Edison wasn't the first to be working on incandescent lighting; work began as early as 1802. However, by Edison's period, the time was ripe, and Edison seized the opportunity. What made the crucial difference in his success—as he boasted—was the fact that he had an organized group, an organized laboratory, better resources, and a powerful methodology. His practical orientation also made a real difference. He analyzed the gas lighting industry, studied its strengths and weaknesses, its method of distribution, its customers, economics—everything. Only after this study did he begin bending electricity to the solution of the problem. From then on, the road to success was certain—at least in Edison's vision.

(EPRI Journal, March 1979)

SEIZING THE MOMENT

Age of the Inventor-Entrepreneur

Edison, age 30

The breakthrough came late in 1879 in Edison's laboratory in Menlo Park, New Jersey. Sometime between the evening of October 21st and the evening of October 22d, Edison and a small group of his associates maintained a watch over a thread that burned undiminished hour after hour in a glass bulb from which most of the air had been removed. Although the records are conflicting, that long watch came to be known as the 40-hour vigil, during which the researchers of Menlo Park realized that after more than a year of agonizing efforts, of seemingly endless trials, and of a near-blind process of elimination they had crossed over the threshold to success in their cooperative quest.

The dim reddish light of the incandescent filament, as Edison had named it, seemed to them one of the most beautiful sights in the world. As it became clear that the fragile carbonized thread could survive, Edison concluded the experiment by turning the voltage higher and higher so that the light grew brighter and brighter until suddenly it burned out. As Matthew Josephson depicts the scene in his classic biography of Edison, the men broke into cheers, and Edison announced, "If it can burn that number of hours, I know I can make it burn a hundred."

It was a mere nothing, a fragile glass bulb, a carbonized piece of ordinary sewing thread, two pieces of platinum, and a sealed vacuum—not a perfect vacuum, but the very best achievable at that time. Yet this bare nothingness became the most breathtaking and elegant solution to one of the most perplexing problems of that period—namely, how to make a solid material luminous without burning it up. The incandescent light was the key to a system of domestic electric lighting that was to displace gas illumination.

Microscopic examination of the carbon filament revealed that the carbon had changed in character while it burned. It had become harder, more durable, more resistive, and more stable in its behavior, thus obviating the need for various regulatory devices that Edison had thought might be necessary. The solution, for the incandescent light at least, looked simpler and cleaner than they could have hoped for. Through earlier trials in the late summer and early fall of 1879, Edison and his men had come to realize that carbon could serve as the high-resistance element they had been seeking and that the key to success could lie in the development of an extremely high vacuum. In an authoritative article on the invention, Francis Upton, Edison's mathematician, attributed the success to advances in vacuum technology. Had vacuum technology been sufficiently advanced, preceding decades of experiments with enclosed incandescent lights and evacuated bulbs by other inventors might conceivably have succeeded.

However, there were many other factors that contributed to Edison's success at that moment. One, absent from many other inventors and researchers, was the irrational persistence, the lust for success that was Edison's special demon and made him appear a near-wizard in many people's eyes.

As Josephson observes, "Edison himself never wavered in his assertion that he was not a wizard or a genius—in fact, he despised the designation. When an acquaintance once referred to his 'Godlike genius,' Edison snorted, 'Godlike nothing! Sticking to it is the genius! Any other bright-minded fellow can accomplish just as much . . . if he will stick like hell and remember nothing that's any good works by itself just to please you. You got to make the damn thing work'."

That persistence and overweening ambition had seen Edison and his crew—Batchelor, Kruesi, Upton, Jehl, Boehm, and others—through countless obstacles and had drawn their combined inventiveness and skills to extraordinary lengths. From the time Edison seriously started his pursuit of the incandescent light in September 1878, his "invention factory" had made thousands of trials in the Menlo Park laboratory, using uncounted numbers of materials for filaments and leads, and had designed and invented numerous elements—generators, regulators, wiring methods, insulation materials—that would be needed in a practical system of domestic lighting.

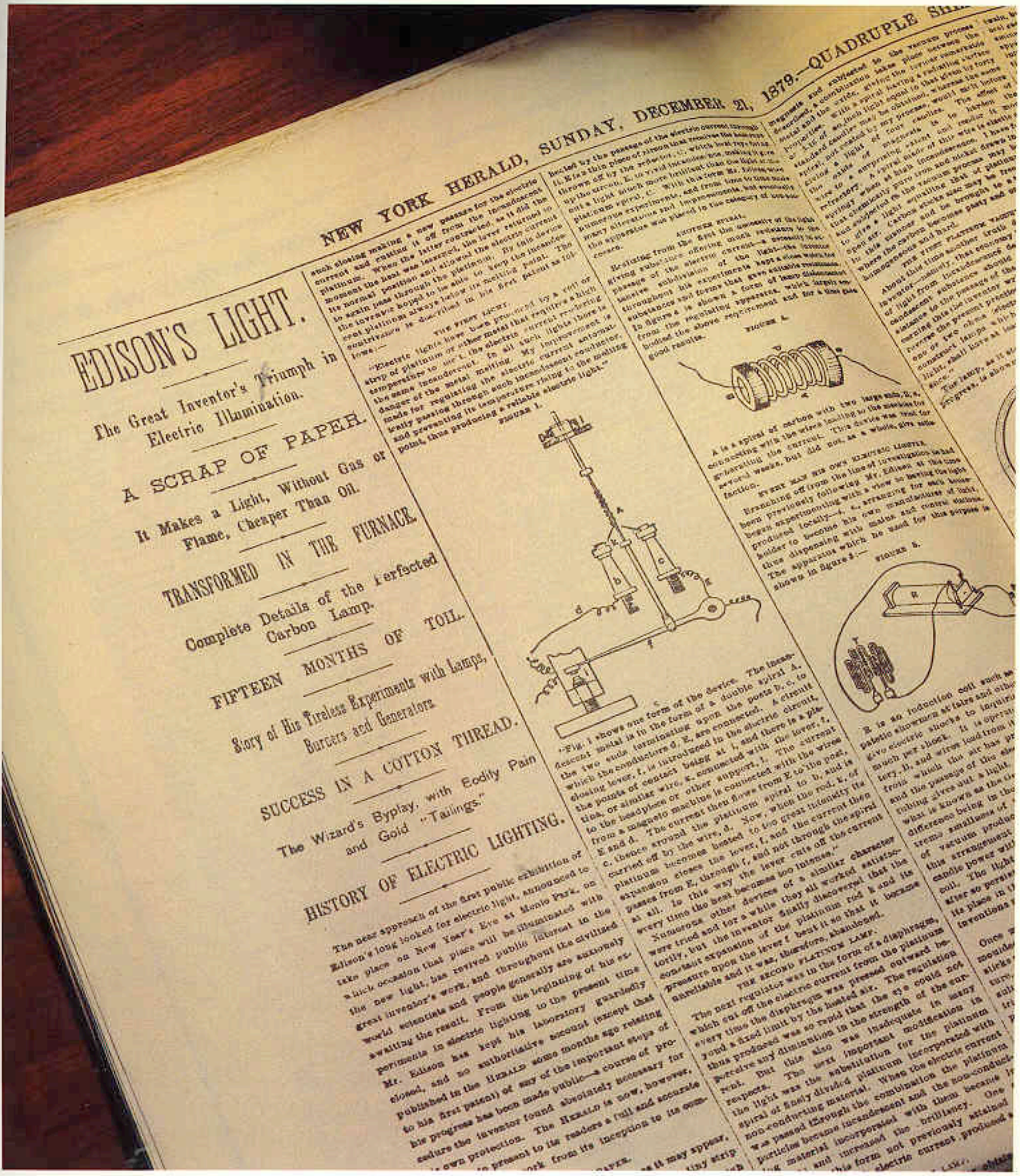
Edison had started with carbon for the burners, a material he had come to understand and appreciate in his work with telephones, but he had moved on to other materials. Then, after long efforts with platinum and as different experimental results began to fall together, he returned to carbon in July 1879 after reading about new experiments by Joseph Swan in England. Swan, who had abandoned incandescent experiments a decade earlier, had returned to the effort under the impetus of new and better vacuum equipment. It allowed him to keep a piece of carbon lit for several minutes in a vacuum. However, the crucial design decision that allowed Edison to outdistance Swan and others and that was a factor in later lawsuits on both sides of the Atlantic was Edison's development of a very fine, high-resistance filament that could be subjected to a constant voltage and that could carry a very small current, the opposite objective of other inventors.

On October 6th, using a new vacuum pump designed by Upton and another colleague, Edison's team discovered that they could create vacuums in which only one millionth of an atmosphere of air remained. About that same time, Charles Batchelor noted that silicon might be a good insulator for the platinum contacts; moreover, silicon was compatible with glass, thus reducing the problems of getting good seals on the vacuums. These and other factors lent a great air of anticipation and renewed intensity to their research efforts.

Yet, toward the end Edison had almost concluded that the incandescent light might indeed be an impossibility (he had set out to prove the case one way or the other), and he had begun to turn his thinking toward central stations to generate electric power for running motors, elevators, traction machines, sewing machines, and the like. At one point, when Edison was nearly overwhelmed by failures, when he was being derided in the press for his ridiculous claims, when his financial backers (including the giant J. P. Morgan) had become extremely skeptical and were trying to make him appear in New York for an accounting, he took to his bed. But supposedly after several days he rose refreshed and went back to the battle and soon was issuing typical announcements through the press that the electric light was an accomplished fact.

But Edison had made his boastful claims too often, and the financiers, the press, and the public remained skeptical. When Edison finally did make the breakthrough, there was still skepticism and derision. Only as visitors began to trickle out to Menlo Park in the latter weeks of 1879 to see the actual lights did doubt begin to be transformed into belief. Then, on December 21, 1879, the New York *Herald* printed its exclusive full-page account of Edison's spectacular success. By New Year's Eve, the news of Edison's invention had created such excitement that several thousand people went to Menlo Park by special trains and every other conveyance possible. The visitors were ecstatic at what they saw—lights strung up on poles around Menlo Park and the laboratory buildings aglow. It was reported that people found it difficult to tear their eyes away from those marvelous new electric lights.

Facsimile of the famous New York *Herald*'s exclusive story announcing Edison's success.



The process of invention and the factory system

A leading American historian of technology, Thomas Hughes, has called the factory system "the most impressive general concept explaining the Industrial Revolution." It is clear, in fact, that the use of inanimate motive power based on steam encouraged a division of labor that was translatable, through machinery, into a division of power.

The mechanization of production had been going on for more than 50 years before Andrew Ure, a British engineer, gave it definitive expression in *The Philosophy of Manufacture*, published in 1835. Ure's system called for the substitution of mechanical science for hand skill, the division of the productive process into basic mechanizable components, and the organization of those components into a steady repeatable process of assembly of desired products. (In his teens Edison had studied his work.)

Conceived in Britain, the factory system and the methods of mechanization took root in the United States, where shortage of labor, costliness of skilled labor, and abundance of raw materials all supported its adaptation and where there was little craft-based opposition to mechanization. By the 1860s the habits of mechanical analysis and synthesis became a prominent stimulus to American inventiveness. Meanwhile, in Germany (the other nation that would surpass Britain technologically by the close of the century) British factory techniques were imported and implemented. They were also incorporated into an educational system that helped develop the German technical institute system.

The factory system method of production, the arrangement of mechanized action to produce a desired output, may well have inspired the invention of organized invention. For instance, the work at Menlo Park used an orderly division of labor, although it wasn't steam-driven machinery that dictated the division. The "motive force" was Edison and Edison's vision that the system of electric light could be developed through a methodical process of trial and error. It was abetted by strong belief that the goal could be achieved through development of a high-resistance incandescent filament.

In order to realize the goal, Edison structured the work in the Menlo Park laboratory. Highly skilled workers performed tasks that compensated for the unavailability of basic theory or knowledge of the relevant structure or properties of materials. Hands and senses sought what theory might today predict, although a working background in physics and chemistry did influence many of the decisions.

The workers carried out a disciplined attack; they used a standard procedure through most of their 4000 or so trials of potential filament materials. For each trial, Edison himself selected the raw materials to be tested and prepared a filament. Another man carbonized the filament; a third supplied hand-crafted copper and platinum elements; and a fourth blew a glass stem and inserted the copper and platinum wires. The chain continued. The carbonized filament was placed on the glass stem by one man; the stem and filament were enclosed in a glass bulb by another man. The next worker placed the bulb on a vacuum pump and evacuated the air. Then Edison heated the filament, removed the gases released by the heated metal, and forwarded the bulb for systematic observation and testing.

This concept of arranging a rational search procedure and persisting in it in trial after trial has been of lasting significance. So has the scale of Edison's research (prohibitive for inventors less credible to investors than Edison). The scale and the repeated procedure are just two suggestive resemblances between the factory method and Edison's method.

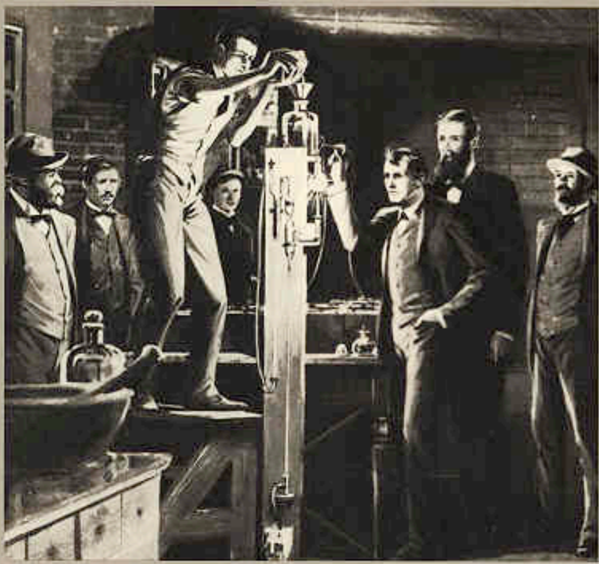
Today, research, development, and production have all evolved into highly specialized functions. They can be carried out in isolated environments under controlled conditions, whether in laboratory or factory. Certain aspects of both the scientific method and factory production rely on precise repetition to ensure reproducible results or standardized products.

In both, the identity of the individual carrying out the task is relatively unimportant; one might even assert that once an inventive process is organized, any competent worker can carry out the specified functions.

On the eve of the breakthrough, Edison and his colleagues prepare the incandescent lamp for testing: (from left) John Kruesi, Martin Force, Francis Jehl, (pouring mercury in the Sprengel vacuum pump), Ludwig Boehm, Edison (driving out occluded gases from the filament with electric current from a battery), Francis Upton, and Charles Batchelor.

he mercury pump for producing high vacuums was the crucial technology that made the incandescent light ossible. Wrote Upton, "Following the laws of discovery, it has been for some time a speculation of the writer that the wonderful perfection to which vacuums d been brought pointed historically toward some direct connection between them and the electric lamp."

Below is Edison's Menlo Park laboratory as re-created at the Henry Ford Museum in Dearborn, Michigan.



Growth of the legend

Around that moment of a century ago, many legends have been woven about the making of the magic light, about the laboratory in Menlo Park in which the problem was solved, and about the person of Edison—legends that Edison himself helped to foster. To enliven his first official biography, for instance, he evidently told his biographers (Dyer, Martin, and Meadowcroft) a lot of stories with little concern for accuracy, and that early biography became the source for many successive writers. So interwoven were fact and fiction that today they are still difficult to sort out. This might seem slightly amazing; after all, it all happened just a century ago. Extensive laboratory records and notebooks were kept by Edison and his colleagues; "authorized" and scholarly biographies, such as that by Josephson, have been written; and thousands of articles have been published. Yet, a new biography of Edison, written by Robert Conot, who spent many months in the enormous Edison archives in West Orange, New Jersey, raises many new questions regarding the established image of Edison, and a newly launched 10-year scholarly program based at Rutgers University promises fresh insights into this seminal figure of universal electrification.

The evidence indicates that Edison, who had grown up in the Midwest when the telling of tall tales was an indigenous American art, was not loath to embellish the details of his own life. For instance, the famed 40-hour vigil may have been a transposition of a death watch that Edison and his colleagues actually conducted in 1879 between Friday, October 17th, and Sunday, October 19th, while they waited for news about Edison's nephew, who lay dying in Paris. Even Edison's famed ability to go without sleep is now disputed as more Edison theory than Edison fact. Said one familiar, "His genius for sleep equaled his genius for invention. He could go to sleep anywhere, anytime, on anything." And according to Conot, a colleague wrote to

Edison was a man of many sides, one being that of the practical jokester. On one occasion, when Edison was about to be interviewed, a colleague relates, "While the reporter was being ushered in, the Old Man disguised himself to resemble the heroic image of 'The Great Inventor, Thomas A. Edison' graven in the imagination of those who have no imagination. Suddenly gone were his natural boyishness of manner, his happy hooliganism. His features froze into immobility, he became statuesque . . . and his unblinking eyes assumed a faraway look like a circus lion thinking of the Nubian desert. He did not stir until the reporter tiptoed right up to him, then he slowly turned his head, as if reluctant to lose the vision of the Nubian desert." The next day the journalist wrote of the formidable "Wizard of Menlo Park." On many other occasions, however, Edison was the irrepressible storyteller.

Edison after reading one of his early accounts, "You can invent history as easy as other things. Now that Mark Twain has retired as humorist you are in line of promotion."

The new studies, however, do not threaten to disturb his image as an American culture hero or diminish his achievements. They will undoubtedly verify his role in the introduction of universal electrification, and they may succeed in illuminating further his role in establishing an organized process of invention, which may be seen as one root of modern R&D. As Edison's colleague Francis Jehl said in observing how closely Edison worked with his collaborators, "Edison is in reality a collective noun and means the work of many men." Such an appraisal is much more consonant with modern R&D experience than with the legend of towering individual genius.

To appreciate the specific nature of Edison's achievements and inventive drive, one must step back into the post–Civil War era to look at the state of the art of the electric light, at the preelectric society, at the entire field of inventive activity, both in the United States and abroad, at Edison's earlier career and approach to invention, and at the gas illuminating industry. Even a brief look reveals why Edison became a legend in his own time. More important, it shows that Edison not only invented a system of electric lighting, but he was also the principal creator of a system of invention that has had as deep an effect on this past century as electrification itself. Alfred North Whitehead, among others, regards the Edison approach to the method of invention as the greatest invention of the nineteenth century.

What emerges is the picture of a man who was defiant of authority, stubborn in his own path, willing to borrow freely, unlettered in the traditional sense, uncredentialed, and caustic about theorists.

Early influences on Edison

It is probably impossible to determine all the forces and influences that turned the young Edison into a professional inventor, but it is likely that the Civil War and its aftermath helped to shape his direction and his character. Edison was in his teens during the war and became an itinerant telegrapher soon after. Although he had been fascinated with chemical and electrical experiments from early childhood, it was during his period as a telegrapher that he took his first steps toward becoming a full-time inventor.

The Civil War precipitated profound changes, not only by its ferocity but also by its enhanced mechanization, and gave industrialization preeminence in America. In the two decades following the war, as if in preparation for electrification, industrialization gathered power and prestige. The freed blacks of the South and the immigrant laborers from Europe poured into the industrial basins of the North—Detroit, Cleveland, Chicago, Pittsburgh, New York. Thus, the old, nearly equal split of power between the planters and the traders was decisively altered. The traders—the capitalists and industrialists—were in charge, and the railroad and the telegraph rather than the horse, the canal, and the Mississippi steamboat were the emblems of change.

Inventions and inventors flourished in this period. The American conviction that each man was as good as the next spurred the mass production of former luxuries and transformed them into common household necessities. By 1865 mechanized apple peelers, knife cleaners, clothes wringers, and egg beaters, for instance, were found in many American homes.

A long line of commercial inventors—Whitney (cotton gin, 1792), Fulton (steamboat, 1806), Hunt (safety pin, 1825), Colt (revolver, 1835), Morse (telegraph, 1844), Howe (sewing machine, 1846), Scholes (typewriter, 1867), and Hills (lawnmower, 1868)—had become American heroes and inspired young men to follow in their tracks. In the 1830s Alexis de Tocqueville had noted how Americans esteemed technologists: "Every new method," he wrote, "that leads by a shorter road to wealth, every machine that spares labor, every discovery that facilitates pleasures or augments them, seems [to Americans] to be the grandest effort of the human intellect." The prestige associated with practical inventions was in itself a powerful incentive to young men like Edison and many of his contemporaries.

In the post–Civil War period itinerant telegraphers like Edison possessed a craft and a skill that allowed them to work and drift wherever they would. They were a fraternity, were all in touch with one another, and could easily find a bed and a new post. They experimented and learned, sharpening their skill and making gradual improvements in the equipment. At an early age many of them acquired an understanding of electrical connectivity for the continent and with Europe via the trans-Atlantic cable (successfully laid in 1866). These young men probably also understood the meaning and significance of such connectivity and communication in the building of the nation. From railroad scheduling and business messages to Reuters and other international dispatches, the telegraphers were privy to the hour-by-hour workings of national enterprises. From telegraphy, Edison moved to improvements and inventions in stock tickers, which took him a step closer to grasping the central operations of finance and capitalist maneuver. It was undoubtedly a part of his training in becoming an entrepreneur with his own inventions.

Edison's conscious appreciation of the power of telegraphy came at the age of 14 when he was selling newspapers on the Grand Trunk Railroad, which ran between Port Huron and Detroit. It was April 1862, and the first accounts of the terrible Battle of Shiloh were coming in by telegraph. Seeing the awful newspaper headlines—60,000 reportedly killed and wounded—and the excitement in Detroit, Edison had the Detroit telegrapher wire ahead to all the stops so the news he was carrying could be chalked up on station notice boards. He ordered a thousand

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The story is most provocative. The young Edison saw the conjunction of several media carrying the same message—newspaper, train, chalkboard, telegraph—and he saw the commercial power of that conjunction. People grasped the message with greater vividness because it came through different media, at different levels, and therefore conveyed a greater sense of reality. For Edison, the lesson was never forgotten. In fact, a large proportion of Edison's inventions were related to communications media.

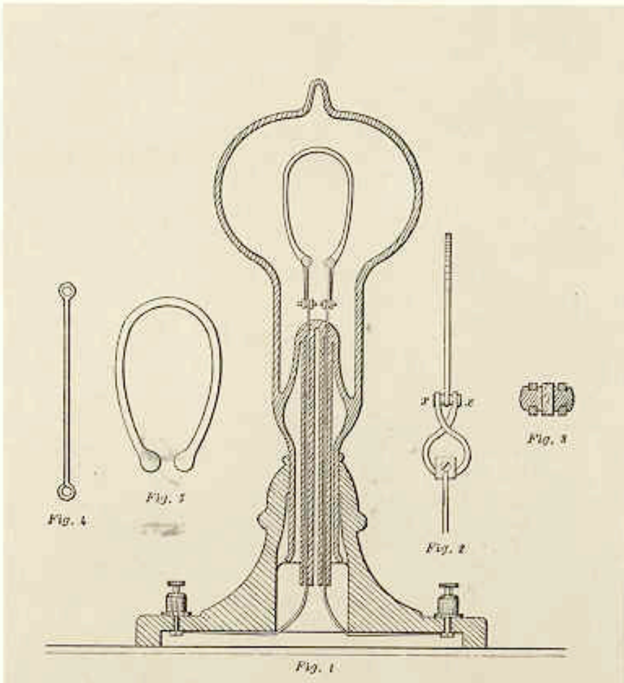
Building on earlier work

When Edison turned his attention to electric light in 1878, there was already a long history of developmental effort, and the field abounded in competitors. As early as 1802, the British chemist Sir Humphry Davy demonstrated the phenomenon of incandescence before the Royal Society in London. Using a stack of voltaic cells, he ran current through a platinum strip, causing it to turn white hot before the material eventually burned away. In fact, Volta's development of the first electric battery only two years earlier (1800) provided the basis for such experimentation. Following on Volta's work, Davy demonstrated the voltage arc light in 1808, which, with but few refinements, became the electric light for the better part of a century. By forcing an electric voltage to leap across a gap between two wire tips, he produced a brilliant arc of light five inches in length. Later experiments showed that carbon was the best material for such tips. It was possible to produce a fairly constant light, if the current was kept flowing and the distance between the tips was properly regulated.

Although they gradually came into practical use, arc lights suffered serious drawbacks. The tips gradually burned away (in anywhere from 2 to 10 hours) and had to be replaced. The lights required complicated regulating devices to maintain the length of the gap; they emitted noxious fumes and gave off such a brilliant, glaring light that they could only be used outside for street illumination or in very large indoor spaces, such as theaters and factories.

Early experiments in incandescent lighting fared less well. In 1845 a 24-year-old American named J. W. Starr obtained an English patent for a carbon incandescent light in vacuo (even though this may have been based on work by De Moleyns, who in 1841 used incandescent charcoal in an evacuated globe). But such early vacuums were not sufficient, and the insides of the glass bulbs became blackened from the interaction of the carbon and remaining oxygen. The first experiments with a bulb shaped like those we recognize today were those of M. J. Roberts in 1852, but his light proved ineffective.

Meanwhile, British inventor Joseph Swan, who was destined to rival Edison, had become interested in incandescent lighting after hearing a lecture by electric lighting pioneer W. E. Staite in 1845. Studying existing patent publications, Swan found Starr's description of his carbon light. He began a series of experiments, combining features of Starr's lamp and one designed by Staite. Swan deduced that thin, high-resistance burners would be better than thick ones—the thinner the strip, the greater the heat, the brighter the light, he reasoned—and he made various horseshoe-shaped burners of platinum, which has a higher resistance than carbon. Although he was in advance



Edison's patent application of December 8, 1879, for the paper carbon filament contains the following description: "Fig. 1 is a vertical section complete; Fig. 2 is a side view on large size of the clamping device; Fig. 3 is a section at the line *xx* in still large size; Fig. 4 is the wire forming one of the clamps before it is bent up to shape; Fig. 5 is the paper blank before it is carbonized."