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The Romance of Nature

The worlds of natural philosophy at the beginning of the nineteenth century were changing rapidly. As we have seen already, many observers regarded natural philosophy as having been (and still being) deeply implicated in the political convulsions that were still sweeping Europe. It seemed to many commentators on both sides of the political fence that the French Revolution and its aftermath were, to at least some degree, the results of Enlightenment philosophies challenging traditional ideas about nature and society. Those political convulsions themselves were responsible for major changes in the institutional structures of European natural philosophy as well. New institutions proliferated and campaigns gathered pace across Europe to reform the moribund structures of ancien régime science. In many ways the social role both of natural philosophy and of its practitioners was up for grabs in such a volatile situation. Not only the institutional context, but the content of science was being quite literally re-formed in the wake of the transformations surrounding the French Revolution. New notions concerning what science should be about—what kind of nature natural philosophers should be searching for—went hand in hand with new visions of what kind of person the natural philosopher should be and how his role in society should be understood and appreciated. Fashioning nature and fashioning the natural philosopher were part of the same process.

One response to the changing contours of natural philosophy and the natural philosophical community was the cultural movement now known as Romanticism. Particularly in the German lands a new generation of natural philosophers tried to identify natural philosophy with the search for a transcendental unity in nature. Reacting against what some of them, at least, perceived as an impoverished Enlightenment insistence on focusing on appearances, Romantic philosophers such as Johann Wolfgang von Goethe, Johann Wilhelm Ritter, and Friedrich Schelling in the German lands and Humphry Davy in England argued for the importance of looking beneath the phenomena in an effort to capture the real underlying unity of nature. Increasingly as well, the search for such unity was held to be the province of a particular kind of individual. Natural philosophy required genius. Only a genius—an inspired individual with access to unique reserves of imagination and intuition—could peer beneath the fractured surface of appearances at the transcendental reality beneath. This novel cult of genius was not unique to natural philosophy. In many ways it was a defining feature of Romanticism across culture in the early nineteenth century. In the arts, literature, and music, as well as natural philosophy, being a genius was very much in vogue.

Laboratories across Europe appeared to be providing more and more grist for the mills of those philosophers intent on discovering unity. Experimenters were finding more and more ways of apparently transforming one kind of natural force into another. The voltaic pile, according to the proponents of the chemical theory at least, seemed to turn chemical forces into electricity. The novel technology of photography seemed to provide a way of using light to produce chemical reactions. Following Hans Christian Oersted's experiments in 1820, it seemed to many that there was some intimate link between electricity and magnetism as well. The most visible technology for turning one kind of force into another was increasingly ubiquitous during the early nineteenth century; the steam engine, according to some natural philosophers, was simply a machine for producing mechanical force from heat. Far from being a transcendental unity, Nature was increasingly seen by some natural philosophers as a laboratory for manipulating and transforming the forces. Conversely, what nature did naturally, the experimenter could now perform in his laboratory. New links could be found in all of this between the natural and the political economy. The way nature's forces were organized provided a powerful model for the way in which human economies should be organized as well.

Laboratory practice revolved more and more about the task of finding new ways of making one kind of force produce another. Such practices could also be used as the foundation of new philosophies of nature—as well as new kinds of politics. A number of natural philosophers before midcentury made efforts to base new systems on the experimenter's ability to transform one kind of force into another. New vocabularies were adopted to express these views concerning the unity of nature. William Robert Grove argued for the correlation of physical forces. Michael Faraday argued for the mutual conversion of forces. James Prescott Joule suggested that force was conserved from one transformation to another. Force was the primary focus in these discussions. Many natural philosophers, particularly in Britain, argued that force should be the fundamental concept of physical science. In their view everyone had an intuitive understanding of what force meant as a result of their own everyday interactions with the world around them—they were continually aware of exerting force, or of having force exerted on them. They argued that this provided a good way of making sure that natural philosophy stayed grounded in the real world of everyday experience. The grand philosophical schemes constructed around the mutual relations of the various forces of nature had another implication too. To claim that the forces of nature were all linked together was to argue as well for the primacy of a natural philosophy that could explain that linkage. In other words, it was a way of reasserting the continued superiority of a general natural philosophy (and a generalist natural philosopher) in the face of what many natural philosophers regarded as a worrying trend towards disciplinary fragmentation and specialization.

By the 1850s and 1860s, however, a new candidate had emerged supreme as the focus at which the physical sciences were united. The second half of the nineteenth century saw the rise of the new science of energy. According to this new science, energy, not force, was the fundamental concept of physics. William Thomson and Peter Guthrie Tait's *Treatise on Natural Philosophy* of 1867 was a quite self-conscious effort to replace Newton's *Principia* as the foundational text of a new kind of natural philosophy. James Clerk Maxwell's work on electromagnetism, culminating in his *Treatise on Electricity and Magnetism* of 1873, was a prime exemplar of the new science's versatility. His powerful synthesis of electricity and magnetism showed how energy could be the new unifying principle of natural philosophy. There was nothing transcendental, however, about this science of energy. Energy, according to this new world picture, was embodied in the ether—a substance that filled all space and operated according to the principles of mechanics, just like a factory engine. Understanding the mechanics of the ether was the holy grail of physics for late nineteenth-century experimenters such as Oliver Lodge.

There was a close link throughout the nineteenth century between the ways in which physics as a discipline was organized and the ways in which physics organized the world. For early nineteenth-century Romantic philosophers, natural philosophy required a particular kind of individual. Apprehending nature's hidden unities required someone with the innate capacity to look beneath the surface of events and see what others could not. Midcentury experimental natural philosophers such as William Robert Grove suggested that the natural philosopher needed to be someone educated to look beyond the limitations of particular disciplinary preoccupations and see the wider picture of the correlation of forces. By the end of the century, proponents of energy physics argued that only those like them, deeply trained in the complexities of mathematical physics, could see the world as it really was. It needed their grasp to comprehend the subtle workings of the ether. Their understanding of that subtle and universal medium gave them the ability to police the sciences—to adjudicate what was and what was not an acceptable way of looking at the world.

Romantic Science

To modern eyes, the conjunction of science—particularly physics—with Romanticism seems somehow peculiar, or at least surprising. Romanticism evokes images of wild-eyed poets, drugs, and Gothic castles. Physics is taken to be a far more sober affair. That apparent disjunction, however, is very much a product of subsequent history. The Romantic movement, in its origins, was deeply concerned with the problems of constructing a new philosophy of nature and as such quite straightforwardly took the understanding of the physical world as part of its project. In many ways, Romanticism was a response to what its proponents regarded as Enlightenment excesses—an increasing distance from nature that came along with civilization and an increasingly mechanized world picture. In their art, their literature, their poetry, and their science, the Romantics sought to find ways of bridging the gap they saw emerging between modern society and modern individuals and a true understanding of their natural selves and the natural world. What was needed, they argued, was an intuitive understanding of things that transcended mere phenomena and got to the true meaning and unity of nature and man's place in it.

It was a central tenet of Romantic philosophy that nature should be apprehended as a coherent and meaningful whole, rather than as an aggregation of disparate and fragmented phenomena. Romantic philosophers were quite often deeply contemptuous of the Enlightenment tendency towards understanding nature by breaking it down into its constituent parts. The Enlightenment metaphor of the Universe as a clock or a machine whose operations could be understood by taking it apart was the subject for irony, if not of outright mockery. The Romantics instead thought of the Universe as something organic. Like a living thing, the Universe was best approached and appreciated by seeing it as a connected, animated unity. Rather than being taken as separate objects of study, the various phenomena and powers of nature were to be understood as different manifestations of a single underlying and all-embracing cause. The aim of natural philosophy from this perspective was synthesis rather than analysis. Unlike Newton, who insisted that he would not "feign hypotheses" but build his theories on the phenomena, Romantic philosophers insisted that by imaginatively feigning hypotheses they could approach an understanding of a more meaningful reality beneath the surface appearance of things.

The Romantics celebrated a new kind of human being who possessed this capacity to look beneath the surface of things for their true meaning—the genius. A genius, as the term was increasingly used in the late eighteenth and early nineteenth centuries, was possessed of unique capabilities which placed him (and it was invariably a "him") outside conventional limitations. Genius was an innate, rather than a learned, capacity. A man was born with the powers of genius. Quite often the language of possession was used quite literally as well. Genius was an active power that took over a particular individual rather than being something that was under that person's control. There was a strong sense in which it was held that there was a kind of symbiosis between the individual's genius and the natural world that genius allowed him to comprehend. In the fragmented world of early nineteenth-century natural philosophy, this cult of genius played a crucial role in providing a new kind of social place for the man of science. Natural philosophy was represented as a deeply individualistic process in which imagination and inspiration took precedence over collective effort in forging scientific progress.

The monumental German playwright and poet, Johann Wolfgang von Goethe, established many of the parameters of Romanticism in literature, architecture, and the arts, as well as in natural philosophy. Goethe considered his contributions to optics and the science of colors as among his most important works: "I make no claims at all to what I have achieved as a poet. Fine poets were my contemporaries, even finer ones lived before me, and there will be others after me. But that I alone in my century know what is right in the difficult science of colour, for that I give myself some credit, and thus I have a consciousness of superiority to many."[1] Goethe saw his work as a direct attack on Newton's then triumphant theory of optics. In *Zur Farbenlehre* in 1810 he declared that as soon as he saw Newton's "celebrated phaenomena of colours" for himself by looking through a prism, "I immediately said to myself, as if by instinct, that the Newtonian teaching is false."[2] Newton's theory, he argued, was a house of cards built on partial and inconclusive experiments. Newtonians were accused of ignoring observations that contravened their hero's doctrines. At Weimar and in nearby Jena, Goethe built up and participated in a circle of similarly minded philosophers and poets committed to creating an alternative worldview that could be used to challenge, among other things, the Newtonian, mechanistic hegemony in natural philosophy.

The philosopher F. W. J. Schelling arrived in Jena as professor of philosophy in 1798, three years after Prussia had been forced into a peace treaty with revolutionary France; he concurred with Goethe that more was required of natural philosophy than a partial examination of the phenomena. As tutor to a brace of young Saxon aristocrats at the University of Leipzig, Schelling had already published his *Ideen zu einer Philosophie der Natur*, in which he argued forcefully for the necessity of establishing physics on a firm a priori foundation. According to this ambitious master plan for a new *Naturphilosophie*, all of physics was to be deduced from first principles. He elaborated this radical new worldview in 1798 with his *Von der Weltseele*, in which he articulated his grand vision of nature as a living organism. The task of the *Naturphilosoph* was to try to understand the soul of this cosmic being. The end of physics was to be the full comprehension of nature's latent and hidden spirituality, which would, in turn, become a mirror for the further exploration of man's own spiritual nature.

Like Goethe, Schelling was adamant that this higher physics was to be understood quite explicitly as a counter to the sterile mechanics of Newtonianism. He set his vision of the world soul in direct opposition to the world clock that he regarded as encapsulating Newtonianism. Where

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[1] Quoted in Sepper, "Goethe, Colour, and the Science of Seeing," in A. Cunningham and N. Jardine (eds.), *Romanticism and the Sciences*, 189.

[2] Quoted ibid., 190.

Newton had studied the phenomena of nature as separate cogs and wheels in some grand universal clockwork mechanism, Schelling wanted to see them as mutually interacting members of one single and unified cosmic organism. The key to unlocking the secrets of this world soul was the idea of polarity, or opposites. The heartbeat of the cosmic organism was maintained by the constant interplay and interaction of opposing forces—just like positive and negative electrical forces and the attractive and repulsive powers of magnetism. It was from this grand hypothesis that the rest of physics was to be worked out. In opposition to Newton and his grand dictum of *hypotheses non fingo*—"I do not feign hypotheses"—Schelling insisted that not only was hypothesis permissible, but that it was an essential and integral part of physics. The phenomena of nature were to be understood through his grand hypothesis of polarity—not the other way round. The latest philosophical discoveries were marshaled by Schelling to provide a litany of confirmations and examples of polarity's cosmic role.

Other Romantic thinkers congregated around Jena in about 1800 concurred with many of Schelling's claims concerning the need for a new natural philosophy. Friedrich Schlegel was keen to found his own philosophical system, boasting to a friend that "notebooks on physics I have already, therefore, I think I will soon have a system of physics as well."[3] Schlegel was anxious to bring about a reintegration of science and the literary arts, advising a student that "if you want to penetrate into the very core of physics, have yourself initiated into the mysteries of poetry."[4] The poet and mining engineer Friedrich von Hardenberg (known as Novalis) was also a keen student of natural philosophy, aiming to produce a "scientific bible"[5] that would enumerate and transcend the sum of human knowledge. Another member of the Jena circle, Johann Wilhelm Ritter, was regarded by his interlocutors there as being well on the way to producing the Romantic science they yearned for. Novalis remarked of his friend that "Ritter is indeed searching for the genuine world-soul of nature."[6] A keen follower of Schelling's *Naturphilosophie*, Ritter regarded his task as being to discover the secrets of the *All-Thier* (All-Animal) of the universe. To this end he embarked on an ambitious experimental program to elucidate the notion of polarity in nature.

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[3] Quoted in W. Wetzels, "Aspects of Natural Science in German Romanticism," 48.

[4] Quoted ibid., 50.

[5] Quoted ibid.

[6] Quoted ibid., 53.

Ritter, born in Silesia in 1776, had been apprenticed to an apothecary before enrolling as a student of natural philosophy at the University of Jena in 1796. Enthused by Luigi Galvani's and Alessandro Volta's new discoveries in animal electricity as well as by Schelling's claim that electricity was the principle of life in nature, he set out to systematically map the ubiquity of electrical phenomena throughout the natural world. His early work focused on examining the workings of galvanism on organic matter and its relationship to the phenomena and processes of life. He speculated that, at least in principle, electricity might even be used to raise the dead. This, however, was only the first link in a cosmic chain that led back to the fundamental unity of all things: "Where is the sun, where is the atom that would not be part of, that would not belong to this organic universe, not living in any time, containing any time?—Where then is the difference between the parts of an animal, of a plant, of a metal, and of a stone?—Are they not all members of the *cosmic-animal*, of *Nature*?"[7] For many of his Romantic contemporaries in and around Jena and elsewhere, Ritter's experiments were putting the empirical flesh on the bones of Schelling's speculative *Naturphilosophie*.

One avid English reader of these exciting new German speculations in natural philosophy was the poet Samuel Taylor Coleridge. Coleridge immersed himself in writings on natural philosophy while living in the West Country following his departure from Cambridge. As early as 1796 he was planning to visit the German lands in search of philosophical inspiration; after considering Jena he eventually matriculated at the University of Göttingen in 1799. *Naturphilosophie* was central to his efforts during the early years of the nineteenth century to develop a coherent system of thought. Like the Romantic philosophers at Jena, he was convinced that mind was active in nature and that nature itself was an animate, organic whole. In a draft of his seminal *Biographia Literaria* of 1815, he argued that there was a correspondence between the powers of mind and those of nature: "Our Business then is to construct a priori, as in Geometry, intuitively from the progressive Schemes that must necessarily result from such a Power with such Forces, till we arrive at Human Intelligence, and prospectively at whatever excellence of the same power can by human Intelligence be schematized."[8] Nature could, in other words, provide the grounds for the powers of human intelligence that could then be used to

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[7] Quoted in W. Wetzels, "Johann Wilhelm Ritter: Romantic Physics in Germany," in A. Cunningham and N. Jardine (eds.), *Romanticism and the Sciences*, 203.

[8] Quoted in T. Levere, *Poetry Realized in Nature*, 119.

reflect back on the powers of nature themselves. There was, he argued, a kind of symbiosis between nature and the human mind. It was this symbiosis that made human understanding of nature possible in the first place. Like the Germans, he condemned English science for its mechanistic sterility, contrasted to what he regarded as the dynamism of the new German school.

Coleridge's close friend Humphry Davy was another English advocate of Romantic science. Davy, who like Ritter had started his career as an apothecary's apprentice before joining the radical chemist Thomas Beddoes at his famous (or infamous) Pneumatic Institute in Bristol, also like his German contemporary founded his early reputation on the exciting new science of galvanism. Closely associated with the poets Robert Southey and William Wordsworth as well as Coleridge, during his sojourn in the West Country, Davy dabbled in poetry himself while engaged in his chemical and electrical experiments. Like the German Romantics, Davy was simultaneously obsessed with the powers of nature and the powers of human genius (of which he regarded himself as being a preeminent example). The discovery of nature was taken to be a means to self-discovery in Davy's scheme of things—sometimes quite literally so. In early experiments on the newly discovered gas nitrous oxide, Davy experimented with breathing the new air as a means of investigating his own mind and wrote rapturous poetry of the resulting experiences.

After leaving the Pneumatic Institute to take up a post lecturing at the new Royal Institution in London, Davy seemed, at least to some of his erstwhile collaborators, to have abandoned his radical and Romantic roots for the carrot of metropolitan success. His experimental researches throughout the 1800s and 1810s, however, continued to focus on uncovering the active powers of nature and establishing their fundamental unity. For Davy, the various powers of chemical affinity, electricity, heat, and light were all to be regarded as different manifestations of one underlying and all-embracing active principle. The natural philosopher's task, as he saw it, was to make these different powers available for mankind's material benefit as well as their spiritual uplifting. The philosopher's genius that led to an intuitive understanding of nature also conferred power over it: "By means of this science man has employed almost all the substances in nature either for the satisfaction of his wants or the gratification of his luxuries. Not content with what is found upon the surface of the earth, he has penetrated into her bosom, and has even searched the bottom of the ocean for the purpose of allaying the restlessness of his desires, or of extending and increasing his power."[9] This utilitarian twist on Romantic philosophy was particularly apposite to his position at the Benthamite-inspired Royal Institution and later in the 1820s as president of a reforming Royal Society.

Romantic science in the early nineteenth century was a loose collection of practices and ideas rather than a coherent school or system. Even Romantics like Novalis, for example, could be scornful of some aspects of Schelling's *Naturphilosophie*, dismissing it as little more than the "boasting of a fanciful mind."[10] In some respects, maybe, a philosophy that placed so much emphasis on the role of individual inspiration in the discovery of nature was not aimed in any case at producing a collective research program. Future generations of natural philosophers, particularly in the German lands, were scathing in their condemnation of the metaphysical excesses of their predecessors. Romanticism provided, however, some practical and intellectual tools for self-fashioning and disciplinary fashioning in the opening decades of the nineteenth century. In the face of massive social and intellectual upheaval at the turn of the century it helped construct a new vision of nature as a unified, organic whole, which in turn provided a resource both for constructing new scientific disciplines—including physics—and for constructing a new image of the natural philosopher and his place in society.

The World's Laboratory

New laboratories sprang up all over Europe during the first few decades of the nineteenth century. As we shall see, these early nineteenth-century laboratories differed from their predecessors in kind as well as number. They were starting to be regarded as spaces for research in their own right rather than merely as adjuncts to the lecture theater. Experiment increasingly looked like the key to unlocking nature's secrets and putting them to the service of humankind. Furthermore, what more and more experimenters in these new laboratories seemed intent on doing was finding ways of turning one kind of force into another. To Romantic natural philosophers, these proliferating instances of the apparent conversion of one kind of force to another seemed to be powerful confirmatory evidence

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[9] Quoted in Lawrence, "The Power and the Glory: Humphry Davy and Romanticism," in A. Cunningham & N. Jardine (eds.), *Romanticism and the Sciences*, 221.

[10] Quoted in W. Wetzels, "Aspects of Natural Science in German Romanticism," 49.

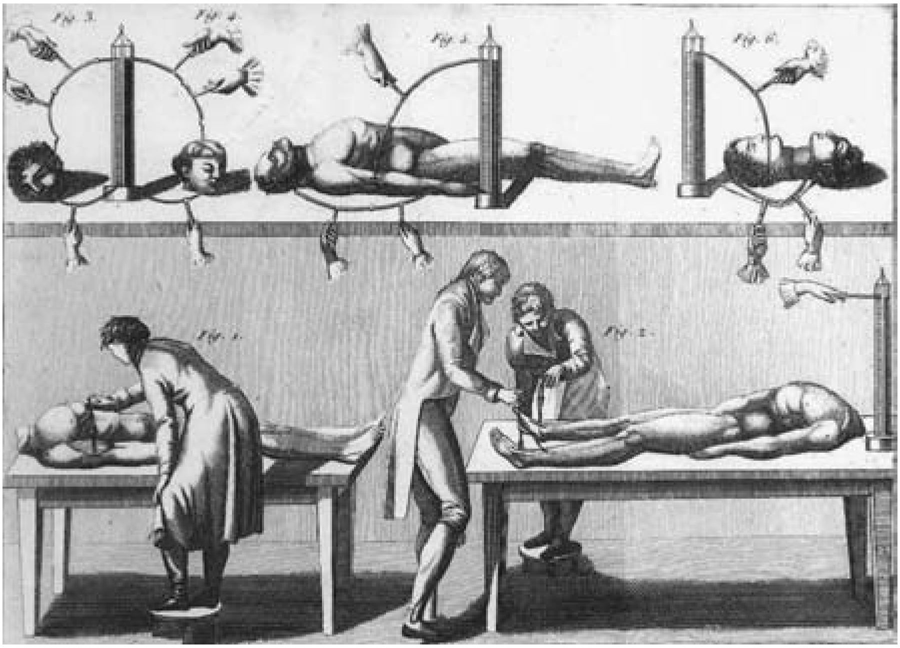
of the underlying unity of all the forces of nature. They were mutually convertible because they were all simply different manifestations of the one underlying power. More pragmatically perhaps, others saw economic potential in this ability to turn one force into another. Laboratory experiments might prove to be the means of delivering inexhaustible new sources of exploitable power. Not only the powers of wind and water (or humans and animals) might be made to do useful work, but the forces of chemistry, electricity, heat, and light might all be made available.

There was an underlying metaphysics behind this kind of economic interest as well, however. By the end of the eighteenth century many natural philosophers agreed that nature had its own economy and that the political economy mirrored (or at least ought to mirror) the natural one. Putting the resources of the one at the disposal of the other seemed appropriate. Some argued that the natural economy was designed to be placed at the disposal of humanity in any case. The geologist James Hutton argued in his *Dissertations on Different Subjects in Natural Philosophy* of 1792 that nature should be regarded as a self-regenerating system of active powers with the Sun as the source of regenerative power. Adam Walker in his *System of Familiar Philosophy* of 1799 maintained that light, fire, and electricity were simply different manifestations of a single principle of repulsion and that nature's economy was maintained as a perpetual balance between this principle of repulsion and the attractive principle of gravitation. The radical natural philosopher and political writer Joseph Priestley regarded phlogiston—the active principle of combustion—as underlying all of nature's economy. Humphry Davy in his *Essay on Heat, Light and the Combinations of Light* (1799) asserted that electricity, light, and chemical action were different manifestations of the same thing.

The flamboyant American émigré and Royalist, Benjamin Thompson, ennobled as Count Rumford by the elector of Bavaria, was a keen advocate of the utility of the experimental sciences. As such he was to play a crucial role in promoting utilitarian scientific enterprises at the beginning of the nineteenth century. He was a key figure in the establishment of the Royal Institution in London in 1799, having helped convince a group of reforming landowners of the prospects for putting chemistry and natural philosophy to work in improving agriculture. Rumford was a staunch opponent of the caloric theory of heat—the notion that heat was an imponderable fluid. He carried out experiments on cannon boring, showing how friction produced heat. He argued that the amount of heat produced during the process was indefinite and suggested therefore that heat could not be a fluid but was instead the result of particles in motion. Humphry Davy, professor of chemistry at Rumford's Royal Institution within a few years of its foundation, was similarly an opponent of the caloric theory, then popular in Revolutionary France. Its last great advocate there had been Lavoisier, whose wife Rumford had married following her former husband's death at the guillotine. Like Rumford, Davy carried out some confirmatory experiments, in this case on the melting of ice due to friction. By showing that blocks of ice rubbed together melted, Davy suggested that the heat produced by the process was the result of friction and that heat was simply a kind of motion.

As we shall see in considerably more detail in a later chapter, heat and its relationship to motion was a matter of particular concern to early nineteenth-century experimenters. With the Industrial Revolution in full swing, the steam engine in particular was taken to be the preeminent example of a device that turned one kind of force—heat—into another—motion. It also seemed to be a machine designed to make the power tied up in the "vast storehouse of nature" available to humankind. The young Mancunian brewer's son, James Prescott Joule, in the 1840s devoted considerable experimental effort to improving the efficiency of steam engines. That was what underlay his efforts to experimentally determine what he called the "mechanical equivalent of heat." He had already made a name for himself carrying out experiments assessing the efficiency of electromagnetic engines. His famous paddle wheel experiment was a way of showing that motion and heat were literally interchangeable and of providing the data that allowed him to calculate the exact rate of exchange.

Many of the early nineteenth century's laboratory conversion processes were offshoots of the voltaic battery—the dramatic new technology that was the culmination of Alessandro Volta's dispute with Luigi Galvani concerning the origins of animal electricity. Ironically, however, Volta himself did not consider the voltaic battery a conversion device. He regarded the source of electricity in the battery as the simple contact of the metals. Only for his opponents who like Davy held that the electricity was produced from chemical affinity, or Galvani himself, who held that electricity was identical with the nervous force of the body, was the battery the instrument of the conversion of one kind of force or power into another. Galvani's nephew Giovanni Aldini used the battery to spectacular effect to confirm his uncle's claims concerning animal electricity. Experimenting on the bodies of dead animals and of executed felons, he could show how electricity seemingly reproduced the appearance of life in otherwise inanimate corpses (figure 3.1). The Royal Humane Society in England speculated that Aldini's experiments might prove to



3.1 Electrical experiments on recently executed criminals from Giovanni Aldini, *Treatise on Galvanism* (1803).

be the key to restoring life to the prematurely dead. The Scottish chemist Andrew Ure made similar claims when he carried out electrical experiments on an executed murderer in Glasgow in 1818.

The body, human and animal, was increasingly a focus for experimentation on relationships among the powers and forces of nature. Ritter, coming as he did from a Romantic perspective that regarded the entire Universe as a single connected organism, was deeply involved in experimental work on the relationship between electricity in particular and the nervous powers responsible for animating animal and human bodies. His *Das elektrische System der Körper*, published in 1805, was an ambitious effort to construct a cosmic electrical system in which electricity was held up as the basic organizing principle of all animate and inanimate matter. To this end Ritter experimented copiously on the actions of electricity on the body, its effects on the growth of plants, and so forth. Much of his work was dismissed as fanciful by contemporaries and successors anxious to dissociate themselves from the *Naturphilosophie* that informed his experimental researches. A few decades later the Italian natural philosopher Carlo Matteucci embarked on his own experimental program to investigate the electrical properties of living tissue and the question of the relationship between electricity and the nervous force. He produced a long series of papers through the 1840s, translated into English and published in the *Philosophical Transactions* of the Royal Society, on experimental efforts to measure electrical currents in the body.

Hans Christian Oersted, a friend of Ritter's and like him an admirer of Schelling's *Naturphilosophie*, carried out experimental work aimed at finding links among the different powers of nature as well. Oersted was particularly fascinated by the possibility of establishing a relationship between electricity and magnetism. It seemed to many experimenters that there must be such a connection, if only because of the many analogies they perceived between electricity and magnetism. In 1820 Oersted, by now professor of physics at the University of Copenhagen, succeeded in finding the long sought-for link. He found that when a magnetized needle was suspended near a copper wire carrying a flow of electricity from a voltaic battery, the needle deflected (figure 3.2). Oersted interpreted his findings in terms of an "electric conflict" surrounding the wire and interacting with the needle's magnetism. He argued that heat and light should be regarded as the result of such electric conflicts as well. Oersted's work was enthusiastically reproduced at the Royal Institution in London, where the young Michael Faraday succeeded in making an electric wire rotate around a magnet. A decade later he succeeded in producing electricity from magnetism as well. To those looking for unity in nature, it appeared that more and more links in the chain were being forged all the time.

Another link was forged in Berlin. Thomas Johann Seebeck, an independently wealthy experimental enthusiast and devotee of Goethe's theory of colors, had been fascinated by the possibility of finding connections between heat and light since 1806. He was particularly interested in the relationship between heat and the colors of the solar spectrum. Inspired by Oersted's discovery, he set out on an experimental examination of the connections between electricity, magnetism, and heat. His aim was to produce magnetic phenomena by heat. Instead, he found a way of producing electricity from heat. He found that if he constructed a circuit partly of copper and partly of bismuth and heated one of the junctions where the two metals joined, a current was registered by a magnetized needle suspended nearby. William Sturgeon in England used Seebeck's discovery to good effect, showing how a spherical cage made of the wire of the two metals could be made to rotate about a central magnet when the junctions were heated. This was the solution to why the Earth

3.2 A nineteenth-century artist's impression of Hans Christian Oersted's 1820 observation that a magnetized needle held near a wire carrying a current of electricity was deflected.

rotated on its axis, according to Sturgeon, a self-taught natural philosopher and former artilleryman based in Woolwich near London and the inventor of the electromagnet. The currents produced by the Sun's heat made the Earth rotate about the central magnetic core—as well as producing spectacular electrical storms in the tropics. A dozen years later, in 1834, the Frenchman Jean Charles Peltier added another link, showing that electricity could absorb heat as well, reversing Seebeck's experiment and using electricity to produce cold.

Heat and light were also coming to be regarded by some investigators as different manifestations of the same thing. The astronomer William Herschel, internationally fêted for his discovery of the planet Uranus, had carried out experiments on the temperature of the solar spectrum in the 1790s and had shown that temperature varied from one end of the spectrum to the other—the red end of the spectrum being hotter than the violet one. From this Herschel proceeded in 1800 to the discovery of infrared light beyond the red portion of the spectrum. Inspired by Herschel's discovery and anxious to preserve the spectrum's symmetry, Ritter postulated that there must be yet another invisible part of the spectrum at the other, violet end. In 1801, Ritter succeeded in showing that something emanating from just beyond the violet end of the spectrum darkened a silver chloride compound just as ordinary light did. He had found the ultraviolet part of the spectrum. The Italian Macedonio Melloni's experiments on radiant heat during the 1830s—showing that it could be made to manifest physical properties similar to those of light—were also widely regarded as making the identity of light and heat secure.

Another new and rapidly developing technology of the early nineteenth century seemed to demonstrate conclusively the relationship between the powers of light and chemical affinity. Experimenters had long known that light had an effect on certain chemical compounds (like the silver chloride in Ritter's experiments on ultraviolet light). The development of photography, however, had the effect of making this relationship graphically visible. Light shining onto surfaces specially treated with certain chemicals could produce stunning images of real-life scenes, objects, and even people. Louis Jacques Mandé Daguerre in France and William Henry Fox Talbot in England both developed successful techniques for creating and preserving these impressive and novel images. Fascinated commentators regarded the new technology as an unprecedented example of nature's powers being put at the service of humankind. As the experimental natural philosopher William Robert Grove joked, the day would soon come when "instead of a plate being inscribed, as 'drawn by Landseer, and engraved by Cousins,' it would be 'drawn by Light, and Engraved by Electricity!'"[11] Michael Faraday enthused over Talbot's

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[11] W. R. Grove, "On a Voltaic Process for Etching Daguerreotype Plates," *Philosophical Magazine*, 1842, **20**: 24.

"photogenic drawings," exclaiming that "what man may do, now that Dame Nature has become his drawing mistress, it is impossible to predict."[12]

Many commentators regarded these proliferating examples of the apparent conversion or interchangeability of one force for another as evidence of at least some kind of underlying unity, though just what kind of unity it might be was a subject for debate. In England certainly, many took a similar perspective to that of Humphry Davy, who had argued that all these manifestations of force were to be regarded as different ways in which nature's powers had been made available for humanity's benefit. Charles Babbage in his *Economy of Machinery and Manufactures* in 1832, providing his perspective on the sources of economic wealth and progress, started with an overview of the natural powers that produced useful work and the machines that could be used to make those powers available for exploitation. Central to that analysis was Babbage's insistence that all these various machines should be regarded as technologies that transformed power rather than creating it. Windmills, waterwheels, steam engines, and so on were properly seen as machines that converted the powers of nature into a form that could be made useful. Other commentators on political economy concurred. Nature presented a wealth of interrelated powers. The task of natural philosophers and experimenters was increasingly plausibly regarded as finding practical ways to put those powers to work.

There was a big difference between the grand metaphysical accounts of nature's unity that prevailed in the late eighteenth century—and in many ways reached their apogee with Schelling's *Naturphilosophie*—and the proliferating force transformations of the first few decades of the nineteenth century. The force transformations resulted from practical laboratory technologies. The experiments that produced these transformations often ended up looking more like machines designed to convert one kind of power into another than like indications of underlying organic unity. New analyses of political economy looked to machinery as a way of explaining progress. As human labor (itself from this perspective the result of yet another force transformation) was increasingly replaced by more and more productive machinery, economic progress would be indefinite. New technologies like batteries, electromagnetic engines, thermoelectric couples, and even cameras could be slotted conveniently into economic stories that pointed to machines designed to maximize the efficient production of power from natural resources as the source of new

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[12] Quoted in I. R. Morus, *Frankenstein's Children*, 175.

social and economic progress and of wealth. They provided new ways of forging links between the progress of natural and political economies.

Correlating the Forces

Several natural philosophers, particularly in Britain, turned to the new laboratory experiments developed during the first half of the century to provide the building blocks for ambitious new accounts of the natural economy. At the very least, practical examples of how the unity of nature could be made tangible and useful provided vivid illustrations of metaphysical principles. Audiences at William Robert Grove's lectures at the London Institution or at one of Michael Faraday's Friday evening discourses at the Royal Institution during the 1840s could literally see forces being transformed one to another. It is no accident that the first public utterances by both these natural philosophers concerning the interconvertibility of natural powers were made in lectures before a popular audience. As well as spectacular demonstrations, however, experiments like these provided flesh for the bones of new accounts of nature and the progress of natural laws. In an increasingly hardnosed and utilitarian culture they also provided solid examples of why such accounts of the natural economy really mattered. They showed how natural philosophical principles could be used to make nature's work useful. They were a good way, therefore, of explaining to the Victorian public how natural philosophers themselves were useful and productive as well.

Grove, a Welshman from Glamorganshire, had been appointed professor of experimental philosophy at the London Institution in 1841. That institution, founded in 1805 by a clique of City businessmen as a rival to the more aristocratic Royal Institution on Albemarle Street, was itself devoted to solidifying the link between science and commerce. Charles Butler declared at the London Institution's inauguration ceremony that science and commerce combined would "record the heavens, delve the depths of the earth, and fill every climate that encourages them with industry, energy, wealth, honour, and happiness." When they are separated, "Science loses almost all her Utility; Commerce almost all her dignity."[13] Grove, a graduate of Brasenose College Oxford who had trained for the bar at Lincoln's Inn, had made his scientific reputation with his work on the construction of powerful and long-lasting electric batteries. He would have agreed with Butler's sentiments. One of his first tasks

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[13] C. Butler, *Inaugural Oration* (London, 1816), 40.

following his appointment as professor at the London Institution was to deliver a public lecture on the progress of the physical sciences since the institution's founding. He took advantage of the opportunity to deliver his own encomium on the importance of linking science and industry.

Grove's lecture placed recent developments in physics within the context of a progressive ideology that saw developments in science and society as necessarily going hand in hand. The discoveries he would discuss, he claimed, had already "wrought epochal changes in our knowledge, and will work gradual changes in our political history."[14] His lecture provided his audience with a tour of the latest science, from the steam engine ("the grandest mastery of mind over matter") through electricity and magnetism to photography ("the most remarkable discovery of modern times"), with constant emphasis on their utility and contribution to social progress. As Grove put it, "The student who in his closet successfully interrogates Nature, not only gives to man new physical knowledge, but works an indelible change in his moral destinies."[15] Running through the lecture was the view that the recognition that nature's powers were interconnected lay at the root of recent discoveries and their social benefits: "Light, Heat, Electricity, Magnetism, Motion, and Chemical-affinity, are all convertible material affections; assuming either as the cause, one of the others will be the effect."[16] It was humankind's capacity to manipulate these relationships that resulted in scientific, social, and economic progress: "Why is England a great nation? Is it because her sons are brave? No, for so are the savage denizens of Polynesia: She is great because their bravery is fortified by discipline, and discipline is the offshoot of Science. Why is England a great nation? She is great because she excels in Agriculture, in Manufactures, in Commerce. What is Agriculture without Chemistry? What Manufactures without Mechanics? What Commerce without Navigation? What Navigation without Astronomy?"[17]

Grove soon coined a new phrase for his conviction that nature's powers were mutually convertible: the correlation of physical forces. In a series of popular lectures at the London Institution, published as an essay when Grove left his post there in 1846, correlation was used as the organizing principle around which he arranged his survey of the physical sciences. His position was "that the various imponderable agencies, or

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[14] W. R. Grove, *On the Progress of the Physical Sciences* (London, 1842), 6.

[15] Ibid., 30.

[16] Ibid., 30–31.

[17] Ibid., 37.

the affections of matter which constitute the main objects of experimental physics, viz. Heat, Light, Electricity, Magnetism, Chemical Affinity, and Motion are all Correlative, or have a reciprocal dependence. That neither taken abstractedly can be said to be the essential or proximate cause of the others, but that either may, as a force, produce or be convertible into the other, thus heat may mediately or immediately produce electricity, electricity may produce heat; and so of the rest."[18] Correlation played a role as a rhetorical device for Grove, providing him with a narrative structure that held together the experimental displays that made up his lectures, while at the same time, of course, the experiments' role became that of making correlation visible (figure 3.3).

The theatricality of correlation is evident in one of Grove's examples, designed to show the production of all the other modes of force from light. In this experiment a Daguerreotype plate was placed in a glass-fronted box filled with water, along with a grid of silver wire connected to the plate to form a circuit along with a galvanometer and a Breuget helix. When light fell on the plate following the removal of a shutter covering the glass front, the galvanometer needles twitched and the Breuget helix expanded. As Grove explained, "[T]hus, Light being the initiating force, we get chemical action on the plate, electricity circulating through the wires, magnetism on the [galvanometer] coil, heat in the helix and motion in the needles."[19] This kind of display of correlation was important in Grove's own experimental work as well. For him, the main significance of the gas battery (the ancestor of the modern fuel cell), which he invented in 1842, was that it represented "such a beautiful instance of the correlation of natural forces."[20] In the gas battery, electricity was produced through a process that combined oxygen and hydrogen to produce water. The electricity produced could then be used to decompose the water into its constituent elements once more. Grove saw this as the ultimate example of correlation in action.

Like Grove, Faraday first made his thoughts concerning the interrelationships of nature's powers public in a lecture, this time to one of the Royal Institution's popular Friday evening discourses. Faraday had been instrumental in first establishing the discourses in the 1820s as a forum for showcasing the latest scientific discoveries and spectacular new inventions. By the 1840s they were immensely popular, Faraday himself

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[18] W. R. Grove, *On the Correlation of Physical Forces* (London, 1846), 7–8.

[19] Ibid., 28.

[20] W. R. Grove, *Literary Gazette*, 1842, **26**: 833.

3.3 The frontispiece of Henry M. Noad's *Lectures on Electricity* (1844) showing an idealized (if messy) electrician's workshop. In the foreground is an Armstrong hydro-electric machine, and a Wheatstone and Cooke five-needle telegraph hangs on the wall behind it. Various items of electricians' apparatus such as induction coils and batteries are scattered around. On the right, on top of the arch, is Grove's gas battery, illustrating the correlation of physical forces.

drawing enthusiastic crowds of hundreds when he performed. This was the context in which Faraday first made public his speculations concerning the interconvertibility of the forces and the relationship between force and matter. He kicked off the 1844 season of Friday evening discourses on 19 January with a lecture entitled "A Speculation Concerning Electric

Conduction and the Nature of Matter." He attacked conventional notions of matter as solid particles, suggesting instead that matter should be regarded as being a manifestation of force. His argument was that since matter is only recognized through the forces it exerts, matter and force should be regarded as in some sense identical. Rather than visualizing the material world as made up of solid particles in space, Faraday saw it as a plenum through which forces acted on each other.

Faraday's claims concerning the conservation of force and of matter was in many ways a theological imperative. God had created a certain, finite amount of matter and of force. Since this was created by God, it could in no way be destroyed by any other agency than God's. Force was therefore conserved in any interaction. Faraday was less convinced, however, that forces were interconvertible. He was clear that they were interrelated—much of his experimental work was devoted to demonstrating such relationships, as with his work on electromagnetism and magneto-optics and his efforts to find a relationship between electricity and gravitation—but was unconvinced that this interrelationship could produce actual conversion from one kind of force to another. In his referee's report to the Royal Society on James Prescott Joule's experiments on the mechanical equivalent of heat, Faraday recommended that Joule modify his conclusions for precisely these reasons. Joule wanted to argue that his experiments showed that heat and motion really were mutually convertible—that a particular amount of motion could be turned into a particular amount of heat and vice versa. Faraday disagreed. He argued that all the experiments showed was that a certain amount of motion always resulted in the same amount of heat and that nothing further could legitimately be inferred from the experiments. Joule had to modify his conclusions to suit Faraday's objections.

Like Faraday, however, Joule took the conservation of force to be a fundamental theological principle. The difference between their views is perhaps best encapsulated by the observation that Faraday believed in the conservation of forces while Joule believed in the conservation of force. Joule took it as axiomatic that nothing that God had created could be destroyed by man and that force, therefore, simply had to be conserved in any interaction. It was a fundamental assumption rather than an experimentally derived generalization. Coming from provincial Manchester rather than the metropolis, Joule had to find alternatives to the prestigious London institutions in order to make his voice heard. By 1842 he had been elected a member of the local Manchester Literary & Philosophical Society, having delivered a paper there a few months previously entitled "The Electrical Origin of the Heat of Combustion." He also performed before the British Association for the Advancement of Science when they gathered in Manchester later that year and on other occasions later in the 1840s, notably in 1847 when his experiments caught the attention of the young William Thomson. The most comprehensive presentation of his views on the conservation of force was made, however, to a local and provincial audience gathered for a public lecture at St. Anne's Church School in Manchester in 1847.

Illustrating his performance with such force transformations as experiments with voltaic batteries and electromagnetic engines, Joule aimed to convince his audience of the reality of conservation and conversion processes in nature. It was an ambitious program. He needed to demonstrate conclusively that "the phenomena of nature, whether mechanical, chemical or vital, consist almost entirely in a continual conversion of attraction through space, living force and heat into one another. Thus it is that order is maintained in the universe—nothing is deranged, nothing is ever lost, but the entire machinery, complicated as it is, works smoothly and harmoniously."[21] Any apparent loss of living force (as he translated the eighteenth-century Latin mathematical term, *vis viva*) was simply the result of the conversion of that force into another form according to a strict principle of equivalence. As in the case of Grove and his principle of correlation, Joule was using his notion of the conservation of force to place his kind of physics right at the center of natural philosophy. If he was right, then all nature and all natural processes were governed by the principle to which he laid claim.

Grand and overarching accounts of natural philosophy like this were increasingly popular during the 1830s and 1840s in England. John Herschel's *Preliminary Discourse on the Study of Natural Philosophy*, published in 1830 as the introductory volume of Dionysius Lardner's Cabinet of Natural Philosophy, laid out a synthetic framework for the sciences. The same could be said for William Whewell's magisterial *History of the Inductive Sciences* and its companion *Philosophy of the Inductive Sciences*. Mary Somerville's *Connexion of the Physical Sciences* published in 1834 had a similar agenda. Such texts were bestsellers for their time, going through numerous editions and revisions. They laid out a range of visions of the sciences as a unified whole at just the historical moment when natural philosophy seemed to be fragmenting into a myriad specialist disciplines. The conjunction is hardly coincidental. Texts like these could

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[21] Quoted in C. Smith, *The Science of Energy*, 72.

be used to try and hold the edifice of science together when it appeared to be in danger of breaking up. Crucially, they offered a range of new accounts as to what kind of role in culture the natural philosopher might hope to play.

This spate of mid-nineteenth-century syntheses of the physical sciences were exercises in marking out new territory. All these scientists—a word coined by William Whewell in 1832—were trying to redefine the field of their science, as well as the cultural role of science and scientists. New accounts of the correlation, conservation, and conversion of forces served as means of redefining and restating the importance of physics, both as an intellectual exercise and as an economic one. Syntheses such as these, drawing on the latest experiments, showed how nature could be put to work in earnest. The natural philosopher's role, on this showing, was to manage the process of making nature's powers part of the workforce. The laboratory technology that was used to make correlation or conversion visible—the voltaic batteries, electromagnetic devices, and photographic apparatus—could be made to join the steam engine on the factory floor. In these new articulations of the ways in which nature was hooked together, laboratory apparatus could be used to forge secure links between progress in nature and progress in society. From this perspective, the implication was that natural philosophers had a central role to play, not only in uncovering nature's secrets but in placing them firmly at the center of the cultural stage.

Energy's Empire

A new word appeared in physics at about midcentury: energy. The word was bound up with a new doctrine as well: the conservation of energy. By the end of the nineteenth century all of physics and much of the other sciences as well revolved around this new concept. Its early proponents—physicists such as William Thomson (later Lord Kelvin) and James Clerk Maxwell—argued vociferously that physics needed to be reorganized around this fresh idea if it was to be placed on a secure footing. Opponents, particularly the eminent astronomer Sir John Herschel, disagreed strongly. They argued that the old concept of force should retain its preeminence since everyone had an instinctive appreciation of its meaning from their everyday experiences. Energy in comparison was a chimera, a theoretical construct with no tangible expression in the real world. By the end of the century, by contrast, many physicists would have argued that energy *was* the real world. For its promoters, energy was the hidden link that bound the disparate phenomena of nature together. Energy, not force, was the quantity conserved during the transformation of electricity into heat, or heat into motion. They aimed to use the new concept to forge a powerful new science, tailored for the modern industrial age.

The promoters of this new science of energy were quite self-conscious in their efforts to revolutionize not just physics but the whole of natural philosophy. They aimed at an achievement comparable to Newton's in providing a new and secure foundation for their science. A good indication of what was at stake was the recurrent bickering over who could be credited with the discovery of the grand principle of the conservation of energy. William Thomson and his irascible close ally Peter Guthrie Tait, professor first at Queen's College Belfast and then at Edinburgh, hailed James Prescott Joule as the discoverer. The materialist John Tyndall, friend of T. H. Huxley and admirer of German science, pointed to the obscure German physician Robert Mayer instead, unwilling to give the laurels to the devout Anglican Joule. William Robert Grove pointed to his own *The Correlation of Physical Forces* as an early enunciation of the principle. For the energy physicists, however, Grove's claim was "humbug" and the man himself though "not a bad fellow" was "woefully loose and unscientific."[22] For them, Grove was one of the old guard, lacking in the rigorous mathematical apprenticeship needed to appreciate the new theory in all its glory.

The doctrine of conservation soon acquired its bible with the publication of the ambitious *Treatise on Natural Philosophy*, coauthored by William Thomson and Peter Guthrie Tait between 1862 and 1867. The aim of the book in many ways was to make energy real—to bring the abstractions of the Cambridge mathematical Tripos down to Earth. As one reviewer put it: "The world of which they give the Natural Philosophy is not the abstract world of Cambridge examination papers—in which matter is perfectly homogenous, pulleys perfectly smooth, strings perfectly elastic, liquids perfectly compressible—but it is the concrete world of the senses, which approximates to, but always falls short of the mathematical as of the poetical imagination."[23] James Clerk Maxwell agreed: "The two northern wizards were the first who, without compunction or dread, uttered in their mother tongue the true and proper names of those dynamical concepts which the magicians of old were wont to invoke only

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[22] P. G. Tait to W. Thomson, 2 December 1862, quoted ibid., 176.

[23] Quoted ibid., 192.

by the aid of muttered symbols and inarticulate equations."[24] It was an answer to the complaint that the new energy physics was too abstract, too divorced from mundane reality. The text provided a comprehensive articulation of the doctrine of the conservation of energy, insisting on and illustrating its universal application throughout the physical world and on its foundational role in physics. It also invoked a highly distinguished pedigree for the new idea.

Energy's precursor was no less a sage than the illustrious Isaac Newton. In their preface, Thomson and Tait (or T and T′, as they facetiously referred to each other in private correspondence) announced this heritage proudly: "One object which we have constantly kept in view is the grand principle of the *Conservation of Energy*. According to modern experimental results, especially those of JOULE, Energy is as real and indestructible as Matter. It is satisfactory to find that NEWTON anticipated, so far as the state of experimental science in his time permitted him, this magnificent modern generalization."[25] They were themselves, they announced, "Restorers" rather than "Innovators." They presented the conservation of energy as placing physics back onto the true path first blazed by Newton himself. This was, in part, a campaign to guarantee for energy an impeccably British ancestry against the claims of German interlopers such as Mayer and Helmholtz. In the same way, the insistence that Joule, in particular, should be recognized as the discoverer was, as much as it was aimed to satisfy English amour propre, also aimed at underlining the claim that the conservation of energy was a firmly empirical discovery, solidly based on experimental evidence rather than being derived from airy and abstract speculation.

In popular lectures, magazine articles, and books, Thomson and Tait, along with allies such as Balfour Stewart, professor of natural philosophy at Manchester's Owens College, set out to proselytize for the new doctrine. They wanted to show fellow scientists and the broader public that the conservation of energy was far more than just a narrow scientific principle but that it applied to the whole of natural philosophy and beyond. It was an idea that could explain everything from the movements of the stars and planets down to the mechanism of life itself. As Stewart put it in his *The Conservation of Energy* (1873), the Universe could be regarded "in the light of a vast physical machine" and "the laws of

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[24] J. C. Maxwell, "Thomson and Tait's Natural Philosophy," *Nature*, 1879, **20**: 215.

[25] W. Thomson and P. G. Tait, *Treatise on Natural Philosophy* (Oxford, 1867), vi.

energy as the laws of working of this machine."[26] His popular introduction, published as part of the International Scientific Series, took the reader through energy and its transformations from the energy of a rifle bullet fired from a gun to the infinitesimal chemical reactions taking place in the human or animal body. In *The Unseen Universe or Physical Speculations on a Future State* (1875), Stewart and Tait proclaimed the complete conformity of the new physics to Christian orthodoxy. They went on to show that even "immortality is strictly in accordance with the principle of Continuity (rightly viewed); that principle which has been the guide of all modern scientific advance."[27]

The new doctrine of energy was also at the heart of James Clerk Maxwell's attempt to construct a comprehensive theory of electromagnetism from Faraday's experimental researches and scattered speculations. Born into a genteel Edinburgh family in 1831, Maxwell was first taught natural philosophy by James Forbes at the university there while imbibing metaphysics from Sir William Hamilton. In 1850 he went to Cambridge to study for the mathematical Tripos, first at St. Peter's and then at Trinity College. He made quite an impression, graduating as second wrangler and joint Smith's prizeman in 1854 and obtaining a college fellowship at Trinity a year later. (The Smith's Prize for mathematical proficiency was established by the bequest of Robert Smith, a former master of Trinity College, on his death in 1768.) Cambridge's rigorous training in mathematical analysis provided him with the skills he would need as an ambitious young physicist eager to make his mark on the new science of energy. Maxwell was encouraged by Thomson to familiarize himself with Faraday's researches; his paper "On Faraday's Lines of Force," read to the Cambridge Philosophical Society in 1855 and published in their *Transactions* a year later, was his first essay into the field. He returned to the topic some years later, publishing "On Physical Lines of Force" in the *Philosophical Magazine* between 1861 and 1862. The papers were part of a concerted effort to turn Faraday's speculations about lines of force in space into something more concrete.

Maxwell appropriated Faraday's speculations to provide a solid pedigree for his mathematics of energy. "Nothing is clearer," he told Faraday, "than your description of all sources of force keeping up a state of energy in all that surrounds them . . . You seem to see the lines of force curving round obstacles and driving plump at conductors and swerving towards

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[26] B. Stewart, *The Conservation of Energy* (London, 1873), v.

[27] B. Stewart and P. G. Tait, *The Unseen Universe* (London, 1875), 28.

certain direction in crystals, and carrying with them everywhere the same amount of attractive power spread wider or denser as the lines widen or contract."[28] As far as Maxwell was concerned, those lines of force were real. His task was to find the mathematics that described their behavior. In "On Physical Lines of Force" he elaborated a complex mechanical model of molecular vortices and idle wheels to represent his theory. This was the kind of medium that his mathematics described—the ether. It might not be the model that existed in reality, but it was "a mode of connexion which is mechanically conceivable, and easily investigated."[29] In "A Dynamical Theory of the Electromagnetic Field," published in the Royal Society's *Philosophical Transactions* in 1865, Maxwell refined the theory yet again drawing on the latest mathematics to flesh out his understanding of the ether—the space-filling medium in which electromagnetic energy was stored and through which it traveled.

Maxwell's electromagnetic theorizing culminated with the *Treatise on Electricity and Magnetism* (1873), published just two years after he had been appointed first Cavendish Professor of Physics at the University of Cambridge (figure 3.4). Like his energetic allies Thomson and Tait, he was trying to build the foundations of a comprehensive new science based on the concept of energy. The treatise brought together and elaborated the fruits of his earlier papers, putting the flesh on the bones of the electromagnetic ether. As Maxwell had already explained in his "Dynamical Theory," "In speaking of the Energy of the field . . . I mean to be understood literally. All energy is the same as mechanical energy, whether it exists in the form of motion or in that of elasticity, or in any other form. The energy in electromagnetic phenomena is mechanical energy. The only question is, Where does it reside?"[30] The treatise provided a comprehensive account of just where that energy resided, spelling out the mathematical properties of the space-filling ether. It showed, among other things, how waves of electromagnetic energy traveled through the ether at the speed of light, suggesting that light was itself an electromagnetic phenomenon. In Maxwell's hands, the ether became the new focus for the physics of energy.

As far as British physicists were concerned, the defining feature of the ether was that it was a mechanical construct. While Maxwell was clear

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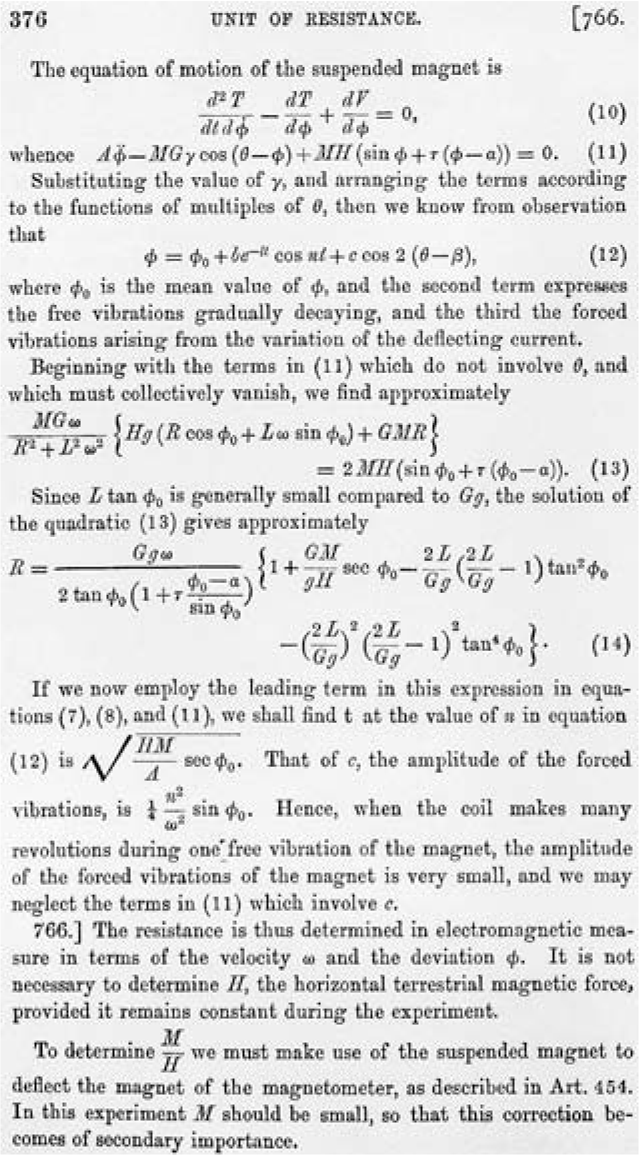
[28] J. C. Maxwell to M. Faraday, 9 November 1857. In L. P. Williams, *The Selected Correspondence of Michael Faraday* (Cambridge: Cambridge University Press, 1971), 2: 882.

[29] Quoted in C. Smith, *The Science of Energy*, 227.

[30] Quoted ibid., 232.



376 UNIT OF RESISTANCE. [766.

The equation of motion of the suspended magnet is

$$\frac{d^2 T}{dt\, d\dot{\phi}} - \frac{dT}{d\phi} + \frac{dV}{d\phi} = 0, \qquad (10)$$

whence $A\ddot{\phi} - MG\gamma \cos(\theta - \phi) + MH(\sin\phi + \tau(\phi - \alpha)) = 0. \qquad (11)$

Substituting the value of γ, and arranging the terms according to the functions of multiples of θ, then we know from observation that

$$\phi = \phi_0 + be^{-lt}\cos nt + c\cos 2(\theta - \beta), \qquad (12)$$

where ϕ_0 is the mean value of ϕ, and the second term expresses the free vibrations gradually decaying, and the third the forced vibrations arising from the variation of the deflecting current.

Beginning with the terms in (11) which do not involve θ, and which must collectively vanish, we find approximately

$$\frac{MG\omega}{R^2 + L^2\omega^2}\left\{Hg(R\cos\phi_0 + L\omega\sin\phi_0) + GMR\right\}$$
$$= 2MH(\sin\phi_0 + \tau(\phi_0 - \alpha)). \qquad (13)$$

Since $L\tan\phi_0$ is generally small compared to Gg, the solution of the quadratic (13) gives approximately

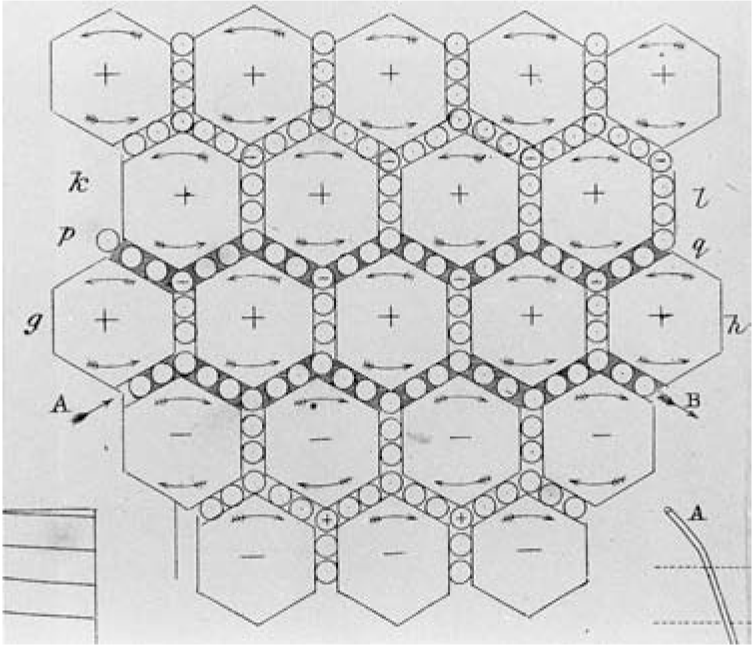
$$R = \frac{Gg\omega}{2\tan\phi_0\left(1 + \tau\dfrac{\phi_0 - \alpha}{\sin\phi_0}\right)}\left\{1 + \frac{GM}{gH}\sec\phi_0 - \frac{2L}{Gg}\left(\frac{2L}{Gg} - 1\right)\tan^2\phi_0\right.$$
$$\left. - \left(\frac{2L}{Gg}\right)^2\left(\frac{2L}{Gg} - 1\right)^2\tan^4\phi_0\right\}. \qquad (14)$$

If we now employ the leading term in this expression in equations (7), (8), and (11), we shall find t at the value of n in equation (12) is $\sqrt{\dfrac{HM}{A}\sec\phi_0}$. That of c, the amplitude of the forced vibrations, is $\frac{1}{4}\dfrac{n^2}{\omega^2}\sin\phi_0$. Hence, when the coil makes many revolutions during one free vibration of the magnet, the amplitude of the forced vibrations of the magnet is very small, and we may neglect the terms in (11) which involve c.

766.] The resistance is thus determined in electromagnetic measure in terms of the velocity ω and the deviation ϕ. It is not necessary to determine H, the horizontal terrestrial magnetic force, provided it remains constant during the experiment.

To determine $\dfrac{M}{H}$ we must make use of the suspended magnet to deflect the magnet of the magnetometer, as described in Art. 454. In this experiment M should be small, so that this correction becomes of secondary importance.

3.4 A page from Maxwell's *Treatise on Electricity and Magnetism* (1873). He is describing William Thomson's method for determining the value of the standard unit of resistance (the ohm) as used by the British Association for the Advancement of Science's Committee on Electrical Standards.



3.5 Maxwell's representation of a possible mechanical structure for the electromagnetic ether.

that his 1862 model of vortices and idle wheels was only a hypothesis and not necessarily an accurate representation of what the ether's structure was really like, there was no question but that the ether had some kind of mechanical structure (figure 3.5). Just as the machines on Britain's factory floors were made up of pistons and pulleys, flywheels and governors, cranks and gears, so was the electromagnetic ether. The conservation of energy was meant to be a theory that applied in the real world. The link between the engines and machines of Britain's factories and the electromagnetic ether was that both could be approached with the same physics, the same theories and models. This was because they had the same kind of structure—they were made of the same kind of things. In this way the high mathematical physics of Maxwell and his successors really did have universal applicability. It explained the factory as much as it explained the ether—and derived its credibility from its capacity to explain both.

In his review of Oliver Lodge's *Modern Views of Electricity* (1889), the French philosopher and physicist Pierre Duhem condemned the British proclivity towards mechanical models: "Here is a book intended to expound the modern theories of electricity and to expound a new theory. In it there are nothing but strings which move around pulleys, which roll around drums, which go through pearl beads, which carry weights; and tubes which pump water while others swell and contract; toothed wheels which are geared to one another and engage hooks. We thought we were entering the tranquil and neatly ordered abode of reason, but we find ourselves in a factory."[31] Lodge, professor of physics at University College Liverpool and an enthusiastic modeler of the ether, would happily have concurred with this assessment. Like his fellow Maxwellian at Trinity College Dublin, George Francis FitzGerald, he took modeling the ether to be a crucial heuristic and pedagogical activity. Since the ether was a mechanical system, trying to construct mechanical models that reproduced its properties was a valuable way of finding out more about it. It was also a useful way of demonstrating its properties to others.

Lodge and FitzGerald were convinced that the Holy Grail of physics would be a purely mechanical model of the ether—one that was not only useful heuristically and pedagogically, but that could be taken to be a true representation of the ether's real structure. According to Lodge, "If a continuous incompressible perfect fluid filling all space can be imagined in such a state of motion that it will do all that ether is known to do; if, simply by reason of its state of motion, it can be proved capable of conveying light and of manifesting all electric and magnetic phenomena which do not depend on the presence of matter; and if the state of motion so imagined can be proved stable and such as can readily exist, the theory of free ether is complete."[32] This was the late nineteenth-century version of the end of physics. Lodge had a likely candidate in mind as well in the form of FitzGerald's vortex sponge model, first devised in 1885. From the 1880s through the end of the century, refining this model into an adequate representation of the real ether was the central goal of British physics. Success would mean the reduction of all physics to mechanics—the science of matter and motion. Maxwell's equations defining the operations of the electromagnetic field could then be rewritten in purely mechanical terms.

By the end of the nineteenth century the physics of energy was triumphant. The doctrine of the conservation of energy was a central and indispensable plank not only in physics but across a whole range of

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[31] P. Duhem, *The Aim and Structure of Physical Theory* (Princeton: Princeton University Press, 1954), 70–71.

[32] O. Lodge, *Modern Views of Electricity* (London, 1889), xi.

sciences. This physics of energy was widely accepted as being the physics of the ether as well. The ether in some form or other was generally accepted as the universal medium through which energy traveled (at the speed of light) and in which it was stored. As Pierre Duhem had rather snootily noted, this energy physics was also the physics of the factory. It forged a link in the chain binding the high mathematics of Cambridge analysis to the realities of industrial culture. The conservation of energy was a broad church, however, and not all its adherents understood it in the same way as its high priests. William Robert Grove, in the final edition of the *Correlation of Physical Forces* (1874), was still staking his claim to its discovery. In his obituary of Grove in the scientific magazine *Nature* in 1896, the physicist Andrew Gray, Lord Kelvin's successor to the chair of natural philosophy at Glasgow, acknowledged his theory of correlation as a precursor of the conservation of energy. The phrases "correlation of physical forces" and "conservation of energy" were still interchangeably used in the popular (and even occasionally in the professional) sphere at the end of the century. Energy did nevertheless provide its adherents and practitioners with a powerful tool, not only for understanding nature, but for carving out a niche for themselves as professional scientists in fin de siècle industrial culture.

Conclusion

The nineteenth century was a period of massive and unprecedented social upheaval. Populations exploded, national borders were redefined, new political systems and ideologies were forged, industrialization and urbanization destroyed old ways of life and created new ones. Natural philosophy's place in this new social order needed to be redefined. This was a highly contested process. Not everyone—not even all men of science—agreed what natural philosophy should look like and what it should say about nature and society. The perspective of, say, an early nineteenth-century German enthusiast for *Naturphilosophie* would in this respect be very different from that of a midcentury advocate of the correlation or conversion of forces, regardless of any superficial similarity in their views about the unity of nature. To realize their competing visions, practitioners of natural philosophy had to forge new spaces and new institutions for themselves. They had to turn their science into something that mattered for their rapidly changing industrial culture. They had to convince their audiences that natural philosophy made a difference. In this process, physics and physicists were transformed. In many ways, the history of nineteenth-century science was one of constant refashioning as natural philosophers and scientists tried to find a secure cultural niche for themselves and their productions.

Physics certainly was transformed by the end of the century. New institutions and laboratories proliferated and chairs were established in new civic universities. It was the dominant science, and its practitioners wielded the power to adjudicate over the proceedings of disciplines far removed from theirs. Physics, thanks to the conservation of energy, was recognized as the foundational discipline. This may seem self-evident to modern sensibilities—what other science should be regarded as the model against which all others have to measure themselves? That position was not purchased without a fight, however. In the early years of the nineteenth-century chemistry might have appeared a better candidate. At midcentury, astronomy still ruled the roost as the exemplar of scientific methodology. Physics in the nineteenth century reorganized itself and reorganized the world around it at the same time. The conservation of energy turned out to be the ideal tool for creating and holding together a new discipline that crossed the boundaries between factories, laboratories, and university studies and lecture halls. Its affiliations with the mathematical world of the mind made lab work respectable for the sons of gentlemen, while its connections with the world of telegraph cables, electric power, and factory engines made it a practical occupation for the sons of trade.