to be put to the philosophical test. In an earlier letter to Campbell, from 1852, he writes of his "great plan" of "*Search* and *Recovery*, or Revision and Correction": "The Rule of the Plan is to let nothing be wilfully left unexamined. Nothing is to be *holy ground* consecrated to Stationary Faith, whether positive or negative." One of Maxwell's twentieth-century biographers, Ivan Tolstoy, supposes that Maxwell could not consistently retain his Christian faith at the same time as he left nothing "wilfully unexamined." But Maxwell saw it the other way around, writing:

> Christianity...is the only scheme or form of belief which disavows any possession on such a tenure. Here alone all is free. You may fly to

> the ends of the world and find no God but the Author of Salvation. You may search the Scriptures and not find a text to stop you in your explorations....
>
> [A] candle is coming to drive out all Ghosts and Bugbears. Let us all follow the Light.

Moreover, we have ample evidence from Maxwell's writings that he did deeply examine his faith, from his essays written as an undergraduate to his later, broad metaphysical inquiries with the group called the Apostles, an exclusive intellectual discussion society of the Cambridge elite. In letters written during his 1858 engagement to Katherine Mary Dewar, Maxwell describes his spiritual beliefs and practice. Despite protesting his lack of skill in scriptural exposition, he writes, in letters that read like short sermons, insightful explanations of passages from the New Testament, and refers to a Sunday school class he taught while visiting Lewis Campbell. Katherine and James's common Christian faith was an important bond from the beginning of their marriage.

"The Point at Which Science Must Stop"

In the summer of his third undergraduate year, Maxwell spent some time at the Suffolk home of the Reverend C. B. Tayler, the uncle of a classmate. Living with this large, extended family impressed Maxwell—himself an only child—who later said it gave him a glimpse of the Love of God. He fell ill for over a month while there, and was nursed by the minister and his wife. As his classmate later recounted concerning the experience,

> It was then that my uncle's conversation seemed to make such a deep impression on his mind. He had always been a regular attendant at the services of God's house....Also he had thought and read much on religious subjects. But at this time (as it appears from his own account of the matter) his religious views were greatly deepened and strengthened.

On his return to Cambridge, Maxwell writes to his recent host a chatty and affectionate letter, including this testimony:

> I maintain that all the evil influences that I can trace have been internal and not external, you know what I mean—that I have the capacity of being more wicked than any example that man could set me, and that if I escape, it is only by God's grace helping me to get rid of myself, partially in science, more completely in society,—but not perfectly except by committing myself to God.

This is a thoroughly evangelical Christian affirmation of dependence on God's grace for salvation from sin; but notice how Maxwell identifies his science as part of God's plan for this salvation. We can only speculate about what thoughts along these lines he and Reverend Tayler had discussed during the days of his recuperation.

Maxwell's Fellowship at Trinity lasted but one year, ending when he was appointed Professor of Natural Philosophy at Marischal College in Aberdeen. (It was through this appointment that Maxwell would meet his wife, whose father was Principal of Marischal.) In 1860 the two Aberdeen colleges were merged, and despite his seniority, Maxwell was out of a job. However, he was almost immediately appointed to the Chair of Natural Philosophy at King's College London, where he remained until 1865. In the inaugural lecture, which new professors traditionally gave, Maxwell explored various philosophical questions of science—for example, "whether the fundamental truths of Physics are to be regarded as mere facts discovered by experiment, or as necessary truths, which the mind must acknowledge as true as soon as its attention has been directed to them." On balance, in accordance with Whewell's views, Maxwell sides with the latter, the view of necessity, though his position is still far from clear.

He also refers to an idea that he would later develop in more detail: "that every atom of creation is unfathomable in its perfection." A version of this idea was eventually published, among other places, in the journal *Nature* in 1873; discussing astronomical observations of characteristic wavelengths of radiation from atoms, Maxwell concludes:

> We are thus assured that molecules of the same nature as those of our hydrogen exist in those distant regions, or at least did exist when the light by which we see them was emitted....
>
> Each molecule, therefore, throughout the universe, bears impressed on it the stamp of a metric system as distinctly as does the metre of the Archives at Paris, or the double royal cubit of the Temple of Karnac....
>
> None of the processes of Nature, since the time when Nature began, have produced the slightest difference in the properties of any molecule. We are therefore unable to ascribe either the existence of the molecules or the identity of their properties to the operation of any of the causes which we call natural.
>
> On the other hand, the exact equality of each molecule to all the others of the same kind gives it, as Sir John Herschel has well said, the essential character of a manufactured article, and precludes the idea of its being eternal and self-existent.

> Thus we have been led, along a strictly scientific path, very near to the point at which Science must stop.

He offered more detail in a letter written three years later: "What I thought of was not so much that uniformity of result which is due to uniformity in the process of formation, as a uniformity intended and accomplished by the same wisdom and power of which uniformity, accuracy, symmetry, consistency, and continuity of plan are as important attributes as the contrivance of the special utility of each individual thing."

This is a somewhat unfamiliar, inverted form of argument from design: the fact that molecules are perfectly identical to one another suggests that they are manufactured (so to speak) according to an intelligent plan. His oblique reference to molecular perfection in the 1860 lecture came the year after the publication of Darwin's *Origin of Species*, and he was likely well aware of the extent to which that book undermined popular arguments from design based on the perfection of biological adaptation. Maxwell was pointing to a different perfection in creation, one which he thought could not be attributed to evolutionary adaptation. Though he wasn't strictly correct that atoms are immutable, his aim was to highlight the ordered uniformity of nature, rather than its peculiarity and complexity, as signs of the creator.

Wonder and Materialism

In 1865, Maxwell retired from his London position. It had been an extremely productive tenure, which saw much of his experimental work on gases brought to fruition, and the publication of *On Physical Lines of Force* and his famous equations. But Maxwell wanted to complete the building of the house at the Glenlair estate, as a "sacred trust" to his late father. His independent wealth permitted him to resign from the rather heavy burdens of teaching and devote his time to the estate, to travel, to an extensive correspondence, and to writing his masterly *Treatise on Electricity and Magnetism* (1873). The house was finished in 1867, but governing it was just one aspect of being "Laird" of the estate. Other aspects that were pursued assiduously, by both James and his father before him, were daily prayer and Bible-reading sessions for the servants, and an almost proprietorial sponsorship of the church at Corsock, the nearby village.

Maxwell was persuaded to leave his retirement in 1871, accepting the newly created Cavendish Professorship of Experimental Physics at Cambridge, and the duties as a public figure that it entailed. It was not surprising, then, that the Bishop of Gloucester and Bristol consulted Maxwell about his ideas concerning faith and science. The Bishop wondered whether the creation of the sun after the creation of light in Genesis can be harmonized by regarding the latter as referring to "primal vibrations"—that is, the aether. Maxwell replies to this rather naïve question with politeness and great wisdom:

> If it were necessary to provide an interpretation of the text in accordance with the science of 1876 (which may not agree with that of 1896), it would be very tempting to say that the light of the first day means the all-embracing æther, the vehicle of radiation.... But I cannot suppose that this was the very idea meant to be conveyed by the original author of the book to those for whom he was writing....
>
> The rate of change of scientific hypothesis is naturally much more rapid than that of Biblical interpretations, so that if an interpretation is founded on such an hypothesis, it may help to keep the hypothesis above ground long after it ought to be buried and forgotten.
>
> At the same time I think that each individual man should do all he can to impress his own mind with the extent, the order, and the unity of the universe.

Thus Maxwell penetratingly criticizes the misuse of partial scientific knowledge to interpret scripture, let alone to shore up faith by supposed harmonization with the latest science. He has no need of scientific proofs of Christianity. Instead, his expressed concern is that ill-judged linking of specific scientific theories with religion will be an impediment to the growth of science. His emphasis, in relating science and faith, is on science's enhancement of our wonder at the glory of creation—certainly a much more enduring theme than the aether, which has long since been discarded.

Despite his deep philosophical and scientific knowledge, his prominent position, and his occasional public reference to religious matters, Maxwell mostly avoided the era's fierce public debates on science and religion. But we can be sure he followed them closely, and we can appreciate his more moderate style from his response to John Tyndall's "Belfast Address." In 1874, Tyndall famously delivered an address to the British Association for the Advancement of Science arguing for scientific materialism. Tyndall praised the ancient atomists, Epicurus and Lucretius, and asserted the superiority of professional scientists to the clergy: "We shall wrest from theology, the entire domain of cosmological theory. All schemes and systems which thus infringe upon the domain of science must, *in so far as they do this*, submit to its control, and relinquish all thought of controlling it." In passing, he also critiqued Maxwell's molecular perfection argument. Maxwell's response was not an angry letter to the Times (though there were such responses by others) but a gently satirical summary of Tyndall's very long address, in two pages of verse neither fierce nor condemnatory, but funny enough to be published in *Blackwood's Magazine.* Maxwell's Christian conviction was not threatened by the growing materialism of the age.

Maxwell died of abdominal cancer in 1879 at the age of 48. Those who met with him in the final months and weeks of his illness recounted his composure, his continued interest in science, his concern for the well-being of his wife, and his unstinting daily religious devotions.

Contingency, Coherence, and Creation

While the culture of Victorian Britain was more Christian than that of either Britain or the United States today, the Christian commitments of Michael Faraday and James Clerk Maxwell were not just incidental conformities to now-faded cultural norms. Nor were they intellectual deformities that prevented these giants from reaching their full scientific potential. On the contrary, their spiritual beliefs were essential parts of the strength of character and the view of nature that empowered them to make their transformative contributions to science.

One might wonder about the source of the robust Christian commitments of Faraday and Maxwell. What enabled them to negotiate the intellectual challenges that emerged from the new scientific knowledge of the nineteenth century? Although their firmly held faith was not unusual among scientists of the era, there were many others who lost it: Darwin is an oft-cited example, though his reasons, insofar as they were intellectual, are now widely thought to have been difficulties with theodicy more than with science.

A few tentative suggestions may be offered concerning the common sources of Maxwell's and Faraday's enduring religious convictions. Each grounded his faith in personal religious experience, not just intellectual investigation. And each found the source of spiritual authority and conviction more in the witness of the Bible and the person of Jesus than in natural theology or philosophical argument. Both were concerned to express their faith through the practice of Christian virtues, charity, good works, spiritual discipline, and service. And both carried their honesty and integrity into their intellectual work, reinforcing their commitment to the rigors of scientific practice. Both, moreover, had an independence of spirit and personal conviction that made them comfortable holding views contrary to the current fashion. They were in that sense nonconformists.

The spiritual commitments and ideals of Faraday and Maxwell also influenced their scientific ideals. Neither Maxwell nor Faraday supposed that creation's being intelligently designed enables us to deduce the experimental content of natural philosophy. Instead, they emphasized the wonder and contingency of creation, believing that God had choices about how the world was created, and that only direct experimental engagement with nature enables us to determine what those choices are.

Maxwell's and Faraday's persistent sense of the createdness of nature, their theistic worldview, should not be supposed indispensable to all successful science, then or now; but for these two exceptional scientists, it proved far from a handicap. It undergirded their belief in the coherent unity of nature. It encouraged analogy as an explanatory strategy, whereby an understanding of one aspect of nature could be transferred conceptually to help make another comprehensible—for example, fluid flow as an analogy for electromagnetic fields (even though the actual physical relationship between these two is highly indirect). And it encouraged the idea of conservation as a fundamental unifying principle.

While these two great British electricians of the nineteenth century remain in many ways a study in biographical contrasts, their similar views on nature, faith, and the relation between them illuminate a common and constructive intellectual thread. The scientific principles to which their approach led them remain foundational to today's physics, even as many claim to have voided it of any theistic underpinnings. What Faraday and Maxwell, in their study of nature, were committed to most fundamentally was the discovery of lawfulness and coherence: the conceptual unification of apparently distinct phenomena, such as electricity and magnetism and light. Lawfulness was not, in their thinking, inert, abstract, logical necessity, or complete reducibility to Cartesian mechanism; rather, it was an expectation they attributed to the existence of a divine lawgiver. These men's insights into physics were made possible by their religious commitments. For them, the coherence of nature resulted from its origin in the mind of its Creator.