Prologue: "An Imperial Science"

In January 1889, in the wake of Heinrich Hertz's dramatic discovery of electromagnetic waves, the British physicist Oliver Lodge declared that with this experimental confirmation of James Clerk Maxwell's electromagnetic theory of light, "the whole domain of Optics is annexed to Electricity, which has thus become an imperial science."[1] Lodge had hit on a very up-to-date way to express the preeminence electrical science had achieved by the last decades of the nineteenth century. But in 1889 electricity was an imperial science in a less metaphorical sense as well: it lay at the scientific heart of submarine telegraphy, one of the characteristic technologies of the Victorian British Empire. Often described as the "nervous system of the empire," the web of undersea wires that British firms stretched around the globe in the second half of the nineteenth century carried information streaming toward London from the far reaches of the world and commands flowing back out, extending and reinforcing Britain's military, naval, commercial, and cultural power.[2] Cable telegraphy "annihilated space and time," in the phrase of the day, and cut the time it took to send a message from, say, London to Australia from weeks or months to hours or, for some messages, mere minutes. For the first time, the world was wired up, setting in motion changes in commerce, government, the dissemination of news, and the workings of everyday life that continue to play themselves out today. The advent of global telecommunications stands as one of the watersheds of modern history.

It was a watershed that transformed science as well. One of the perennial questions in the history of both science and technology concerns the

[1] Oliver J. Lodge, "Modern Views of Electricity," *Nature* (January 31, 1889) *39*: 319–22, on 322. This was the last installment of Lodge's long series of articles on the subject, collected and published later that year as *Modern Views of Electricity* (London: Macmillan, 1889); revised editions appeared in 1893 and 1907. The "imperial science" remark appears on p. 309 of the 1889 edition.

[2] See, e.g., George Peel, "Nerves of Empire," in *The Empire and the Century* (London: John Murray, 1905), 249–87.

relationship between the two. Should technology be understood simply as "applied science," with scientists, driven purely by their own curiosity, making discoveries that engineers and entrepreneurs then turn to practical use? Or is the pursuit of scientific knowledge instead sometimes shaped in fundamental ways by the technological context in which it is produced? Which way does the arrow of influence run? It is well known, for example, that electromagnetic field theory initially drew adherents only in Britain, and only in the mid-nineteenth century. But why then, and why there? The answer, as we will see, lies not just in the details of the lives and ideas of a few great men but also in the principal context in which electricity was studied in the middle decades of the nineteenth century: the telegraph industry, particularly submarine telegraphy. British firms dominated the world cable industry from its beginnings in the 1850s until well into the twentieth century, and the demands and opportunities presented by submarine telegraphy steered British electrical research into areas – particularly the study of how pulses of current travel along insulated wires – that fostered the spread of a field approach. Michael Faraday had been developing his field ideas since the 1830s, but they attracted little support until the 1850s, when physicists and engineers began to take them up in connection with submarine telegraphy. The Maxwellian field theory that grew to fruition in the next few decades was also shaped in important ways by the British cable industry, as was the whole system of electrical units and standards that is still used around the world today. By examining the links in the nineteenth century between cable telegraphy and the rise of electrical science, particularly field theory, we will be able not only to shed light on several important episodes in the history of physics but also to broaden and clarify our understanding of how science and technology interact.

1 "An Ill-Understood Effect of Induction"

Telegraphy and Field Theory in Victorian Britain

The men who made and laid the first submarine telegraph cables in the early 1850s gave little thought to electrical theory or precision measurement. Over the preceding decade they had watched as networks of landlines – most of them little more than bare wires strung from poles – had spread across the United States, Britain, and Continental Europe and had seen how the new telegraph systems were making money for their owners while also transforming the operation of markets and the dissemination of news. The prospect of extending such networks across the English Channel, and perhaps eventually across the Atlantic, was tantalizing. The promoters of the first submarine cables thought if they could just contrive a suitable way to insulate their wires, they would find it just as easy, and at least as profitable, to send signals under the sea as it had been to send them along overhead telegraph lines.

It turned out not to be so simple. Signaling through a submarine cable, particularly a long one, proved to be a far more complex and challenging task than sending dots and dashes along an overhead wire. Enormous resources were brought to bear on the problem in the 1850s and 1860s, and the effort to make cable telegraphy a success drove some of the most important advances in electrical science in the second half of the nineteenth century. This was especially true in Britain. As the leading industrial, commercial, maritime, and imperial power of the day, Britain had both the greatest effective demand for transoceanic telegraphy and the greatest resources with which to try to make it work. British firms dominated the cable industry from its beginnings, and British scientists and engineers were the first to encounter the new phenomena presented by submarine telegraphy. They responded by devising new electrical instruments, new measuring techniques, and even the basic units of ohms, amps, and volts that are still used today. More profoundly, their exposure to the peculiarities of submarine telegraphy, particularly the distortion or "retardation" that signals suffered in passing along undersea cables, led British scientists and engineers to rethink the basic nature of electric and magnetic phenomena. Instead of focusing on the supposed flow of electrical fluids within the conducting wires, they shifted their attention to the subtle interplay of energies in the surrounding space – that is, to what came to be called the "electromagnetic field." It has long been recognized that British physicists were the first to take up and extend this new field approach to electromagnetism, at a time when most of their counterparts on the Continent continued to treat electric and magnetic phenomena in terms of particles acting directly on each other from a distance. What explains this sharp difference in national scientific styles, which persisted from the 1850s until at least the 1890s? As we shall see, much of the answer can be found in differing technological contexts. To put the point simply and a bit too baldly, the British did field theory because they had submarine cables, and the French and Germans did not because they had none.

Technology has often been conceived, or even defined, as "applied science." On this view, scientists, driven mainly by their own curiosity, make discoveries in their studies and laboratories that engineers and inventors then take up and turn to practical use. Many cases could be cited to illustrate this pattern; indeed, the telegraph itself grew out of laboratory discoveries Alessandro Volta and Hans Christian Oersted made in the early 1800s, and in the two centuries since then such science-based technologies have become increasingly common. But sometimes the arrow of influence runs the other way, with scientific advances growing out of encounters with new technologies and the new phenomena they produce. It is widely recognized that the science of thermodynamics emerged in the mid-nineteenth century in large part from efforts to understand the workings of steam engines.[1] In a similar way, important developments in electrical science in the second half of the nineteenth century, particularly the adoption and extension of field theory, were driven in part by the demands and opportunities presented by cable telegraphy. James Clerk Maxwell, the Scottish theoretician who was the first to formulate the mathematical laws of the electromagnetic field, recognized this connection very clearly. In his seminal *Treatise on Electricity and Magnetism* (1873), he remarked:

> The important applications of electromagnetism to telegraphy have . . . reacted on pure science by giving a commercial value to accurate electrical measurements, and by affording to electricians the use of apparatus on a scale which greatly transcends that of any ordinary laboratory. The consequences of this demand for electrical knowledge, and of these experimental opportunities for acquiring it, have been already very great, both in stimulating the energies of advanced

[1] D. S. L. Cardwell, *From Watt to Clausius: The Rise of Thermodynamics in the Early Industrial Age* (Ithaca: Cornell University Press, 1971); Bruce J. Hunt, *Pursuing Power and Light: Technology and Physics from James Watt to Albert Einstein* (Baltimore: Johns Hopkins University Press, 2010).

electricians, and in diffusing among practical men a degree of accurate knowledge which is likely to conduce to the general scientific progress of the whole engineering profession.[2]

In what follows, we will trace how cable telegraphy shaped the development of electrical science in the nineteenth century, particularly in Britain, and seek to shed light on broader patterns in the interaction between science and technology.

Telegraph Business

The telegraph did not spring fully formed from the mind or workshop of any one person. The basic idea of using electricity to convey messages dates back to the eighteenth century, but practical ways to do it were not found until after Oersted discovered in 1820 that electrical currents can produce magnetic effects. By the early 1830s several inventors had devised rudimentary electromagnetic telegraphs, and after witnessing a demonstration of one in Munich in 1836, W. F. Cooke, a young English medical student, set out to produce a commercially viable system. Back in London, he teamed up with Charles Wheatstone, professor of natural philosophy at King's College London, and in 1837 they secured a patent on a telegraph that used pulses of electric current to deflect magnetized needles and so indicate letters.[3] By 1839, Cooke and Wheatstone had completed a short line along a railway just west of London, insulating the wires with varnished cotton and burying them beside the tracks in iron pipes. Such lines were expensive to build and slow to catch on, but by 1846, when the Electric Telegraph Company was formed to take over Cooke and Wheatstone's patents, underground lines had largely given way to cheaper overhead wires strung from poles, and the telegraph network began spreading rapidly across England.[4]

In the United States, the enterprising artist Samuel F. B. Morse heard of European work on electric telegraphy and in the mid-1830s set about devising a system of his own. His "canvas stretcher" telegraph was remarkably clumsy and in its initial form barely worked across a room;

[2] Maxwell, *Treatise, 1*: vii–viii. In nineteenth-century usage, "electrician" did not mean an electrical tradesman but rather an expert in electrical theory or experiment.

[3] Brian Bowers, *Sir Charles Wheatstone* (London: Her Majesty's Stationery Office, 1975), 103–23. On the role the culture of electrical performance played in the origins of telegraphy, see Iwan R. Morus, "Telegraphy and the Technology of Display: The Electricians and Samuel Morse," *History of Technology* (1991) *13*: 20–40.

[4] Jeffrey Kieve, *The Electric Telegraph: A Social and Economic History* (Newton Abbot: David & Charles, 1973), 46–51. A thorough account of the "Electric" and other early telegraph companies in Britain, with many original documents and images, can be found on Steven Roberts's website "Distant Writing": distantwriting.co.uk.

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what later became known as the "Morse" system, using a simple key to tap out dots and dashes, was devised later by Morse's young associate Alfred Vail.[5] Whatever skill Morse lacked as a practical inventor, however, he made up for as an energetic promoter. After a long lobbying campaign, in 1843 he secured a Congressional grant to build a demonstration line from Baltimore to Washington. Morse initially planned to use copper wires insulated with varnished cotton and buried in lead tubes, but such underground lines proved slow and expensive to construct, and in spring 1844 he switched to bare wires strung from poles. The work went ahead quickly after that and the line reached Washington in late May. The Democratic convention was then meeting in Baltimore, and Morse created a sensation in Washington by reporting the nomination of James K. Polk for president hours ahead of messengers arriving by rail.[6] The federal government declined to make telegraphy part of the postal system, however, and its further development in the United States, as in Britain, was left to private companies. Lines soon spread up and down the East Coast and by 1848 reached as far west and south as Chicago and New Orleans. Service in the early years was often erratic, but the "lightning wires" were nonetheless widely hailed as one of the wonders of the age.

Not everyone was impressed. In a passage of *Walden* that he drafted in 1849, Henry David Thoreau dismissed the telegraph, along with most other new inventions, as "but improved means to an unimproved end." "We are in great haste to construct a magnetic telegraph from Maine to Texas," he said, "but Maine and Texas, it may be, have nothing important to communicate."[7] Whatever the ultimate significance of what they had to say, however, people were eager to say to it, and the telegraph companies soon found their wires filled with traffic. Newspapers clamored to obtain even brief accounts of distant events and began to feature columns of "News by Electric Telegraph." Around 1846 a group of New York newspapers began to cooperate to share the costs of gathering and distributing telegraphic news reports, and the New York City Associated Press and similar "wire services" soon came to play leading

[5] Kenneth Silverman, *Lightning Man: The Accursed Life of Samuel F. B. Morse* (New York: Alfred A. Knopf, 2003), 148; on Vail's contributions, see 163–64, 235–36; Robert Luther Thompson, *Wiring a Continent: The History of the Telegraph Industry in the United States, 1832–1866* (Princeton: Princeton University Press, 1947), 10–11; and J. Cumming Vail, *Early History of the Electro-Magnetic Telegraph, from Letters and Journals of Alfred Vail* (New York: Hine Brothers, 1914).
[6] Silverman, *Lightning Man,* 237–38.
[7] Henry David Thoreau, *Walden; or, Life in the Woods* (Boston: Ticknor & Fields, 1854), 57. The text first appears in this form in Version C, drafted in 1849; see the "Fluid Text" of *Walden* on the "Digital Thoreau" website, www.digitalthoreau.org.

roles in mediating the delivery of news in both the United States and Europe.[8]

The effects of the telegraph on commerce were even more far-reaching. The telegraph companies in both the United States and Britain found merchants and traders to be their best customers, and from the first most of the traffic on their wires concerned commodity prices, sales orders, and similar business information. By the early 1850s the spread of telegraph networks had helped to reduce transaction costs, integrate wider regional markets, and facilitate the growth of commodity exchanges and futures markets.[9] Merchants were now able to place orders directly from a distance, reducing the need for middlemen and warehouses holding large inventories. As early as 1847 *The Republican* of St. Louis declared that "The Magnetic Telegraph has become one of the *essential means of commercial transactions*. … Steam is a means of commerce – the Magnetic Telegraph is now another, and a man may as well attempt to carry on successful trade by means of the old flatboat and keel, against a steamboat, as to transact business by the use of mails against the telegraph."[10] Operating in increasingly close concert with the railroads, the growing telegraph network soon transformed large sectors of the American and British economies, working both to smooth and expand the operation of markets and to promote the growth of large and often monopolistic enterprises.[11]

In 1850, there remained one great obstacle to the spread of the electric wires: water. An ordinary river could be spanned by a bridge; a wider one by wires strung from high masts erected on either shore. But the Hudson at New York City was too wide even for that, and attempts to cross it with a wire insulated with tarred cotton and laid on the riverbed proved abortive, as the insulation quickly failed, even when ships' anchors did not snag and snap the line. For years, telegraph messages that had come hundreds of miles at lightning speed had to be taken down in Jersey City and carried to Manhattan by boat.[12] The English Channel presented an

[8] Richard A. Schwarzlose, *The Nation's Newsbrokers. Volume 1: The Formative Years: From Pretelegraph to 1865* (Evanston, IL: Northwestern University Press, 1989), 94–95, 108; Donald Read, *The Power of News: The History of Reuters, 1849–1989* (Oxford: Oxford University Press, 1992).

[9] Richard B. Du Boff, "The Telegraph and the Structure of Markets in the United States, 1845–1890," *Research in Economic History* (1983) *8*: 253–77; William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York: W. W. Norton, 1991), 120–23.

[10] *Republican* (St. Louis), September 18, 1847, quoted in Richard B. Du Boff, "Business Demand and the Development of the Telegraph in the United States, 1844–1860," *Business History Review* (1980) *54*: 459–79, on 471–72.

[11] Richard B. Du Boff, "The Telegraph in Nineteenth-Century America: Technology and Monopoly," *Comparative Studies in Society and History* (1984) *26*: 571–86.

[12] Thompson, *Wiring a Continent*, 45–46. The Mississippi posed a similar obstacle at St. Louis, and when telegraph lines first reached the east side of the river in

even more daunting barrier. The prospect of linking the enormous markets at London and Paris was enticing, not least to those trading shares in the City and on the Bourse, and for years before the technical means to accomplish it were available, ambitious entrepreneurs dreamt of somehow laying a telegraph line across the Channel.

The first practical steps toward spanning the Channel were taken by an unlikely pair of English brothers. John Watkins Brett was a painter and an art dealer who had cultivated a wide acquaintance among the moneyed elite of both Britain and France while also dabbling in some slightly shady financial dealings. He shared a house in London with his younger brother Jacob, who in 1845 enthusiastically took up an American-designed printing telegraph and began to lay grand plans for a system of "ocean telegraphs" to connect England not only with "Continental Kingdoms" but also with America, India, and the entire British Empire.[13] The elder Brett was soon also swept up by the idea of undersea telegraphs and proceeded to put matters on a slightly more practical footing, drawing on his art world connections to secure an exclusive concession from the French government to land a telegraph line on the coast near Calais.[14] (The British government declined to grant such monopoly rights but gave the Bretts permission to land a line near Dover, if they could manage it.) The Bretts' first concession lapsed before they could build anything, but in 1849 Louis Napoleon (later Napoleon III), the newly elected president of France and an enthusiast for all things electrical, granted them a ten-year monopoly on telegraphic communication between England and France, provided they succeeded in transmitting messages across the Channel by September 1, 1850. This would be a challenge, however, as the Bretts as yet had little idea how actually to make or lay a submarine cable.

John Watkins Brett had already sold much of his art collection to raise money for the new project. He now set about rounding up more financial backers and hiring engineers and a contractor. In perhaps their most important step, he and his engineers turned to the Gutta Percha

December 1847, messages had to brought across to St. Louis by boat. Wires strung from high masts were used for a time but often broke. An insulated cable was first laid across the river in 1850, and an improved one, using a surplus length from the first Atlantic cable, was laid in 1859; see J. Thomas Scharf, *History of Saint Louis City and County, From the Earliest Periods to the Present Day*, 2 vols. (Philadelphia: Louis H. Everts and Co., 1883), *2*: 1422–30.

13 Roger Bridgman, "John Watkins Brett," *ODNB*; Steven Roberts, "The Moving Fire: A Biography of Johns Watkins Brett, Father of Submarine Telegraphy," atlantic-cable.com//CablePioneers/Brett. The provisional registration of the "General Oceanic Telegraphic Company," filed by Jacob Brett in 1845, is reproduced in John W. Brett, *On the Origin and Progress of the Oceanic Electric Telegraph* (London: W. S. Johnson, 1858), 44.

14 Correspondence concerning the French concessions, as well as the Bretts' contacts with the British government, is reproduced in Brett, *Origin and Progress*, 15–25.

Company to provide the twenty-five nautical miles of insulated wire they would need to span the Channel. Gutta-percha is a natural plastic derived from the latex of the *Palaquium gutta* trees of Malaya. Although chemically similar to rubber, it is not springy; when heated above 60°C (140°F), it softens and can be easily molded. Malayans had been using gutta-percha for centuries to make hats, whips, and knife-handles, but it did not become an item of European commerce until 1843, when William Montgomerie, an East India Company surgeon, sent samples to London and published an account of its uses.[15] Tons of gutta-percha were soon being shipped out of Singapore, and British firms began offering bottle stoppers, chess pieces, golf balls, and other products made of the new material. In 1848 Michael Faraday drew attention to its excellent electrical-insulating properties and urged "working philosophers, both juvenile and adult," to use gutta-percha in their electrical experiments.[16] British telegraphers soon adopted it as well, finding gutta-percha to be far superior to the tarred or varnished cotton with which they had earlier tried to insulate their underground lines. By 1849 they were stringing wires covered with gutta-percha through damp tunnels and burying them beneath the streets in cities where overhead lines were not allowed. The Bretts looked upon gutta-percha as a godsend. They knew they would not be able to realize their dream of spanning the Channel, and eventually the oceans, by telegraph until they could find a suitable form of insulation, and now it seemed that British industry – and the Malayan forests – had provided just what they needed, and at just the right time.

The 1840s were the heyday of "economic botany," as Europeans sought to gather and study plant specimens from around the world for possible commercial exploitation.[17] The availability of gutta-percha was a product of that effort and of British imperial expansion into Southeast Asia. The cable network that would spread around the globe in the second half of the nineteenth century relied heavily on this exotic latex from Malaya, and British firms' control of the gutta-percha market in Singapore gave them a virtual monopoly over what would become a strategically important material. This became a self-reinforcing loop, as Britain's imperial and commercial power gave it favored access to Malayan gutta-percha supplies, and so facilitated the construction of

[15] Bruce J. Hunt, "Insulation for an Empire: Gutta-Percha and the Development of Electrical Measurement in Victorian Britain," in Frank A. J. L. James, ed., *Semaphores to Short Waves* (London: Royal Society of Arts, 1998), 85–104.

[16] Michael Faraday, "On the Use of Gutta Percha in Electrical Insulation," *Phil. Mag.* (1848) *32*: 165–67.

[17] Lucile Brockway, *Science and Colonial Expansion: The Role of the British Royal Botanic Garden* (New York: Academic Press, 1979); Daniel R. Headrick, "Botany, Chemistry, and Tropical Development," *Journal of World History* (1996) *7*: 1–20.

a cable network that, in turn, strengthened the Empire and British commerce – including British control of the gutta-percha trade. Ecologically, however, the cycle was not so sustainable; gutta-percha was typically harvested by felling rather than just tapping the trees, and by 1900 the *Palaquium gutta* trees had been virtually wiped out over much of their range.[18]

All of that still lay far in the future when the Bretts placed their initial order with the Gutta Percha Company. The company was still working out how best to insulate such great lengths of wire, and the coils it eventually produced were, by later standards, quite crude, with an unevenly applied layer of gutta-percha and misshapen joints where the wire had been spliced.[19] The completed wire was what would later be called a “core” rather than a “true cable,” since it lacked an outer armoring of wire rope; it had little tensile strength and could be easily snapped by an errant anchor. The electrical tests made on it were rudimentary at best; the Bretts’ chief engineer, Charlton Wollaston, reportedly sometimes used his tongue to check for the flow of current.[20]

After a delay while the Bretts lined up last-minute financing, the coils of insulated wire were shipped out of London on the steam tug *Goliath* and finally unspooled from Dover to Cap Gris Nez on August 23, 1850, just ahead of the September 1 deadline (Figure 1.1). After sending a few simple signals to establish that the line was working, the operators hooked up Jacob Brett’s printing telegraph and tried to exchange some congratulatory messages, but found they were garbled in transmission. By the next day, the line had gone dead, either abraded on the rocky shore at Cap Gris Nez or, by some accounts, snagged and cut by a Boulogne fisherman.[21] The few signals that had gotten through were enough, however, to secure a renewal of the Bretts’ ten-year concession, as well as to prompt *The Spectator* to imagine what the “transmarine telegraph” might eventually accomplish:

[18] John Tully, “A Victorian Ecological Disaster: Imperialism, the Telegraph, and Gutta-Percha,” *Journal of World History* (2009) *20*: 559–79; Daniel R. Headrick, “Gutta-Percha: A Case of Resource Depletion and International Rivalry,” *IEEE Technology and Society Magazine* (December 1987) *6*: 12–16. On the gutta-percha trade, see especially Helen Godfrey, *Submarine Telegraphy and the Hunt for Gutta Percha: Challenge and Opportunity in a Global Trade* (Leiden: Brill, 2018).

[19] Willoughby Smith, *The Rise and Extension of Submarine Telegraphy* (London: J. S. Virtue, 1891), 1–3. Smith was with the Gutta Percha Company from its earliest days and witnessed every stage in the development of cable manufacturing methods.

[20] Charles Bright, *Submarine Telegraphs: Their History, Construction, and Working* (London: Lockwood, 1898), 6n.

[21] Bright, *Submarine Telegraphs*, 9n.