# ENGINEERING INVENTION

## Frank J. Sprague and the U.S. Electrical Industry

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## MOTIVE POWERS AND MECHANISMS

When people met Frank Julian Sprague, they tended to notice first the sheer intensity of the man. "A virile and aggressive person," General Electric executive E. Wilbur Rice (a sometime adversary, sometime colleague) called him. "You wanted what you wanted when you wanted it and were going to get it," fellow engineer (and early collaborator) W. H. Sawyer reminisced. "He seems to be full of wire springs that constantly coil and uncoil inside of him," another colleague observed. "His eyes are bright and full of motion. His face is alive with insistency and driving force. It is the face of a fighter who is unable to recognize defeat. His sentences end with a click, like the snapping of a switch. He roams, lightfooted, about the room and appears to be literally magnetized."[1]

Indeed, something fiercely compulsive and powerfully propulsive drove Sprague. He invented and ventured incessantly—in electric motors, railways, elevators, train systems, signals, and dozens of sideline projects. He achieved a string of technological breakthroughs, undertook successive rounds of entrepreneurial building, and assembled a succession of companies that earned him (and cost him) fortunes several times over. Yet he never seemed to feel satisfied or finished for long. Something worked within Frank Sprague to send him obsessively, again and again, to the proving ground of invention and the theater of venturing. Sprague sustained his projects by fits of manic energy and framed them as episodes of high drama—drama that Sprague himself, more often than not, created as he invented.

At various points in his career, Sprague left autobiographical accounts of his youth. As a scientifically trained engineer, he might well have distrusted any effort at biographical analysis along "softer" psychological or cultural lines. But certainly the engineer would have appreciated that to understand what drives an engine, the mechanism has to be taken apart and put back together again. What had wound those "wire springs" that were constantly coiling and uncoiling in Frank Sprague?

The question reaches beyond Sprague himself, for his work was ultimately bound up in a generational phenomenon. Over the last several decades of the nineteenth century, electrical inventions proliferated and electrical innovation churned at a highly accelerated rate, attracting inventors, engineers, entrepreneurs, and other agents and accessories. At the heart of this activity, a major new category of technology acquired what historians have characterized as technological momentum,[2] a development in which Sprague and his peers figured centrally. Large social, economic, and cultural forces shaped the direction and outcome of their work. But at the same time, inventors and entrepreneurs (and would-be inventors and entrepreneurs) were working actively on the ground, individually and in teams, to generate, sustain, and help steer that momentum.

## FAMILY BACKGROUND

Sprague was born in Milford, Connecticut, on July 25, 1857, to Frances Julia King and David Cummings Sprague. Both of his parents came from old Yankee families that had settled in New England in the seventeenth century. Ralph Sprague, a patrilineal ancestor, had been one of the founders of Charleston, Massachusetts, and became one of its most prominent citizens. Subsequent generations lived primarily in Massachusetts, many in Malden, as landowners, farmers, and millers. Some were devout, and many played locally notable civic roles in their communities. (Ralph's son, John, became a captain in the Malden militia and fought in King Philip's War in 1676.) Others were adventurers, like Uncle Joshua, who headed west to seek his fortune in the California gold fields and crossed the plains in a prairie schooner. Two Sprague men—Frank's father and his father's brother, George Washington Sprague, died in railroad accidents.[3] Perhaps Frank's later interest in trolley and railway safety and control came from the fact that he lost both an uncle and his father in train accidents. None of Frank Sprague's forebears seems to have exhibited scientific or inventive inclinations. They were respectable citizens and middle-class property holders in a world that was largely agricultural and preindustrial.

Frank J. Sprague's parents began to make the transition to a different economic and social environment. One of ten children, David Sprague took a job as superintendent of a hat factory in Milford just before Frank was born. Young Frank was named after his mother, Frances. An older brother, Seaver, died in infancy, and a younger brother, Charles, joined the family in 1860.

What had been an entirely normal existence collapsed in early 1866, however, when Frances Sprague died. The impact of his mother's death on Frank, who was eight years old, must have been devastating. Certainly it undid his father, who within a matter of months withdrew from the stricken family and went west to seek his fortune. Young Frank and Charles were passed into the care of relatives who lived in North Adams in the hills of western Massachusetts. Years later, a poignant recollection of Frank Sprague's departure from Milford surfaced. "One day word came that sudden death had taken the mother of one of our little boys," a classmate remembered. "Soon after, the father decided to move his family from Milford and the little boy came for his books. I can see him now, a pathetic figure standing in the doorway, with spelling book, reader and slate under his arm, while we at the teacher's bidding all shouted in unison: 'Goodbye, Frank.'"[4]

## NORTH ADAMS

David Sprague's departure must have seemed like abandonment, and Sprague's subsequent relationship with his father was cool.[5] The move may have been a blessing in disguise, though. The two boys were put in the care of one of David's sisters, Elvira Betsy Ann Sprague, who lived in North Adams, Massachusetts, where she made a living as a part-time schoolteacher. Aunt Ann was thirty-eight, intelligent, and unmarried when Frank and Charley came to live with her (she married Samuel Parker several years after the boys arrived). An early 1850s photograph depicts a severe and unsmiling young woman with a round face, high forehead, and jet black hair parted in the middle and pulled back tightly behind her head. Her dark eyes are penetrating. She was strict, by Sprague's account, and exacting on matters such as politeness, good manners, honesty, and cleanliness. Yet her sternness was tempered with affection, and he became devoted to her. "She was a woman of the finest New England type and striking beauty," he would later attest. "Living in a modest, frugal way as an occasional school teacher, with great sacrifice she devoted herself to her charges with sanity of judgment, but with high regard for much needed oversight. She was indeed a stern disciplinarian, but I think that something vital must have been instilled in me by this devoted woman which race inheritance alone could not account for."[6] Life with Ann appears to have restored domestic stability and some measure of emotional security to the boys. In later years, Sprague described Aunt Ann as an exceptional foster mother and North Adams as his first home.

Other relatives may have helped Ann care for the children. Ann's father (and Frank's paternal grandfather), Joshua Sprague, had settled in North Adams in 1836 and set up shop as a builder and carpenter. Of Joshua's ten children, at least half lived in North Adams. His oldest daughter, Lucy, married Henry Whitney and had seven children, including Martin Whitney, who worked in the Print Works (later the Arnold Print Works).[7] Yet if other Spragues helped out with the boys, they apparently made little emotional impact on Frank: nearly everything he later said or wrote about his life in North Adams focused on the life that he and Charley had with Aunt Ann. The only hint that other family members might have been involved in their upbringing can be found in some personal notes that he wrote just before he died. In later accounts, he indicated that he lived "most of the time" with Aunt Ann,[8] yet the 1870 U.S. Census indicates that both Frank and Charley were living with a first cousin, Martin Whitney and his family, on Prospect Street and no longer with Aunt Ann on Eagle Street. This appears to have been a temporary arrangement, which took place sometime after she became Ann Parker, since later town records show Charley living at Aunt Ann's house during the 1880s long after Frank had left and even after Aunt Ann died in 1884.[9]

During Frank's early years in North Adams, the town was a community in transition. From a small and relatively isolated village outpost in the hilly northwestern corner of Massachusetts, the place was transforming into an industrialized and economically expanding community by the mid-nineteenth century, when Frank and Charley arrived. Abundant sources of waterpower, particularly the Hoosac River, attracted a variety of industrial enterprises. The Windsor Print Works, a cotton mill, introduced textile manufacturing in the region early in the nineteenth century. That venture had collapsed in the Panic of 1857, but others followed. The largest and most successful of these was the Arnold Print Works, a relatively sophisticated textile manufacturing business that John, Harvey, and Oliver Arnold moved from Rhode Island in the 1860s. Listed as "Calico Print Manufacturers" in business directories of the day, the Arnolds' mill operated complex machinery and employed a skilled workforce. Dunn & Bradstreet's agent calculated the firm's profits in 1874 at $100,000, indicating a substantial and successful establishment.[10]

North Adams during Sprague's boyhood was a somewhat isolated inland town, then, but it was by no means an agricultural hamlet. In addition to the textile mills, other small to midsize manufacturing businesses thrived. These included shoe manufacturers, dyeing businesses, and numerous ancillary industrial establishments such as makers of leather belting, "manufacturers' supplies," lime and cement, rope and cordage, and so on. This was a community connected to and embedded in a wider marketplace. The town boasted three hotels and several oyster dealers. North Adams stores sold "Fancy Toilet Articles," gloves and mittens, gas fixtures, locks, "Meridan Plated Ware," millinery goods, hats and caps, "Parisian vases and statuettes," patent medicines, "carriage trimmings," and a multitude of other commodities.[11]

Sprague joined the economic bustle. "While attending . . . High School," he later recalled, "I tried to add to the [household's] meager income, selling lemonade from a can carried by a shoulder strap, or apples from a basket to shoe shop workers, as well as collecting newspaper and doctor's bills and soliciting orders for papers and book bindings."[12] Such jobs would have required him to circulate throughout town. Given his subsequent work in motors and other mechanisms, it is easy to picture him drawn to the machinery of the town's textile mills or perhaps more generally to the larger impressions that they suggested—of energy, of enterprise, of motive power harnessed, of complex mechanisms meshed in coordinated systems. The local episode that Sprague himself singled out as a formative experience, though, was the engineering spectacle of building the Hoosac Tunnel.

## THE HOOSAC TUNNEL

An ambitious underground passage boring nearly five miles through the base of the Green Mountain range to open direct rail linkage from North Adams east to Boston and (via Troy and the Hudson River) south and west to New York City, the Hoosac Tunnel was in its day a massive undertaking and a newsworthy engineering accomplishment. Schemes for constructing a tunnel of this sort dated back as far as 1819 (when it was conceived as a canal project), and digging began in

1851. When the railroad undertaking the project ran out of funds, the Commonwealth of Massachusetts took over, but the state ran out of funding when construction was less than one-third complete. Intervening priorities (not the least of them the Civil War effort) preoccupied the Commonwealth. Then just as the Sprague brothers arrived in North Adams, the project revived, this time under the energetic and resourceful leadership of Walter Shanely, a Canadian engineer.[13]

For the next six years, as Frank Sprague grew from boyhood into adolescence, work on the tunnel steadily progressed. Shanely imported state-of-the-art machine drills to burrow into the mountains' slate and mica core, employed elaborate compressed air systems, and pioneered with nitroglycerine blasting techniques. An average of five hundred workers toiled on the project at any given time. By the time they were done, costs on the project had risen to $17 million, an astronomical figure for the period, and nearly two hundred men had died in workplace fatalities, most of them in violent accidents. A final blast in 1873 completed the initial digging.

According to contemporary accounts, "as the deafening thunder from the explosion" of the final blast "died away, a shout announcing the successful opening between the headings rang from the crowds assembled in the sections. The wildest enthusiasm prevailed; a headlong rush followed, each eager to be the first that should step through the opening."[14] In February 1875, the first train of cars passed through the tunnel. "A royal pathway has been made," declared a journalist observer.[15]

Sprague would have been sixteen years old and in his last year in high school. It is hard not to imagine him deeply engaged in the project's progress. "I was particularly interested in the [tunnel project]," he later recounted, "courting the acquaintance of the engineers in charge and the contractor, Walter Shanely, [who] later proved a most valued friend." Perhaps it was witnessing the completion of the Hoosac Tunnel that drew Sprague to the central problem of making rail transportation work. The episode certainly planted a distinctly bold and heroic impression of engineering in his imagination.

## TO ANNAPOLIS

Sprague, meanwhile, had his own pathway out of North Adams to excavate. After finishing his primary education in the local public schools, he entered Drury Academy, a local private preparatory school where he received his first formal introduction to the sciences. Intelligent and hard-working, he excelled in mathematics and attracted the attention of several local patrons. In 1874, the superintendent of Drury Academy urged Sprague to travel to Springfield, Massachusetts, to take a competitive examination for admission to the U.S. Military Academy at West Point, New York. When Sprague arrived in Springfield, he learned that the examination was not for West Point but for appointment as a cadet to the U.S. Naval Academy at Annapolis, Maryland, from the district of Congressman Thomas Dawes. Undaunted (and in any event in no position to pick and choose his opportunities), Sprague sat for the examination. Competing "against a large field of boys, the majority of whom had had greater educational advantages,"[16] he won. To help finance his enrollment at Annapolis, several North Adams citizens (unfortunately now unidentified) loaned him $400.[17]

The choice of Annapolis may have been reached circumstantially, but it proved fateful and fortuitous for Sprague. It carried him out of North Adams, of course, but more significantly, it equipped Sprague for invention and primed him for innovation.

Historians tend to characterize the U.S. Navy in the decades immediately following the Civil War as an institution that was indifferent and indeed hostile to innovation. Elting E. Morison, for example, has described the 1870s as an interlude of "little science, less technology, little invention and fewer ideas" for the U.S. Navy. Annapolis, by implication, is easily overlooked as an institution of higher learning. But Morison's characterization is not entirely fair. Innovation and technological trials were nourished within the navy during this period, including significant work in torpedoes, electric dynamos, and naval architecture.[18]

The United States Naval Academy participated in and helped to nurture some of this spirit. The curriculum included not only seamanship, navigation, naval strategy, and tactics but also relatively sophisticated science and technology-oriented coursework. Sprague's arrival in 1874 coincided with the appointment of a new superintendent, Rear Admiral C.R.P. Rodgers, who oversaw an overhaul of the curriculum, including adding upper-level electives in mathematics, mechanics, physics, and chemistry. In 1878 (the year of Sprague's matriculation), Annapolis received international recognition as the "best system of education in the United States" when it earned the Diplome de Medaille d'Or.[19]

Courses at the Academy were conducted by the recitation method and supplemented, at upper levels, by problem-solving exercises. After entering a classroom, midshipmen "drew slips" with written problems or questions and "manned the boards," working out answers on blackboards around the room.[20] The program was rigorous. In 1877, "plebe" Harry Phelps wrote home reporting: "I stayed at the library all yesterday afternoon and I find that they have nearly every book that there is. I have been writing up a 'skinny' [slang for physics and chemistry] lecture all this afternoon and I will have to bone calculus as soon as I get through this letter." A few weeks later, Phelps elaborated: "The lessons are easy but we have so much outside work that all our time is taken up. We have to copy up note books, write skinny lectures every week and work a problem in descriptive."[21]

The program may have entailed considerable make-work, but it also focused students on problem solving, creating a potent blend of theory and practice. In one famous example, Albert A. Michelson, an instructor in physics and chemistry who joined the faculty in 1875, set up a classroom project to measure the speed of light by terrestrial measurement using equipment on hand, such as a heliostat and a mirror.[22] (In 1907, Michelson, who moved to the Case School of Applied Science in 1882, became the first American to win a Nobel Prize; his was in physics.)

Sprague entered the Academy on September 29, 1874, in a class of 104 and graduated four years later as a "passed midshipman." He was ranked seventh (in a final enrollment of fifty) and earned honors in math, chemistry, and physics. At Annapolis, he later recounted, "I developed something of a flair for mathematics, and particularly for naval architecture and physics, the latter under the teaching of that great Admiral, William T. Simpson, one of the Navy's most brilliant officers." The formal academic training in both physics and mathematics provided him with a sound theoretical approach to grasping electrical technologies. At the same time, the practical, problem-solving framework prepared him for the concrete, mechanical challenges of invention, including assembly, improvisation, and refinement of designs. Sprague came out of Annapolis equipped with both a fundamental grasp of scientific electrical theory (circa 1878) and a resourceful capability for "craft knowledge" (in the sense of hands-on trial and error) as a means of working toward technical solutions.

Exactly how much formal instruction in electricity the Academy offered is not entirely clear. Virtually no higher-education programs offered programs dedicated specifically to the physics of electricity or electrical engineering. In the classification of the period, electricity was typically covered within chemistry. Still, the subject featured in various problems and lectures, and years later Sprague recalled "taking an electricity course" at the Academy.[23] Indeed, the program at Annapolis seems to have led a number of young men to work in the field. "One of the most striking features of recent electrical development in America," *Electrical World* observed in 1888, "has been the close connection between the United States Navy and the various electrical industries. It was humorously remarked the other day that no electrical establishment now considered itself complete that did not number at least one former navy man on its staff, and that electricity would not have been so far advanced here but for the fact that the United States Navy was not large enough to afford occupation to all the brilliant young officers trained at Annapolis."[24]

## TOWARD ELECTRICITY

Sprague would be one of these "young officers." "I hope and feel that you have a very bright future before you," Sprague's father wrote, formally and somewhat awkwardly after learning that his son would be attending Annapolis. "Who can say but you may carve out a name in the country's history equal to a Perry or Farragut."[25] The prospects for a naval career were not promising in the 1870s, though, as the navy downsized from its Civil War dimensions. Sprague, in any event, was drawn in other directions. In the summer of 1876, he found a consuming focus for his talents and ambition when he traveled to

Philadelphia with several classmates to visit the Centennial Exposition. By his own account, the trip was a pivotal episode that put him on the path of electrical invention as a career and a life's work.

Sponsored by the U.S. Congress to celebrate the nation's one hundredth anniversary and held in Philadelphia from May to November 1876, the Centennial Exposition was one of a series of international exhibitions that staged displays of economic, cultural, and technical accomplishment. Hundreds of thousands of spectators from across the country and around the world attended. The Exposition's central buildings included an iron and glass Main Building (occupying a twenty-acre footprint), a Machinery Hall (fourteen acres), an Agricultural Hall, a massive Art Gallery (also called Memorial Hall), and many smaller buildings.

A multitude of attractions and exhibits filled these structures. Industrial machinery was arrayed in artful displays. ("There is the sense of too many sewing machines," William Dean Howells wearily observed. "A whole half mile of sewing machines seems a good deal; and *is* there so very much difference between them?") Agricultural exhibits piled lush cornucopias of fruits, vegetables, and grains. Costumed tableaus depicted cultures and people from around the world in room-size set pieces. New mechanical inventions and other technologies were exhibited, demonstrated, tested in competitive trials against each other.

Sprague was drawn particularly to Machinery Hall. He likely paused to admire the Hall's most prominent exhibit, where a 1,400 horsepower Corliss steam engine powered many of the Hall's mechanical displays and awed visitors. (Here Howells was more impressed, marveling at the engine's "vast and almost silent grandeur. It rises loftily in the centre of the huge structure, an athlete of steel and iron with not a superfluous ounce of metal on it; the mighty walking-beams plunge their pistons downward, the enormous fly-wheel revolves with a hoarded power that makes all tremble, the hundred life-like details do their office with unerring intelligence.")[26]

Sprague gravitated toward the Exposition's electrical exhibits. There was a lot to take in. The Western Union Telegraph Company set up a large display featuring sounders, registers, relays, keys, insulators, and other apparatus. Duplex and quadruplex telegraph machines demonstrated their capacity to transmit and receive two or four messages simultaneously. The Western Electric Manufacturing Company exhibited a complete set of railway signaling equipment. Various British firms displayed cables and other apparatus that were used in transatlantic submarine telegraph cables. Electric burglar alarms, fire alarms, and household annunciators also vied for attention. On one especially momentous occasion (which, nevertheless, drew less publicity than the Corliss engine), Professor Alexander Graham Bell of Boston demonstrated three of his new telephone devices, inspiring an "astonished and delighted" panel of judges to proclaim the invention "perhaps the greatest marvel hitherto achieved by the electric telegraph."[27]

Sprague was probably unable to attend Bell's demonstration. (He recorded no recollections, at least.) On the other hand, he certainly studied another, equally significant display in Philadelphia—the electric dynamos exhibited by both the Gramme Electric Company and Farmer-Wallace that supplied the power for arc lighting that illuminated part of Machinery Hall. The Farmer-Wallace dynamo, designed by Moses Farmer and manufactured by Wallace & Sons, represented state-of-the art technology in that the machines were self-excited, meaning that they used permanent magnets to produce a magnetic field. Even more impressively, Farmer's design enabled the dynamo to feed part of the current that it generated in the coils of its rotating armatures back into the coils of the electromagnets, increasing the magnetic strength. It was much more powerful than other designs—a quality demonstrated conclusively in an "official examination of Magneto-Electric Machines" in June, which pitted several dynamo designs against each other, measuring how much power they generated for the Exposition's arc lighting. Whether or not Sprague managed to be on hand for the "official examination," the dynamo exhibits evidently made a big impression: Within a few years after graduating from Annapolis, he found his way into Farmer's laboratory in the navy's Newport Torpedo Station (where Farmer was stationed as the electrician).

More generally, the Centennial Exposition created a sense of technology that Sprague imbibed deeply and definitively. In Philadelphia, the cadet joined the crowd marching along a grand, panoramic view of progress. Inventions, mounted on pedestals and put to work, glittered and dazzled. "Technology" within this framework took on a seemingly abstract, disembodied form. Apparatuses were set off and exhibited as artifacts—spot-lit, disassociated from immediate context, and yet at the same time showcased in tableaus signifying the inexorable progress of civilization. The effect was to create a staged enactment of self-evidently new and seemingly inevitable technology. On Sprague as on so many around him, the impact was potently theatrical and deeply compelling.

At Philadelphia in 1876, electricity was still a largely latent idea. It lurked on the threshold of popular awareness, occupying a position within Machinery Hall that was a few stages removed from center stage. The Centennial Exposition, as historian David Nye has observed, was "the last great exposition based upon steam power."

Within a few years, at future fairs, electricity assumed pride of place in main-stage attractions, positioned "quite conspicuously at the apex of an evolutionary framework."[28]

Three ensuing fairs over the next half dozen years marked the transition—and figured centrally in Sprague's career. The Corliss engine may have garnered more press than the electricity exhibits, but Sprague saw clearly what the next big thing was going to be and fixed his sights on participating in it. Within a few years, he would be serving on a panel judging electrical exhibitions. Within a few years after that, he would be staging exhibitions of his own.

He returned to Annapolis full of zeal, meanwhile, "putting in a good deal of time on possibly impossible inventions" whenever he found the opportunity, stealing out of his quarters "during study hours," he later recalled, to "seclud[e] myself in a blacksmith's shop, where I was busily engaged cutting into telephone discs, some ferrotype plates which I had wheedled out of the official photographer."[29]

## GATHERING CURRENTS: SPRAGUE IN CONTEXT

The specific circumstances of Sprague's background, youth, and education doubtless shaped his subsequent career in idiosyncratic and significant ways . The experience, for example, of losing one parent at an early age (or both, if one counts the withdrawal of Sprague's father from his two sons' lives) must have had a major effect on him. Being installed in a second household that was economically strained and perhaps occasionally emotionally unreliable could help to explain the man's drive—the intensity of Sprague's ambition and perhaps as well the streaks of insecurity and iconoclastic stubbornness that characterized much of his career. As an inventor and as an entrepreneur, Sprague often seemed to seek out confrontation, manufacture it, and use it to pursue a personal form of vindication.

The larger social context is also instructive, though. When Sprague's circumstances are lined up against those of contemporary parallel figures, significant patterns appear. By the time he arrived at adulthood and the brink of bigger things, Sprague was preparing to plunge into a crowding field of technological ferment. "Ours is the age of electricity," observed the editors of *Electrical World* in 1883: "everywhere electricity is fast becoming the all-inspiring, all-controlling influence. It may be said to be 'fashionable' in the extreme just now as the most popular agent at the disposal of man. It fills everybody with interest and curiosity." Indeed, new technologies in telegraphy, in arc lighting, in incandescent lighting, in electric motors and railways, in telephony and phonographs and motion pictures, in power generation and transmission—in a host of experiments and applications—were appearing everywhere. They were transforming the material landscape and attracting inventors and entrepreneurs—would-be "Wizards"—by the dozens, hundreds, perhaps thousands. Between 1870 and 1895, the U.S. Patent Office issued over 17,500 electrical patents.[30]

Sprague, in short, was preparing to join a significant generational phenomenon. In addition to being an "age of electricity," the editors of *Electrical World* continued, "ours is also an 'age of inventors.'"[31] Sprague was to be part of a movement—scrambling for position among what *Electrical World* characterized (in 1883) as "a whole tide of immigration." This influx of talent, ambition, and energy itself generated a potent, if not exactly quantifiable, measure of technological impetus. Sprague and his peers were intent on invention. They were primed for innovation, and they helped to catalyze a culture that enabled, recognized, and drove technological transformation. They pooled their efforts, learned and stole from each other, argued with each other, and competed against each other—and in the process sustained the momentum that was building behind technological churn.

The core population driving this phenomenon was diverse and difficult to characterize or categorize collectively. Nevertheless, some broad generalizations suggest themselves. To begin with, Sprague and many of his peers came out of distinctly industrial environments. Sprague grew up in mill towns among the textile manufacturing establishments that were emblems of the first industrial revolution. As a curious boy, he may well have had gained access to the machinery that powered North Adams's textile mills. In any event, they dominated his immediate landscape. A striking number of other electrical inventors came out of similar landscapes. Hiram Maxim (b. 1840) apprenticed as a coachbuilder and then worked in his uncle's machine works at Fitchburg, Massachusetts. Charles Brush (b. 1849), who played a pioneering role in arc lighting, was the son of a woolens manufacturer in Euclid, Ohio.[32] Charles J. Van Depoele (b. 1846) was working as a furniture manufacturer in Detroit when he began experimenting with electrical apparatus.[33] George Westinghouse (b. 1846) worked for his father's agricultural implements manufacturing business, haunting the machine shop and conducting mechanical experiments.[34] Elmer Sperry (b. 1860), Alexander Meston (b. 1866), and Charles Meston (b. 1868) (the Mestons founded Emerson Electric Company) worked as young men for the railroad car manufacturer Michigan Car Company in Detroit.[35]

The electrical innovations that these people introduced came out of a distinct milieu. This generation's technology, as Thomas Hughes observed of Sperry's work, was "expressed through the conception and construction of things."[36] Many of their innovations, in fact, were designed and prototyped in the machine shops and workshops that adjoined factories, and these factories thus became both platforms of technology-making and engines of economic expansion—emblems of mechanical and technical possibility.

Although Sprague was an American, a significant number of his peers worked in or immigrated from European countries. Leo Daft (an early inventor of electric streetcar systems who immigrated from England as a young boy), Charles Van Depoele (Belgium), Nikola Tesla (Croatia), Elihu Thomson (England), and the Meston brothers (Scotland) all settled in the United States, either as boys or young men. Other inventors remained in Europe and did important work there—perhaps most notably, Werner Siemens in Germany. And Sprague, like many of his contemporaries, crossed the Atlantic repeatedly to pursue projects and sustain the process of innovation. The electrical revolution was a distinctly transatlantic phenomenon that benefited from cross-pollination.

These inventors came from a wide range of educational backgrounds. Sprague's college education at the U.S. Naval Academy allowed him to enter the field with more formal training and a stronger theoretical grasp of electricity than many. Others arrived similarly advantaged. Tesla worked his way through electrical engineering courses at the Austrian Polytechnic in Graz and at the University of Prague. William Stanley attended Williston Academy in Massachusetts, followed (briefly) by a period at Yale University. Elihu Thomson, after studies at Central High School in Philadelphia, attained the position of "professor of chemistry" (in what resembled a high school setting more than a university) and began inventing in collaboration with another faculty member, E. J. Houston.[37] Charles Brush earned a chemistry degree from the University of Michigan and set himself up as a chemical consultant in Cleveland before embarking on innovation in dynamos and arc lighting.

On the other hand, the science was still raw and the field still unorganized, which allowed amateurs with far less formal education to make their marks in the field. Edison worked his way toward "wizardry" largely by dint of assiduous self-education, reading classic works by people like Michael Faraday and tinkering incessantly with apparatus. Sperry was educated at the Courtland Normal School and afterward continued to read and attend lectures.[38]

The field of invention that Sprague encountered as he came out of Annapolis, in other words, was beginning, but only beginning, to become professional and permanent. Electricity was moving from the phase of novelty and stage show into a force that could be harnessed within larger systems that could generate powerful applications. Sprague and his peers made this cluster of inventions into a distinct program of academic study, a tightly organized profession, a cluster of invention and business ventures, a sector of investment, and ultimately an industry—in short, an economic and social system that was capable not just of generating innovation but of sustaining it.

## TOURS OF DUTY

By the time Sprague emerged from Annapolis (he later recalled), "the creative urge had the full possession, and in the following two years . . . I was guilty of nearly three score inventions."[39] Few of these designs got beyond the drawing board. Most remained unbuilt and undeveloped. Sprague at this stage was creating abstractions, not artifacts; technical ideas, not technologies. As he himself later acknowledged, "many of these inventions were really worth while, but neither naval duties nor available money made possible their development then."

He was already inventing but only beginning to confront the more complicated, multifaceted dimensions of constructing or engineering technology. Over the next few years, bursting with ideas, Sprague searched for ways to launch a career and develop his designs into artifacts. The range and pace of his efforts at invention in the years immediately following Annapolis indicated a strong theoretical grasp of the basic science and a busy technical imagination. But finding ways to build out his designs, prototype them, test them, translate them into commercial prospects, refine them technically, promote them, make them viable and persuasive as technological alternatives, and cultivate acceptance for them: all of that was less familiar. Sprague spent the next few years not just inventing but looking for points of entry, useful contacts, and ways and resources for carrying his ideas past the stage of abstract invention. He would cobble together a critical period of improvised apprenticeship. And in the process, he began to piece together ways to engineer not just electricity but also innovation.

The hurdles before him were formidable, but the timing was fortuitous. Sprague was coming on the scene at a distinct point of technical inflection in a cultural context that was primed for the introduction of new technologies, particularly electrical ones. A series of incidents shaped Sprague's early technological projects. These tightly clustered developments helped to generate a vital measure of momentum behind Sprague's work and, indeed, the development of electrical technologies and systems generally.

Notable among these developments was the ascendance of the electrical inventor as a figure of fame and influence. The emergence of Alexander Graham Bell's telephone, staged in events such as the Centennial Exposition, was already whetting the popular appetite for electrical marvels. Thomas Edison's invention of the phonograph several years later ratcheted enthusiasm to yet a higher pitch—captivating the popular imagination, catapulting its inventor to celebrity status, and throwing open the process of invention as a public spectacle. Edison did not merely tolerate journalistic coverage of his inventions; he courted it. As a telegrapher, he had worked closely with newspapers. He appreciated their powers of promotion and was comfortable in journalists' company. Affable, accessible, and quotable, he made good copy. And he readily invited journalists into the process of invention—showing them around his laboratory, demonstrating apparatuses, and describing how they worked. In the middle of projects and indeed as he first set to work on them, he did not hesitate to predict confidently (and sometimes prematurely) that he would solve the technical problems they presented in, say, six months (as he did, for example, when he took up the challenge of adapting his phonograph design to developing a hearing aid technology—a prediction that proved rash).[40] And as he closed in on breakthroughs, he rushed announcements to press, even before he had fully worked out or refined his designs. ("I have it now!" he declared to a reporter of the *New York Sun* in September 1879 of the incandescent light, though significant technical problems remained unsolved at that point.)[41] In short, Edison made a very public performance of invention, cultivating an atmosphere of excitement that fed (and was fed by) an avid press and readership. By the late 1870s, dozens of magazines and newspapers were covering Edison and Menlo Park, New Jersey.

Recent scholarship in the history of technology has picked away at the conceit of heroic invention. Technology, historians point out, is rarely if ever fashioned by a single will or vision. It takes shape organically in relation to its larger technical, social, cultural, and political contexts. "Invention," in these broader dimensions, almost always entails a period of refinement and a process of development in which numerous players, including other inventors and engineers, economic agents, public policy makers, and consumers all participate. The final product ends up being a many-layered construct—all of which is true, and all of which would have direct bearing on the work of Bell, Edison, Sprague, and their colleagues.

Nevertheless, the concept of the heroic inventor played a critical, galvanizing role in driving the technology of Sprague's generation—and worked a powerful influence on Sprague personally. The myth gripped the popular imagination, encouraging anticipation of new technologies, and it gave vital impetus—psychological and social—to those aspiring to take up the role of heroic inventor. It drove people like Sprague to experiment, to design, to venture. The concept may have been a conceit, but it generated real (if not quantifiable) motive power. "Menlo Park is the electrical Mecca," *Newark Daily Advertiser* observed. "Thitherward will the pilgrims of science turn their expectant eye, . . . [to] Mr. Thomas A. Edison, the high priest of the temple."[42]

The year 1878 marked Edison's ascendancy as a mythical figure in the popular imagination. That year, the *New York Daily Graphic* bestowed on him the title of "Wizard of Menlo Park." And 1878 was also the year that Sprague emerged from Annapolis and embarked on his own career of invention. On the way from Maryland to North Adams, Massachusetts, for leave before his final cruise, Sprague made the pilgrimage to Menlo Park to call on Edison. Edison received the midshipman courteously and took him on a tour of the laboratory.

Edison was reaching the threshold of momentous technological transformations. The year 1878 also marked his visit to William Wallace at Ansonia, Connecticut, to inspect Wallace's and Moses Farmer's work on electrical generator designs. Wallace and Farmer had designed what they called a "telemchon," a generator that was capable of lighting eight arc lamps. As crude as the design was, Edison perceived at once the significance of a distribution system that supplied electric power from a central generator to multiple apparatuses. When he returned to Menlo Park, he threw himself into work on an incandescent light—the beginning of a larger project that ultimately encompassed a central power station, a grid, and the first major electrical system architecture.[43]

## AT SEA

At this critical juncture, when Sprague was on the threshold of joining the excitement, he found himself taken off the scene and transported to the other side of the world. After completing class work at the Naval Academy, midshipmen undertook a two-year cruise before returning to Annapolis for examination and a final rating. Sprague was assigned to the Asiatic squadron and the USS *Richmond*. "A year ago yesterday I left Boston," he wrote to a friend from Manila, Philippines, in December 1879. "Who would have thought that I would be in this port, four or five hundred miles and more in the Tropics, spending my Christmas 'neath a burning sun. But so it is."[44]

For Sprague, the posting was a mixed blessing—more accurately, a frustrating displacement. He traveled to exotic ports (including Gibraltar, Naples, Singapore, Hong Kong, Manila, and Nagasaki) and earned extra money filing dispatches from Asia for the *Boston Herald*. But the voyage removed him from the United States (as well as Europe, which would have been preferable to Asia) at a time of gathering technological momentum and historic episodes of invention. He was separated by thousands of miles, for example, from Edison's very public breakthrough in incandescent lighting. Sprague felt the distance keenly. He chafed at the interruption in his efforts to participate directly in the technological ferment and searched futilely for ways to escape his assignment. "I have introduced a new application of a lately discovered principle, the same as used in Edison's carbon telephone, and I hope to meet with success," he wrote to a young woman named Frances Scott in summer 1879 (six months into the cruise). "Since there is not a satisfactory governor in the service, and as, furthermore, it is of great importance that there should be, I rely on being able to be ordered home on that plea, if on no other." His desire to return to the United States was urgent by this point: "I must," he wrote, "and if living, I will be in the United States next summer, if it is possible to get there."[45]

Sprague's correspondence with Frances Scott had by this point developed a warm and perhaps a romantic rapport, creating an unusually intimate view into the young man's plans and aspirations. Sprague ached to achieve and to be recognized. "Why do I tell you this?" his letter continued. "It seems natural to confide my ambitions to you, perhaps because I feel some ways, that you have at least a silent sympathy in my work, if not a confidence in its successful accomplishment. That confidence, none can have as I possess it, and I cannot blame them. Let me have but breath, and I *will* prove to all, that I have not spoken quite in vain." The urgency of his ambition is plain, and beneath it, there is an undercurrent of insecurity. Sprague for much of his career was repeatedly driven by the feeling that he had to "prove" himself and the value of his ideas "to all."[46]

Meanwhile, with what materials he could scrounge together and with the focus of a resourceful and disciplined technical imagination, Sprague invented—or imagined—electrical inventions. He sketched them and drew them on paper. While at sea circuiting the Pacific, he filled 169 pages of a notebook with plans, diagrams, and schematics. These were the "nearly three score of inventions" that he later referred to, and they chronicle a feverish mind at work.

The range of apparatus is striking. Sprague drew out blueprints of lighting applications ("Electric Light, Yokohama plan," "Electric Light, self-regulating and independent of current variation," "Self regulating Electric Light, Similar to that of July 17, in main principle"), telegraph equipment ("Duplex telegraph," "Single current recorder, Quadruplex system," "Arrangement of Printing Telegraph Using Magpict System and Varying Current of Multiplex System, with Inductible Coil," "Shunting Resistance Coils, Quadruplex Telegraph," "Vibratory Telephonic Octuplex," "Facsimilist, or Writing Telegraph," "Proposed Decaplex," "Data for Quadruplex System"), motor and generator components and systems ("Electric Motor," "Diagrams for Steam Turbine," "Electric Governor," "Reversible & Adjustable Commutator," "Sections of Armature Ring with Armature," "Diagram of Action of Electric Motor," "Constant Force Electric Governor"), and a multitude of other miscellaneous inventions. A few had naval or shipboard applications ("Marine Governor," "Reversible Pump," "Water Cooler and Filterer"). Many others looked far beyond the USS *Richmond* and the Asiatic squadron.

Some of these inventions were loosely sketched. Others were highly detailed and carefully drawn. Sprague dated most of them (the span runs from May 1879 through February 1880) and usually indicated a location ("Richmond," "at sea," or the names of specific ports). A number of them he had witnessed by shipmates, clearly anticipating or at least keeping open the possibility of eventually developing them as proprietary claims.

Taken as a whole, the notebook conveys a vivid impression of inventive fecundity. The work demonstrates that Sprague had by this point acquired a technically sound grasp of electrical engineering and a wide-ranging awareness of recent applications—even though he had a limited store of equipment and material at his disposal with which to model or test these inventions. They were taking mental shape as his mind turned over what he had learned and (presuming he had access to texts, journals, or papers, which seems likely) what he was still picking up. The voyage must have been an exhilarating period for the midshipman—and a supremely frustrating one, too, because most of this work necessarily remained abstract. He had no laboratory or machine shop at his disposal on board and probably only minimal equipment.

Alongside this remarkable bloom of imaginative ideas, the more prosaic nautical pages—descriptions and drawings of sails, yards, masts; notes on navigation; and log data for the cruise—are easily overlooked. This was the kind of stuff that usually appeared in volumes titled "Midshipman's Note Book." Still, this material reveals important aspects of Sprague's outlook. He never considered himself much of a seaman, but one senses that Sprague took at least indirect lessons from his naval experience. The ships (and other sailing vessels) on which he served were themselves complex technological systems that meshed highly articulated social organisms (crews, ranks, roles) with intricate technical apparatuses (sails, rigging, hull) that were capable of navigating natural, oceanographic force vectors (winds, tides, currents). Midshipmen were taught to think concretely, abstractly, and above all systemically. The connection between these aspects of Sprague's apprenticeship and the episodes of system building that were to come is entirely conjectural, but those future episodes of electrical invention would require analogous feats of orchestration.

## SHORE STATIONS

Sprague did not manage to extract himself from the Asiatic squadron until March 1880, when he was ordered to return to Annapolis for examination. Over the next several years of his naval career, he took various shore assignments, angling constantly for ways to continue working on his electrical inventions. He managed to get a short leave, for example, to "experiment . . . with a new type of arc light mechanism" at the Stevens Institute of Technology in Hoboken, New Jersey.[47] Here he made initial contact with several important people in the field, including Dr. Henry Draper, William Wallace, and Professor Moses Farmer.

The Farmer connection proved particularly important a few months later when the vessel to which Sprague was assigned, the USS *Minnesota,* was restationed to Newport, Rhode Island, which provided Sprague with access to the Newport Torpedo Station, where Sprague found opportunities to continue his research. Established by the U.S. Navy in 1869, the Newport Torpedo Station had grown into a naval research and development center for the study of technologies with potential naval applications. A staff of twenty-five manned the station, including a chemist, a "pyrotechnist," and Moses Farmer, the facility's electrician.

In Farmer, Sprague encountered a mentor, a highly accomplished inventor, and something of a kindred spirit. A civil engineer and teacher originally, Farmer had been delving in electrical investigations since the 1840s, developing in the process a series of telegraph inventions, an electric fire alarm system, a method for electroplating, an incandescent light (employing a galvanic battery for power), and a miniature electric train that he built in the yard of his house. Most significantly, Farmer in 1866 had designed a "self-exciting dynamo" (which fed some of the current from the generator back into a coil around the magnet). Years later, Sprague recognized the important contributions that this "distinguished scientist" made to the field.[48]

Working partly under Farmer's guidance (though largely on his own), Sprague during this period developed the design that would result in his first patent, for a "Dynamo-Electric Machine" (filed October 4, 1881, and issued August 26, 1884). Aiming (as Sprague himself put it in the patent application) "generally at compactness, efficiency, economy, and steadfastness of the current generated,"[49] Sprague's design put the field magnet inside the armature (rather than in an external magnetic field assembly), enclosing the coils with "an outside shell of iron wire and inwardly projecting ribs."[50]

The novel construction impressed Farmer, who supported the young midshipman when Sprague applied to the navy for permission to attend an international electrical exhibition in Paris in 1881. Despite Farmer's endorsement, permission was denied.

Sprague seized a second opportunity, however. After arranging an assignment on the USS *Lancaster* in the Mediterranean squadron, he reached Europe and promptly took a three-month leave—too late to reach Paris but in time to attend another electrical exhibition in London early the next year. He arrived, he later recounted, "with about $20 and the necessity of presenting urgent needs to the U.S. Despatch Agent." Reaching the Crystal Palace, he secured an appointment on the Exhibition's Jury of Awards as secretary for the panel testing gas engines, dynamos, and electric lights.

### CRYSTAL PALACE: "THE ENGINES OF THE FUTURE"

Sprague eventually submitted a meticulously precise report to the navy on the Crystal Electrical Exhibition. The midshipman credibly surveyed the technologies on display and neatly summarized the state of the art circa 1882 as it had been assembled for display in London. Sprague explained the mechanical, chemical, and physical principles at work in various apparatus designs, tabulated and quantified the results of rigorous, carefully controlled testing, and ranked their performance. He indulged in no romantic rhetoric about wizardry or the sublime here but spoke in the cool, scientific voice of a professional engineer.

Yet the entire report was nevertheless imbued with a strong belief in the transformative power of the technology that it was assessing. As a secretary of a panel of judges, Sprague was sorting out performance—and in the process, he revealed important underlying assumptions about technology and the dynamics of innovation. So, for example, in the section covering the performance of gas engines displayed at the Exhibition, Sprague began with an assessment of existing engine technologies—notably, steam engines. Here, Sprague asserted, was a technology that faced imminent, inevitable obsolescence: "While very perfect as a machine, its economy is very low, and always will be." The basic technology was inherently inefficient, Sprague explained: "the very best engines" managed to convert only between nine and thirteen percent of the coal energy they consumed into mechanical power. In short, "the steam engine has nearly reached its maximum theoretical efficiency."[51]

An unspoken assumption was at work here, and it was common to many of Sprague's peers and indeed to their entire generation—a faith in linear progress and technological determinism. New technologies, when they offered superior performance and technical advantage, would in the natural course of things supplant older ones. Briskly, matter-of-factly, and confidently, Sprague redirected readers' attentions in more promising directions: "We must look, then, to other forms of heat engines in the hope of higher economy," he concluded. The steam engine had proven serviceable in its day. Now, its dusk was approaching as newer, more efficient technologies became available—as if summoned by society's need for them. As Sprague described the situation: "such are the promises of other methods that scientific men already predict that in the coming century at farthest the steam-engine will take its place among the things of the past, and the engines of the future will be probably neither the solar or the hot-air engines, but either a flame engine . . . or the gas engine." (Sprague added, as if to ground the whole discussion back in solid, empirical terms: "Of these forms I will speak of one type only, as it is with this that I have any practical experience.")[52]

In dismissing the steam engine as a technology that was facing imminent and inevitable obsolescence, Sprague was expressing a general consensus that had begun forming in scientific and engineering circles several decades earlier. "The necessities of the age require a new motive power," *Mining Magazine* had declared as early as 1853. "The steam engine has become burdensome to man; it has had its day; the progress of the age requires a more portable and powerful agent." Historians Louis Hunter and Lynwood Bryant sound almost as though they are paraphrasing Sprague (though they are not) when they observe, "By the 1870s . . . there was general awareness among informed engineers of the theoretical and practical limitations of the steam engine and a growing interest in proposals for improving the process of converting heat energy into mechanical power."[53] And as things turned out, the prediction in this case was largely accurate: gas engines have proven more serviceable than steam engines.

The deeply rooted assumptions that framed Sprague's pronouncements indicate that he saw himself as being part of one technological age that was on the cusp of another. He subscribed to a distinctly nineteenth-century notion of progress, and he believed in the power of technology to evolve on a "pure," technical basis of what worked "best." Old technologies, in the scheme of things, would become obsolete. New technologies would take their place, and "scientific men" would judge, sort, and guide the transformation.

Similar language and the same basic convictions colored Sprague's account of the lighting technologies that were exhibited at the Crystal Palace. "I consider that the incandescent lamp is the lamp of the future for all purposes except where very large and powerful lights are desired at one focus," Sprague pronounced, "and that the arc lamp will surely be replaced for general lighting purposes." Following a brief technical explanation of the physical principles at work behind both arc and incandescent lighting, he provided an account of the recent emergence of successful (meaning, as far as Sprague was concerned, technically sound and commercially viable) incandescent lighting designs. Earlier would-be inventors ("Starr, King, Staite, and others") had worked on the problem. Solutions proved elusive, however, until "Edison and Swan began the investigations which have wrought the great change which the last four years has witnessed." Edison's work—specifically, the attempt to employ platinum wire—had "marked the era of a great advance," in Sprague's view. Subsequently, Edison had discarded platinum in favor of carbon filaments—a decision that Swan reached independently and more or less simultaneously. "Since then both inventors have worked for the perfection of the incandescent lamp," Swan concentrating on refining his lamp designs while Edison (Sprague noted approvingly) "sought to make domestic lighting of the most practical character by also working out a most elaborate system."[54]

## WORKING FOR EDISON

Clearly, Sprague was drawn to the idea of developing and building that "most elaborate system," meaning not just the light bulb or the lamp but the central power station and grid that would feed them electricity. He recognized that this larger system architecture would become the core infrastructure of the technology. And when he saw a chance to work on it, he leapt at the opportunity. While in London, Sprague met Edward H. Johnson, one of Edison's business partners and managerial lieutenants who was in England to supervise the exhibition of incandescent lighting entry at the Crystal Palace. Johnson, impressed by Sprague's technical knowledge, recommended him to Edison.

A short, awkward interim followed. Johnson encouraged Sprague to resign his commission in the U.S. Navy, which he did (with a year's leave) in March 1883.[55] But back in the United States, Edison delayed. "I hear nothing from you as to young Sprague," Johnson prodded Edison in April. "An ensign in the U.S. Navy doesn't have enough surplus pocket money to allow him to loaf long. Beside, he is not one who can endure it long. He is very anxious to get to work." Sprague, Johnson added for effect, had already received "good offers from outside parties . . . but will not go into anything except Edison."[56]

"I received your favor of the 11th this morning and at once cabled you 'Send Sprague,'" Edison replied. "I propose using him in connection with the establishment of the 'Small Town Plants.'"[57]

Work in Edison's Construction Department was not Sprague's first choice. He and Johnson had been discussing the possibility of putting Sprague to work on other development projects. Sprague "was telling me a few days ago about some excellent ideas he has in re to electric motors and railways, & was asking me to advise him in the matter," Johnson had informed Edison. But Edison's operation needed skilled electrical engineers to work on power station construction. "I arrived home on the day the Brooklyn Bridge opened," Sprague later reminisced, "and promptly reported to my employer, who seemed to think that a salary of $2,500 was per year unduly munificent."[58] He was sent first to Sunbury, Pennsylvania, to assist with the final stages of installing Edison's pilot overhead three-wire system and then to Brockton, Massachusetts, to oversee construction of the first underground three-wire system.

The assignment stationed Sprague in the field rather than at Menlo Park near Edison and moreover put him under the supervision of Samuel Insull (one of Edison's lieutenants), an arrangement under which Sprague soon began to chafe.[59] Nevertheless, the work proved an invaluable experience. It put Sprague on the ground and immersed him in the challenges of constructing a functional system. Installation entailed a host of technical adjustments and refinements, most of which were minor and some of which Edison weighed in on from New Jersey as the system took physical form. Soon Sprague was figuring out how to wire particularly narrow streets, how to cope with the objections of neighbors (and competing telegraph interests) to putting up new poles, and how to structure usage so that the system would not just work but operate profitably.

All of these extratechnical aspects of the project were vital to the success of the system and ultimately the technology itself, taking the technology from the stage of invention into the wider work of innovation. And they prepared Sprague for future projects of his own. Arguably, he managed successfully to construct a full-scale electric railway system in Richmond, Virginia, in just a few years in no small part due to lessons that he had acquired managing similar work for Edison during this period.

Meanwhile, Sprague also found opportunities to make academic contributions to Edison's operation. Discovering that the Construction Department had been determining the size of a given system's mains and feeders by constructing scale models and testing the equipment in miniature, Sprague proposed a more efficient and elegant solution. Taking a planned layout for Ithaca, New York, as a test case, he devised a formula for making the necessary calculations mathematically. "I proceeded," he explained, "on the theory that there should be a like maximum drop of potential at the low voltage points of all mains, and that feeder resistances should be inversely proportional to the loads they had to carry." When this method proved sound and converted what had been the work of days into a matter of hours, Sprague inherited responsibility for running the calculations to map out future installations.[60]

## MOTORS

Sprague's apprenticeship with Edison thus gave him opportunities to exercise both his academic training and his engineering skills. It also provided him with enough apparatus and free time to pursue independent projects. And the work at Brockton, in particular, surrounded

Sprague with access to a nearby machine shop as well as a supply of electrical materials and components. Restless and ambitious, he surveyed his options and prepared to build.

He chose to develop his electric motor designs. Other electrical applications—telegraphy, lighting, and dynamos—were beginning to look too crowded to permit the kind of dramatic breakthrough and heroic impact of invention that Sprague was seeking. He was looking for bigger, bolder fields of enterprise. His work on power plant systems, meanwhile, implied that broad new categories of electrical application were opening—categories that looked both heroic and feasible from an engineering point of view. Not yet in a position to accomplish substantive work on a large-scale project such as an electric railway, Sprague could at least work on smaller apparatus. If he did pull out his USS *Richmond* notebook, it was his motor designs that he studied most intently.

The motors that Sprague assembled during this period (the last few months of 1883 and the first few months of 1884) drew in part on existing motor designs as well as Sprague's dynamo ideas. Like all motors, they operated on the basic principle of exposing a current sent through a wire (creating one magnetic field) to another magnet, generating mechanical power as the two magnetic fields repelled each other.

Sprague made important breakthroughs, however, as he broke down and reengineered the electrical forces that were at work inside the apparatus. At sea on the USS *Richmond,* he had displayed (and probably further developed) an uncanny ability to map the abstract electrical forces working in electrical designs. As he worked on the motor problem, this ability produced a critical insight: Sprague realized that on a constant circuit, the mechanical effects of the motor action—

variations of speed and power output—could be controlled by (in his words) "inverse variation of the strength of the magnetic field to determine the differential of the line and motor electromotive forces." Using a pair of magnetizing field coils, "one of high resistance across the line for the main field excitation and another of a few turns in opposition to it and in series with the armature," Sprague devised a motor with reverse wiring in proportions that would equip it to operate at the same speed regardless of the size of the load that it was carrying.[61]

This design represented an entirely new approach to motor design, with significant implications for application. Because they were "self-regulated," Sprague's motors could be bent to such speed-sensitive tasks as industrial uses and transportation. And they revealed what was becoming a distinctive approach to the challenge of invention. In his subsequent patent application, Sprague explained that he had developed the idea by first devising and following what he called "Sprague's laws" aligning E (initial electromagnetic force), e (counter electromagnetic force), m (magnetic movement of the motor's main shunt coil), and u (magnetic movement of the differential series coil).[62] Characteristically, Sprague had developed the theory from mathematical principles, made dynamo and motor prototypes, measured their performance, and adjusted his "laws" accordingly.

## THE BREAK AND THE BRINK

By April 1884, Sprague was feeling that he was poised on the threshold of substantial technological accomplishment. He may well have been looking for some way to withdraw gracefully from Edison's employ. Matters soon came to a head when Edison (perhaps gathering wind of Sprague's motor work) asked him (in Sprague's words) to "take up certain problems relative to the transmission of power." The request put Sprague in a quandary. He had been pursuing "experimental work" in this area, he revealed to Edison, and "advanced far enough to wish it entirely apart from whatever duties are owing to you." In other words, Sprague wanted this work to be recognized as his own rather than considered the product of Menlo Park or Edison. "You will surely understand me," Sprague continued, "when I say that I desire to identify myself with the successful solution to this problem." Indeed, he admitted, he was "actuated by the same spirit with which you attacked the electric light, with the result of making yourself world-famous."[63]

There it was, stated as baldly as Sprague ever admitted: he wanted, he hungered for, the acclaim of heroic invention. He yearned to become "world-famous."

Sprague had nurtured that ambition for some time, at least since emerging from Annapolis and likely well before. It had led him through a brief, busy, improvised period of apprenticeship. And now it had carried him to the brink—of inventing in his own name, of independent venturing, of innovation in the wider world.