4

The Science of Showmanship

Throughout the nineteenth century, the most visible of the physical sciences in many ways was the burgeoning science of electricity. Electricity provided the technology for a whole range of vivid and spectacular demonstrations of nature's powers, and of man's powers over nature. As the century advanced electricity gave rise to a whole range of new industrial technologies as well. Across Europe and America, many identified their century with unprecedented economic and social progress. Many agreed also that the combined forces of science and industry could be identified as being at the root of this newfound prosperity. For these observers, it was precisely the development of new ways of understanding nature and exploiting her resources that seemed to promise never-ending progress. Electricity in many ways seemed to epitomize this process. New industrial technologies like electroplating provided luxury goods for the growing middle classes; the electric telegraph provided practically instantaneous communication across the globe; by the end of the century electrical energy was providing light and power in households all over the Western world. The electrical future increasingly seemed to promise more. Much of nineteenth-century physics was inextricably embedded in these new industries as well. The science of electricity was very much about making this new power spectacularly visible and making it useful too.

These kinds of links between electricity and the worlds of showmanship and industry were hardly new by the nineteenth century. Since the early eighteenth century spectacular electrical demonstrations of nature's powers had been part of the stock in trade of philosophical showmen. They could use electricity to show off not only God's powers in nature but their own abilities to control those powers. Natural philosophical lecturers, performing in coffeehouses and salons across Europe, vied to produce more and more spectacular experiments. New and more powerful electrical machines were constructed, along with new devices like the Leyden jar to store and concentrate the electric effluvium (as it was often described). Genteel coffeehouse habitués could be amazed, shocked, or even beatified (crowned by a fluorescent halo) by the new electric fluid. As we saw in the introduction, there was an entrepreneurial edge to many of these electrical activities in the eighteenth century as well. Popular lecturers such as John Desaguliers and Benjamin Martin in England and instrument makers such as the Dutchman Martinus van Marum had their eye on attracting potential patrons to make their productions commercially viable. The American Benjamin Franklin's invention of the lightning rod was motivated by practical commercial concerns as much as by philosophical curiosity.

Exhibition played a crucial role throughout nineteenth-century culture for a number of reasons. The rising middle classes flocked to a whole range of public entertainments as the century progressed, from theatrical productions to grand musical soirees or fireworks displays. Following the unprecedented success of the Great Exhibition at the Crystal Palace in 1851, imitations sprang up all over Europe and the United States. By the final decades of the century, international exhibitions and world fairs were annual events in cities throughout the western hemisphere. Other forms of display were also proliferating. As relationships between producers and consumers of goods changed, department stores featuring gaudy displays of commodities on sale became common features of metropolitan streets. Advertising developed new ways of drawing the consumer's attention. Natural philosophers had their place in this world of display. Many earned their living through popular lectures drawing crowds through spectacular experimental demonstrations. They had to compete directly for customers with the theaters, panoramas, dioramas, and magic lantern shows of metropolitan culture. Electricity was a crucial resource for such performances, and electrical experimenters worked hard to find new and spectacular ways of making electricity visible.

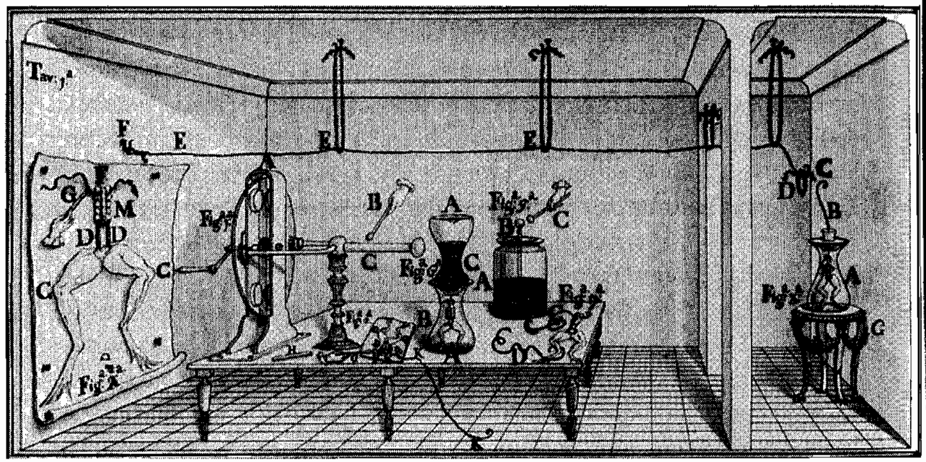
The nineteenth century witnessed an upsurge in invention as well. Hopeful entrepreneurs and inventors flocked to the patent offices, aiming to make their fortunes through this or that new improvement or spectacular breakthrough. Arguments raged concerning the relationship between science and the industrial arts. Some, like Charles Babbage, insisted that there was an inseparable dependence. The natural sciences, according to Babbage and his allies, were the powerhouse that generated economic progress through a constant supply of new ideas to be applied in new machines and technologies. Others disagreed, arguing that there was no link between the rarefied ideals of natural philosophy and the grubby business of invention and salesmanship. Electricity had an important role to play in these kinds of debates too. To many, it was the prime example of science applied successfully to the arts. New technologies such as the electric telegraph seemed to demonstrate conclusively the central role of natural philosophical discovery in inventive activity. Again, others disagreed, suggesting that the history of such inventions tended to show they were the products of inspired tinkering by practical men rather than the systematic application of natural laws.

There was, of course, a close connection between these joint concerns with exhibition and utility. There was in the first instance very little practical difference between the process of producing a new piece of electrical apparatus as part of a public lecturer's or demonstrator's box of tricks and inventing a new device with an eye to the marketplace. The devices themselves were as often as not practically identical, or at least closely related. When lecturers put themselves and their demonstrations of nature in action on show, they were frequently quite literally inhabiting the same space as that where hopeful inventors exhibited their own productions. In the Victorian public's mind there was very little difference between a device designed to demonstrate some natural principle and an item of economic utility on sale. Again like the telegraph, the two could often be the same. Crucial cultural events such as the Great Exhibition played an important role in crystallizing such perceived relationships as well. The Crystal Palace was only one of the more impressive spaces where invention and discovery rubbed shoulders.

The place of the physical sciences and of electricity in this culture of exhibition and entrepreneurship was not uncontested or uncontroversial. Many men of science argued determinedly that the sciences had no proper role in such a context. Crass utilitarianism and grubby display were alike beneath the dignity of natural philosophy. Others had no such qualms. Many such arguments in the end boiled down to the simple question of who the man of science—in this case the electrician—was. Was he (he was almost invariably a "he") the disinterested discoverer of natural principles, the polite purveyor of new experimental knowledge to a genteel middle class or aristocratic audience? Or was he the flamboyant showman shocking (sometimes quite literally) his audience with the latest example of man's dominance over nature, demonstrating his mastery over nature through his control of the machines he exhibited? Or was he the hardheaded inventor of revolutionary new technologies, industriously playing his part in transforming the nineteenth-century economic landscape? As the century progressed, the science of electricity was to be a key battleground in resolving such questions.

Foundations of a New Science

In the early 1780s, Luigi Galvani, the professor of anatomy at the University of Bologna, carried out a series of experiments that demonstrated, he claimed, that there was a specific electricity produced by animal bodies (figure 4.1). He found that when the nerves and muscle of a frog's leg were connected by means of a metallic conductor, the leg twitched. This indicated, according to Galvani, the existence of a flow of electricity running through the dead frog's nervous system. This animal electricity—or galvanism as it was soon to be designated in honor of its discoverer—was to be a source of major controversy. Galvani and his adherents insisted

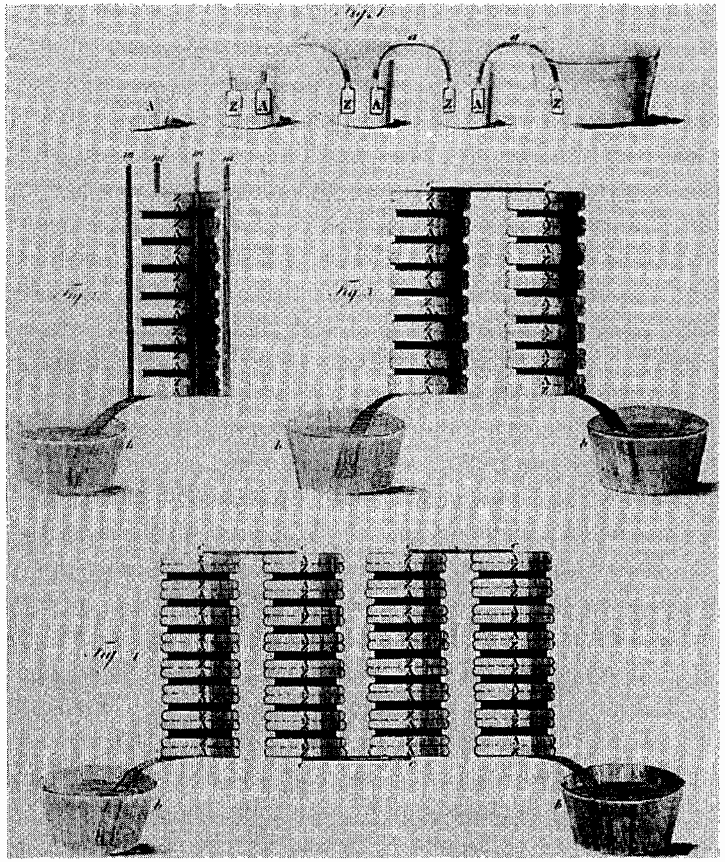


4.1 Some of Luigi Galvani's experiments on animal electricity.

that the source of the electricity was the animal tissue and that Galvani had therefore discovered an entirely novel variety of electric fluid. His opponents, notably Alessandro Volta at the University of Pavia, were just as adamant that the metal in contact with the tissues was the source. The electricity was simply produced by the contact of two dissimilar metals according to this view. All the animal tissue did was facilitate that contact. The dispute raged over two decades as both Galvani and Volta produced experiment after experiment, each proving his own and disproving the other's claims. No one denied the existence of this novel form of electricity. The issue was its origin. Was there, as Galvani claimed, an innate electricity in animal bodies, or was the electricity found in such circumstances merely the result of metals in contact, as Volta asserted?

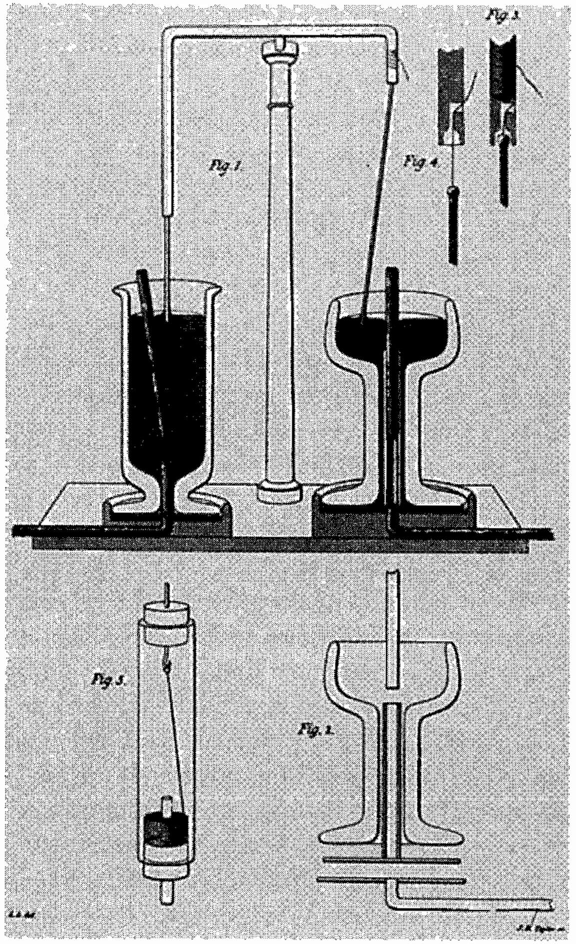
In 1800, Volta made public a new experiment that he thought was decisive. When a pile of zinc and copper discs was constructed, each copper and zinc pair separated by a paper disc soaked in acid or a saline solution, an electric current flowed from one end of the pile to the other. This was Volta's final model of what happened in Galvani's experiment. No animal tissue was needed, suggesting, of course, that there was no specific animal electricity after all. Volta toured Europe with his voltaic pile, as it soon became called, demonstrating to excited savants at the Institut de France in Paris and elsewhere the power of his new instrument (figure 4.2). Galvani's nephew, Giovanni Aldini, likewise went on a Grand Tour to demonstrate that electricity could be produced from animal tissue without the intervention of metallic conductors. In London he even carried out spectacular electrical experiments on the corpse of an executed felon. The focus of European attention, however, was Volta and his new instrument in its various permutations. It seemed that he had discovered a new and powerfully versatile source of the electric fluid. In 1801, Napoleon, the new French emperor, awarded him a medal for his services to science and to celebrate the grand discovery made on what was, by then, newly conquered French territory. The question of the source of electricity in the voltaic pile remained open, however. Volta and his newfound French allies insisted that it was the contact of the metals. Others, notably among the revolutionary French state's enemies across the English Channel, insisted that it must lie elsewhere.

The rapidly rising star of English science in the 1800s was Humphry Davy, newly arrived at the Royal Institution in London, itself just established to place natural philosophy at the service of the embattled English state by improving agriculture and the industrial arts. Davy seized on the voltaic pile as a powerful new weapon in his armory of chemical



4.2 Some early examples of Alessandro Volta's voltaic piles.

apparatus. Along with other pioneering English experimenters such as William Cruickshank and William Nicholson, he transformed Volta's small-scale device into a giant instrument for chemical demonstration and analysis. Davy used this potent new resource to dazzle and amaze his genteel Royal Institution audience with his capacity to subjugate nature. It provided the foundation for his growing reputation as a consummate philosophical performer. At the same time it provided the evidence for Davy's chemical view of electricity. Davy could use the powerful electrical forces produced by the voltaic battery to tear chemical compounds apart and reveal their constituent elements. Soils could be analyzed, new chemical elements such as chlorine could be isolated by subjecting them to the currents from the Royal Institution's batteries. The implication was

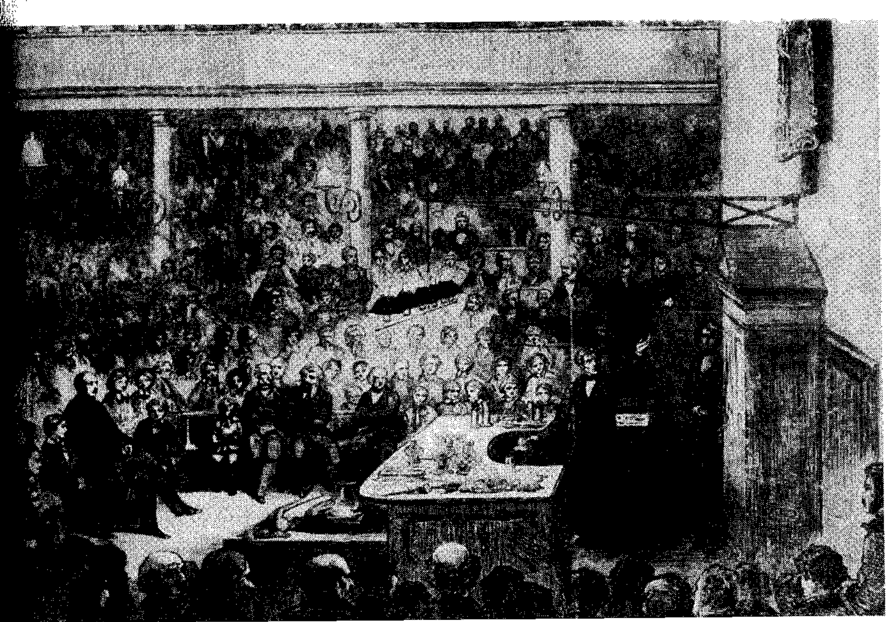


4.3 Michael Faraday's demonstration apparatus showing that a current-carrying wire could be made to revolve around the central magnet. Michael Faraday, *Experimental Researches in Electricity*, vol. 2, plate 4.

that the electric force was chemical in origin as well. Davy claimed that the voltaic pile's electricity derived from chemical reactions rather than from the contact of its metals. His French counterparts, particularly those in the Laplacian camp, still followed Volta in maintaining that metallic contact was what mattered.

While English, French, and Scottish experimenters continued to debate the respective merits of the chemical and contact theories of galvanic action, their counterparts elsewhere, particularly in the German lands, took a different perspective. They saw the electricity produced by the voltaic battery as a microcosm of the metaphysical unity of nature. As we saw earlier, Romantic natural philosophers such as Johann Wilhelm Ritter in Jena hoped to employ the galvanic battery as an instrument of metaphysics. It could be used to demonstrate the fundamental unity of the seemingly different forces that governed the Cosmos. The breakthrough in this respect was made by Ritter's Danish collaborator Hans Christian Oersted, professor of physics at the University of Copenhagen, in 1820. A keen exponent of Kantian metaphysics, Oersted aimed to use the battery to find a link between electricity and magnetism. After careful experimentation he succeeded in showing that a magnetized needle could be made to deflect in the presence of a current-carrying wire. News of the amazing discovery fascinated Europe's philosophical community. Oersted's short Latin publication was rapidly translated into English, French, and German. His experiment was repeated before skeptical audiences (particularly in Paris) as electrical experimenters tried to make sense of this strange new phenomenon.

Some of the most diligent efforts to repeat and expand on Oersted's work were made at the Royal Institution by Davy's laboratory assistant, Michael Faraday. Faraday had come under Davy's patronage following the end of his apprenticeship as a bookbinder. He had joined Davy on his Grand Tour through war-torn Europe in 1813, when his master was invited to Paris to be fêted by Napoleon and awarded a medal for his philosophical discoveries. By 1820, Faraday was starting to experiment in his own right and was anxious to make a name for himself as an independent philosopher. In 1821, in a careful series of experiments he demonstrated that a current carrying wire could be made to rotate around a magnet. His work not only verified Oersted's claims concerning the relationship of electricity and magnetism, it also seemed to confirm that the force from the wire did not act as forces usually did—towards a central point—but that it rotated around the wire instead. Faraday's achievement was not universally acknowledged at the genteel Royal Institution. One of the institution's patrons, William Wollaston, was already engaged in a series of experiments to investigate the apparent rotatory motion of current carrying wires near magnets. It appeared unseemly that a mere laboratory assistant should have preempted his discoveries. The discovery was, however, sufficient to establish Faraday as a philosopher in his own right, a position that he carefully consolidated at the Royal Institution over the next decade.



4.4 Michael Faraday lecturing before an audience including Prince Albert and the prince of Wales at the Royal Institution.

By 1830, Faraday was a fellow of the Royal Society and director of the laboratory at the Royal Institution. He was widely recognized as having stepped into Humphry Davy's shoes as the foremost exponent of natural philosophy to the English upper classes (figure 4.4). In 1831, he embarked on an ambitious experimental program that was to make him one of Europe's premier electrical experimenters as well. In what turned out to be only the first installment of his *Experimental Researches*, presented before the Royal Society on 24 November 1831, Faraday showed that magnets could be used to create electricity. When a bar magnet was inserted into a wire coil and again when it was removed, a brief current was recorded on a galvanometer connected to the coil. Also, when a current was passed through a coil of wire wrapped around a soft iron ring, a current could also be recorded on another, unconnected coil of wire wrapped around the same ring whenever the original current was switched on or off. Faraday called this effect induction, to remind his auditors and readers of the familiar field of ordinary (static) electricity. As in his demonstrations of a decade earlier, Faraday had opened up a whole new field of enquiry into the links between electricity and magnetism, as well as spawning a whole range of new electrical instruments and devices to put the new phenomena on show. Over the next three decades, Faraday produced twenty-nine series of these *Experimental Researches*, translating the results of his endeavors in the Royal Institution's basement laboratory to an increasingly expectant audience.

A few years later Faraday made another breakthrough. In his "third series" he outlined a number of experiments designed to confirm and demonstrate the identity of the electricities. It was still an unresolved issue whether the electricity deriving from a galvanic battery was the same as the electricity derived from an electrical machine or Leyden jar. This was particularly so in that many of their effects seemed very different in scale and kind. Faraday set out to show by careful measurement that the electricities were in fact identical in that the effects of a given electricity could be reproduced with electricities from different sources. The differences usually observed could be attributed to variations between sources in the quantity and intensity of electricity being made available. In further research he established as well the chemical equivalence of electricity. A given amount of electricity used to break down a chemical compound would do so in proportion to the elements contained. When water was decomposed by electricity, for example, twice as much hydrogen as oxygen was given off in keeping with water's chemical composition of two parts hydrogen to one part oxygen. Faraday used this apparently absolute relationship to propose a new way of measuring electricity. He suggested that the amount of gas given off when electricity was passed through a tube of water could be used as an absolute measure of the quantity of electricity. He baptized the new instrument the Volta-electrometer.

By the beginning of the 1840s Faraday was firmly established as one of Britain's foremost (if not the foremost) experimental natural philosophers. He was also beginning to publish some of his private speculations concerning the nature of electricity, force, and matter. He was increasingly convinced that electricity should be regarded as a force occupying the space surrounding conductors rather than as a fluid (or fluids) flowing through the conductors themselves. He elaborated this view in papers such as "Speculation touching Electric Conduction and the Nature of Matter" (1844) and "Thoughts on Ray Vibrations" (1846). His views were bolstered by his magneto-optic experiments of 1845, in which he demonstrated that a ray of polarized light passing through glass along a magnetic line of force would be rotated according to the direction of the line of force. There is an interesting link between the view of matter that Faraday was promoting here—that what mattered was the distribution of

lines of force in space—and his pedagogical strategy. Faraday's aim in the lecture theater was to direct his well-bred audience's attention away from the grubby details of the apparatus he used to produce the phenomena. He wanted them to see that nature (not he or his instruments) was doing the work. His view of matter directed attention away from the instruments and towards the space surrounding them as well. His pedagogy and his ontology went hand in hand.

Very few natural philosophers took Faraday's strange views on lines of force in space seriously until they were picked up by James Clerk Maxwell a decade later. Most British electricians maintained the view, implicitly at least, that electricity should be regarded as some kind of imponderable fluid. Their task was to make that fluid visible. In France, a more mathematical approach to electricity developed, drawing largely on the Laplacian tradition of looking at natural processes as resulting from the action of central forces. The initial response in France to Oersted's experiment was to see if it could be fitted into the Laplacian straitjacket. Jean Baptiste Biot and his student Felix Savart reduced the phenomenon to a simple law. Imagining the needle as consisting of molecules of magnetism each with a north and south pole, they wrote early in 1820: "Draw from the pole a perpendicular to the wire; the force on the pole is at right angles to this line and to the wire, and its intensity is proportional to the reciprocal of the distance."[1] Such language had the virtue of preserving the Laplacian insistence on simple forces acting on points (or molecules) in space and transformed the phenomenon into a mathematical generalization.

Biot's fellow Frenchman and adversary André-Marie Ampère, on the other hand, was less wedded to the Laplacian worldview. He used Oersted's experiment to try to break down the distinction between electricity and magnetism. He argued that the best way to understand the way in which electricity and magnetism interacted was to think of the two forces as identical. Magnetism was the result of electricity in motion. Permanent magnets could be regarded as consisting of a number of loops of electric current. The direction of the current in the loop determined the magnet's polarity. Ampère bolstered this view by showing how a current-carrying helix could be made to act like a magnet. He showed that current-carrying wires attracted and repelled each other as well—just like magnets. Ampère—a coconspirator with anti-Laplacians such as Arago, Fourier, and Fresnel—saw himself as the founder of a new science of electrodynamics that moved away from Laplacian shibboleths.

[1] E. Whittaker, *History of the Theories of Aether and Electricity: The Classical Years*, 82.

Carefully contrived experiments were crucial for Ampère's work, both as demonstration and measurement. His claims concerning the electrodynamic nature of magnetism were considerably more credible to his skeptical academical colleagues in Paris once he could show them (as he did on 25 September 1820) that current-carrying helices really could be made to act like feeble magnets.

By the 1830s and 1840s, distinct ways of doing electricity were emerging. Volta's invention of the voltaic pile (precursor of the modern electric battery) provided a powerful new source of the electric fluid. Oersted's experiment of 1820, followed by Faraday's and Ampère's experiments, forged a new, intimate connection between electricity and magnetism. Different languages of electricity were also emerging. Faraday, addressing as he did a primarily lay if socially prestigious audience at the Royal Institution, presented his work in the vernacular. Ampère across the Channel, speaking as he did to his colleagues at the Académie des Sciences, spoke the language of mathematics. Faraday was in any case deeply suspicious of any efforts to express natural philosophy in abstract mathematical terms. This was a common view among British experimenters, who argued that the abstract manipulations of algebraists led the natural philosopher too far away from the phenomena they were meant to be studying. French experimenters tended to take the opposite view, arguing on the contrary that mathematics provided a language of precision that allowed for clear and unambiguous descriptions of real phenomena. What underpinned both languages, however, was an increasing array of experiments and instruments designed to make electricity visible.

The Technology of Display

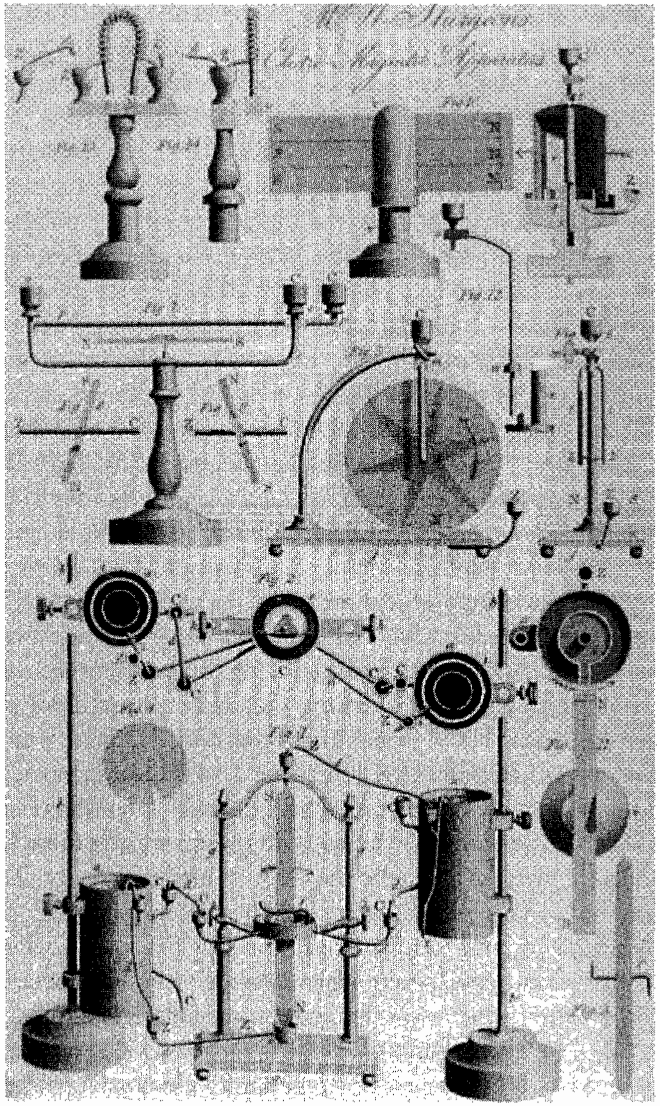
While electricity had provided natural philosophers with a source of spectacular demonstrations of nature's powers since the eighteenth century, Volta's invention of the battery and Oersted's demonstrations of the link between electricity and magnetism provided experimenters with the raw materials for a whole range of new technologies. Ways of rendering the electric fluid visible on a grand scale proliferated during the first half of the nineteenth century. There was more to this quest for striking displays of the forces of nature than simply a desire to put on a good show, though as many experimenters were dependent on income earned from lectures for their living this was certainly a consideration. The arrays of batteries, electromagnets, galvanometers, induction coils, magneto-electric machines, and voltameters that made up the technology of display in a

very real sense constituted the electrical world as well. They provided models for the operations of natural systems. The cosmos could quite literally be seen as being composed of machines, analogous to the ones that electricians demonstrated at lectures and exhibitions. A conducting sphere rotating around a magnet by means of thermoelectricity, for example, was "obviously analogous to the natural state of the earth"[2] and explained its rotation as the result of the difference in temperature between the equator and the poles. This perception also had an important role to play in sustaining electricians' authority as interpreters of the natural world. By demonstrating their skills in constructing, manipulating, and controlling their instruments, they guaranteed to their audiences their mastery over nature as well.

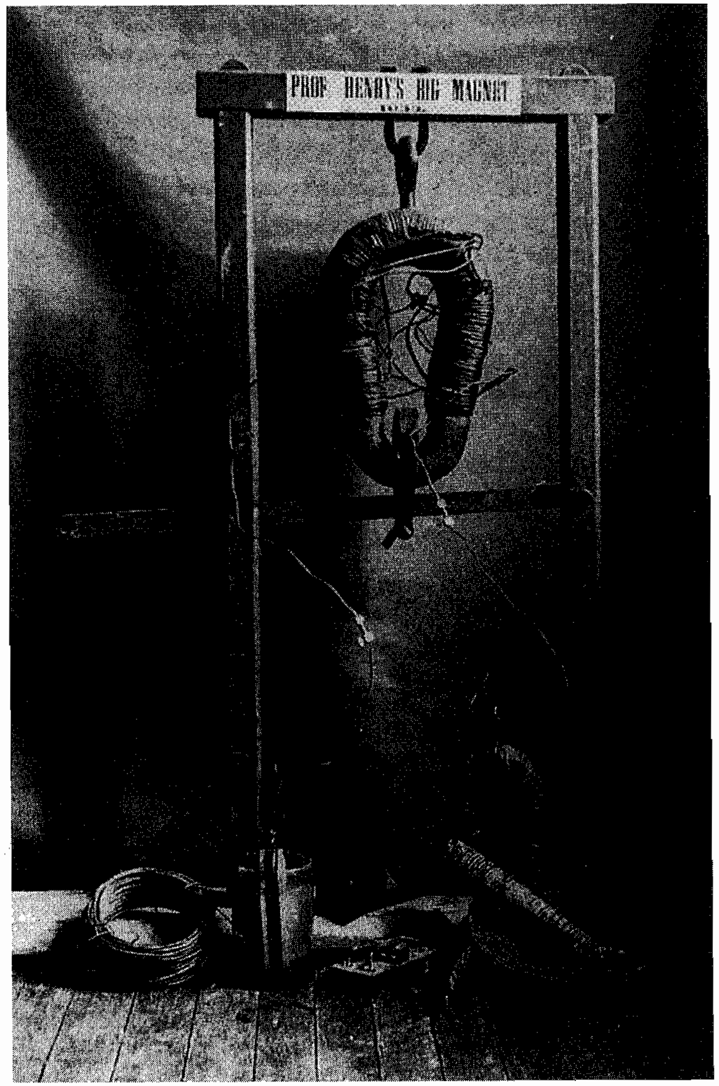
One of the centerpieces of the technology of display was the electromagnet, invented in 1824 by the English electrician William Sturgeon. Sturgeon,—the author of the analysis of the Earth's rotation mentioned in chapter 3—earned a precarious living through instrument making and lecturing. The electromagnet—a coil of copper wire wound around a soft iron horseshoe—was one of a number of devices he submitted to the Royal Society of Arts, for which he won a prize of thirty guineas and a silver medal. The explicit aim in constructing this portable set of tabletop apparatus was to find ways of making the electric fluid more visible as economically as possible (figure 4.5). To this end, Sturgeon was looking for ways of maximizing the effects produced with his apparatus without a concomitant increase in the size of the source of power. In this process he found that by wrapping a wire coil around a soft iron core, he could dramatically increase its magnetic power. An added advantage of this new device was that the magnetic power could be switched on and off instantaneously simply by connecting or disconnecting the source of electricity. The new instrument could graphically demonstrate the powers of electricity and magnetism and the demonstrator's ingenuity by raising and dropping large weights at will.

Sturgeon's electromagnet was a comparatively small-scale device—literally a piece of tabletop equipment. In other hands, however, the instrument became truly gigantic. The Dutch natural philosopher Gerrit Moll found ways of significantly increasing the power of the electromagnet by rearranging the ways in which the wire was coiled around the arms of the magnet. Innovations introduced by the American experimenter Joseph Henry massively increased the instrument's power. Henry,

[2] W. Sturgeon, "On Electro-Magnetism," *Philosophical Magazine*, 1824, 64: 248.



4.5 The electromagnetic table-top apparatus that William Sturgeon presented to the Society of Arts in 1824. His electromagnet is shown in the top left-hand corner.



4.6 The massive electromagnet built by Joseph Henry for use in classroom demonstrations at New Jersey College in Princeton.

professor of natural philosophy at the Albany Institute and later at New Jersey College (now Princeton University) found that by packing the coils tightly and varying both the length and thickness of the wire he could significantly augment the magnet's lifting power (figure 4.6). In his first experiments, Henry succeeded in constructing electromagnets that could support between 20 and 40 pounds of weight. Within a few years, however, his skills at electromagnet construction had developed to the extent that he could construct instruments capable of supporting more than 600 pounds using the electricity from a single voltaic pair. The electromagnet he constructed for Yale College in 1831 could sustain 1,600 pounds. Like his English counterpart Sturgeon, and for similar reasons, Henry was concerned to maximize the power of his instruments for the minimum outlay in terms of battery power.

The production of economical and effective batteries was a perennial concern for early nineteenth-century electrical experimenters. Volta's original design of a pile of zinc and copper discs provided only a comparatively feeble current and was soon superseded. Volta himself developed an alternative design—the *couronne des tasses*—in which plates of zinc and copper were placed in cups of acid. Early English battery designers such as William Cruickshank and William Nicholson favored a trough design. A long wooden trough was divided into a number of partitions each containing a plate of zinc and copper. The metal plates were connected and the trough filled with acid to produce a battery of several elements or pairs of metals as required, allowing for the development of a powerful current of electricity. Designers recognized that different kinds of batteries were required for different purposes. An intensity battery consisted of a number of pairs of small plates connected consecutively (in series, in modern terminology). Quantity batteries, on the other hand, consisted of a single large pair of plates. Intensity or quantity batteries were used according to what kind of electrical effects were required for a particular demonstration or experiment. Some of these batteries could be huge. William Pepys at the London Institution, for example, in 1823 had constructed a quantity battery consisting of two plates fifty feet long by two feet wide.

A perennial problem with early battery designs was their constancy. The current in a basic voltaic cell tended to decrease rapidly with time as polarization effects built up. As a result, effective displays of battery power could be carried out only with freshly charged apparatus and could not be sustained for lengthy periods of time. Much effort was devoted to solving this difficulty. In 1836, John Frederic Daniell, professor of chemistry at King's College London, designed the first constant battery. A few years later, in 1839, William Robert Grove, soon to be appointed professor of experimental philosophy at the London Institution, designed a more powerful cell using nitric acid and platinum plates instead of copper. Robert von Bunsen in Germany soon produced his own version of the

Grove cell, using cheap carbon rods instead of the more expensive platinum. This underlines the importance of economy as well as constancy for instrument makers. As John Shillibeer, an English battery designer, remarked, what was needed was a battery that "requires but a little food, and with that little will perform a good honest day's work."[3] More than simply financial imperatives were at stake in this concern with economy (though again, these mattered). Electrical instruments were held to mirror the operations of nature. Since nature was held to operate with due economy, so battery makers aimed at economy in their designs as well.

In order to convince others of the superiority of their battery designs, experimenters needed reliable and generally recognized ways of assessing battery power. One of the earliest instruments designed to this end was the galvanometer, itself a comparatively straightforward application of Oersted's original needle experiment. In a simple galvanometer a magnetized needle was suspended inside a coil of wire connected to a battery. The extent to which the needle deviated was an indication of the battery power. The instrument was first developed by Johann Schweigger, professor of chemistry at the University of Halle, as a way of augmenting the Oersted effect, hence its original designation as an "electromagnetic multiplier." As we saw previously, Faraday in the early 1830s suggested that the amount of gas given off by the decomposing action of an electric current could provide a measure of the quantity of electricity involved. Other experimenters proposed the length of wire that could be rendered red-hot by a current; the length of a spark that could be produced between the terminal wires; or the weight that could be suspended from an electromagnet connected to a battery, as alternative measures of a battery's power. Typically, battery designers lauding their instrument's powers would employ a whole range of different methods of assessment.

A crucial question was what precisely these various methods and instruments should be regarded as measuring. Faraday's assertion that the amount of gas decomposed by the passage of electricity could be taken as an absolute measure of the quantity of electricity passing was subjected to scathing criticism by William Sturgeon. Sturgeon pointed to the range of factors that could in practice affect the decomposition process, such as the area submerged in the decomposing liquid or the distance between the poles. He also denied that there was any such straightforward correlation as Faraday had described between quantity of current and

[3] J. Shillibeer, "Description of a New Arrangement of the Voltaic Battery," *Annals of Electricity*, 1836–37, 1: 225.

decomposition of gases. His main point was that no single method of assessment should be taken as providing an absolute measure. Different methods provided information about different things. Electromagnets or galvanometers provided information about the magnetic powers of a battery, voltameters provided information about the chemical powers, and so forth. In many ways the issue at stake was what was being measured. While Faraday and others wanted "absolute" measurements of electricity, Sturgeon and some of his fellow instrument makers simply wanted ways of comparing the capacities of various kinds of batteries to produce different kinds of effects. Their concern was simply to make electricity visible to greatest effect. This was what mattered for public demonstration.

Rival instrument makers rapidly picked up on the potential of Faraday's experiments on electromagnetic induction as well for the cause of spectacular public exhibition. Efforts were made to replicate his experiments even before their publication in the *Philosophical Transactions* of the Royal Society, much to Faraday's dismay. The Italian experimenters Vincenzo Antinori and Leopoldo Nobili published their own experiments on induction before the end of 1831, directing their efforts in particular to broadening the range of visible electrical effects that could be produced with the induced current. Faraday himself soon designed an apparatus that allowed him to demonstrate the production of an electric spark from the induced current to his Royal Institution lecture audiences. In Paris, the prominent instrument maker Hippolyte Pixii set about producing an instrument that could produce an extended current rather than the short-lived bursts that Faraday had detected. Pixii's machine, in which a horseshoe electromagnet was rotated in front of the poles of a horseshoe magnet, could be used to decompose water into its constituent gases, for example—an effect that required a lasting current. Faraday's transient effect was in the process of being transformed into something robust, reliable, and replicable.

A similar effort to build a machine for generating a continuous current by means of electromagnetic induction was produced in 1832 by the American instrument maker Joseph Saxton, then working in London at the National Gallery of Practical Science, Blending Instruction with Amusement, or the Adelaide Gallery as it was popularly and understandably abbreviated. Saxton was soon embroiled with Pixii in a priority dispute concerning their respective inventions, which was only resolved by a public contest at the Adelaide Gallery in which both the Pixii and the Saxton machines were put through their paces. It was not long before yet another such machine, developed by the London instrument maker

Edward Clarke, was entered into contention. By the mid-1830s, machines such as these were sufficiently reliable to produce the whole range of effects from an induced current. Shocks, sparks, chemical decomposition, electromagnetism could all be produced at the turn of a handle. Instrument makers learned that, just as with electromagnets, the length and thickness of wire in the coil could be varied to produce different effects to best advantage. Short, thick wires produced quantity effects, while long, thin wires were best for intensity. The priority disputes that surrounded each announcement of a new effect produced by means of the induced current underlines the importance of the technology of display to electricians' culture. It mattered a great deal who could legitimately claim the property rights to such productions.

Another electromagnetic apparatus developed during the mid-1830s to exploit the potential for display of induced currents was the induction coil. Consisting of two coils of wire, one placed inside the other, and both wound around a central iron core with one coil connected via some switching mechanism to a battery, the induction coil could be used to magnify the electrical effects that could be produced from a comparatively small battery. The first such devices were produced by the Irish priest and natural philosopher, Nicholas Callan, at the Catholic seminary of St. Patrick's College, in Maynooth near Dublin. Induction coils in particular had the advantage of being comparatively small and easily transportable. By the 1840s they were increasingly popular as means of administering electricity for medical purposes. Such devices were commonly sold with a clockwork ratchet or electromagnet attachment to accomplish the automatic switching on and off of the battery current without the need for constant manual intervention to ensure a continuous flow of electricity. From the 1850s onwards, more powerful and larger induction coils, commonly called Rühmkorff coils after their inventor, the German Heinrich Rühmkorff, were increasingly employed for the production of large currents of electricity. They were particularly useful for the production of large electric sparks for spectroscopic analysis and for the study and display of electrical discharges through vacuum and low-density gases.

By the 1840s and 1850s instruments of all kinds to display and show off electrical effects were ubiquitous. Devices like Barlow's wheel or Marsh's pendulum, along with a whole range of other electrical paraphernalia, were to be found in any philosophical instrument maker's catalogue in the United States, Britain, France, and the German states. Barlow's wheel, invented by Peter Barlow, the English mathematician and professor at the Woolwich Royal Military Academy, demonstrated electromagnetic rotation by means of a copper disc suspended between the poles of a magnet. When a current was passed along the radius of the disc it rotated. Marsh's pendulum, invented by James Marsh, a Woolwich instrument maker, worked on a similar principle. In Ampère's cylinder, an entire voltaic cell, cunningly mounted around a central magnet, could be made to rotate on its own axis. These devices were not meant exclusively for laboratory or even lecture theater use. They were designed for a wider public consumption as well. Parlor game tricks involving electricity had a long pedigree by the 1840s and 1850s. A favorite was the Venus kiss, where a girl—suitably electrified and sitting on an insulated stool—challenged her male admirers to kiss her. The result, of course, was shocking. These philosophical toys, as they were commonly known, were additions to a repertoire of electrical showmanship stretching well back into the eighteenth century.

Despite the apparent frivolity or ephemerality of some of the electrical technology of display, its importance in understanding the culture of electrical science at midcentury is clear. For many if not most electricians, the business of designing and demonstrating instruments that could be used to make electricity visible was constitutive of the science of electricity. Quite simply, as practicing electricians this is what they spent their time doing. By producing such instruments they were quite literally reproducing nature. It is certainly the case that it was through devices and instruments such as these that the mass of the public both in America and Europe encountered and made sense of the science of electricity. As the case of the induction coil and its descendant the Rühmkorff coil illustrates very well, the extensive electrical technology of display developed by midcentury also constituted the direct ancestors—often very little changed—of later nineteenth-century laboratory teaching apparatus. In many ways the age of classical physics rested on a base provided by early nineteenth-century electricians' technology of display.

Electricity for Sale

As noted at the beginning of this chapter, there was an intimate connection between electrical exhibition and entrepreneurship. The technology of display could be and was adapted to put electricity to work in a very real sense. An important part of the rationale for the emphasis on making various machines designed to make electricity visible was that the result was to demonstrate the economy of nature as well. Hopeful inventors

quickly picked up on the possibilities of putting nature's economy to work for their personal benefit also. Regardless of strictures from high-minded gentlemen of science who believed that any effort to turn science into profit was beneath their dignity and the high standing of their vocation, inventors flocked to the patent offices with a plethora of schemes to turn electrical gadgetry into hard cash. The batteries, coils, electromagnets, and measuring instruments that constituted the stock in trade of the electrician could be exploited to make electrical science a serious commercial proposition. By midcentury, electricity was being used to produce cheap luxury goods for the middle classes, to communicate practically instantaneously over massive distances, to power locomotives, and to illuminate city streets.

Electrometallurgy was the first successful commercial technology (or family of technologies) to be developed from the electricians' technology of display. In its simplest form, this was a process whereby electricity was used to coat an artifact made from some electrically conductive substance with a layer of more expensive or more durable metal, usually silver. The technique was, in many ways, a by-product of efforts during the 1830s to improve the performance of electrical batteries. In a Daniell cell, in which the copper plate of the battery was submerged in a solution of copper sulfate, it was noticed that the copper reduced from the sulfate solution while the battery was active tended to coat the copper plate and that in some circumstances it could be peeled off to produce a relief copy of the plate to which it had adhered. The refinement of this process led to two electrometallurgical technologies: electroplating and electrotyping. In electroplating, a layer of more expensive metal could be coated onto a less expensive metal, providing a way of mass producing luxury goods such as silverware for the middle classes. In electrotyping, the layer of metal building up on the plate would be removed to produce a relief image. This provided a cheap way of mass reproducing images for printing, for example.

Several individuals laid claim to being the inventors of electrometallurgical processes. Moritz Hermann von Jacobi in St. Petersburg claimed priority in invention of the process he named "Galvanoplastik." A Liverpool entrepreneur, Thomas Spencer, claimed for himself the honor of having been the inventor of electrotyping. The disputes surrounding the question of priority, in England in any case, were particularly virulent. Spencer was accused of having stolen other people's work. Some went so far as to suggest that there was literally nothing to have invented, since the whole technology was simply a spin-off from a well-established and recognized side-effect of the action of constant electrical batteries. The passions involved in these debates serve to underline, however, both the importance and the sensitivity of such issues for contemporary electricians' culture. Being able to claim priority in invention of a process such as this could, in some circles at least, provide as much kudos as a claim to philosophical discovery. This was a feature of practical electricians' concerns with the minutiae of technical processes. The first "strictly electro-metallurgical patent" (as it was described by Alfred Smee in his history of the process) was granted however, to a Birmingham merchant, James Shore, in March 1840. Shortly afterwards the cousins George and Henry Elkington were granted a patent for various electroplating processes. Within a decade, electrometallurgy was big business.

The basic technologies of electric telegraphy also had their origins in the machines and instruments making up the technology of display. The early English telegraph pioneer William Fothergill Cooke was inspired to consider the possibilities of using electricity to transmit signals across large distances in 1836, when he attended a lecture at Heidelberg, where a device for displaying electrical effects over long wires, invented by the Russian diplomat Pawel Schilling, was demonstrated. Like many others, however, Cooke soon found that there was a big difference between getting such a device to work on the small scale of a laboratory or lecture theater and making it work in the outside world. He was soon collaborating with the experimental philosopher Charles Wheatstone, professor of natural philosophy at King's College London, in an effort to turn his demonstration devices into a robust and practical technology. Wheatstone had himself been working on the possibilities of exploiting electricity for long-distance communication and had been working on the problem of making electrical effects visible at a distance. In particular, he was aware of Joseph Henry's work on increasing the power of electromagnets—a crucial part of telegraph technology. Henry had visited London only recently on a European tour to acquire philosophical instruments for New Jersey College and had demonstrated his experiments to Wheatstone in person. He knew, therefore, of the importance of winding the coils on an electromagnet properly to maximize their power.

The key to Wheatstone's success in making telegraphy work over distances, however, was his knowledge of the German experimenter and mathematician Georg Simon Ohm's experiments. In 1827, Ohm, a schoolteacher at the Jesuit Gymnasium at Köln, had published a number of experiments on the relationship between current strength and exciting force in current-carrying wires. Ohm's law established that

current strength was equal to the exciting force divided by a constant he designated "resistance." Ohm's work was not widely read at the time. It was not published in English until 1841, for example. Wheatstone could read German, however, and recognized that Ohm's work was what he needed in order to understand the problems of transmitting electricity over long distances, as required to build a successful telegraph. It was through telegraphy that the new electrical terminology of currents, potential differences, and resistances came to replace the older terminology of quantities and intensities, though many electricians, like Michael Faraday, strenuously resisted the newfangled concepts. When Wheatstone became embroiled in a series of disputes with his erstwhile collaborator Cooke over their respective roles in inventing the electrical telegraph, it was to his understanding of Ohm's work that he pointed to demonstrate the privileged knowledge that made the telegraph possible. In the meantime, however, Wheatstone and Cooke acquired an English patent for their electric telegraph in June 1837.

In the United States, Samuel F. B. Morse was also working on the possibility of transmitting messages over long distances by means of electricity. Like Cooke, he had stumbled on the idea after encountering examples of electrical demonstration devices during a trip to Europe. In his own famous words: "If the presence of electricity can be made visible in any part of the circuit, I see no reason why intelligence may not be transmitted instantaneously by electricity."[4] In many ways, this notion of exhibition at a distance was exactly what telegraphy was about and underlines its dependence on the technology of display. Like Wheatstone and Cooke, Morse too found himself in difficulties over the problem of how to get electrical effects to work through long wires. Again, Joseph Henry's work on electromagnets proved to be the key to making this version of the telegraph work. The basic principle of the telegraph was quite straightforward. All that was required was a source of electricity (like a battery), a circuit breaker of some kind to enable specific signals to be sent, and a way of making the signal visible. Making such apparatus work, however, required skill, ingenuity, and a detailed knowledge of the ways electrical instruments worked in practice as well as entrepreneurial acumen. In 1840, Morse and his backers were awarded a grant of $30,000 by the U.S. Congress to build a test line between Baltimore and Washington, D.C. Morse's success in America, along with Wheatstone's and Cooke's in Britain, made the telegraph a reality.

[4] E. L. Morse, *Samuel F. B. Morse: His Letters and Journals* (New York, 1914), 2: 6.

A few years after Morse's deployment of an electric telegraph on the Washington-to-Baltimore line, the U.S. Congress awarded a substantial grant ($50,000 in this case) to another electrical project. Charles Grafton Page, a Harvard graduate and official at the U.S. Patent Office, had put forward to Congress a proposal to build and test an electric locomotive. Like the telegraph, early electromagnetic engines had their roots firmly in the technology of display. The first motors had their origins in William Sturgeon's electromagnet. The electromagnet's capacity to rapidly switch its magnetic power on and off raised the possibility of producing a motive force by means of electricity. A number of electricians and instrument makers constructed different kinds of electromagnetic motors during the 1830s. Joseph Henry in the United States developed two kinds of motors—rotatory and reciprocating—for use in classroom demonstrations. Francis Watkins, a London instrument maker, had electromagnetic motors of his own design on sale from the mid-1830s onwards. William Sturgeon also developed his own version of the engine, as did William Ritchie, professor of natural philosophy at the Royal Institution.

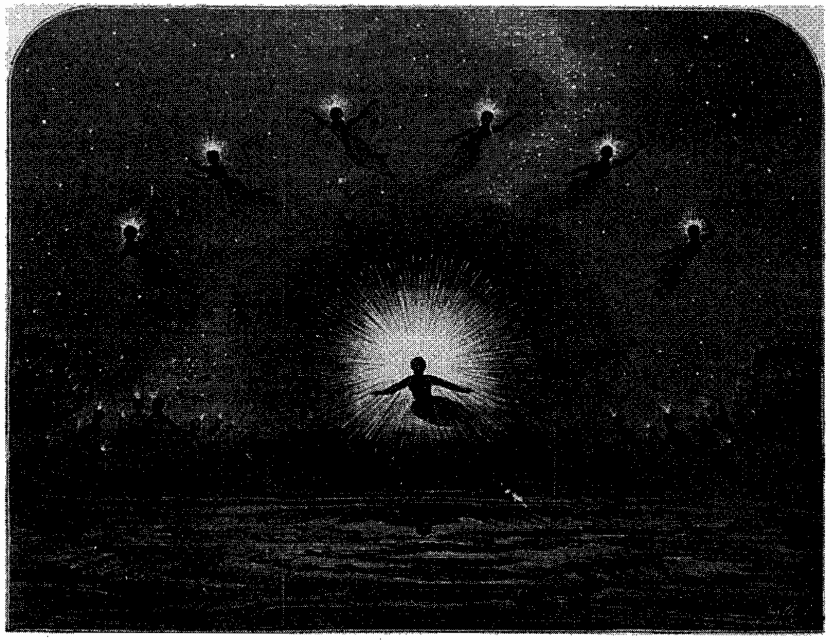
A good example of the ways in which the possibilities of electrical locomotion could enthuse inventors is the case of Thomas Davenport, a Vermont blacksmith. By his own account, Davenport was completely untaught in electricity until he came across one of Joseph Henry's electromagnets during a visit to some iron works in Crown Point, New York. Excited by the possibilities of electromagnets for producing motive power, he set about learning all he could about the science and practice of electricity and was soon constructing massive electromagnets of his own. According to a possibly apocryphal account, being short of funds he used silk from his wife's wedding gown as insulation for the wires (Henry was also reported to have used his wife's silk underwear as a source of insulating material for his early electromagnets). By the mid-1830s he was touring the eastern seaboard of the United States exhibiting a rotatory electromagnetic engine and attempting to acquire funds to purchase a patent, which he eventually did in 1837. Settling in New York, he financed his inventive activities by exhibiting his engine to presumably less than enthusiastic crowds before returning penniless to Vermont in 1842. In Russia in the meantime, an electromagnetic engine was famously put on show by Jacobi, who succeeded in propelling a boat along the River Neva by means of its powers.

Inventors and pundits alike were optimistic that transforming relatively small engines like those of Davenport or Jacobi into something capable of performing useful work on a truly commercial level was

simply a matter of scale. Making an economically viable engine was simply a matter of bigger electromagnets. Commentators were hopeful that "half a barrel of blue vitriol, and a hogshead or two of water, would send a ship from New York to Liverpool."[5] A systematic effort to investigate this potential was soon carried out by James Prescott Joule by means of detailed experiments aimed at assessing the "duty" of electromagnetic engines—"duty" being an engineering term for the amount of work done for a given quantity of fuel consumed. Joule soon came to the pessimistic conclusion that electromagnetic engines could never outperform those powered by steam and expanded his researches to embrace the study of engine efficiency more generally. Joule's pessimism had little immediate effect, however. In 1842 Robert Davidson, an instrument maker from Glasgow, was carrying out experiments financed by the Edinburgh and Glasgow Railway Company on electric locomotion. Charles Grafton Page in the United States was using his congressional funding to good effect to build an electrical locomotive.

While most electrical patents entered during the 1840s concerned electrometallurgy and telegraphy, an increasing number detailed improvements in ways of providing illumination. Edward Staite in England applied for a number of patents covering his electric arc light, which used the spark between two points of charcoal as the source of light. Like many such entrepreneurs, Staite was a consummate publicist of his new inventions. In 1848 he held a grand exhibition in Trafalgar Square in London, in which his latest light was put into action so impressively that "the Nelson column, which was selected as the principal point, [was] frequently as conspicuous as noonday."[6] In 1849, there was even a new ballet, *Electra*, performed in London and specifically commissioned to show off the brilliance of Staite's electric arc light (figure 4.7). From the 1850s onwards, arc lights like the ones developed by Staite were an increasingly common feature of theatrical performances. The new lights were striking in their verisimilitude. When the French engineers Lacassagne and Thiers put their arc lighting system on show in Lyon, pundits marveled at the light, which was "so strong that ladies opened up their umbrellas—not as a tribute to the inventors, but in order to protect themselves from the rays of this mysterious new sun."[7] Requiring high-intensity currents as they did, arc lights also provided a commercial use for induction coils that

[5] *Mechanics Magazine*, 1837, 27: 405.
[6] *Patent Journal*, 1849, 6: 80.
[7] Quoted in W. Schivelbusch, *Disenchanted Night*, 55.



4.7 The ballet *Electra* at Her Majesty's Theatre in London in 1849. With electric lights.

could be used to give high intensity from comparatively small electric batteries.

Enthusiasm concerning the economic possibilities of electricity was rife from the 1840s onwards. The success of telegraphy in particular seemed to augur well for future developments. Alfred Smee enthused that "to cross the seas, to traverse the roads, and to work machinery by galvanism, or rather electro-magnetism, will certainly, if executed be the most noble achievement ever performed by man."[8] William Robert Grove, in his inaugural lecture at the London Institution, itself established to promote the alliance of science and commerce, similarly hailed the power of electricity: "Had it been prophesised at the close of the last century that, by the aid of an invisible, intangible, imponderable agent, man would in the space of forty years, be able to resolve into their elements the most refractory compounds, to fuse the most intractable metals, to propel the vessel or the carriage, to imitate without manual labour the most costly fabrics, and, in the communication of ideas, almost to annihilate time and space;—the prophet, Cassandra-like, would have been

[8]Quoted in I. R. Morus, *Frankenstein's Children*, 184.

ughed to scorn."[9] Even before midcentury, electricity's past seemed to bode very well indeed for future triumphs of man's powers over nature. seemed to be only a matter of time before electricity not only provided e key to unlocking nature's secrets, but established itself as the ultimate ource of continuing economic power and progress as well.

ience on Show

lectricity's technology of display and the culture of entrepreneurship litally shared the same cultural space in the Victorian era's exhibition halls d galleries. From the 1830s onwards, a number of galleries of practical ience appeared in London and in some provincial cities. These were aces where the Victorian public could go to see the latest developents in science and the arts, displayed for their edification. Shows and hibitions of various kinds were staples of Victorian popular culture. he metropolitan public could sample a whole range of enlightening tertainment. Magic lantern shows provided glimpses of natural and anmade curiosities of various kinds. Dioramas and panoramas transorted the paying customer to exotic and historic times and places. One the specialties of London's Regent's Park Colosseum, for example, was huge panorama of the city, viewed as it would be seen from the dome St. Paul's cathedral. A range of exhibition halls catered for a wide variety of tastes and interests. Exhibitions of scientific and technological tifacts and processes took their place in this context. They were aimed the kind of clientele that attended other forms of exhibition. In cities uch as London, Paris, and Philadelphia, natural philosophical enterainments were part of metropolitan life. Electricity played a key role in any of these exhibitions. As the century progressed and national and ternational exhibitions proliferated, electricity continued to be crucial. xhibitions were crucial for electricity as well. They were where, for most f the century, the public went to see and admire electricity in action.

Electrical entertainments came in all kinds of guises. They could be uite formal and elite occasions such as the Friday evening discourses t the Royal Institution in London, presided over by Michael Faraday. At hese affairs, prominent men of science would be invited to demonstrate he latest discovery, invention, or curiosity to an audience largely composed of the cream of London society and the metropolis's scientific elite. Faraday himself was a frequent and popular performer, demonstrating

[9]W. R. Grove, *On the Progress of the Physical Sciences* (London, 1842), 24.

the latest of his electrical discoveries. Less formal, but almost as prestigious, were the occasional gatherings organized by John Peter Gassiot, a wealthy wine merchant, enthusiastic electrician, and treasurer of the London Electrical Society. When notable foreign natural philosophers visited, such as Auguste de la Rive in 1843, Gassiot hosted "electrical soirees," where the latest and most spectacular electrical experiments were on show. Such events were in some ways extensions of the long-standing tradition of performing crucial experiments before prominent witnesses so that their authoritative presence could underwrite the experiment's credibility. Events such as these, however, were at the higher end of the social spectrum. Most of the public witnessed electricity in less exalted company.

The National Gallery of Practical Science, Blending Instruction with Amusement, known simply as the Adelaide Gallery, was established between Adelaide Street and Lowther Arcade on the Strand in London in 1832. Its founder, Jacob Perkins, was an American inventor and entrepreneur who had settled in London a decade or so previously. A native of Philadelphia, Perkins was familiar with Peale's Museum of Natural Science and Art, founded by Charles Willson Peale as a repository for natural historical and philosophical curiosities of all kinds. Perkins may well have had Peale's Museum in mind when he set about founding his own gallery, initially designed to showcase his own inventions but soon expanded to encompass the arts and sciences generally. Electricity was an important feature of the gallery's exhibitions. Perkins had hired Joseph Saxton, another recent Philadelphian arrival in London, as the gallery's instrument maker. Saxton's time was largely devoted to electrical matters, such as the magneto-electric apparatus discussed earlier in this chapter. The gallery as a whole was famous as a place where there "were artful snares laid for giving galvanic shocks to the unwary,"[10] including, according to one possibly apocryphal tale, the duke of Wellington.

The Adelaide Gallery soon had a competitor in the Royal Polytechnic Institute, which opened its doors on Regent Street in 1836. Similarly designed to attract the paying public through exhibitions of the latest in invention, one of the polytechnic's star attractions from the early 1840s onwards was a custom-built Armstrong hydro-electric machine. These devices, invented by the industrialist W. G. Armstrong, exploited the capacity of steam released from a high-pressure boiler to produce static

[10]Quoted in W. H. Armytage, *A Social History of Engineering* (London: Faber & Faber, 1961), 146.

electricity. The polytechnic's machine could produce electric sparks a spectacular twenty-two inches in length. By the 1850s, London had another commercial exhibition hall for the arts and sciences in the Royal Panopticon of Arts and Sciences on Leicester Square. Its proprietor was Edward Clarke, previously a philosophical instrument maker and himself a prolific inventor of magneto-electric gadgetry during the 1830s. In the provinces, the Royal Victoria Gallery for the Encouragement and Illustration of Practical Science (usually called simply the Royal Victoria Gallery) was established in Manchester in the late 1830s. William Sturgeon was hired as superintendent and experimented there with, among others, the young James Prescott Joule. As the example of the inventor Thomas Davenport suggests, such exhibitions were increasingly common in the United States as well.

Exhibitions such as these in which the paying public (the usual fee in London was one shilling) came to ponder natural philosophical curiosities in the same space in which they could witness the latest invention or industrial product had a very important effect on the way in which sciences such as electricity and its products were made sense of. To a very large degree, these were the places where the broader public encountered electricity as well as other scientific artifacts and devices. The context in which they saw science in action, therefore, was one in which commodities were on show. The machinery on show at exhibition halls such as the Adelaide Gallery or the Royal Polytechnic Institute were commodities to be bought and sold. They were not for sale at the exhibitions, but the purpose for which their inventors or owners had put them on show there was straightforwardly commercial. They were there to be advertised, to attract potential buyers and customers. This, therefore, was the context for electricity at the exhibitions as well. This was clearly the case for the electric telegraphs, the products of electrometallurgy, and the prototype electromagnetic engines that went on show from the 1840s onwards. It mattered for other, less avowedly commercial, electrical productions as well. Electricity at the exhibition was being turned into a commodity itself, just like the objects surrounding it.

Nineteenth-century exhibition culture in many ways reached its zenith with the Great Exhibition of the Works of Industry of all Nations, held at the Crystal Palace (especially designed for the occasion by Joseph Paxton) in London's Hyde Park in 1851. The Great Exhibition had its precursors, notably in France, where a series of national exhibitions took place regularly in Paris between 1798 and 1849. The original impetus for organizing the Great Exhibition came from the Royal Society of Arts, which had itself been organizing small exhibitions of arts and industry for several years. Under the patronage of Prince Albert, Queen Victoria's husband, the aim was to exhibit on a grand scale the industrial progress of mankind. The exhibition was going to provide a visual instantiation of the grand principle of the division of labor and provide an impetus to international competition and commerce. The exhibition was also designed to instantiate the relationship between science, industry, and art. As Prince Albert put it, "Science discovers these laws of power, motion, and transformation; industry applies them to the raw matter which the earth yields us in abundance, but which becomes valuable only by knowledge. Art teaches us the immutable laws of beauty and symmetry, and gives to our productions forms in accordance with them."[11]

Electricity was well represented at the Great Exhibition. Electric telegraphs of various kinds were among the more common electrical exhibits. Albert himself had drawn attention to the way in which in the new progressive era, "thought is communicated with the rapidity, and even the power, of lightning."[12] Queen Victoria was also duly impressed by the powers of the telegraph, noting in her diary after a visit to the Crystal Palace that "it is the most wonderful thing . . . Messages were sent out to Manchester, Edinburgh &c., and answers received in a few seconds—truly marvellous!"[13] Also on show were a spectacular array of examples of the electroplater's art, mainly supplied by Elkingtons. Various examples of electromagnetic motors were also on show, notably a new design by the Danish inventor Soren Hjorth, who was awarded a prize for his exhibit. There was an electromagnet constructed by James Prescott Joule on show as well, capable of supporting a weight of more than a ton. Edward Staite had examples of his electric arc lights on show. One of the more visible and spectacular electrical exhibits was Charles Shepherd's electric clock, which was prominently displayed in the Great Transept of the Crystal Palace. The main clock was 1.5 meters in diameter and kept time in synchronism with two others placed elsewhere in the building, all powered by a battery of Smee voltaic cells. Voltaic batteries of various kinds were also on display.

The Great Exhibition's success inaugurated a new era of increasingly spectacular international exhibitions throughout the second half of the nineteenth century. Cities and nation-states vied to provide the most

[11]Quoted in R. Brain, *Going to the Fair*, 24.

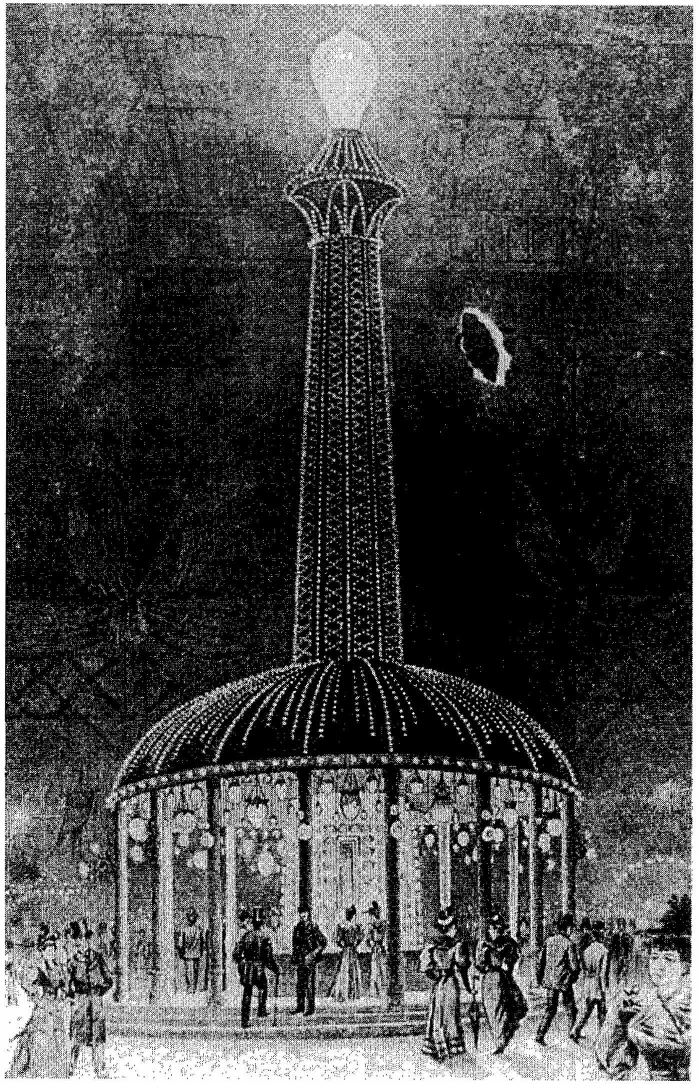
[12]Quoted ibid., 24.

[13]Quoted in K. Beauchamp, *Exhibiting Electricity*, 84.

successful performance. The scale that such exhibitions aimed at is illustrated by the Paris Universal Exposition of 1867, whose site at the Champ de Mars covered forty-one acres. The exhibition's main building, the Palais du Champ de Mars, was designed by Gustave Eiffel, who later in the century was to design the Eiffel Tower as part of another Parisian international exhibition. Cyrus Field was awarded a grand prize for his work on the recently completed transatlantic telegraph cable, parts of which were on show. The Vienna International Exhibition of 1873 staged a massive public demonstration of the motive power of electricity. The Palace of Industry featured machines by the Gramme company, generating electricity, powering machine tools, and lifting water. At the Berlin International Exhibition of 1879 the exhibits included a Siemens & Halske electric traction locomotive that could carry eighteen passengers around 300 meters of narrow-gauge circular track. More than 100,000 passengers took the trip around the track during the exhibition.

Electricity was particularly visible in the increasing number of American exhibitions held during the last quarter of the nineteenth century. The Philadelphia Centennial Exhibition of 1876 featured a number of telegraphs on display as well as a repeat by the Gramme company of its Vienna display. The highlight, however, was the first display of Alexander Graham Bell's telephone, which won a prize at the exhibition. By the time of the World Columbian Exposition in Chicago in 1893 truly spectacular electrical displays were increasingly a staple of such events. The Electricity Building was lit by 120,000 electric lights (figure 4.8). Visitors could travel from building to building around the site by electric railway. Edison and the Westinghouse Company battled fiercely for the privilege of providing the power plant to drive the exhibition's electrical exhibits. At the California Midwinter International Exposition in San Fransisco's Golden Gate Park a year later, a copy of the Eiffel Tower, which was built for the French exposition of 1889, was constructed. Unlike the original however, this tower featured some 3,200 colored electric lights as well as a powerful searchlight mounted on top. Being seen at the exhibitions was becoming increasingly vital for budding electrical entrepreneurs and inventors. These were the places where electricity encountered its publics.

By the end of the nineteenth century, exhibitions like these were, therefore, crucial forums for electricians and their publics alike. The fight between Edison and Westinghouse (which Westinghouse won) for the honor of electrifying the Columbian Exposition is a good illustration of the extent to which fin de siècle electrical concerns valued the opportunity such events afforded them of putting their wares before the public.

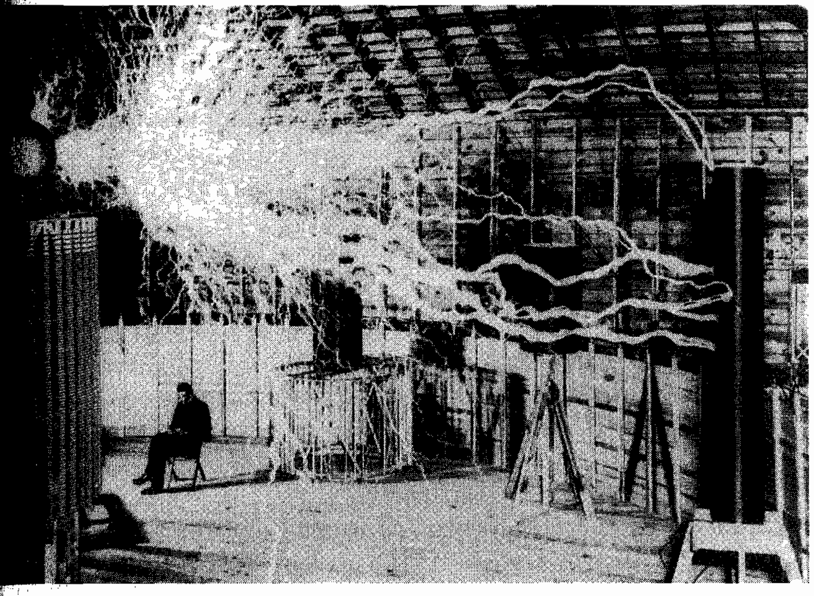


4.8 The spectacular central display in the Electrical Building at the World Columbian Exposition in Chicago in 1893.

Exhibitions, however, were important for electricity and electricians for reasons beyond the opportunity they afforded inventors and public to display and admire electrical commodities. By providing a showcase for electricity they provided a showcase for electricians as well. Prominent men of science such as Lord Kelvin and Hermann von Helmholtz acted as

rors on such occasions, highlighting their role as arbiters of progress for e Victorian industrial culture. Electrical experimenters such as James erk Maxwell used the exhibitions to survey the latest available equip- ent for their laboratories. International exhibitions were also occasions r international congresses of scientists. At the Columbian Exposition 1893, the International Electrical Congress took place as well. They mpleted the work begun at the previous congress in Paris in 1881 self also associated with an electrical exhibition) of establishing secure ndards for electrical measurements.

Late nineteenth-century inventor-entrepreneurs often represented emselves as flamboyant characters. In many ways showmanship seems have been part and parcel of the business of electrical invention. A good ample is Nikola Tesla, the Serbian immigrant to the United States who de a particular name for himself as an inventor and showman. Tesla's blic lectures were a byword for dramatic display. His high-potential, gh-frequency electrical apparatus could produce a whole array of spec- ular lights and amazing sparks and effects of all kinds (figure 4.9). e highlight of Tesla's performances was when he placed himself in e circuit of his electricity-generating equipment, holding illuminated



.9 Nikola Tesla showing off with one of his gargantuan high-frequency, high-potential induction coils.

lightbulbs in his hands and passing sparks between his fingers. Literally making himself a part of his invention was ideally calculated to demonstrate his own mastery over it. The French physicist Arsène d'Arsonval, like Tesla known for his researches into electrical effects at high potentials and frequencies, gave demonstrations in which he made himself part of his experimental apparatus as well. Other electrical inventors such as Thomas Edison in the United States and Sebastian di Ferranti in England similarly fashioned themselves through exhibition. Edison was certainly very conscious of the role his image as the "wizard of Menlo Park" played in bolstering his status as inventor. In a way, electrical inventors were putting themselves as well as their inventions on show.

From the galleries of practical science of the early Victorian years through to the massive and flamboyant international exhibitions of the nineteenth century's closing years, exhibitions were crucial for the science of electricity and for electricians themselves. These were preeminently the places were electricians (and a whole range of other men of science) placed themselves and their productions before the public. Exhibition throughout the century had a central role to play in defining electricity's place in culture. Not only did the electrician William Sturgeon lecture at the Adelaide Gallery and later the Royal Victoria Gallery in Manchester, but his instruments and inventions were on show there as well. The same could be said of Edison's, Tesla's, and even Lord Kelvin's appearances at international exhibitions in the 1880s and 1890s. Electricity as a science and as a string of ever more spectacular inventions was made sense of by the public—placed in context—in terms of the places where it appeared. In the nineteenth century that place was the exhibition. The *Telegraphic Journal and Electrical Review* editorialized in 1892 that "[i]t would be interesting if we could know how the future historian will deal with an institution which is peculiar to the nineteenth century. Commencing with the second half of the century, we have had International, General and Special Exhibitions of all kinds. Bazaars and marts are old enough, but an exhibition, though allied to both, is neither one nor the other, and no preceding institution will be found to exactly compare with it."[14]

Conclusion

The science of electricity underwent a massive transformation during the first half of the nineteenth century. As new ways of producing electricity

[14] *Telegraphic Journal*, 1892, 30: 120.

roliferated, there were more and more places where electricity and its roducts could be encountered. Novel electrical technologies, experiments, and instruments made up a new world to be explored and articlated. New sources of electricity raised questions about the identity of ectricity, for example. Was the electricity generated by a voltaic battery an electromagnetic machine the same as that derived from a static ectricity generator? In particular, electricity provided new terrain for xperimenters anxious to make their reputations. Humphry Davy and ichael Faraday in England, Hans Christian Oersted in Denmark, and ndré-Marie Ampère in France, to cite only a few examples, forged caers and names for themselves as natural philosophers by means of eleccal experiments. Thus, they were instrumental in forging meanings for ectricity as well. The new science produced through electricity was ntested territory. Electricity was a fluid, it was a force; it was evidence the unity of nature, it was just one more imponderable power; it was e product of practical experiment, it was the product of abstract mathatical reasoning. Whatever electricity was, all the nineteenth-century otagonists agreed that it was well worth fighting for.

Nineteenth-century commentators were certainly aware of the central le exhibitions played in the century's public life. The *Telegraphic Journal* ncluded its discussion of exhibitions with the observation that "the stitution existed in the latter half of the nineteenth century, because it s one suited to the requirements of the period."[15] Exhibitions provided way of bringing science, scientists, and scientific productions inside blic culture. In many ways they were expressions of late Victorians' nfidence in their capacity to transform nature and culture through chnology. Electricity was key in these temples to progress. In many ys it was the absence of a good account of what electricity really was at made it so attractive. In a joke making the rounds at the time, a college ofessor asked a student what electricity was: "The student hesitated, d tried to think of an answer, but in vain, it was no use. He could t recall it, but in self-defence said, 'I did know, but have forgotten.' e professor replied, 'This is terrible. The only man who knew what ctricity was has forgotten!'"[16] It was this mysterious quality that made ctricity so amenable as a conduit for progress. Its effects could be put show in spectacular fashion despite the uncertainty surrounding their

[15] Ibid.

[16] *Telegraphic Journal*, 1886, 18: 281.

origins. Seeing electricity at work made tangible the prospects of future power when its secrets finally were revealed.

In many ways exhibitionism became more culturally acceptable as the nineteenth century went on. In the first decades of the century, while showmanship was certainly central to the natural philosopher's activities—take the careers of Humphry Davy or Michael Faraday as examples—that showmanship was restricted to a particular context. There was a big difference between dazzling audiences with spectacular science in the genteel setting of the Royal Institution on the one hand and pulling in the crowds at the Adelaide Gallery on the other. By the end of the century however, few eyebrows would have been raised by Lord Kelvin's activities as a juror at International Exhibitions. Science had ceased to be a gentlemanly vocation and become a hard-nosed profession. Science and electricity at these massive fin de siècle scientific gatherings were weapons in the cause of imperialist expansion. Exhibitions from the Crystal Palace onwards were the occasion for a great deal of rhetoric concerning their role in establishing international harmony, mutual understanding, and peaceful commerce. In reality, however, their internationalism had a hard competitive edge. These were occasions for the ostentatious display of commercial, technological, and scientific supremacy. The heated discussions between German and British delegates at the 1881 International Electrical Congress organized at the Paris Exhibition that year concerning the introduction of absolute standards of measurement in electricity are—as we shall see in the final chapter—a good indication of the extent to which that national competitiveness could be found at the very core of scientific culture. Electricity's very visibility and the way in which it increasingly permeated Victorian culture made its disciplining increasingly crucial.