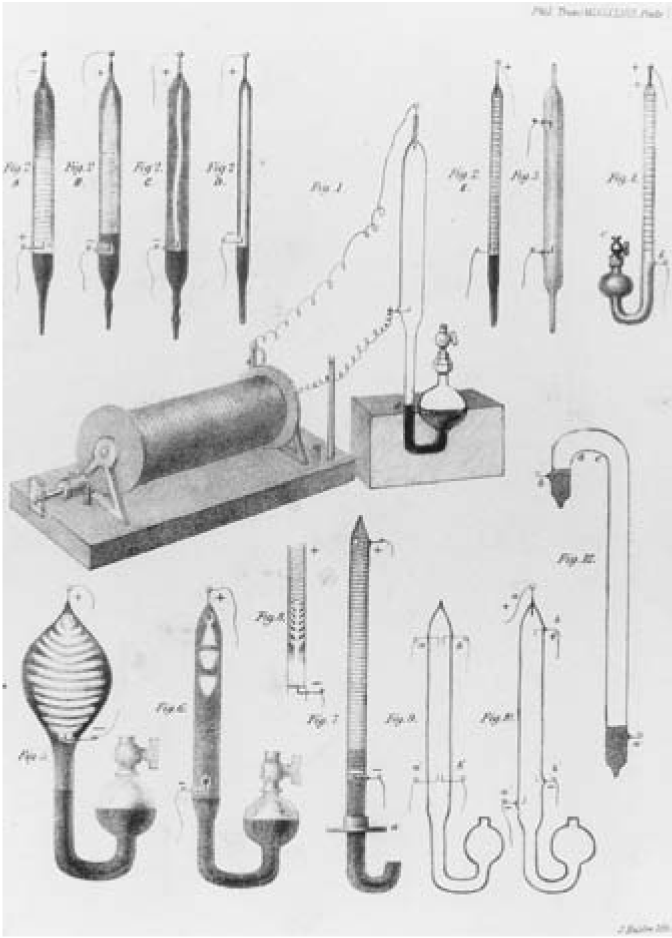
6

Mysterious Fluids and Forces

As we have seen already, the new science of electricity appeared to promise a great deal to nineteenth-century people. The mysterious fluid seemed capable literally of performing wonders. Commentators and pundits waxed lyrical about the capacity of electricity to send signals almost instantaneously over vast distances. The electric telegraph was "a spirit like Ariel to carry our thought with the speed of thought to the uttermost ends of the earth."[1] Despite the gloomy prognostications of James Prescott Joule for one, that electricity could never economically replace steam, popular observers remained sanguine that electricity's unleashed power would provide the key to indefinite economic expansion and progress. As audiences flocked to exhibitions to witness more and more examples of electricity's wonders, electricity seemed to be the key that might unlock more of nature's secrets as well. Natural philosophers, electrical engineers, entrepreneurs, and showmen were all keen, therefore, to delve deeper into the strange fluid's mysteries. By the end of the nineteenth century, electricity had been joined by a plethora of other previously unheard-of fluids and forces. These new powers held out the promise of communication without wires, miracle cures for diseases, and even of ways of talking to the dead. In a world where the potentialities of science, technology, and human

[1] [A. Wynter], "The Electric Telegraph," *Quarterly Review*, 1854, **95**: 119.



6.1 John Peter Gassiot's experiments with discharge tubes from the *Philosophical Transactions*, 1858.

ingenuity appeared to some at least to be limitless, who was to say what new powers science might find?

As early as the 1850s, men such as William Robert Grove and John Peter Gassiot were working on the strange glowing effects produced by passing electrical currents through partly evacuated tubes (figure 6.1). Humphry Davy had shown back in the 1820s that the color of electrical sparks varied according to the metal making up the poles. The glowing, multicolored tubes seemed to be a variation on the same phenomenon. By the 1870s more and more experimenters were working on trying to explain these mysterious discharges. William Crookes thought they were evidence of a fourth state of matter, on top of the traditional triumvirate of solid, liquid, and gaseous states. Experimenters showed how the glows varied according to the strength of the currents passing through the vacuum tubes as well as the type of gas and its concentration in the tubes. Analysis of the discharges promised a new way of identifying the elements as well. The color of the glow seemed specific to the chemical elements present in the discharge tube. Experimenters discovered that magnets could be used to change the shape and even the direction of the strange discharges—cathode rays, as they were later called. Lecturers showed off photographs of the myriad shapes and arrangements the mysterious glows exhibited.

While many, if not most, practical telegraph and electrical engineers still tended to discuss electricity in terms of a fluid flowing down wires in just the same way that water flowed down a pipe, a new generation of theoretically inclined physicists—followers of James Clerk Maxwell's electromagnetic theories—took seriously the notion of electromagnetic fields. As far as they were concerned, most of the interesting things took place away from the wires that made up electrical circuits. They focused their attention on the field surrounding them. Self-taught mathematical physicist Oliver Heaviside developed his own sophisticated mathematical take on Maxwell's physics, showing how electrical energy moved through the ether. The experimenter and prolific public lecturer Oliver Lodge was convinced as well that ways could be found of detecting the propagation of electromagnetic waves through the ether. Both were pipped to the post in 1888 by the German physicist Heinrich Hertz, a student of Hermann von Helmholtz (himself one of the towering figures of nineteenth-century German physics) who announced to the world that he had found a way of propagating and detecting these long-sought-for electromagnetic waves. To Maxwellians in Britain it seemed to be the final proof that demonstrated the real existence of their master's hypothesized electromagnetic ether—after all, you could not have waves without a medium for them to move through.

Others were finding more novel ways of communicating at a distance. Late nineteenth-century Europe and America saw a groundswell of interest in spiritualist phenomena. More and more people claimed to be able to receive and transmit messages from the dead. Successful mediums (as they were called) became household names. While some scientists dismissed these men and women as charlatans, others argued that the phenomena they produced cried out for proper scientific investigation.

The Society for Psychical Research was established in 1882 for just that purpose. Maybe mediums' brains could somehow receive messages transmitted through the ether from beyond the grave. If so, then electrical theory and electrical experimentation were what was needed to find out what was going on. William Crookes was one of the most prominent of these psychical researchers. He put his expert knowledge of electricity to work in trying to find out whether mediums were lying when they claimed to be able to materialize ghosts that would walk around in Victorian drawing-room séances. It seemed to many that there was nothing preeminently outrageous about such claims. Electricity had already produced wonders—why should it not turn out to be a way of communicating with another world?

After the discoveries and breakthroughs of the 1880s, the 1890s seemed to many to be on the cusp of further and greater innovations. The search was on for more new forces and powers. Despite the expectations, Wilhelm Röntgen's discovery of some extraordinary rays in 1895 took the world by surprise. Röntgen seemed to have found a new kind of radiation that made it possible to see through solid objects. The mysterious X rays appeared to pass through solids in just the same way that rays of ordinary light passed through transparent materials such as glass. Within months of the discovery, X rays were already being applied in medicine. It took only a little longer for schoolboy jokes about the virtues of X-ray spectacles to start circulating. Within a few years, Marie and Pierre Curie in Paris had come up with another new kind of radiation. Radioactivity revealed a whole new world of energy, hidden away in apparently solid matter. The Curies' discovery opened up a new vista in physics too. It provided a window into the ultimate structure of matter and provided new clues as to how the building blocks of the universe might be held together.

The discovery and investigation of these mysterious fluids and forces during the second half of the nineteenth century played a pivotal role in the transformation of physics. As the new discipline became institutionalized in university laboratories across Europe and America, more and more budding practitioners turned to them as a source of experiments with which to make their reputations. They were turned into the raw material of a new culture of experimental research and theoretical speculation in physics. They demonstrated also how inseparable the new discipline still was from showmanship and exhibition. Doing physics still involved finding new ways of making the forces and powers of nature visible in as spectacular a way as possible. New technologies such as cathode ray tubes, radio transmitters, and X-ray photographs provided graphic evidence of humanity's hard-won power over nature and the possibilities for future progress. They were powerful arguments as well for those who wished to argue for the practical material benefits of training and research in physics for national economies. While these technologies formed the material basis for the consolidation of Maxwellian physics, however, they also planted the seeds of its downfall in the early decades of the twentieth century. An ambitious new generation of physicists could use these tools to refashion a new physics just as the previous generation had used them to bolster the old.

Tubes That Glow in the Dark

Electrical enthusiasts throughout the early part of the nineteenth century were continually on the lookout for spectacular new experiments that could be used to make electricity visible. Particularly following Oersted's discovery of electromagnetism and the proliferation of demonstration devices that followed from Ampère, Barlow, Faraday, and Sturgeon, among others, a whole technology of display was developed with the aim of making it possible for audiences to see electricity in action. As we saw earlier, apparatus for showing the production of mechanical effects by means of electromagnetism, for demonstrating electrical shocks, and for exhibiting chemical effects such as the decomposition of water took pride of place in lecture theaters and exhibition halls as well as laboratories. Some of the most spectacular effects that electricity could produce, however, involved the electric spark. Striking multicolored scintillations could be produced between the poles of powerful galvanic batteries. Different colors could be produced by using different metals for the poles. Copper produced one color, platinum another, and so on. These powerful discharges had a utility beyond their impressive appearance. The powerful light they produced seemed a good candidate for commercial exploitation. As a result of all this, by the 1840s much experimental attention was being devoted to the physics of the electric spark and the circumstances surrounding its production.

William Robert Grove had been experimenting with electrical discharges from at least 1840. In particular, working with his newly invented nitric acid battery, he had been carrying out a series of experiments on the appearance and behavior of electrical sparks in different media, arguing that "the voltaic arc bears a similar relation to common flame, to that which electrolysis bears to ordinary chemical action."[2] By the 1850s, Grove was long departed from his professorship of experimental philosophy at the London Institution and the resources that position provided him. His experimental work was increasingly focused on working out the phenomena associated with electrical discharges under various conditions. In 1852 he published in the *Philosophical Transactions* of the Royal Society his observations that when the electrical discharge between two poles took place inside a tube evacuated of air, a diffuse glow was visible and that dark gaps or bands could also be seen at various points along the tube. He accounted for these bands in terms of the interrupted electrical discharges produced by the coil. Grove continued with this work for the following decade. In 1858 he described as well how he had found some interesting magnetic effects on the discharge. It seemed that by moving magnets around the tube in which the electrical discharge was taking place, he could make it change its shape and direction, just as Davy in the 1820s had found he could deflect an electric arc with a magnet.

Grove had come across the possibility of using magnets to manipulate the electric discharge in the work of the University of Bonn physicist Julius Plücker. Plücker had been struggling with his position in Bonn for more than a decade. A student there, he had originally been appointed a *Privatdozent* in mathematics and physics there in 1825, being promoted to extraordinary professor of mathematics in 1828 and then to ordinary professor in 1835. For most of the 1840s and early 1850s he was to all intents and purposes in charge of the physics cabinet at the university as well, despite efforts to persuade him to restrict his attention to his mathematical teaching. His discharge tube experiments in the late 1850s were in many ways the culmination of his experimental career. He observed that when a simple point was used as a negative electrode in his experiments, the glowing light between the electrodes was concentrated along the line of the magnetic force passing through that point as if the glow was following the line of the magnetism. He found, as well, that the walls of the vacuum tube itself glowed under the effect of the discharge and that holding magnets near the tube could alter the position of that glow.

John Peter Gassiot, Grove's friend and ally in ongoing battles to reform the Royal Society, was also involved in experimenting on electrical

[2] W. R. Grove, "On some Phenomena of the Voltaic Disruptive Discharge," *Philosophical Magazine*, 1840, **16**: 482.

discharges during the 1850s. Gassiot, once a leading member and treasurer of the London Electrical Society, was the scion of a wealthy wine merchant family. He had the wherewithal to invest in experiment on a scale that few of his contemporaries could. The "electrical soirées" at his house in Clapham Common during the early 1840s are a good indication of his fascination with making electrical effects spectacularly visible. Like Grove, too, he was interested in the striae, or "stratifications," of the electrical discharge and the conditions under which they were produced. He could experiment on a large scale, noting that he "had the opportunity of experimenting with upwards of sixty of Geissler's vacua-tubes, in which many beautiful and novel results are produced; in some, for several seconds after the discharges had ceased, the tubes remained throughout their entire length highly phosphorescent."[3] The mercury air-pump, developed in 1855 by German glassblower Heinrich Geissler, had dramatically improved the production of evacuated tubes for such experiments. Gassiot took the view that the stratifications in the discharge "arose from pulsations or impulses of a force acting on highly attenuated matter."[4]

Discharge experiments like these rapidly became established as part of the technology of display of electrical performers of various kinds. In British eyes at least, the new technology remained intimately associated with the names of Grove and Gassiot. Cromwell Varley, in a communication to the Royal Society on electrical discharges in rarified media in 1871, commenced with an effusive acknowledgment of "the labours of Mr. Gassiot" and an apology "lest he should appear to be attempting to appropriate the glory which so justly belongs to that gentleman and to Professor Grove."[5] Varley, a leading telegraph engineer, was particularly interested in using photography as a means of capturing the appearance of the glowing tubes. Photographic technology could capture images that were beyond the power of the naked eye. "The light was so feeble that, though the experiment was conducted in a perfectly dark room, we were sometimes unaware whether the current was passing or not. An exposure of thirty minutes' duration left, as will be seen, a very good photographic record of what was taking place." Varley's description of the way in which the discharge glow developed with increased current

[3] J. P. Gassiot, "On the Stratification in Electrical Discharges," *Philosophical Transactions*, 1859, **149**: 137.

[4] Ibid., 156.

[5] C. Varley, "Some Experiments on the Discharge of Electricity through Rarified Media and the Atmosphere," *Proceedings of the Royal Society*, 1871, **19**: 236.

was striking: "a tongue of light projected from the positive pole towards the negative, the latter being still completely obscure. The light around the positive pole was to all our eyes white, while the projecting flame was a bright brick-red."[6]

The most prolific and energetic researcher into discharge phenomena during this period was William Crookes. Crookes, the son of a well-off businessman and a successful entrepreneur in his own right, was an enthusiastic experimenter. He had studied at the Royal College of Chemistry and been impressed by Michael Faraday's lectures at the Royal Institution. Early in his career, he attracted the attention and patronage of the natural philosopher and telegraph entrepreneur Charles Wheatstone, who steered him in the direction of his first Royal Society grant. During the 1860s, Crookes was particularly concerned with elucidating the behavior of a curious piece of apparatus he called a radiometer. Puzzled by the apparent gain in weight of substances weighed in a vacuum when they were heated, Crookes built an instrument in which a delicately balanced vane, enclosed in a flask from which the air had been removed, could be made to rotate under the influence of heat or light. Crookes first argued that the movement was caused by pressure exerted by the radiation itself. He soon changed his mind however, arguing instead that residual air molecules in the flask caused the movement. He raised the question, however, of whether the substance remaining in the flask "should not be considered to have got beyond the gaseous state, and to have assumed a fourth state of matter, in which its properties are so far removed from those of a gas as this is from a liquid."[7] Looking for further examples of his newly proposed "fourth state of matter" Crookes lighted upon those curious glowing electrical discharges.

His interest was initially captured not so much by the glowing discharges themselves, but by the dark space that observers agreed could be seen around the negative pole in these kinds of experiments. Crookes interpreted this dark space as further evidence of his fourth state of matter. He argued that it was the result of "molecular pressure" of the same kind that caused movement in his radiometer. "This dark space is found to increase and diminish as the vacuum is varied in the same way that the ideal layer of molecular pressure in the radiometer increases and diminishes. As the one is perceived by the mind's eye to get greater, so the

[6]Ibid., 238.

[7]W. Crookes, "Experimental Contributions to the Theory of the Radiometer," *Chemical News*, 1876, **34**: 277.

other is seen by the bodily eye to increase in size."[8] In Crookes's view, the difference between ordinary gases and his fourth state of matter lay in the hugely increased mean free path of the gas molecules—that is to say the average distance the molecules traveled before colliding with each other. This mean free path was much longer in the fourth state, and according to Crookes the dark space was a measure of it. "The thickness of the dark space is the measure of the length of the path between successive collisions of the molecules. The extra velocity with which the molecules rebound from the excited negative pole keeps back the more slowly-moving molecules which are advancing toward the pole. The conflict occurs at the boundary of the dark space, where the luminous margin bears witness to the energy of the discharge."[9]

According to Crookes, as the vacuum in the discharge tube was increased, so did the mean free path of the molecules. This explained the way in which the glass of the tube itself appeared to phosphoresce at a very high vacuum. When the mean free path of the negatively charged molecules streaming across the tube reached the same length as the size of the tube, the molecules collided with the sides of the tube as well as with each other, causing the glass to glow. When a cross was placed between the negative electrode and the wall of the tube, a shadow was formed on the glass where the stream of molecules was prevented from hitting it. Crookes even found that when the cross was removed, the area that had been in its shadow now glowed more brightly. "Here, therefore is another important property of Radiant Matter. It is projected with great velocity from the negative pole and not only strikes the glass in such a way as to cause it to vibrate and become temporarily luminous while the discharge is going on, but the molecules hammer away with sufficient energy to produce a permanent impression upon the glass."[10] One of Crookes's most striking illustrations of the power of these streams of radiant matter is also a graphic illustration of the exhibitionist tendency of his experiments. In this experiment, a little glass railway, carrying a tiny locomotive with a paddle wheel was placed between aluminum poles in an evacuated tube. The streams of radiant matter flowing between the

[8]W. Crookes, "Molecular Physics in High Vacua," *Proceedings of the Royal Institution*, 1882, **9**: 140.

[9]W. Crookes, "On the Illumination of Lines of Molecular Pressure," *Philosophical Transactions*, 1879, **170**: 135.

[10]W. Crookes, "On Radiant Matter," *Chemical News*, 1879, **40**: 106.

poles would strike the paddle wheel, causing it to rotate and propel the little locomotive along its miniature track.

Few of his contemporaries found Crookes's claims concerning the fourth state of matter convincing. In particular the length of mean free path for molecules required by his notions of the fourth state were glaringly at variance with those posited by the kinetic theory of gases. For a physicists' culture that increasingly lauded high mathematical theory, Crookes's experiments, however spectacular, could never ultimately compete with the theory-laden pronouncements of a Maxwell. Even a mathematical physicist such as George Gabriel Stokes remained an admirer of Crookes's work, however. "For enlarging our conceptions of the ultimate workings of matter, I know of nothing like what Crookes has been doing for some years," he marveled to a friend. "I wish you could see some of the work in his laboratory."[11] Enthusiasm for discharge tube (or cathode ray tube) experiments continued. Plücker's student Wilhelm Hittorf had been working on them throughout the 1870s, having published work on magnetic deflections and the production of shadows as early as 1868. In Britain, Warren de la Rue and Hugo Müller carried out detailed experiments aimed at elucidating the exact circumstances under which the discharges were produced to best effect and producing some stunning illustrations along the way. They were insistent that far from being some manifestation of a fourth state of matter, the "electric arc and the stratified discharge are modifications of the same phenomenon."[12]

Experiments with cathode ray tubes were at the cutting edge of experimental physics for much of the second half of the nineteenth century. Their performers were convinced that understanding those mysterious glowing tubes would provide the key that could crack open the secrets of matter, even if they disagreed over just what those secrets might be. Everyone agreed that powerful forces were at play inside those tubes that could tear apart the bonds that usually held matter together. Exhibiting those powerful forces was a matter of some concern to these experimenters as well. William Crookes certainly kept a weather eye on the show-off potential of his experimental apparatus even as he and his assistants were working away in the laboratory. Crookes, as a self-made man who plied his scientific trade outside the walls of academe, was

[11] Quoted in R. deKosky, "William Crookes and the Fourth State of Matter," 58.

[12] W. de la Rue and H. Müller, "Experimental Researches on the Electric Discharge with the Chloride of Silver Battery," *Philosophical Transactions*, 1880,**171**: 109.

particularly alert to such possibilities. The strange, flickering glows inside the discharge tubes were a potent image of the mysteries of nature that modern physics promised to lay bare. They pushed at the boundaries of mundane reality and posed the question of what else was out there waiting to be uncovered. They emphasized the newfound powers of their creators as well—and their claims to authority in the modern world.

Waves in the Ether

Developments like Crookes's and his fellow-experimenters' work on cathode rays made it clear to their contemporaries just how much more lay out there, waiting to be discovered. The search was now well and truly on for new and mysterious manifestations of nature's forces. The discovery of new phenomena like these could provide forceful demonstrations of the power of modern physics and its practitioners. They were graphic illustrations of the ways in which physicists could impose their mastery over nature. They promised new utilitarian advances as well. Telegraphy had already demonstrated how electricity could revolutionize the world and by the 1870s other electrical technologies were making their mark too. Who was to say what equally unprecedented advances might be made on the backs of other novel discoveries? These new findings provided powerful backing for new theoretical generalizations as well. For many ambitious young physicists, in Britain in particular, they provided the final proof of the existence of an electromagnetic ether—that the ether was the medium through which electromagnetic as well as simply optical phenomena manifested. Looking back from the vantage point of the 1890s, Oliver Lodge was adamant as to what the past two decades' experiments demonstrated: "Persons who are occupied with other branches of science, philosophy, or with literature, and who have not kept quite abreast of physical science, may possibly be surprised to see the intimate way in which the ether is now spoken of by physicists, and the assuredness with which it is experimented on. They may be inclined to imagine it is still a hypothetical medium whose existence is a matter of opinion. Such is not the case."[13]

The publication of James Clerk Maxwell's *Treatise on Electricity and Magnetism* in 1873, with its rich theoretical synthesis, laid the groundwork for a new generation of his followers, committed to his view of the ether as the anchorage for electromagnetic energy. This perspective,

[13] O. Lodge, *Modern Views of Electricity* (London, 1892), viii.

which drew the physicist's attention away from the coils and wires of electrical apparatus and towards the apparently empty space around them, was at gross variance with the approach of the hands-on electrical engineers who dealt with such apparatus every day as they maintained the nation's telegraph lines. Their view of electricity was robustly simple. It was just like water running down a pipe. Few of them had much time for Maxwell and his newfangled ideas, which seemed to bear little relevance to their everyday experiences. Maxwell's followers, on the other hand, saw this ongoing battle of practice versus theory as an ideal opportunity to press their own claims to expertise over and above those of the practical men. If they could show that they understood better than the engineers themselves what was going on in the telegraph network, then they would have shown that theory really mattered. It would be a major boost for the cultural authority of physics.

The major protagonists in this war between physicists and practical men were William Henry Preece—who ran Britain's nationalized telegraph network through the Post Office—for the practicals, and the two Olivers, Heaviside and Lodge, for the theoreticals (figure 6.2). Heaviside, a self-trained mathematician of considerable brilliance, had been working on his own reformulation of Maxwell's theory, producing along the way the four Maxwell's equations that are central to modern understandings of Maxwell's work. His work drew attention in particular to the problems of self-induction in rapidly oscillating currents—self-induction being the tendency first noted by Faraday for an electric current to oppose changes in its own strength. According to Maxwell's (and Heaviside's) theory, the faster the oscillations, the less like a fluid in a pipe electricity became. In very rapidly alternating currents, the electricity ran almost entirely along the surface of the wire rather than along the interior. This meant that under such circumstances, self-induction rather than the resistance of the wires became the major factor in designing cables. Preece dismissed this as nonsense. It was no more than "a bug-a-boo." Lodge encountered self-induction as well in his work on lightning. He argued in lectures before the Society of Arts that self-induction mattered far more than resistance in the design of lightning conductors and that traditional conductors designed for low resistance were useless for handling sudden lightning bolts. Preece, a member of the 1882 Lightning Rod Conference whose conclusions Lodge was attacking, dismissed his conclusions as absurd.

As far as the Maxwellians were concerned, the key to establishing Maxwell's theory and demolishing the practicals' pretensions to down-to-earth knowledge was to find a sure way of showing that electromagnetic

6.2 The satirical magazine *Punch*'s view of the debate between scientific and practical electricians in 1888. The triumphant practical man William Henry Preece is walking all over the recumbent Maxwellian, Oliver Lodge.

energy really did travel through the ether. In the early 1880s, the Dublin professor George Francis FitzGerald had worked out in some detail the theory of the matter and had calculated the amount of energy that would be given off. The trick was to find some way of detecting those mysterious vibrations in the ether. Oliver Lodge, by 1881 professor of physics at Liverpool, was determined to solve the problem. Lodge had been intrigued by the ether for years: "At an early age I decided that my main business was with the imponderables—as they were then called—the things that worked secretly and have to be apprehended mentally. So it was that electricity and magnetism became the branch of physics which most fascinated me."[14] Lodge was no Cambridge-trained mathematician, though. His route to understanding "things that worked secretly" would be through experimentation. He modeled his Liverpool laboratory on the lines recommended by the illustrious Sir William Thomson and traveled to Germany to pick up the best equipment available.

One of Lodge's projects was to investigate lightning at the behest of the Royal Society of Arts. It was a practical project aimed at improving the design of lightning rods. As a practical electrical experimenter in the tradition of William Sturgeon, Lodge set about finding a laboratory model for the way lightning worked and struck upon the Leyden jar. Lightning was like the discharge from a Leyden jar magnified a thousandfold. This had an important consequence. As all electricians knew, Leyden jar discharges oscillated rapidly. This meant that lightning did so as well. Far from being a single discharge of electricity from heaven to Earth, a stroke of lightning was a rapid succession of discharges in both directions. The trick to understanding lightning, for Lodge, was to carefully investigate the characteristics of Leyden jar discharges in his laboratory. Lodge wanted to show that what mattered in such situations was self-induction rather than resistance. If he showed in his Leyden jar experiments that the discharges would follow a path of high resistance and low self-induction, rather than one of low resistance and high self-induction, he would have shown that was how lightning behaved as well. It was his announcement of the results of these experiments that so aroused the ire of William Henry Preece at the Post Office, incensed by the interference of a mere physicist in the affairs of hardheaded practical men.

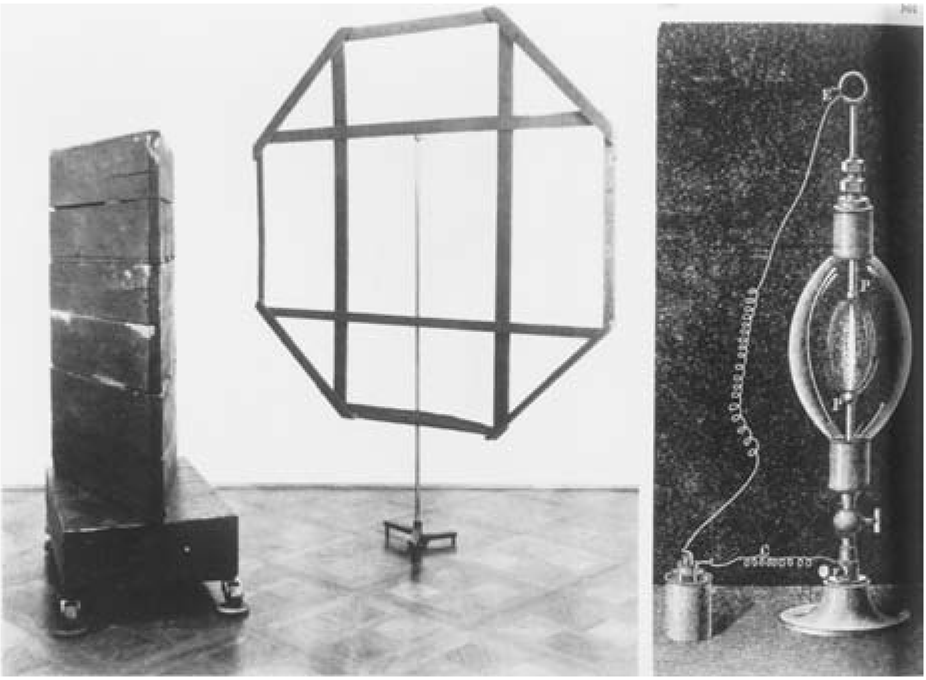
Lodge soon realized, however, that more was at stake in his experiments than lightning rods. His experiments with Leyden jars convinced him that he was well on his way to finding ways of producing and—more importantly—detecting those elusive oscillations in the ether that FitzGerald's work predicted. The electrical currents that surged back and forth along the wires of his experimental apparatus in imitation of the lightning could be made, by proper arrangement, to stabilize into static, standing waves that could be measured. This was his next task. In the run-up to the British Association for the Advancement of Science's meeting

[14] O. Lodge, *Past Years* (London: Stodder & Haughton, 1931), 111.

at Bath in 1888, Lodge worked hard to produce a spectacular experimental demonstration to convince the crowds of the existence of electromagnetic waves. "A long wire about one-eighth or one-sixteenth of an inch in diameter was stretched round the theatre at South Kensington, several times round," he recalled in his autobiography. "On now sending a series of oscillating pulses along that wire, a glow was to be seen on the wire in the dark at the ventral segments of each pulse, while it was dark at the nodes, exactly in accord with Melde's experiments of a string attached to a tuning-fork . . . The point of the experiment was not another demonstration of the oscillations, but a proof that true waves ran along the wires, being thereby guided and prevented from spreading into space, and by reflexion were converted into stationary waves which showed themselves by nodes and loops."[15] He had found what he was looking for; he had vindicated himself and his fellow Maxwellians against the recalcitrant practical men. He was too late, however. Before the Bath meeting the young German physicist Heinrich Hertz announced to the world his detection of electromagnetic waves in space (figure 6.3).

Hertz was in many ways the golden boy of German physics. He was one of Helmholtz's Berlin products, having turned to physics after an early flirtation with engineering. He had been trained, therefore, by one of the grand masters of German physics, one moreover who had made his reputation as an experimentalist as much as he had as a theorist. Working with Helmholtz in his laboratory, Hertz slowly built up a reputation for himself during the late 1870s and early 1880s as a diligent and skilled experimenter. His early interest in engineering gave him a distinct edge over many of his German contemporaries. The view of electromagnetism that Hertz acquired from his teacher was very different from that held by his Maxwellian contemporaries in Britain. Helmholtz had little time for Maxwell's electromagnetic ether filling all space. Action took place at a distance rather than directly through an intervening medium. Hertz first made a name for himself as an independent experimenter with an experiment designed to confound the theories of Helmholtz's rival in the field of German electricity, Wilhelm Weber. By the mid-1880s, when Hertz was his own man first at Kiel and later from 1885 at Karlsruhe, he was still working on problems largely defined by Helmholtz's perspective on physics and aimed at bolstering his mentor's theories against local German adversaries.

[15] Ibid., 183–84.



6.3 Some of the apparatus that Heinrich Hertz used to demonstrate the existence of electromagnetic waves in the ether.

At Karlsruhe, Hertz initiated a series of experiments into the properties of electrical discharges. He still saw himself as working on problems initiated by Helmholtz—and in particular on a prize question proposed by Helmholtz in Berlin as early as 1879 on the electrical effects of dielectrics (substances like air or glass that do not, under normal circumstances, conduct electricity) on neighboring conductors. In his Karlsruhe laboratory he became increasingly intrigued by the properties of some of the demonstration apparatus. In particular, he was interested in the sparking effects of coils arranged so that they were adjacent to each other. Hertz worried away at the problem, trying to find better ways of experimentally reproducing the phenomena. After spending some time trying (and failing) to get rid of some irritating "side sparks" that detracted from what he regarded as the main phenomenon, he gave up in disgust and switched his attention to the side sparks themselves. He found he could use these side sparks as indicators of surges of current across nearby spark gaps (in other words, dielectrics). They could be used to probe for interesting electrical effects. Over the next few years, he gradually built up a repertoire of what seemed to be wavelike effects by manipulating his apparatus. He could demonstrate nodes in standing waves. He could detect reflections and even interference patterns just as if the mysterious waves were rays of light. Finally, in 1888 he revealed his experiments to the world.

Looking back at his experimental endeavors of the past few years from the vantage point of a successful conclusion, Hertz now placed his work firmly in the context of Maxwellian physics. His electric waves were a vindication of Maxwell. While the experiments and the phenomena they produced stood independently of any theory, their significance largely lay in the way they sorted out the wheat from the chaff in electromagnetic theory. "Since the year 1861 science has been in possession of a theory which Maxwell constructed upon Faraday's views, and which we therefore call the Faraday-Maxwell theory. This theory affirms the possibility of the class of phenomena here discovered just as positively as the remaining electrical theories are compelled to deny it . . . as long as Maxwell's theory depended solely upon the probability of its results, and not on the certainty of its hypotheses, it could not completely displace the theories which were opposed to it. The fundamental hypotheses of Maxwell's theory contradicted the usual views, and did not rest upon the evidence of decisive experiments. In this connection we can best characterise the object and the result of our experiment by saying: The object of these experiments was to test the fundamental hypothesis of the Faraday-Maxwell theory, and the result of the experiment is to confirm the fundamental hypothesis of the theory."[16] His electric waves were to be interpreted as the jewel in the crown of Maxwellian physics.

Lodge in Liverpool responded to Hertz's triumph with commendable humility, his chagrin tempered presumably by the knowledge that these Hertzian waves provided some very heavy ammunition for his battle with the practical men. He was unequivocal in his interpretation of their significance: "In 1865, Maxwell stated his theory of light. Before the close of 1888 it is utterly and completely verified. Its full development is only a question of time, and labour, and skill. The whole domain of Optics is now annexed to Electricity, which has thus become an imperial science."[17] Lodge was soon out demonstrating electric waves to excited audiences, with sometimes spectacular results. As he recalled, "I exhibited many

[16]H. Hertz, *Electric Waves* (London: Macmillan, 1893), 19–20.

[17]O. Lodge, *Modern Views of Electricity* (London, 1892), 336.

of the Leyden Jar experiments both to the Royal Institution and the Society of Telegraph Engineers, in a lecture on 'The Discharge of a Leyden Jar,' where were shown many striking experiments. The walls of the lecture-theatre, which were metallically coated, flashed and sparked, in sympathy with the waves which were being emitted by the oscillations on the lecture-table—an incident which must be remembered by many of those present. This was a novel result, surprising to myself also, and I hailed it as an illustration or demonstration of the Hertz waves."[18] When Hertz died at the early age of thirty-six in 1894, Lodge paid generous tribute to his memory in a lecture at the Royal Institution.

Other Maxwellians were quick to jump onto the Hertzian bandwagon. William Crookes concurred with Lodge in his assessment of what had happened. "Whether vibrations of the ether, longer than those which affect us as light, may not constantly be at work around us, we have, until lately, never seriously enquired. But the researches of Lodge in England and of Hertz in Germany give us an almost infinite range of ethereal vibrations or electric rays, from wave-lengths of thousands of miles down to a few feet." The business-minded Crookes was not slow to grasp the commercial possibilities either. "Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wave-length of which I have spoken will easily pierce such mediums, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances." This was, he insisted "no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery."[19] Nor was telegraphy the only possibility. Crookes speculated that the "ideal way of lighting a room would be by creating in it a powerful, rapidly-alternating electrostatic field, in which a vacuum tube could be moved and put anywhere, and lighted without being metallically connected to anything."[20] Crookes was quite right. By the 1890s Guglielmo Marconi was already experimenting with wireless telegraphy under the aegis of the British Post Office. Nikola Tesla was experimenting to realize the dream of electric light without wires. It all went to confirm Oliver Lodge's robust claim that one could no more deny the existence of the ether than one could deny the existence of matter.

[18] O. Lodge, *Past Years* (London: Stodder & Haughton, 1931), 185.

[19] W. Crookes, "Some Possibilities of Electricity," *Fortnightly Review*, 1892, **51**: 175.

[20] Ibid., 177.

Not everyone subscribed to this imperialist reading of Hertz's experiments, however. When George Francis FitzGerald asserted at the Bath meeting of the British Association that the existence of electric waves was the final proof of Maxwell's theory, an opponent from the practical men's camp retorted that so far as he could see "the Hertz experiments prove nothing."[21] From the practicals' perspective, the Maxwellians' efforts to use their expertise as physicists to adjudicate over matters of practical, hands-on electricity were impertinent attempts by young upstarts to foist their book learning on men who had imbibed their craft through hard-won experience. This kind of debate underlines the point that, as in many other cases, what was at stake here was authority. Physics and physicists had to find a cultural role for themselves if the new discipline was to be ultimately successful. Hertz's waves were from this perspective a gift, albeit a hard-fought-for one. They demonstrated graphically the physicist's power to manipulate nature, to make things happen as if by magic. For large sections of the public they raised the possibility as well that discoveries of more mysterious forces in the ether were yet to be made and that other kinds of transmitters and receivers were waiting to be found.

The Other World

Many late nineteenth-century commentators clearly felt that new discoveries like cathode rays and electric waves were only the tip of the iceberg. A whole order of forces was waiting to be discovered in the ether. Crucially, many argued that physics was on the verge of delivering answers to fundamental questions of life and death. The Victorian period was in many ways the heyday of alternative scientific practices. Mesmerism and table turning flourished in the early part of the period. There was intense interest in spiritualism around the end of the century. For many (though by no means all) of their practitioners, these practices were not alternatives to science—they were scientific themselves. The phenomena they produced could be studied and manipulated in just the same way as physicists could study and manipulate electricity or the ether. Significant numbers of physicists in Europe and America concurred with this assessment. A far larger number disagreed vociferously. Practitioners of mesmerism or spiritualism were either frauds or dupes and men of science who took their practices seriously were themselves deceived.

[21] Quoted in B. Hunt, "Practice vs. Theory," 351.

Nevertheless, such phenomena were the subject of serious inquiry. To some physicists at least, they seemed ripe for incorporation into the new physics of the ether.

An early example of such an effort was the work of the German natural philosopher Karl von Reichenbach. His announcement in 1845, in the pages of the *Annalen der Chimie und Pharmacie*, edited by the illustrious Justus Liebig, that he had discovered a new kind of force was greeted with considerable interest. This odic force, as he called it, seemed to emanate from the poles of magnets and from living beings. It could be sensed only by particularly sensitive female subjects—typically, hysterical or nervous women. Such subjects could actually see the new force as a flame emanating from the poles of magnets or as an aura surrounding living matter. Reichenbach was emphatic that what he had discovered was a physical force just like electricity or magnetism, albeit one that seemed to have a particularly close affinity with the processes of life. He and others speculated that it might be correlated with other physical forces and therefore fitted in to the grand new universal systems of interrelated forces being offered by natural philosophers like William Robert Grove. Odic force was a subject of intermittent experimental research for much of the century. Its apparent close relationship to living matter made it a particularly intriguing topic of inquiry. A proper understanding of odic force's relationship to other forces might deliver the secret of life itself.

Many enthusiasts for odism had interests in another flourishing midcentury practice as well—mesmerism. Mesmerism, or animal magnetism, already had a long history by the Victorian period. The practice was developed in the late eighteenth century by the Viennese physician Anton Mesmer. He argued that living matter contained an innate animal magnetism that he and similarly adept practitioners could manipulate in various ways to produce trancelike states in their subjects. A number of early Victorian natural philosophers, like the radical doctor John Elliotson and the popular writer and lecturer Dionysius Lardner, professor of mechanical philosophy at University College, were convinced of mesmerism's reality. To Lardner it was clear that the mysterious agent behind the phenomena "is material, is propagated through space in straight lines; that various corporeal substances are pervious by it with different degrees of facility, and according to laws which still remain to be investigated; that it is reflected from the surfaces of bodies, according to definite laws, probably identical with or analogous to those which govern the reflection of other physical principles, such as light and heat; that it has a specific action on the nervous systems of animated beings, so as to produce in them perception and sensation, and to excite various mental emotions."[22] It was just like any other force of nature.

Even many of the mesmerists' most committed opponents found it difficult to deny the reality of the phenomena that could apparently be produced by animal magnetism. Their strategy instead was to deny the existence of the magnetic fluid that, according to the mesmerists, caused the phenomena. In effect, they tried to transform mesmerism from a practice that might legitimately be studied by physicists into one that was best dealt with by another rising new discipline—psychology. According to the physiologist William Benjamin Carpenter, for example, the mesmeric trance was simply the result of pathological processes in the brain rather than the outcome of some mysterious force: "ideas which take possession of the mind, and from which it cannot free itself, may excite respondent movements; and this may happen also when the force of the idea is morbidly exaggerated, and the will is not suspended but merely weakened, as in many forms of insanity."[23] People in mesmeric trances were simply people who had allowed themselves to lose control over their own minds and bodies. Not everyone was convinced, however. Even as interest in mesmerism waned significantly during the second half of the century, many experimenters remained convinced that there was some hitherto undiscovered connection between mental and nervous processes and the operations of the ether.

Many attempts to make sense of the human mind and body in terms of electrical processes had been made by the final decades of the nineteenth century. The telegraph, in particular, was an increasingly common metaphor for the nervous system from midcentury onwards. The nerves were characterized as telegraph wires carrying messages to and fro between the brain and the body's peripheries. Electrophysiologists were thought to have "tapped the wires of the living telegraphic system."[24] The brain itself from this perspective was a mass of electrical circuits. "Could we picture to ourselves the changes in the brain when its higher centres are in a state of molecular disturbance, as when one is thinking rapidly . . . could we, in such circumstances of mental turmoil, examine the phenomena of the brain, we could, in all probability, obtain evidence

[22] Quoted in A. Winter, *Mesmerized*, 55.

[23] W. B. Carpenter, *Human Physiology* (London, 1853), 672.

[24] J. G. McKendrick, "Human Electricity," *Fortnightly Review*, 1892, **51**: 638.

of rapid changes of potential, and of currents flashing in a thousand directions, pursuing paths the intricacies of which are many times greater than if all the telegraphic and telephonic wires of London were concentrated in one vast exchange."[25] As ether physics gained ground over its opponents towards the end of the century it seemed to offer a new way of looking at the human mind and body as well.

Oliver Lodge was one of the first to suggest that the latest electric wave technology could be used to model the body. The eyes, he suggested, acted just like coherers—a kind of detector for electric waves. Others took up the suggestion enthusiastically. The medical electrician William Hedley argued that Lodge's work showed how human beings interacted with the ether. "The conductor, whether it be a wire or a living body, only *guides* the energy and concentrates it for useful work. Applying this to that very imperfect conductor, the human body, it is evident that the latter may be regarded as an appliance capable of utilising in a variety of ways energy transmitted by the ether."[26] The sense organs were a set of receivers "syntonised for the reception of similarly vibrating etherial impulses radiating from some given source."[27] Others took matters further. William Crookes speculated that "other sentient beings have organs of sense which do not respond to some or any of the rays to which our eyes are sensitive, but are able to appreciate other vibrations to which we are blind . . . Imagine, for instance, what idea we should form of surrounding objects were we endowed with eyes not sensitive to the ordinary rays of light but sensitive to the vibrations concerned in electric and magnetic phenomena."[28] Furthermore, he argued, "In some part of the human brain may lurk an organ capable of transmitting and receiving other electrical rays of wave-lengths hitherto undetected by instrumental means. These may be instrumental in transmitting thought from one brain to another."[29]

These kinds of speculations seemed to some, at least, to offer possible answers to puzzles like Reichenbach's odic forces. Maybe the high-strung women who claimed they could see flames emanating from the poles of a magnet were somehow attuned to be able to see magnetic forces. Jean Charcot in Paris carried out experiments to assess the effect of magnets

[25] Ibid., 639.

[26] W. S. Hedley, "Apologia pro Electricitate Suâ," *Lancet*, 1895, **1**: 1103.

[27] Ibid.

[28] W. Crookes, "Some Possibilities of Electricity," *Fortnightly Review*, 1892, **51**: 176.

[29] Ibid.

on sensitive, hysterical women. William Henry Stone, medical electrician, member of the Society for Psychical Research and physician at St. Thomas's Hospital in London, carried out similar experiments in an effort to check Charcot's conclusions. He found some evidence that placing his patient's head between the poles of a powerful electromagnet alleviated her headaches. He felt bound to add though that having tried the experiment on himself, he could notice no definite result. William Barrett, professor of experimental physics at Dublin's Royal College of Science, also carried out experiments under the aegis of the Society for Psychical Research to investigate Reichenbach's odic forces. He concluded that there was a strong case in favor of the existence of some peculiar and unexplained luminosity around the magnetic poles, which could only be seen by certain individuals.

For William Crookes, however, ether physics offered something far more revolutionary than a way of explaining mysterious magnetic auras. It offered a way of communicating with the dead. Spiritualism, as the practice came to be called, was increasingly popular towards the end of the nineteenth century and the beginning of the twentieth. Spiritualism offered a system of practices whereby people could commune with the spirits of the dead. Mediums offered themselves as conduits through which spirit guides could pass messages from the dead to the living, offering condolences, imparting information, and describing their existence in the spirit world. While many spiritualists quite explicitly cast their practices in direct opposition to what they regarded as the excessively materialist stance of modern science, some physicists regarded spiritualist phenomena as being ripe for physical explanation in terms of the ether. Spiritualism was yet another example of the ether's mysterious powers waiting to be unlocked. This was the kind of thing Crookes had in mind with his talk of sentient beings with sense organs responsive to different wavelengths of electromagnetic rays and of humans with organs in their brains that could receive and transmit thought. He and similarly minded physicists were deeply involved in investigating spiritualist phenomena. To many of his fellow physicists it seemed a very dangerous road to follow. He was in danger of becoming the tool of charlatans (if not becoming a charlatan himself).

Crookes and his fellow electrician, the telegraph engineer Cromwell Varley, had been involved in investigating spiritualist phenomena since the 1860s. Electricians, dealing as they did with a mysterious force that seemed to act at a distance through some medium or other, seemed well-qualified to investigate such matters. Some spiritualists agreed with this assessment. The American spiritualist Emma Hardinge argued that her practices made use of "the self-same forces of the telegraph, worked by vital instead of mineral electricity."[30] Varley concurred, going so far as to invoke spiritualism in an attempt to explain the mysterious workings of the telegraph to a skeptical, working-class East End London audience. Making spiritualism scientific however, required the imposition of laboratory standards onto the séance. "Each circle should be under the management of a clever man and each should carry on a continuous and exhaustive examination of the groundwork of the subject. Once establish a clue to the relations existing between the physical forces known to us and those forces by which the spirits are sometimes able to call into play the power by which they produce physical phenomena—once establish this clue there will be no lack of investigators, and the whole subject will assume a rational and intelligible shape to the outside world."[31]

Crookes and Varley entered into their spiritualist investigations by bringing all the impedimenta and paraphernalia of modern science to bear on the problem. Crookes imported the latest and most advanced laboratory precision measurement apparatus into the séance in an effort to measure the psychic force exerted by the medium Daniel Dunglas Home in the early 1870s. Convinced that not only mediums but all human beings could manifest such forces to some degree, he searched hard for a way of reliably detecting such minuscule manifestations. It was no coincidence that these spiritualist researches took place at the same time as his investigations of the equally intangible forces manifested inside the radiometer. With Varley, Crookes devised an electrical means to detect imposture in cases of spirit manifestation—instances in which spirits seemed to become physically tangible and visible during the course of a séance. Photographs demonstrated the spirit's presence while the electric circuit showed that the medium—typically secluded in another room—was not moving during the course of the manifestation. According to Crookes and Varley, their experiments with Florence Cook and the ghostly Katie King provided tangible evidence that whatever else might be going on, Florence and Katie were not the same material person (figure 6.4). As Varley insisted, even an experienced electrician would simply find it impossible to escape the circuit without springing the trap.

[30] E. Hardinge, "What is Spiritualism?" *Human Nature*, 1867, **1**: 568–69. My thanks to Richard Noakes for this reference.

[31] Quoted in R. Noakes, "Telegraphy Is an Occult Art," 445.

6.4 Katie King the ghost captured on a photographic plate.

Oliver Lodge—almost the high priest of ether physics—was also increasingly interested in the possibilities of psychic forces manifesting themselves through the ether. He certainly concurred with Crookes's assessment that there was no reason to doubt that the ether might interact, or provide a vehicle for interaction, with living matter and mind in ways hitherto unimagined. Lodge had started experimenting seriously on such matters a few years after taking up his professorship in Liverpool in 1881. His experiments followed the spiritualist Irving Bishop's performances in the city in 1883, in which incidents of "thought transferences" were claimed to take place on stage. Asked to carry out some experiments on the phenomenon, he did so, being sufficiently impressed by the results to write them up for *Nature*. Somewhat to his surprise, the editor published them. Lodge was convinced that "thought-transference or . . . 'telepathy' from one person to another was a reality."[32] Looking back at the progress of physics in his autobiography, Lodge declared his conviction that "the scheme of physics will be enlarged so as to embrace the behaviour of living organisms, under the influence of life and mind. Biology and psychology are not alien sciences . . . they belong to the physical universe, and their mode of action ought to be capable of being formulated in terms of an enlarged physics of the future, in which the ether will take a predominant part."[33]

Many nineteenth-century physicists regarded the involvement of some of their fellows in matters psychic as being distasteful at best and a surrender to charlatanry at worst. Dabbling in mesmerism, odic forces, or spiritualism was a betrayal of everything the young science of physics stood for. Similarly, many spiritualists regarded the efforts of Crookes, Lodge, and Varley to trespass on their territory as an impertinent irrelevance. Spiritualism was for them in direct opposition to science and had no need for its support. Spiritualism from this perspective was an antidote to the oppressive materialism of scientific culture. Even spiritualists sympathetic to physicists' aims were unhappy at their insistence on imposing laboratory protocols and disciplines on the culture of the séance. For these physicists and their supporters, however, there was nothing unusual about their interest—and nothing inimical to physics either. On the contrary, they regarded their discipline's history as a vindication of their stance. The progress of physics throughout the century was after all punctuated by the discovery of new forces. There was in their view nothing to distinguish psychic forces from the list of those already discovered. Far from it—they offered a rich new field of inquiry and another opportunity to wield physics' newfound cultural authority.

Radioactivity

By the last decade of the nineteenth century, Maxwellian physics, as Oliver Lodge had indicated, appeared supremely triumphant. The discovery of electric waves and the moves that were soon being made to transform wireless telegraphy into a viable commercial technology placed the reality of the electromagnetic ether beyond reasonable doubt. The ether was real because it could be manipulated—it could be made to do things. It was the ultimate vindication of the new physics' claim to cultural authority

[32] O. Lodge, *Past Years* (London: Stodder & Haughton, 1931), 275.

[33] Ibid., 350–51.

in the modern age. Pundits speculated as to what new properties of this universal medium might next be discovered and placed at the service of humanity through the powers of physics. Writers in the new genre of science fiction penned stories in which the citizens of future utopias lived lives of unparalleled luxury and leisure, all fueled with energy harvested from the ether. Other more pessimistic authors warned of a future in which war machines of unimaginable capabilities wreak havoc on the remnants of human civilization utilizing hitherto undiscovered forces latent in the ether. Ether physics seemed to many of its practitioners to be firmly settled as the framework within which future progress would take place. The search was on for new understandings of its properties and for further forces that might lie hidden within it.

The breakthrough came at the tail end of 1895, when the relatively unknown Wilhelm Röntgen announced a spectacular new discovery to the world. Röntgen, born in Düsseldorf in 1845, had studied mechanical engineering at Zurich Polytechnic, emerging with a diploma in 1868. Unsure as to his future career, he turned for advice to August Kundt, the professor of physics at the university, who suggested he consider experimental physics as a possibility. Röntgen took the advice and duly produced a doctoral thesis on the study of gases. For the next two decades he rose slowly through the ranks of the German university system. Moving from institution to institution, he was eventually appointed professor of physics at the University of Würzburg in 1888. Like Hertz, Röntgen had been working during the 1880s on the effects of electrical currents in dielectric media like the air. Also like Hertz, he was making a reputation for himself as an adept experimentalist, helped no doubt by his engineering background. In Würzburg during the mid-1890s he interested himself in experimental research on the properties of cathode rays. The result of that interest was his announcement to the world that he had discovered a hitherto completely unknown form of radiation emanating from the Crookes tubes he used for his experiments. Röntgen dubbed the mysterious radiation X rays.

Röntgen's experiments were designed particularly to examine the properties of cathode rays that had leaked from the discharge tube. To this end, in order to shield the fluorescence caused in the tube by the rays, the tube was masked by a covering of black paper. In the course of his experiments, Röntgen noticed a curious phenomenon. A screen coated with barium platinocyanide placed at some distance from the tube—beyond the range of any stray cathode rays—glowed in the dark whenever a current passed through the tube. Puzzled by the strange effect, he carried

6.5 An X-ray photograph of the hands of the duke and duchess of York in the *Illustrated London News*, July 1896.

out more experiments to try to understand what was going on. Gradually he became convinced that he had discovered a completely new kind of ray—a ray that could pass through solid objects. He even found that he could take photographs with it. A paper announcing his discovery to the world was hurriedly communicated to the Würzburg Physical Medical Society just after Christmas 1895 and copies sent out to eminent physicists throughout Europe. They caused a sensation. According to Röntgen, the rays appeared to behave just like light, except that they could pass through solid objects. His paper included a photograph to illustrate his claims. It was a picture of a human hand—his wife's—made transparent by the rays.

Experimenters rushed to repeat Röntgen's experiment. In England, the electrical engineer A. A. Campbell Swinton was one of the first to succeed, marveling at "the exceedingly curious fact that bone is so much less transparent to these radiations than flesh and muscle, that if a living human hand be interposed between a Crookes tube and a photographic plate, a shadow photograph can be obtained which shows all the outlines and joints of the bones most distinctly"[34] (figure 6.5). In Cambridge,

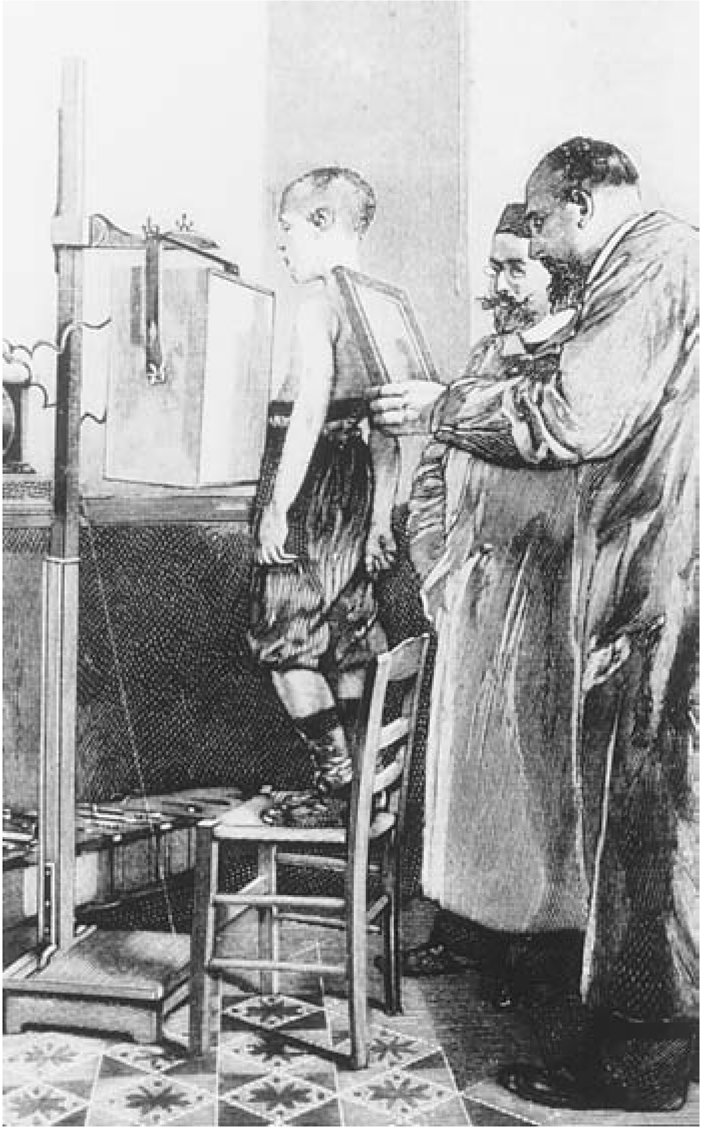
[34]A. A. Campbell Swinton, *Nature*, 1896, **53**: 276.

the physicist J. J. Thomson rushed to investigate the mysterious rays' properties, writing to *Nature* before the end of February with an account of experiments at the Cavendish Laboratory confirming Röntgen's views on the rays' lightlike qualities. In the United States, the flamboyant electrical entrepreneur Thomas Alva Edison quickly recognized the rays' potential, announcing with great fanfare to the press his intention to produce an X-ray photograph of a living human brain. Back in Germany, Röntgen himself performed a demonstration of his discovery for the delectation of the kaiser in person. Experimenters labored hard to improve the technology, finding out what size and shape of tube was best to produce the X rays and trying to understand just what their properties were.

It did not take long for medical men to recognize X rays' potential either (figure 6.6). After all, the first published X-ray photographs were of the bones inside a human hand. The *British Medical Journal* quickly commissioned Sydney Danville Rowland, a young medical student at St. Bartholomew's Hospital in London, "to investigate the application of Röntgen's discovery to Medicine and Surgery and to study practically its applications."[35] Before the end of February he had demonstrated his results before the Medical Society of London. Earlier the same month John Cox, professor of physics at McGill University in Montreal, used X-ray photography to help doctors locate and remove a bullet from a patient's leg. In Cambridge, Edward Douty, surgeon in charge of the gynecology department at Addenbrokes Hospital, took up X rays, while the Cavendish Laboratory provided an informal service to the hospital as well. By May, the first medical journal devoted to X rays had already appeared—the *Archives of Clinical Skiagraphy*. X rays were taken up as therapy as well as for diagnosis. Leopold Freund in Vienna used X rays to remove a mole from a young girl's back. By the early years of the twentieth century, X rays had become a standard part of the armory of hospital electrotherapy departments.

The public was fascinated by X rays and their possibilities. "Roentgen mania," as the *Electrical Engineer* called it, swept across Europe and America. Crowds flocked to X-ray photography studios to have their innards photographed. Edison developed a special fluorescent screen so that people could see their own insides without even having to wait for a photograph to be developed. By 1897 a "Thomas A. Edison X Ray

[35] Quoted in M. Weatherall et al., *On a New Kind of Rays* (Cambridge: University Library, 1995), 5.



6.6 X rays were soon in use for medical purposes, as illustrated here.

kit" was on the market. Such gimmicks soon became popular fairground attractions. People were particularly intrigued by the possibilities X rays offered of making solid objects transparent. Cartoonists had a field day with the concept, with *Punch* publishing a cartoon depicting the kaiser's discomfiture when John Bull's considerable backbone was revealed by

X ray. It did not take long for the more prurient possibilities to be explored either:

> I'm full of daze
> Shock and amaze;
> For now-a-days
> I hear they'll gaze
> Thru' cloak and gown—and even stays,
> These naughty, naughty Roentgen Rays.[36]

as one magazine speculated. Newspapers advertised X ray–proof clothing to protect the public from the prospect of an involuntary scientific striptease. X rays soon became a staple in futuristic science fiction.

Among physicists, X rays quickly proved to be a particularly fruitful field for new experimental inquiries. Ambitious experimenters could hope to make their reputations by expanding physicists' understanding of the mysterious rays and their properties, or even by coming up with the discovery of yet another hitherto unknown kind of radiation. In France, Henri Becquerel, scion of a distinguished scientific dynasty stretching back to the beginnings of the century, took up the search with enthusiasm. He was intrigued by the possibility that the source of X rays might be the phosphorescence in the glass walls of the Crookes tubes and set out to investigate whether other sources of phosphorescence also produced hitherto unknown kinds of radiation. After some false starts, he found that a sample of uranium salts apparently did just that. In his report to the Académie des Sciences, Becquerel described how he had wrapped a photographic plate in sheets of thick black paper to exclude sunlight and then placed a sample of the phosphorescent substance on top of the paper. When the photographic plate was developed, the image of the phosphorescent substance could clearly be seen on the negative. It seemed that the uranium salts gave off some kind of radiation that could pass through the black paper and affect the plate.

A few years later, another French physicist, René Blondlot, professor of physics at Nancy, seemed on the verge of an equally groundbreaking discovery. Like Becquerel, Blondlot had been inspired by Röntgen's researches to carry out his own investigations. He took up the task of looking into the physical properties of X rays, being particularly concerned to find out whether or not they could be polarized, like ordinary

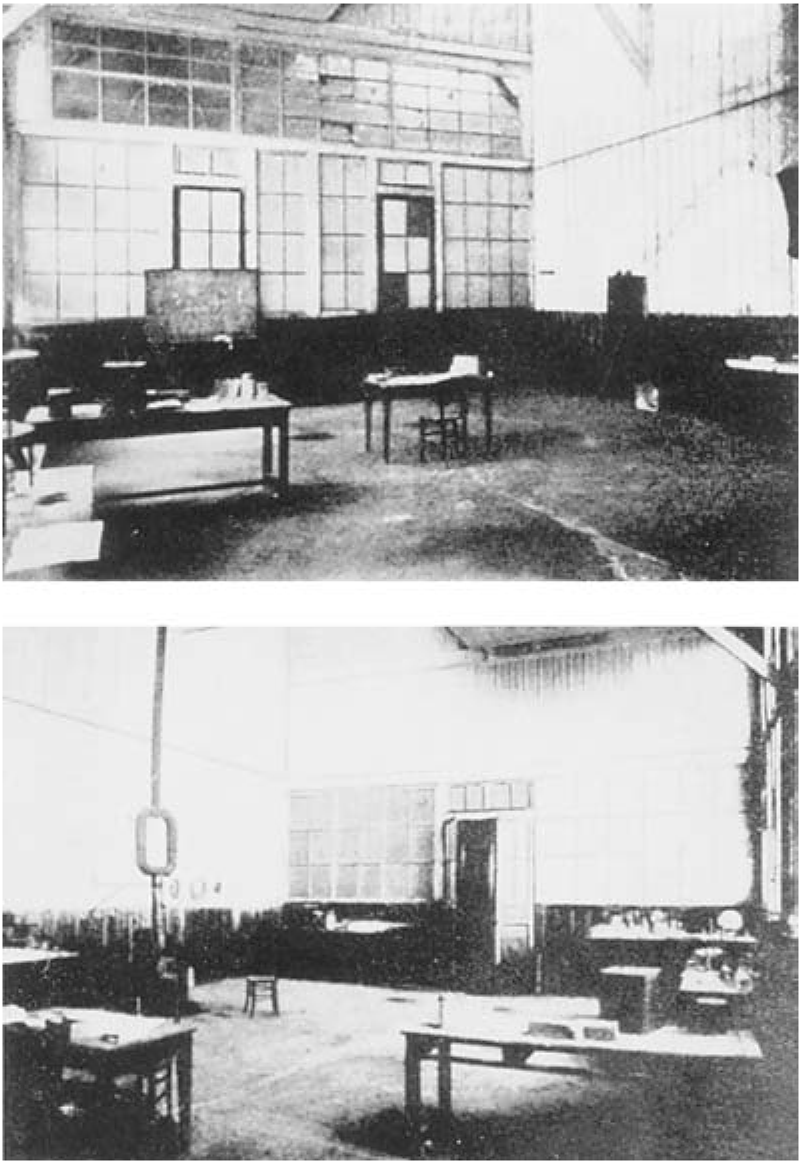
[36] Quoted in C. Caufield, *Multiple Exposures*, 7.

light. Experimenters had so far been unable to find a way of polarizing X rays—something of a problem for those who argued that they were waves in the ether just like other forms of radiation like light or electric waves. Blondlot suggested that X rays might in fact already be polarized and carried out some experiments, using the brightness of an electric spark as a detector to confirm his suspicions. He soon became convinced, however, that what he was detecting with his spark was not X rays at all but yet another new kind of radiation, which he dubbed N rays, after his native city, as he announced his results to the world in spring 1903. Other experimenters rapidly confirmed Blondlot's discovery and added to it. Particularly intriguing seemed the discovery that N rays were given off by the nervous systems of living beings. The eminent French physicist Arsène d'Arsonval, expert on the interactions of electricity with the human body, described how the rays could be detected emanating from Broca's center in the brain during the process of speech. Some laboratories consistently failed to reproduce the French results, however, notably the illustrious Cavendish in Cambridge. In an effort to understand Blondlot's techniques better, the American physicist R. W. Wood visited his laboratory at Nancy. During one experiment he surreptitiously removed a vital part of Blondlot's apparatus. The N rays continued to appear nonetheless. To his opponents the revelation was decisive. N rays were a figment of Blondlot's imagination. By the end of 1904 they had disappeared back into the ether.

Becquerel's radiation did not go away, however. His discovery became instead the starting point for the researches of a recent Sorbonne graduate who was looking for an interesting topic for her doctoral thesis. Maria Sklodowska, or Marie Curie as she became better known following her marriage to the French physicist Pierre Curie, had come to Paris in search of a physics education in 1891. Determined to stay in France following her graduation and marriage, Marie Curie turned to Becquerel's work as a source for further research at the end of 1897 precisely because little had been done with it since 1896. Everyone else in the field was too busy with X rays to pay much attention to the curious rays given off by uranium. Marie Curie's initial aim was to try and understand the ionizing behavior of Becquerel's radiation—its capacity to make air a conductor of electricity. For this she would use the sensitive measuring apparatus recently devised by her husband. She was soon intrigued, however, as she tested different materials, by the fact that pitchblende—a compound of uranium—seemed to give off more of the mysterious rays than did pure uranium itself. She surmised that this meant the strange radiation was not specific to uranium after all and that pitchblende contained another, hitherto unknown, element that possessed the mysterious radiating property to an even greater extent.

Pierre soon abandoned his own researches to help his wife, and the two Curies set about identifying the constituent of pitchblende that seemed to give off the new rays in such copious quantities. This was dirty work. Large quantities of pitchblende had to be broken down into its constituent parts to isolate the tiniest amounts of the mystery element that seemed to produce the rays. They eventually concluded that not one, but two different new elements were hidden away in the pitchblende. In July 1898, they announced the existence of a new element they called polonium (after Marie Curie's native Poland) to the Académie des Sciences. Their joint paper was titled "On a New Radio-active Substance Contained in Pitchblende." A new word had entered the language of physics. The day after Christmas 1898 witnessed another presentation to the academy. This one was titled "'On a New Strongly Radio-active Substance Contained in Pitchblende." They had found their second element, dubbed radium, and had separate spectroscopic evidence of its existence, provided by Eugène Demarçay (figure 6.7). Marie Curie took upon herself the monumental task of distilling a pure sample of the two elements from the necessary mountains of pitchblende. In a presentation to the International Congress of Physics held in Paris in 1900 to coincide with the universal exposition, the Curies outlined their discovery and their latest work on the properties of the strange rays to a fascinated international audience. They ended their lecture with a question: was the source of this mysterious energy to be found inside radioactive bodies, or outside them? As they and their audience were beginning to realize, radioactivity seemed to violate some of the most hallowed principles of physics.

In 1903 the Curies, along with Henri Becquerel, were awarded the Nobel Prize for their discoveries. Following her husband's tragic death in a street accident in 1906, Marie Curie devoted her life to radioactivity. From 1907 onwards she presided over Parisian research on the new phenomenon, carefully garnering and protecting access to the difficult-to-acquire sources of the mysterious radioactivity. Her laboratory was devoted in particular to establishing standards in radioactivity, providing accurate measurements of emissions from different sources. As with X rays, much early interest in radioactivity focused on its possible medical uses. If X rays could cure, then radioactivity, which seemed so similar in its effects on the body, could be used in the same way. The telephone



6.7 Marie and Pierre Curie's shed laboratory, where the first samples of the new element radium were isolated.

inventor Alexander Graham Bell suggested that "there is no reason why a tiny fragment of radium sealed into a fine glass tube should not be inserted directly into the very heart of a cancer, thus acting directly upon the diseased material."[37] Outside of physics laboratories, hospitals and medical practitioners made up most of the market for radioactive substances until well into the twentieth century. The stuff was expensive. Laboratory directors such as Marie Curie had to make sure that they forged good contacts with industrial suppliers to make sure that their research was not hampered by their raw material's running out.

X rays and radioactivity provided the ingredients for a major shake-up of physics. Radioactivity in particular seemed to represent an entirely new kind of energy that seemed to defy established categories. It simply was not clear where it fitted into the physics of energy conservation and the ether. Over the next few decades these strange emanations were to provide the tools and building blocks for an entirely novel picture of the physical world and its constituents. Their discovery and the apparent capacities of physicists to manipulate them at will were the focus of immense public interest. They seemed to be only the first in a long line of discoveries just waiting to be made that would transform human destiny. That X rays and radioactivity appeared to hold the key to curing disease was a major attraction as well. They showed just how valuable physics could be when placed at the service of humanity. Their discovery at the dawn of a new century symbolized the prospects for scientific progress that the future held. Radioactivity seemed set to dominate popular perceptions of physics in the twentieth century as electricity had dominated for most of the nineteenth century. It also appeared to provide a rich new mine of discoveries for the increasing numbers of hopeful young physicists just entering an expanding profession.

Conclusion

Natural philosophy—what became the new discipline of physics—seemed to offer a great deal to thoughtful observers midway through the nineteenth century. It promised an ever deepening understanding of the mysterious forces that governed the Universe. It promised to provide a continually expanding mine of forces and energies that could be put to work, powering an ever growing economy. To its promoters, physics and the capacity it appeared to provide for technological innovation and

[37] Quoted ibid., 26.

unprecedented manipulation of natural powers seemed to be the key to indefinite progress, intellectual, cultural, and economic. It was a given for most of these Victorian commentators that increased knowledge of the workings of the Universe went hand in hand with such progress. Some of them might believe that increasing knowledge was a perfectly respectable end in itself, but few, if any, denied the imperative that such knowledge should be put to work as well. For physics' entrepreneurs, the constant stream of spectacular new discoveries that flowed from new laboratories in Europe and (increasingly) America were an inspiration. Scientific shows and displays of technological marvels underpinned the power of discovery, reminding audiences—if they needed reminding—of just what physics could offer.

The new forces and energies that seemed to appear so effortlessly from the ether during the second half of the nineteenth century were in fact the products of considerable labor and ingenuity. These were the decades during which physics as a discipline was created and consolidated. This was a process that itself required concerted effort. New constituencies had to be persuaded of the benefits that physics could deliver before the laboratories from which these discoveries emerged could be established and supported. Physics' cultural authority—its claims to provide a better way of looking at and understanding the world—did not burst full-grown from Jupiter's head. It had to be argued for. The new discoveries were an important part of this process themselves. They provided hard evidence for the skeptics (of whom there were many) that physics really could deliver the goods. This was one reason why showmanship remained an integral part of physics throughout the century. Physicists had to show their skeptical audience that they had nature under control. Discoveries that could be made spectacularly visible and provide tangible evidence of the action of otherwise unseen forces were central to their success in securing their cultural niche.