EDISON'S ELECTRIC LIGHT

Biography of an Invention

by

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PREFACE

This document is the product of a study commissioned by the U.S. National Park Service's Edison National Historic Site. It owes its inspiration, as well as material support, to the staff of the Site, and it is the authors' hope that this study will prove useful to the Site in carrying out its work in interpreting and preserving the historic resources of the Edison laboratory in West Orange, New Jersey.

The effort represented by this study was very much a cooperative enterprise, both among the authors themselves and among a number of institutions. The many months of intensive research in the Edison archives at West Orange was the work of Paul Israel, whose rapid and thorough mastery of the documentation of the invention of the electric light provided to this project from the beginning to the end the most critical elements of sound historical scholarship. The impetus for our efforts was provided initially by Bernard Finn, whose enthusiasm, encouragement, and material support have remained essential to our work, no less so than his written contributions, represented by the essays labeled "inserts."

No project of this kind, extending as it has over a period of time, could have proceeded successfully without the generous assistance of many individuals, only a few of whom can be named and thanked here. Most essential, of course, has been the help and generosity of the National Park Service and the staff of the Edison Site, including Ray Kremer, William Binnewies, Roy Weaver, Reed Abel, Leah Burt, Anne Jordan, and Edward Pershey. The staff of the Edison Papers Project has also been indispensable, and our thanks are extended to friends and colleagues that make up that Project, including Susan Schultz, Tom Jeffrey, Leonard Reich, Toby Appel, and Reese Jenkins, among others.

A number of individuals at other institutions have been generous with their assistance and advice, and if we neglect to name them all, we beg their forebearance. John Bowditch was our helpful and knowledgeable host at the Henry Ford Museum and Greenfield Village, Dearborn, Michigan, where others of the staff of the Museum and the Henry Ford Archives were also ready to lend a hand. Professor P. L. Kirby of the University of Newcastle-upon-Tyne was a most helpful and generous guide to the documents relating Joseph Swan's electric light research, and the staff of the Tyne and Wear County Council Archives Department also deserve thanks for making these documents available. Diane Vogt provided thoughtful help in sharing relevant materials from the Archives of the Corning Glass Works. Finally, thanks are extended to a number of individuals in the Department of History of Science and Technology and the Division of Electricity of the Smithsonian Institution's National Museum of American History for their kind assistance at several phases of this project, with special mention to be made of the help provided by Anastasia Atsiknoudas and Ray Hutt.

Robert Friedel
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INTRODUCTION

In the nineteenth century, when "technology" was an intellectual concept and not a popular catch-word of politicians and economists, "invention" was the widely accepted mainstay of material and industrial progress. For most of the century, the inventor was a figure worthy of both popular esteem and commercial respect, and the fruits of his labors were viewed as the symbols and sources of the new industrial culture's special strengths. In invention was seen that melding of brain and hand which betokened a new, more democratic and egalitarian world, in which material progress was simply the most obvious manifestation of a spiritual advancement that would eventually extend to all the races of the earth. At least, such was the American creed that propelled the unchecked expansion of industrialism.

The workings of invention normally presented no mystery to an informed citizen of the last century. "Ingenuity," and not "genius," was invention's parent, and ingenuity was within the grasp of any man who had his eyes open, his mind alert, and his hands ready. The same talents that were at work in the Yankee's marketplace sharpness or meetingplace glibness could be applied in the workplace and machine shop as well. To the ordinary American, the models that stood row on row in the Patent Office were more representative of his country's intellect than any books in a library or paintings in a gallery. After all, these models were generally made by common men (and a few women), graced by no special privilege or education, but simply a shade cleverer or a moment quicker or just a bit nimbler than their fellows. Americans shared something of the faith espoused by Samuel Smiles, when he ascribed the accomplishments of the great inventors and engineers of the day to clear thinking, hard work, and common virtue.

There appeared from time to time, however, exceptions -- individuals whose inventiveness seemed to transcend the ordinary and place them and their work on a higher plane. Such individuals were put into the pantheon of cultural heroes, their names to be conjured up to evoke the spirit of progress or, at least, the profitableness of creative enterprise. By the time America had reached its hundredth birthday, in 1876, a fair number of inventors could be said to have achieved such heroic stature and their names were familiar to every schoolchild -- Franklin, Whitney, Fulton, and Morse were perhaps the most obvious examples. At this time, however, there was about to emerge another of these exceptional inventors, whose capacity for creating not only the useful and the clever but, occasionally, the miraculous as well, would earn him the title of "wizard." This was, of course, Thomas Alva Edison, and it is in his wizardry, more than any other single thing, that we can see the beginnings of systematic invention that would regularly go beyond the limits of full comprehensibility for the common man. In Edison we find the transition from the common, ingenious, invention that seemed to move much of the world forward in the nineteenth century to the specialized, scientific, technology that was to be a dominating social and economic force in the twentieth.

It is important to remember that a transitional figure is just that -- an individual who is neither consonant with the old order nor fully integrated into the coming one. This is certainly true of Edison. The "Wizard of Menlo Park" was quickly recognized (when he was barely 30, in fact) as someone who did things differently from the inventors to whom he might be compared. The "invention factory" of Menlo Park was obviously unlike anything in the ken of even the best informed American. And the kind and number of things that seemed to emerge with diurnal regularity from that little New Jersey village simply brooked no comparison. There was certainly something at work here more than ingenuity and hard work applied in a useful way. On the other hand, those who would see in the self-taught, unpolished (and occasionally uncouth) former telegrapher, with his white-clapboard two-story laboratory and his "gang' of faithful mechanics and other helpers, a research and development manager in the twentieth-century mold are far from the mark as well. The workshops and men at Menlo Park did not constitute a technical laboratory of the corporate type, nor did their leader bear any resemblence in style or action to the successful technocrat of a later day. Edison, in fact, showed himself later in life to be constitutionally unable to operate in the style of the new century. There were others of his generation, such as Elihu Thomson or Frank Sprague, who proved to be better able to make the adjustment to the corporate and professional environment of the twentieth - century engineer. Edison's ambiguous position between the old and the modern ways of invention and progress was reflected in his own time by the picture, still familiar more than a half-century past his death, of the folksy, middle-American hero surrounded by the aura of technical genius.

That such an individual should hold a fascination not only for his contemporaries but also for scholars and laymen of a later time is no surprise. Both the life and the myth are too rich and too important not to have a sustained influence. What is surprising, however, is the relative neglect of the internal workings of the Edisonian achievement, and, in particular, of the very stuff of his contribution -- his inventions. This is not to say that Edison's inventions have not been much written about, for they have, but rather that what has been written has too often belonged more to the myth-making than to scholarship. But even when one enters the realm of Edison scholarship -- a not inconsiderable territory -- rarely can one find true probing questions asked about the act of invention itself, and the questions that are asked tend to be answered with less than reliable evidence. The reasons for this neglect are complex. One contributing factor is the nature of historical scholarship, for only recently has the tackling of such technical issues become an accepted part of the historical enterprise. Another is in the nature of the evidence, for, while it is certainly available in great quantity, it is of a type that most humanist scholars will instinctively shy away from, and it has long been organized in a manner uninviting to all but the most persistent researcher. But, ultimately, the primary reason lies in our cultural perceptions of invention. In the nineteenth century, invention called for no explanation, since it was not seen as an intellectual endeavor. In the twentieth century, attention is directed toward technology, and not invention, hence efforts are made to explain the institutional, economic, and social basis for technological change, but not the inventive act itself.

This work is, to an extent, an attempt to address this neglect directly, not only to understand better Edison and the nature of his contribution, but also to suggest the extent to which invention -- as an act and a process -- may be scrutinized as a historical problem. It is fitting, therefore, that the subject under study here is the very epitome of invention in the cultural mythology of the twentieth century -- the incandescent electric light. The electric light is, of course, seen as the pinnacle of Edison's inventive achievement. This is so in spite of the fact that other creations may be said to have shown more originality (such as the phonograph), more technical flair (such as the quadraplex telegraph), more persistence (such as the lead-acid storage battery), or a more ingenious combination of elements (such as the kinetoscope motion picture system). When it came time, toward the end of Edison's life, for the world to pause and applaud the Wizard's fantastic career, the occasion chosen was the "Golden Jubilee of Light," October 21st, 1929, the fiftieth anniversary of the date that, Edison claimed, he invented the electric light. The primacy of the electric light in the constellation of Edison's inventions may be ascribed in part to the size and influence of the industry that grew from the light and its widespread use, in part to its omnipresence as a part of life and work in the twentieth century, and in part to the almost spiritual significance that lamps and lighting have in human culture.

There are other reasons for making Edison's electric light the object of a study of invention. The general outlines of the invention of October 1879 are very familiar parts of each American's picture of his country's material progress in the nineteenth century, and yet the story that is such common knowledge is based much more on hear-say and foggy memories than on historical evidence. For the most part, it is in conformity with the traditional nineteenth-century image of invention; it is the story of persistence and sweat overcoming nature's intractability; of how Edison and his faithful followers tried literally thousands of materials in the search for a suitable light bulb filament, guided by little more than the vision that nature had to provide some substance that would serve such a noble need. The electric light is, after all, the achievement most associated with Edison's famous aphorism defining invention as "99% perspiration." Little research is required to reveal how shallow and inaccurate an image this is of what was really going on at Menlo Park in 1878 and 1879.

There is, of course, a "revisionist" version of Edison's invention which, however, suffers from the tendency to put the inventor into the mold of a twentieth-century manager of scientific and technical systems. This version, in its simplest form, would have us believe that, upon taking up the challenge of the electric light, Edison plotted out a research and development strategy that encompassed current scientific knowledge about his subject as well as an understanding of the complex systems requirements of a complete electric light and power technology. This has served as a useful corrective to the naive popular view, but in fact reflects a naivite all its own, casting Edison into a modern role that he could never have assumed and making his achievement a far more straightforward and predictable act than it actually was. For Edison, the search for a practical incandescent light was a bold, even foolhardy, plunge into the unknown, guided at first more by overconfidence and a few half-baked ideas than by science or system. To suggest otherwise is to rob the inventive act of its human dimension, and thus to miss an understanding of the act itself.

Nor is it right to make Edison's invention simply one of many more or less equal steps in a long path leading from the first glimmerings of the theoretical possibility of electric lighting to the installation of the practical reality in homes, shops, and factories everywhere. The simple fact is that before Edison began his search in 1878, the world had nothing even resembling a practical electric lamp, and, when that search was largely over by the end of 1879 (and certainly by the time Edison's lamp was commercialized in 1882), the principles and form of the modern incandescent lighting system were established. It is not right either to make a great deal of the rivals Edison met in the field, whether in America or overseas, and to see in them equals in the enterprise. The evidence is simply not there to support the claim that any of these men possessed more than a portion of the whole that emerged from Menlo Park as the decade of the 1880s began. It will not even do to make much of the notion that one or two of these portions were, at critical junctures, pieced into the Edison system from the reports of his rivals -- once again, the evidence is not there.

The invention of the electric light was a complex, human achievement, and we shall not understand it unless we fully appreciate that fact. This may seem to be an obvious truth, but little that has been written about the event has taken it into account. This invention, like most inventions, was the accomplishment of men guided largely by their common sense and their past experience, taking advantage of whatever knowledge and news should come their way, willing to try many things that didn't work, but knowing just how to learn from failures to build up gradually the base of facts, observations, and insights that allow the occasional lucky guess -- some would call it inspiration -- to effect success. There is clearly something to be said for trying to understand this process better, not just because it is one of the most important agents for change in the last two centuries, but because it is a part of the human adventure.

A Note on Methodology

Of almost equal importance to the thematic goals in shaping this work have been certain methodological goals. There is an extent to which our effort is a kind of experiment in archival historiography. The experiment derives its rationale from the sponsor of this study, the U.S. National Park Service, which is custodian of one of the richest and largest collections of historical technological documentation in the world, the archives at the Edison National Historic Site in West Orange, New Jersey. Adequately understanding and taking advantage of this unique historical resource has become a significant priority for the administrators and curators of the Site, as evidenced by its partial sponsorship of the Thomas A. Edison Papers Project. While, as a comprehensive archival and publishing effort of more than twenty years planned duration, this Project may be expected to provide the most thorough scrutiny of the archives' resources and potential, it is appropriate that other, more modest, attempts be made to explore their value. We seek, therefore, in this work to understand how to use a large and complete body of technical records to answer interesting historical questions.

As a glance at the references and bibliographical note accompanying our essay will suggest, this study attempts to rely exclusively on the contemporary archival record of the activities surrounding the electric light's development from 1878 to 1882. There has been, over the years, a great deal written about Edison's primier invention and the circumstances surrounding it. Such writings began to appear only a very few years after the event and they have continued up to this day, as exemplified by Robert Conot's well-received Edison biography of 1979, A Streak of Luck, and other studies that appeared coincident with celebrations of a "centennial of light." The earliest works on the subject relied largely on the recollections of the still-living principals, for the archives were not available and Edison and most of his colleagues were usually quite ready to talk about their Menlo Park exploits. It took little time, however, for recollections to dim and for the complexity of events to be overshadowed in hindsight by the magnitude of the achievement. When, therefore, the stories and recollections of the pioneers, including Edison himself, are compared against the archival record, their completeness and accuracy are constantly found wanting. Later, more professional works, such as the biographies by Matthew Josephson (Edison, 1959) and Conot or more specialized studies by historians of science and technology, have relied much more on the archival record, and thus manage to avoid many of the more simplistic shortcomings of the earlier versions. Most of them, however, have still relied in crucial places on recollections (most notoriously, on Francis Jehl's Menlo Park Reminiscences of 1937-1941) or have mis-interpreted important technical elements of the record. In examining these accounts next to the Menlo Park notebooks, correspondence, and other documents, we have found none whose rendering of the events of 1878 - 1882 match our reading of the record. While, of course, some of these differences may be seen as simply matters of historical interpretation, we believe that many of them are due to differences in the degree to which the contemporary documentary record has been critically scrutinized.

This record has presented problems which have inhibited scholars from fully exploiting it. The first problem is the sheer size of the Edison archives. The document holdings at West Orange are said to contain more than three and a half million pages -- as formidable a collection centered around the work of one man as exists anywhere. While there is no estimate for the size of the record that concerns the electric light alone, one can imagine that a four-year slice out of Edison's most productive years constitutes no small body of material. A better idea of just what this consists of may be found by a look at the bibliographical note at the end of this work. The second problem, related to the first, is organization.

A fraction of the Edison archives is arranged by subject, but even that fractional arrangement was, at the time this study was undertaken, a somewhat unreliable and haphazard organization. Most of the relevant material on the electric light must be gleaned from amidst records dealing with other enterprises being carried on at Menlo Park. Some of the problems encountered here are also suggested in the bibliographical note. As well meaning and willing as the custodians of the Edison archives have been over the years, we can hardly wonder if they have been unable to fully allay the difficulties posed to scholars by such records.

Yet another problem is posed by the nature of the material itself. While there is nothing inherently incomprehensible about the notes, correspondence, and other papers generated in the Menlo Park laboratory, they are definitely not like the more literary records that may be left by a political figure, writer, or businessman. They are the creations of men immersed in the mechanical, electrical, and chemical knowledge of their day, in the midst of dealing with some very bedeviling technical problems. If the record they leave behind them is generally without comprehensive explanations for their activities and ideas or interpretations of their abbreviated notes and scribblings, it should be no surprise. Indeed, those few documents that do seem to come forth more fully with delineations of the ideas and purposes behind laboratory activity must be looked upon with some suspicion, for often they turn out to be creations after the fact, put together for purposes of publicity or legal convenience. The papers actually generated in the course of laboratory activity are frequently but rough drawings of a new idea, quick calculations (with little or no labeling), lists of materials or devices, or descriptions of a laboratory procedure or observation with little explanation of why or wherefore. All of this, too, it must be remembered, is in the technical terminology of the nineteenth century electrician or mechanic, an argot that can be as strange to the modern ear as the jargon of a computer programmer would be to one of the Menlo Park "gang." Most scholars and writers have therefore, understandably, retreated to the much more straightforward accounts of the reminiscences for their image of the laboratory's workings and achievements.

We cannot claim that we have overcome these difficulties as completely as we might have liked. But we have made the effort to meet them head-on. The size of the record required the efforts of a full-time researcher for about eight months, spent searching out and noting down every relevant piece of data in the notebooks, correspondence files, scrapbooks, and other sources described in the bibliographical note. The organization of the electric light documents necessitated a broad sweep through the documents of the 1878 to 1882 period. And the mass of technical arcana was dealt with forthrightly, with every effort made to comprehend and respect the technical milieu in which the men at Menlo Park worked. The extent to which we have in fact succeeded is, of course, a judgement we must leave to the reader.

Finally, a word should be said about illustrations. Because we are dealing here with mechanics, chemists, electricians, and other practical men, we must recognize that frequently their most important form of communication was not in words but in the quick sketch, the hasty set of figures, the finely detailed drawing, and the products of their workbench or laboratory table. Because history is largely a literary activity, often these records are translated here into descriptions, but such translation is never completely accurate, and it is frequently impossible. As a number of historians of technology have been at pains to point out, "non-verbal communication" is an essential part of the technical culture, and any student of that culture ignores this at great peril. We have attempted here to suggest the wealth of the non-verbal sources that are such an important part of the documentation of the electric light, but it must be remembered that our inclusions are but a fraction of the non-verbal archival record.

Robert Friedel

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CHAPTER 1

"A BIG BONANZA"

In 1878, Thomas Edison was only 31 years old, but he had already produced enough significant inventions to credit a lifetime. The press recognized this achievement by calling him "the Wizard of Menlo Park." Beginning with his improved stock ticker of 1869, his contributions to telegraphy alone were enough to establish him as perhaps the premier electrical inventor of his day. His systems of automatic and multiplex telegraphy were not only technical marvels, but their possible economic significance made Edison's name as familiar to the financiers of Wall Street as it was to the followers of the technical and scientific press. Successful dealings with the telegraph empire builders of New York had given Edison the means to construct his unique laboratory in the New Jersey countryside. And there at Menlo Park he and a group of loyal co-workers operated a true "invention factory."

Soon after the lab was completed in the Spring of 1876, Edison and his team moved beyond telegraphy. Their first important successes were in the field of telephony. Edison's carbon transmitter of 1877 was a crucial element in turning the experimental devices of Alexander Graham Bell and Elisha Gray into practical instruments for communication. The broad range of approaches Edison used in his inventive efforts sometimes yielded surprising results, as when in late 1877 experiments on repeating and recording devices for use with telegraphs or telephones resulted in the phonograph. The "talking machine" was surely Edison's most surprising invention. Despite the primitive quality of his tin-foil cylinder device, the public was agog at the machine. Most of the first months of 1878 were taken up by travel and demonstrations in response to the public clamor for showings of the phonograph. The "wizard" became the object of enormous press attention, for hardly anything would seem to be beyond the capability of a man who could invent a machine that talked. Indeed, when New York's somewhat flamboyant Daily Graphic ran an April Fool's Day story headlined, "Edison Invents a Machine that will Feed the Human Race", other newspapers repeated it as straight news.[1]

For the first half of 1878 Edison basked in the spotlight of attention. The surprise of the phonograph, along with the enthusiasm that it generated from the public, turned his inventive energies away from its normally doggedly practical direction. He produced devices like the "aurophone" and the "telescopophone", both not very useful amplifying instruments. His observation of the changing resistivity of carbon under varying pressure led to the invention of the "tasimeter", intended as a super-sensitive heat measuring device. All of these efforts were in part simply ways of showing-off his inventive virtuosity, as well as a reaction to the lesson of the phonograph that even the most unlikely avenues of experimentation may yield wonderful discoveries.

The financial needs of the laboratory and its workers assured the continuance of more practical efforts. Much time and energy was devoted during these months to the further development of Edison's telephone components. The jumble of patents and conflicting business interests surrounding the technology of the telephone gave Edison and his backers the incentive to develop telephone devices that would complement the carbon transmitter and yet avoid the patents of Bell and others on receiving equipment. Later in 1878 the Menlo Park efforts would yield the chalk-drum telephone receiver, a clever device that was in many ways an improvement over other instruments, but which turned out to be impractical in broad application. Despite its obvious potential for lucrative profits and its technical similarity with telegraphy, the telephone already represented a crowded field, a field that no longer held out the promise of quick breakthroughs. It should be no surprise, therefore, that in the middle of 1878 Edison was seeking fresher fields for his endeavors.

Edison's biographers describe his condition in the late spring of 1878 as "very tired and ill."[2] The never-ending round of public appearances to demonstrate the phonograph, claims and counter-claims surrounding his telephone inventions, and the constant grind of the lab had worn him down to the point where his need for a vacation was apparent to everyone. To the rescue came Professor George Barker of the University of Pennsylvania, who asked Edison to provide his tasimeter for use on the expedition being organized by Henry Draper to the Rockies for the purpose of observing a total eclipse of the sun due to occur on July 23. Barker accompanied his request with an invitation to Edison to join the Draper party, giving the inventor not only an opportunity to see the "wild West", but also a chance to spend several weeks in the close company of some of America's most eminent scientists. When, on July 13, the scientists and their entourage departed New York for the long train ride west, Edison was with them.

The trip was clearly excellent tonic. While the tasimeter was of no value in its intended purpose (measuring the heat from the sun's corona), the escape from the East and the companionship of men like Barker and Draper restored Edison's energy and enthusiasm for new tasks. Edison's state of mind upon his return is reflected in some notes made by his chief assistant, Charles Batchelor, many years later:

> When he came back from this trip he told me of many projects to be worked up for future inventions, amongst them one for using the power of the falls for electricity + utilizing it in the mines for drills etc. He said he had talked a great deal with Prof. Barker who was his companion in a journey to the Pacific Coast after they had observed the eclipse in Rawlings. Prof. B had told him of some experiments he had seen at William Wallace's place at Ansonia, Ct. + wanted him to go up there + see them.[3]

The date of Edison's return was August 26, 1878. The researches that led to the invention of the incandescent lamp began the next day.[4]

It was almost two weeks later, however, before Edison threw himself and his team whole-heartedly into electric lighting research. The push for this effort was provided by his visit to the factory of William Wallace. Prof. Barker made all the arrangements, and the trip was made, in the company of Barker and Prof. Charles Chandler of Columbia, on Sunday September 8. The firm of Wallace & Sons was the foremost brass and copper foundry in Connecticut and was known also for expert wire drawing. William Wallace himself had been experimenting with electricity for almost a decade and had built his first dynamo in 1874. He joined with the brilliant electrical inventor

Moses Farmer and began manufacture of the Wallace-Farmer dynamo in 1875. Not many months before the visit from Edison, Wallace began development of an arc lighting system and the construction of a powerful elecric motor, which he called a "telemachon", indicating that its primary purpose was the harnessing of electric power generated some distance away. A visit to Wallace's workshop in Ansonia was the best possible exposure to what America had then to offer in the infant field of electric light and power.

Such was Edison's notoriety that it was impossible for him to make such a trip without a newspaper reporter tagging along. The writer from the New York Sun was not disappointed, and he provided a lengthy description of Edison's reaction to what he saw:

> Mr. Edison was enraptured. He fairly gloated over it. Then power was applied to the telemachon, and eight electric lights were kept ablaze at one time, each being equal to 4,000 candles, the subdivision of electric lights being a thing unknown to science. This filled up Mr. Edison's cup of joy. He ran from the instruments to the lights, and from the lights back to the instrument. He sprawled over a table with the
>
> SIMPLICITY OF A CHILD,
>
> and made all kinds of calculations. He calculated the power of the instrument and of the lights, the probable loss of power in transmission, the amount of coal the instrument would save in a day, a week, a month, a year, and the result of such saving on manufacturing.[5]

The somewhat optimistic Sun reporter then went on to describe the possibilities of harnessing Niagara Falls and distributing the resulting electric power throughout the United States. It is significant that the final impetus for Edison's work on the electric light was provided not so much by the challenge of the light but by this vision of universal power through electricity.

While electric lighting was largely a new field for Edison it was by no means virgin territory. Ever since Humphry Davy used his giant battery at the Royal Institution in 1808 to demonstrate how electricity could be made to produce light either by an arc between two conductors or by heating up an infusible material to incandescence, the possibility of making a practical electric lamp had intrigued inventors and would-be inventors. The limited and expensive sources of current that were available before the 1860's, however, restricted serious efforts. Despite this, as early as the 1840's, patents were taken out in several countries for both arc lights and incandescent devices.

The arc light was the subject of the most intensive work. Davy used two pieces of charcoal to show that a small gap in a circuit can be bridged by a strong current, producing a very bright continuous "arc." The technical problems presented by the arc light were straightforward: (1) producing electrodes for the points of the arc that would not burn up too rapidly from the arc's intense heat and, (2) finding a means of regulating the gap between the electrodes so that the arc could be continuously sustained even while the points were being shortened by the arc's destructive action. For more than forty years, a variety of devices were invented and developed to make the arc light practical and useful. By 1878 the fundamental elements of arc light technology were well understood, and considerable progress had been made toward adopting the new light to appropriate uses. The light that William Wallace had on display at Ansonia was a typical example of what was then available - an electro-magnetic regulator that held two carbon electrodes (plates in the case of the Wallace instrument, rods in most others) at the desired distance, producing a blindingly bright light upon the application of current. The arc light had found some use in lighting streets, public halls and large stores, but it was obviously not suitable for domestic lighting, where the desired light was on the order of ten to twenty candle-power (the range of a gas light) rather than in the thousands.

Whereas the arc light was beginning to find some applications, lighting by incandescence was in 1878 far from being a practical technology. Davy had shown that an electric current could be used to heat up a material to the point where it would begin to glow. The basic problem with attempting to apply this phenomenon was that almost all substances either oxidize or melt at temperatures sufficiently high to cause incandescence. One substance that would not melt at such high temperatures was carbon, but the ease with which carbon burns prevented experimenters from getting very far with it. The other popular substance for early efforts was platinum, whose resistance to oxidation was its primary attraction. Platinum's major drawback, besides its high cost, was the difficulty of raising its temperature to the point of incandescence without allowing it to heat up further, past the melting point (about 1770°C). All important efforts to make a workable incandescent lamp before 1878 used one or both of these materials.

As early as 1841, Frederick De Moleyns, an Englishman, received a British patent for an incandescent lamp utilizing both carbon and platinum. In 1845 an American, J.W. Starr, not only patented two forms of incandescent lamp (one using platinum, the other carbon) but also traveled around England giving exhibitions and promoting his inventions. Starr's death at age 25 the next year cut short his efforts, which, while they impressed a number of well-informed British observers, were not truly practical. For the next three decades a steady stream of devices flowed from the workshops of would-be inventors in Britain, America and the Continent. Despite these efforts, in 1878 the fundamental problem of the incandescent lamp - finding the means of heating up an element to glowing without in the process destroying it - was no closer to solution. In the words of the Sun's reporter, "the sub-division of electric lights", was still "a thing unknown to science."

Upon his return from Ansonia Edison dived immediately into the task of producing a practical incandescent light. Notes from the Menlo Park laboratory made on September 9 and 10 refer to a number of platinum wire "burners", with the wire generally shaped into spirals. The notes, in their rough way, make it clear that Edison had been greatly excited by what he had seen at Wallace's workshop. His excitement apparently stemmed not only from seeing what Wallace had accomplished, but, more significantly, from perceiving how much had yet to be done. He described his feelings to the Sun's reporter about a month later:

> (In Wallace's shop) I saw for the first time everything in practical operation. It was all before me. I saw the thing had not gone so far but that I had a chance. I saw that what had been done had never been made practically useful. The intense light had not been subdivided so that it could be brought into private houses.[6]

After only two or three days of experiments, Edison felt that he was on to something -- something big. On September 13, Edison wired Wallace, urging him to send to Menlo Park one of his telemachons, "Hurry up the machine. I have struck a big bonanza."[7] Wallace wrote back the same day to assure Edison that a machine was on its way, adding, "I truly hope you have struck a big bonanza." While the nature of Edison's "breakthrough" is not completely clear from the Menlo Park notes, there is enough evidence for some surmises. On the same day he wired Wallace, he drafted his first caveat on electric lighting, entitling it, "Caveat for Electric Light Spirals." Therein he wrote:

> The object of this invention is to produce light for illuminating purposes by metals heated to incandescence by the passage of an electrical current through them, a great number of pieces of such metals forming part of an electric circuit and distributed at various parts of the same. The invention consists in devices whereby the heat arising from the passage of such current is utilized to regulate the temperature of the incandescent metal which serves to give the light so that it is never allowed to reach its melting point, no matter how strong a current attempts to pass through.[8]

In the following pages of the caveat Edison described 44 different regulator devices, all designed to "cause each spiral to automatically regulate its own temperature."[9] Most of these devices used the expansion of metal -- either the incandescent spiral itself or another piece of metal nearby -- to trigger an interruption or reduction of current when approaching the fusing point of the incandescent metal. The combinations of electro-magnets, switches, resistance elements and levers were clearly products of the telegraphic technology with which Edison was so familiar. It would seem that Edison's confidence in his superior mastery of these mechanisms led him to believe that he could readily devise the workable regulator that had eluded every previous inventor.

Notes from the Menlo Park laboratory show that the next few days were taken up with constructing some of the regulators specified in the caveat, and devising series circuits for them. Despite the fact that these notes do not reflect any signal success for these instruments, Edison's confidence grew into boastfulness. The Sun of September 16 carried a column headlined, "Edison's Newest Marvel. Sending Cheap Light, Heat, and Power by Electricity." " 'I have it now!' " Edison was quoted as saying, " 'and, singularly enough, I have obtained it through an entirely different process than that from which scientific men have ever sought to secure it.' "

> They have all been working in the same groove, and when it is known how I have accomplished my object, everybody will wonder why they have never thought of it, it is so simple. When ten lights have been produced by a single electric machine, it has been thought to be a great triumph of scientific skill. With the process I have just discovered, I can produce a thousand -aye, ten thousand - from one machine. Indeed, the number may be said to be infinite. When the brilliancy and cheapness of the lights are made known to the public - which will be in a few weeks, or just as soon as I can thoroughly protect the process - illumination by carbureted hydrogen gas will be discarded.[10]

He then went on to describe how he would be able to light all of lower Manhattan with a 500 horse-power engine, using Wallace's dynamos, how underground wires would bring electricity into buildings, and how he intended to use existing gas burners and chandeliers as fixtures. The vision of a complete electric lighting system was clearly in Edison's mind in the first days of working on the light.

The Sun's story received considerable attention. Picked up by the Philadelphia Bulletin, it was seen by George Barker, who then wrote Edison regarding his "big strike in electric lighting." Barker remarked that he expected the news to have an effect on gas stocks, and he hoped Edison would be able to let him use some of his "new things" in lectures he was scheduled to give on the electric light that winter.[11] Other newspapers repeated the news, including the Chicago Tribune. The most important impact, however, was back in New York, where the story was read by some of the Wall Street moneymen who had already learned to be wary of Edison's technical genius. On September 17 Edison received a wire from his New York lawyer and friend, Grosvenor P. Lowrey, and some of his associates requesting an urgent meeting.[12] Shortly afterwards came a letter from Tracy R. Edson, an official of Western Union, who requested a meeting soon in his New York offices "in relation to your new discovery of which you spoke to me on Monday last." Thus began several weeks of negotiations between Edison, with Lowrey as his representative, and various financiers who were associated with the telegraph industry, the gas companies, or both. Out of these talks was to come the Edison Electric Light Company, formed solely for the purpose of supporting Edison's experiments at Menlo Park and controlling the resulting patents.

The week that began with the appearance of the Sun's article (September 16-22) was filled with the construction of experimental lamps. These were all based on the ideas put forth in the September 13 caveat -platinum wires or spirals in various forms of holders, with regulating switches to be triggered by the thermal expansion of the metal "burner" or an adjacent element. The belief that this was the right track was firmly held. Some of the sketches of instruments worked on that week show not only the regulating device, but also bases, stands and connections.[13] On Sunday, the 22nd, Edison wired his representative in Paris with the news that he would not be able to visit Europe soon: ."..cannot come, have struck bonanza in Electric Light -indefinite subdivision of light...."[14] He continued to receive inquiries sparked by the newspaper stories. George Bliss who was in charge of promoting Edison's electric pen, wrote from Chicago to tell of the excitement that had been stirred in that city by the stories and asking how much truth there was to all that he had heard. Edison's reply was a proper reflection of his confidence, "Say to Bliss (he instructed his secretary) Electric Light is OK. I have done it and it's only a question of economy."[15]

The "question of economy" was rapidly becoming a major concern, along with solving the continuing difficulties experienced with various versions of the regulator-burner. Notes made on September 20 show calculations of the amounts of copper needed in various circumstances.[16] The large amount of copper that would be needed to supply the huge currents that most assumed would be required by a large number of lights on a single circuit was one of the most glaring problems to be faced by any scheme for "subdividing the light." In the midst of all of his proposed regulators, there is little clue as to how Edison thought he would solve the distribution problem. Its significance was probably not apparent to him in those first few weeks of feverish excitement and boastful pronouncements. It was one thing to conceive of the electric light as part of an extensive and comprehensive light and power system, and another to perceive the technical requirements of such a system.

During the week of September 22, Edison drafted his second electric light caveat. The dozen or so devices described therein represented a hodge-podge of approaches. Self-regulating spirals of platinum were joined by arc light regulators, oxy-hydrogen limelights fueled by electrolysis, sticks of carbon raised to incandescence in a vacuum, and devices that combined carbon, platinum and other materials. Experimental notes from the last week in September indicate that efforts were still concentrated on improving the spiral-regulator lamp. A drawing of a lamp made on September 25 was accompanied by the comment, "We now have a perfectly regulating light spiral wound double to allow for expansion, ...when the spiral and Platina rod are the right size this is a perfectly automatic cutoff...."[17] The various approaches experimented with during this period, however, make it clear that the lamp was really far from "perfect." A variety of materials were tested in numerous ways, with platinum continuing to be favored, but iridium, platinum-iridium and ruthenium were receiving some attention, as was carbon.[18] By the end of September, materials like chromium, aluminum, silicon, tungsten, molybdenum, palladium and boron had been incorporated into parts of experimental lamps, with few positive results. The obvious dissatisfaction with the behavior of platinum in his lamp is a clear indication that, for all the talk of a "perfectly regulating spiral", Edison was by no means certain that he was on the right track.

The pace of experimentation seemed to grow more intense as October rolled around. Some of the complexity of the task he has undertaken began to be reflected in the pace and scope of the activity at Menlo Park. Each day Edison's technicians, especially the talented mechanic John Kruesi, were instructed to make a variety of devices. The shape of the platinum element, the form of the regulator, the lamps' mechanical parts, even the base and the container of the devices were varied in countless ways. Experiments continued on alternative materials, even while platinum remained the subject of most work. Titanium and manganese joined the already long list of experimental substances. Edison's search for the ideal incandescent element was no secret. He wrote to Prof. Barker in Philadelphia, for example, to get his opinion of the usefulness of titanium (which Barker gave a somewhat negative reply).[19] A much more prescient communication, however, reached Edison at about the same time (October 7) from Moses G. Farmer, who was experimenting himself on incandescent lamps. Farmer sent along to Edison a small bar of iridium which he thought superior to platinum in terms of light emitted. Farmer went on to say, however, that he thought none of these materials to be equal to carbon, which, he wrote, "is the most promising --when sealed tightly from oxygen either in a vacuo or in nitrogen."[20] Farmer's iridium sample was probably much appreciated by Edison, who had already begun trying to use the material, but the hint on carbon was ignored, probably because his own brief experiments with the material showed that it was almost impossible to protect from combustion.

As important as the material problem was to Edison, after a month of intensive work it was still the mechanism of his light - the regulator - that commanded most of the effort of the lab. The third caveat for "electric light subdivision" to issue from Menlo Park was prepared on October 3, and a fourth was written up five days later. Both were largely concerned with regulators. "Caveat No .3", as it was headed, introduced the pneumatic regulator, which consisted of a platinum element enclosed in an air-tight container which was equipped at one end with a diaphragm (or unspecified material). As the element heated up to incandescence, the air in the chamber expanded and pressed against the diaphragm, which was connected with a short-circuiting device, which was adjusted to close when the air in the lamp chamber was heated to a certain point, thus diverting current from the lamp element and preventing its destruction. This form of regulator was to receive more attention in the months ahead, eventually becoming the subject of patents. The second October caveat largely covered a number of complex mechanical regulators, variations of earlier proposals. The caveats also reveal continuing concern for determining the best shape for the platinum element, the October 3 document in particular depicting all kinds of spirals and bends. This was made possible by the fact that the pneumatic regulator did not depend upon the expansion of the incandescing element itself for regulation. The new type of regulator also directed attention to the behavior of the element in a closed container - a "bulb."

On October 10 notes were taken for a series of experiments that were significantly different from most of those performed up to that time. Eight discrete experiments were described, most as part of a series to determine the relationship between radiating surface areas, temperatures and the light emission of incandescing elements. These experiments marked the first significant break from the somewhat haphazard construction of various devices, moving toward a more systematic experimental approach. These experiments were not particularly well designed. Even the best two or three involved only a couple of trials, as in one which involved comparing the light output of two platinum strips of the same resistance and the same length, but with one an eighth-inch wide and the other a quarter-inch in width. Edison's explanation for this effort was, "The idea is to ascertain if we do not gain increased light by increased surface without alteration of resistance and also to ascertain if the radiation nullifies the effect of increased surface."[21] By mid-October the Menlo Park experimenters were beginning to sense how much they had yet to learn before the electric light could be a practical reality.

It was against the background of this frenetic experimenting that the complex business arrangements were completed for supporting the increasingly expensive researches and eventually for exploiting the resulting patents. In late September a number of members of the New York legal and financial world had attempted to get commitments from Edison regarding the financing of the electric light research and the disposition of rights to his invention. Three individuals carried on the most active correspondence: Grosvenor P. Lowrey, who had acted as Edison's attorney since 1877; Tracy R. Edson, an officer of Western Union who had supported some of Edison's earlier telegraph efforts; and Hamilton McK. Twombly, another Western Union official who was also the son-in-law of William H. Vanderbilt, whose money was heavily invested in not only telegraph companies but also gas utilities. From an early date, Lowrey sought to represent Edison's financial interests in the matter of electrical lighting. During the last week of September, the Western Union financiers attempted to get Edison's ear, but he was able to avoid them, protesting that no time could be lost in the Menlo Park lab. By early October, Lowrey had the negotiations under control. He worked out an arrangement with the Vanderbilt interests to establish a stock company with a capital of $300,000, half of which would be represented by Edison's interest in his invention and the other half by money supplied to Edison by Vanderbilt, Twombly, Edson and other share holders. At this point, Edison was quite content to let Lowrey make whatever arrangements he thought best, writing in October 3, "Friend Lowrey: Go ahead. I shall agree to nothing, promise nothing and say nothing to any person, leaving the whole matter to you. All I want at present is to be provided with funds to push the light rapidly."[22]

By this time it had become clear to Edison that he was engaged in an effort that would require resources beyond what he already had at Menlo Park. He was anxious for the financial support that Lowrey's arrangements would give him, and apparently had no misgivings about sharing control of his invention. On October 5, he wrote enthusiastically to one of his European representatives (Puskas),

> The electric light is going to be a great success. I have something entirely new. Wm. H. Vanderbilt and friends have taken it in this country and on

> Monday next advance $50,000 to conduct experiments.
> I retain 1/4 of the capital stock of the Co. they are to form and also receive a royalty of $30,000 yearly if it proves more economical than gas, which I am certain it will do. Vanderbilt is the largest gas stock owner in America.[23]

To another European representative, George Gouraud, however, Edison advised a bit of caution. "Say nothing publicly about light", he wired on October 8, "I have only correct principle. Requires six months to work up details. Gas men here hedged by going in with me."[24] It soon became clear to Edison that while his financing would give him the resources his experiments needed, they also increased the pressure on him to produce viable results quickly. For the next year the efforts at Menlo Park had to be directed not only to the creation of the practical light Edison wanted, but also to producing concrete evidence of his progress toward a profitable invention. The two goals turned out to be frequently incompatible.

The need for additional money in early October was the result not only of the seemingly endless experiments with the light and its various forms of regulators, but also of the growing awareness of the need to develop other components of an electric lighting system. The most crucial of these was the generator. It is important to remember that the experiments that began in the Fall of 1878 marked Edison's first real encounter with the production of electric currents by mechanical means. All of his previous electrical work - with telegraphs, telephones and a whole host of minor devices - was satisfactorily powered by batteries. There was never any doubt that a practical electric light could be economical only when it could be powered by an electro-magnetic generator. The beginning of serious work on electric lighting at Menlo Park was marked by the acquisition of the "telemachon" that had so impressed Edison on his visit to William Wallace's Ansonia workshop. For the first few weeks it would seem that Wallace's machine was judged sufficient, but this judgement did not last long. On October 4, a series of wires was exchanged between Edison and Wallace regarding the cost to Edison of a second Wallace machine, perhaps a more powerful one. Edison ordered one immediately, at Wallace's confidential discount price of $750.[25] At about the same time, Edison began shopping around for alternative machines, making inquiry to the firm of Arnoux and Hochhausen and placing an order on October 10 with the Newark supply house of Condit, Hanson and Van Winkle for a "dynamo electric machine" made by Edward Weston.[26] The next day Edison received, apparently in response to an earlier inquiry, information from the Telegraph Supply Co. of Cleveland, Ohio on the generator and arc light of Charles Brush. The ultimate indication of Edison's dissatisfaction with what he had available was the beginning of efforts to design his own generator. The first fruit of this effort was the construction of what was called a "tuning fork magneto", a device of little practical use, but which Edison saw fit to patent (U.S.P. 218,166; granted Aug. 5, 1879). From the middle of October, 1878, the construction of a suitable generator was to be one of the major tasks at Menlo Park, sometimes overshadowing the efforts on the light itself. From this point on, there could be little question that Edison perceived his task in terms that went beyond a practical light, and included the system needed to make it work.

While the work at Menlo Park gradually revealed the complexities and difficulties that lay in the path toward the electric light, public excitement over what was promised from Edison's laboratory was unabated. Indeed, in early October the news from America caused a panic in gas shares in London, where Edison's reputation for wizardry was unequalled. Throughout the month Edison received sometimes frantic letters and cables from George Gouraud in London, who claimed that he was besieged by capitalists. "If I had had my wits about me," he wrote, "when your telegram came announcing your discovery in this connection I might have made you a clean million as it played the very devil with stocks all over the country."[27] The next week Gouraud cabled to say that the "tremendous excitement" continued and that "there never was a time so favourable to the launching of a large company than the present for the Edison Electric Light Company."[28] Edison resisted Gouraud's entreaties, referring all business matters to Lowrey, who in turn preferred to move conservatively and only with the approval of the New York financiers he already had behind him.

The newspaper stories both in America and in Europe continued to be enthusiastic. The lack of public demonstrations after a month of promises was said to be due to the wait for patent protection. Reporters described their visits to Menlo Park, where Edison, busy as he was, seemed always ready to greet them. The visit to the laboratory was usually highlighted by a demonstration of the light. Rhapsodied a reporter from the New York Sun:

> There was the light, clear, cold, and beautiful. The intense brightness was gone. There was nothing irritating to the eye. The mechanism

> was so simple and perfect that it explained itself. The strip of platinum that acted as burner did not burn. It was incandescent. It threw off a light pure and white. It was set in a gallows-like frame. but it glowed with the phosphorescent effulgence of the star Altaire. ...It seemed perfect.[29]

The intensive publicity continued almost until the end of the month. By that time, however, there was little to tell the public but that they would have to wait -- a few technical details, completion of the patent procedures, some financial arrangements, and all would be ready.

At the same time, however, Edison's financial backers in New York were seeking somewhat more concrete assurances. Lowrey wired to Menlo Park to suggest that it was important that Edison be prepared to demonstrate his invention soon.[30] The reply was that it was only a matter of days before some kind of showing would be ready. Nonetheless, the delays were making some nervous, and approaches were made to the rival inventor, William Sawyer, who, with the backing of Albon Man, claimed to have devised a workable carbon incandescent lamp. When Edison received word of the discussions with Sawyer, he was furious, revealing perhaps some of his own anxiety. His secretary, Stockton Griffin, wrote to Grosvenor Lowrey, describing the scene:

> Upon arriving at the Park yesterday, I spoke to Mr. Edison regarding our conversation about the Sawyer-Mann electric light, being careful not to say anything beyond what you told me. I was astonished at the manner in which Mr. Edison received the information. He was visibly agitated and said it was the old story, i.e. lack of confidence. The same experiences which he had had with the telephone, and in fact with all of his successful inventions, was being re-enacted. He also referred to the telephone being loaded with useless encumbrances

> and remarked that if he had a voice in the matter the electric light should not be so treated. No combinations, no consolidations for him. ...He said that it was to be expected that everyone who had been working in this direction, or had any knowledge of the subject would immediately set up their claims upon ascertaining that his system was likely to be perfect. All this he anticipated, but he had no fears of the result knowing that the line he was developing was entirely original and out of the rut.[31]

Lowrey hastened to reassure Edison:

> Do not give yourself the slightest uneasiness from anything you hear from me or anybody else, about other people's efforts or inventions concerning electric light. My confidence in you as an infallible certain man of science is absolutely complete....[32]

Despite Edison's attitude, the backers of the Edison Electric Light Company insisted on some insurance for their investment. At the same time that approaches were being made to Sawyer, Lowrey wrote to Edison that the Company's Board of Directors wanted to hire someone "to examine the state of the art" in electric lighting, and went on to ask if Moses Farmer would not be a good expert for the job.[33] At the same time, Edison himself asked his patent attorney to supply him with a list of all U.S. patents on the electric light.[34] He also suggested to the Light Company directors that Howard R. Butler of the Gold & Stock Telegraph Company be hired to make a thorough search of the patent and technical literature to compile a survey of the work that had been done on electric lighting. The directors agreed a few days later to pay for Butler's work, and the survey began promptly.[35] At about the same time that he was approached to take time from his job at Gold &

Stock, Butler agreed to take into his office a young student of physics who was freshly returned from study in Germany, Francis R. Upton. Upton wrote to his mother on November 7, telling her that Butler did not yet have anything definite for him to do.[36] This changed quickly when the request from Edison arrived, and Upton was given the task of undertaking the search Edison's backers wanted. Thus was recruited the most important single collaborator Edison was to have in the coming year's work.

As November wore on, it became increasingly evident to Edison and to at least some of his associates that the invention of the electric light would be far from the simple matter many had supposed it to be. Edison began to show an active interest in the new effort to investigate all that had been written on electric lighting. On November 12, he wired to Butler in New York that he wanted to meet with Upton, presumably to get a progress report on the literature search.[37] He also began work on the construction of a brick machine shop - a much more substantial building than had hitherto existed in Menlo Park. The new building would require a good portion of the first $50,000 he had gotten from the Light Company, but he felt he needed a place with "all the means to set up and test most deliberately every point of the electric light, so as to be able to meet and answer or obviate every objection before showing the light to the public or offering it for sale either in this country or in Europe."[38] Further in this same letter, written to his agent in Paris, Edison characterized his efforts in revealing terms:

> Before I have done with it I mean to succeed. I have the right principle and am on the right track, but time, hard work and some good luck

> are necessary, too. It has been just so in all my inventions. The first step is an intuition, and comes with a burst, then difficulties arise -- this thing gives out and then that -- "Bugs" -- as such little faults and difficulties are called -- show themselves and months of intense watching, study and labor are requisite before commercial success -- or failure -- is certainly reached.[39]

A keen awareness was beginning to emerge at Menlo Park of the magnitude of the "bugs" that had to be worked out to make a practical electric light, but despite that, there was no question that Edison "meant to succeed."

From mid-November, however, there was a clear change in the path being charted to success. Edison's interest in what Upton was finding in his literature search was one clue to this change. On November 22, Upton wrote a ten-page summary of his findings to that date, referring to a number of patents that he thought Edison should know about. He indicated his desire to learn more from Edison and added some assurances, "I want you to explain me your lamp and tell me exactly what you claim....I feel sure that the total you have is new, no matter if the parts have been used before."[40]

In late November, Edison put in an order to the New York firm of Willmer & Rogers for subscriptions to a long list of technical journals, including the Gas Light Journal, Metallurgical Review, English Coal Gas Journal and others that would allow him to keep abreast of developments in lighting, metallurgical chemistry and other fields of interest.[41] Finally, in late November, Edison instituted a new procedure for recording experimental researches in the lab, and the extraordinary series of laboratory notebooks that document the laboratory's work from that time on began. The long, hard months of "watching, study and labor" - the months of inventive perspiration - were also beginning.

When Thomas Edison launched himself and his laboratory on to the already popular search for a practical, useful means to "subdivide the electric light" the chief characteristic of that search was confidence. In those first weeks, at the end of the summer of 1878, the problem of the electric light was seen as an electro-mechanical problem, and no one in the world had more self-assurance that he could solve problems of this kind than Edison. And, indeed, the world at large shared this confidence. The problem of subdividing the light was, after all, a well-known, oft-attacked challenge, one that had stumped some very good electrical inventors already. But once the Wizard of Menlo Park had announced that the essential solution was in fact a simple one - one that readily fit into that technical domain of which he had already proven himself to be master, then at least the lay press was happy to share that perception. For all the bravado that rings through Edison's pronouncements of those first weeks, the fact is that he genuinely believed that he had indeed solved the problem of the electric light.

The key technical feature of this solution was the principle of the self-regulating element. The key to a successful light was, Edison believed, the devising of a reliable mechanism that would maintain a balance between the power needed to make the lamp element -- entirely or largely of platinum -- incandescent and that which would cause the element to melt or otherwise destroy itself. Edison rapidly came to the conclusion, which he held for the better part of the next year, that the behavior of the incandescing element, could be harnessed to operate a negative-feedback regulator that would help to maintain this balance. In these first weeks, the problem of the electric light was perceived almost solely in terms of making the regulator work. Other aspects were simply not seen as important.

The concentration on the regulator did not mean that Edison was unaware of the ultimate need for a well-worked out system to make his light work. Indeed, everyone who thought for even a moment about the problem of electric lighting perceived the necessity of linking several discrete technical elements into a coordinated system. Edison's perception of the systemic nature of the lighting problem was not especially sophisticated. The models of technical systems surrounded every late nineteenth century inventor - the telegraph, the gaslighting utilities, and the arc light systems themselves were only the most obvious examples. That an electric light would have to have a practical power generation and supply network behind it was not a novel concept. The more elaborate appreciation of the technical requirements and possibilities of an electric light (and power) system that was to emerge from the Menlo Park labors of the next year was hardly present at all in the beginning. Edison did make the point that his electric light would operate in just the fashion of the gas light, but this was more boast than model. And the image that was sometimes drawn of Niagara supplying all of America with light was clearly more dream than plan.

As the fall of 1878 wore on, the spirit behind the work at Menlo Park changed. The serious difficulties encountered in the design and perfection of the self-regulating lamp showed that even the purely electro-mechanical challenges were beyond those which Edison had so handily overcome before. Furthermore, the larger complexities of the electric light began slowly to unfold. The complexity of the system itself -- the need for a generator precisely designed for its task, the necessity for understanding and creating circuits that were soundly based on electrical science as well as suited for the kind of light people wanted, and the ultimate need to create a myriad of components to make the system reliable and efficient - only gradually dawned upon the workers at Menlo Park. The seeking out of financial backing and the construction of new laboratory facilities was one clue to this growing awareness. The recognition of the need to absorb the contents of the technical literature and even to draw upon scientific expertise - a very new thing for an inventor who was not unhappy in his characterization as "wizard" - was another indication of how the perception of the task at hand changed. The invention of a practical electric lighting system would require months of difficult, frustrating and consuming labor -- and a bit of luck.

CHAPTER 2

"THE THROES OF INVENTION"

Up to the end of 1878, Edison's attack on the problem of "subdividing the light" was really little different from that of would-be inventors who had preceded him or of rivals who were then in the midst of their own efforts. What was to distinguish Edison's work in the coming months (and years) was the wealth of men, equipment and facilities that he could mobilize for the campaign. No other inventor in the nineteenth century had at his disposal what Edison had — a team of skilled and intelligent co-workers armed with whatever instrument, tool or material they required and dedicated to the accomplishment of whatever end Edison set out for them. As the search for a practical light moved into 1879, the scope of effort which the Menlo Park team and laboratory made possible began to make an impact.

Between the years 1876, when Edison moved to Menlo Park, and 1881-82, when he began phasing out the laboratory there, the number of men working in the little group of buildings hard by the Pennsylvania Railroad tracks varied considerably. There were, however, never more than half-a-dozen men who were central figures in the lab's work. These individuals differed enormously in background, training and skills, but they possessed in common, at least while they were at Menlo Park, an extraordinary loyalty to Edison and faith in what they could accomplish under his guidance. The loyalty and confidence was perhaps the most important factor in making the Menlo Park laboratory an effective and productive co-operative enterprise. Even if it had been conceivable, the corporate structure of the twentieth-century industrial research laboratory was not necessary in a setting built around the inspiration and leadership of one man. Nonetheless, Menlo Park was also a place that brought out the most important talents of the individuals there — talents that were themselves critical to the successful pursuit of invention.

Unquestionably the chief among Edison's co-workers was the English born mechanic Charles Batchelor. Raised in Manchester and receiving most of his training in textile mills, Batchelor came to America at age 22 to help a Newark factory with its installation of machinery. When he shortly thereafter joined Edison at his Newark shop, he quickly became an indispensable part of the operation. Batchelor was particularly valued for the fineness of his handiwork and the painstaking care and patience he put into all he did. It would perhaps be going too far to call him a foil to Edison, but clearly much of his value lay in the extent to which his methodical manner balanced Edison's more rough-and-ready tendencies. More than anyone else, it was Batchelor who was to be found by Edison's side at the laboratory workbench.

John Kruesi was another valuable Menlo Park hand whose association with Edison dated from Newark days. Kruesi was a master machinist, whose mechanical skills reflected his Swiss background. It was his Menlo Park machine shop that was responsible for turning the roughly sketched ideas of Edison and others into real constructions of wood, metal and wire. If the devices which emerged didn't work, it was because they were bad ideas, not because they were badly made. And when the ideas were good, as in the case of the phonograph, the product of Kruesi's shop would prove it. The fact that the Menlo Park laboratory possessed the mechanical capability of a first-rate machine shop was no small element in its success. Not only did the quality of the shop's output give good designs their best chance of working, but it also allowed the rapid testing and elimination of poor concepts. It was advantages like this that set Menlo Park apart from the environment of any other inventor in the world.

Edison owed much to the members of his team, even if their contributions were not as singular as those of the lab's most skilled or knowledgeable individuals. John and Fred Ott were mechanics who worked for Edison from Newark days until well after Menlo Park. Samuel D. Mott was a draughtsman with an artistic flair who was responsible for the attractively detailed drawings of laboratory devices which are scattered throughout the Menlo Park notebooks. Martin Force was another individual whose name recurs throughout the laboratory records. He came to Menlo Park with little special training, but under Edison he became a valued laboratory assistant. The crew of Menlo Park also included chemists, metal-workers, bookkeepers, secretaries and other general laboratory helpers — all directed in their work toward carrying out Edison's designs.[1]

For years Edison had surrounded himself with skilled craftsmen, men whose abilities with machines and materials made up for his own limitations. In the search for the electric light, however, a new capability, hitherto absent from the Menlo Park lab, was called for, and it was embodied in the person of Francis R. Upton. A graduate of Bowdoin College, and a recipient of post-graduate training in physics at Princeton and under Hermann von Helmholtz at Berlin, Upton brought with him a sophistication in physical theory and scientific practice that had been lacking. That lack had hardly been noticed before, for scientific training — apart from a familiarity with the rudiments of electricity and chemistry — had never seemed relevant to Menlo Park's mission. Indeed, when Edison invited Upton to come to Menlo Park upon completion of the literature and patent survey, he was probably more attracted by the young scholar's diligence and eagerness to please than by his academic credentials. Edison had required no persuading to go along with the literature search that his backers had insisted on in November, and the (apparently) impressive manner in which Upton carried out the search, along with his obvious intelligence, was reason enough to suppose he would be useful at Menlo Park.

The manuscript records from Menlo Park do not themselves tell much about how the laboratory itself operated day by day, except what can be inferred from notebook entries. For a picture of laboratory life and routine, the most vivid source is the popular press. Much has been written about Edison's relations with journalists, and there is little question that a key element in the forming of Edison's reputation and popular following was the almost instinctive way in which he cultivated reporters — tolerating their intrusions when he would stand no others — and the grateful and eager way in which the newsmen reciprocated the favor — chronicling the miracles of Menlo Park with uncritical and bright-eyed wonder.[2] Recognizing this mutual relationship, and the mixture of ego and reportorial license that taints its product, care must be taken in using the newspapers' descriptions and pronouncements as testimony for what actually went on at Menlo Park.

Nonetheless, nothing could better give a flavor of the life and routine there than the journalists' eyewitness accounts, as in this example from the New York Herald of January 17, 1879:

> "The ordinary rules of industry seem to be reversed at Menlo Park. Edison and his numerous assistants turn night into day and day into night. At six o'clock in the evening the machinists and electricians assemble in the laboratory. Edison is already present, attired in a suit of blue flannel, with hair uncombed and straggling over his eyes, a silk handkerchief around his neck, his hands and face somewhat begrimed and his whole air that of a man with a purpose and indifferent to everything save that purpose. By a quarter past six the quiet laboratory has become transformed into a hive of industry. The hum of machinery drowns all other sounds and each man is at his particular post. Some are drawing out curiously shaped wire so delicate that it would seem an unwary touch would demolish them. Others are vigorously filing on queer looking pieces of brass; others are adjusting little globular shaped contrivances before them. Every man seems to be engaged at something different from that occupying the attention of his fellow workman. Edison himself flits about, first to one bench, then to another, examining here, instructing there; at one place drawing out new fancied designs, at another earnestly watching the progress of some experiment. Sometimes he hastily leaves the busy throng of workmen and for an hour or more is seen by no one. Where he is the general body of assistants do not know or ask, but his few principal men are aware that in a quiet corner upstairs in the old workshop, with a single light to dispel the darkness around, sits the inventor, with pencil and paper, drawing, figuring, pondering. In these moments he is rarely disturbed. If any important question of construction arises on which his advice is necessary the workmen wait. Sometimes they wait for hours in idleness, but at the laboratory such idleness is considered far more profitable

> than any interference with the inventor while he
> is in the throes of invention......"

* * * *

As the research at Menlo Park moved on, a constant consideration was financing and the confidence of the Electric Light Co. backers. It continued to be Grosvenor Lowrey's task to keep relations between Edison and the financiers on an even keel. Lowrey had what must have often seemed a thankless job, calming the nerves of the Wall Street men whose consternation at the difference between the promises of imminent breakthroughs and the obvious struggling of the laboratory efforts was quite real (and justified). At the same time, the faithful lawyer had to soothe the easily ruffled ego of the inventor, who bristled whenever doubts of his eventual success were voiced. While Lowrey's diplomacy was important throughout the period of the electric light's invention and development, it was never tested more than in the late fall and early winter of 1878-79. Men who had been lured into backing Edison by the assurances of quick success were understandably upset over the lack of visible progress. The financiers had to learn much the same lesson as Edison -- that the incandescent light was a complex invention, not to be achieved quickly or simply.

Lowrey held Edison's financing together through an adroit combination of candor and bluff. Toward the end of November he suggested to Edison that a visit to the laboratory by the Wall Street people was a good idea, despite the lack of a good light to show them: "It is all the better that they should see the rubbish and rejected devices of one sort and another. Their appreciation thereby becomes more intelligient."[3] Perhaps because he was sensitive about the problems he was running into, Edison did not always greet these visits, so Lowrey found himself delicately balancing the concern of the New Yorkers against the qualms in the laboratory. Early in December, he expressed his difficulties to Stockton Griffin, Edison's secretary:

> I have put them [a group of investors] off once or twice, telling them that we thus take up time which is of great value, but I do not like to repeat this too often. Edison must therefore allow this to be added to the interruptions, and after next Monday's visit I believe everybody will have seen what is to be seen, and he will then be left free to pursue his studies without further interruption, and strongly supported by the sympathy and confidence of his friends and associates.[4]

Following the visit that resulted from Lowrey's arrangements, he wrote Edison:

> The visit yesterday was productive, I think, of solid good results. Our friends had their imaginations somewhat tempered, but their judgements are instructed, and we now have to deal with an intelligent comprehension of things as they are, which makes both your part and mine much easier. They realize now that you are doing a man's work upon a great problem and they think you have got the jug by the handle with a reasonable probability of carrying it safely to the well and bringing it back full.[5]

Lowrey, in fact, continued to have to deal with grumbling investors, but he was always careful in his communications with Edison. After a couple of the New Yorkers returned from a disappointing trip to Menlo Park in late December, Lowrey described their impressions to Edison: "In addition to not finding you, they say that the general dilapidation, ruin and havoc of moving caused the electric light to look very small, and that it looked rather as if you were getting ready to have an auction." He then suggested that Edison should allow the Electric Light Co. men to keep a closer watch on expenses, though he hastened to assure him that whatever was absolutely necessary would be paid for.[6] Although he certainly did not say so in his letters to Menlo Park, Lowrey was probably getting nervous about the appetite for funds being shown by the effort. He hence sought to bring in major additional sources of money, the most important of which was Drexel, Morgan & Company. By negotiating on the basis of the foreign rights to Edison's light patents, Lowrey managed to get the crucial extra backing Edison needed as the new year began.

Edison's efforts were indeed beginning to be expensive. He wrote in early January to his Paris agent: "The fund I have here is very rapidly exhausted as it is very expensive experimenting. I bought last week $3000 worth of copper rods alone, and it will require $18,000 worth of copper to light the whole of Menlo Park] mile radius."[7] Expenditures like these, coming amidst reports from the laboratory that the platinum lamp was unworkable, were enough to make even the sturdiest investor hesitate. It is even more remarkable, therefore, that J. Pierpont Morgan and his associates should choose then to give Edison further backing. In a letter to Edison dated January 25, Lowrey described the remarkable scene in which Morgan affirmed his confidence in Edison's efforts despite setbacks:

> I saw...that these gentlemen were likely, in a stress, to turn out -- as I always supposed they would -- not to be very easily frightened away from a thing they once made up their mind to. All they, or I, shall ask from you is to give confidence for confidence. Express yourself, especially when you come to a difficulty, freely. You naturally, having an experience of difficulties and of the overcoming of them, in your line (which none of the rest of us can have), may feel that it would be prejudicial, sometimes, to let us see how great your difficulties are, lest we, being without your experience in succeeding, might lose courage at the wrong time. This will be true sometimes of all people, but every active mind greatly interested in a particular subject works in its own way when a difficulty is presented in finding out the causes, and reasoning against the probability of their being insuperable; and with our friends I think that would be the result in almost every instance where you yourself should show that you still believe in a possible success.[8]

In accounting for Edison's accomplishments, not least of the advantages he enjoyed over rival inventors was the extraordinary confidence placed in him by some of the greatest financial figures of his time. To be sure, this confidence was earned only after years of astonishing achievements, from which the financiers learned never to take lightly Edison's work or claims. The backing given him in 1878 and 1879, however, marked a new stage in the relationship between money and invention in America -- a glimpse of the era in which giant corporations would routinely expect technical expertise, backed by science and laboratory resources, to turn out newer and better products for profit.[9]

* * * *

As 1878 drew to a close, the work in the laboratory was gradually becoming more systematic. The nature of the technical problems that were important was becoming better understood, and the laboratory's efforts were reflecting this by becoming more focused on crucial details. Equally important, the design of laboratory experiments was changing. No longer were most activities narrowly directed toward making better devices, in hopes that a breakthrough would result, but whole series of experiments were carried out to increase the understanding of the materials being worked on and the forces being manipulated. Edison and his co-workers had absorbed the lesson that the route to success lay through a return to basic principles. Too many new phenomena and poorly understood effects were being uncovered to expect their goal to be achieved by simply redesigning devices until they worked. Backed by his assistants and by a well-equipped and well-financed laboratory, Edison could afford, for perhaps the first time in his life, to seek a deeper understanding of the scientific and technical foundations upon which he must build.

In late November and through December little progress was made in the area that had been the central concern, the lamp itself. Batchelor continued efforts to make platinum spirals that would hold up under the conditions required for incandescence. A complex device was designed for filling spirals tightly with chalk — one approach to making the spirals as tight as possible while still insulating the strands.[10] A few experiments were run to get a better sense of how the platinum wire expanded and contracted as it went through the heating and cooling cycle,[11] but the laboratory notebooks for the most part show that Edison's attention in this period had been diverted elsewhere, primarily to the problem of the generator.

Edison had devoted some effort to the mechanical production of electricity as early as mid-October, when he came up with his first designs for the tuning-fork generator. The tuning-fork design continued to appeal to Edison on into December, when he filed for his patent on the idea. For a few weeks, Batchelor continued to attempt improvements in the tuning-fork machine,[12] but by mid-December Edison was ready to move beyond it, beginning the work that continued steadily for months, until he finally had what he needed. This work started with further testing of the most popular generators then available, leading gradually to a rejection of them all. Edison explained his experiments to a New York Sun reporter:

> "I am all right on my lamp. I don't care anything more about it. Every bit of heat is utilized to producing light as far as art will allow. The theoretical and practical results are perfectly satisfactory. My point now is the generator. The Wallace machine gives me three lights, each equal to a gas light, to a one-horse power. I feel sure that I can get six with an improved machine. Probably I can get more. Now, to make my grand practical experiment here in lighting Menlo Park, I should have to use twenty or thirty Wallace machines. They would cost me from $30,000 to $40,000. They would be useless afterward, for I know that I can make a generator of double their power. So I shall postpone the experiment until I find the machine that will give the greatest amount of electricity per horse power."[13]

When William Wallace read this, he was understandably upset, and he protested to Edison that it was unfair to judge his arc light machine by its performance with incandescent lamps. If Edison would only tell him the sort of device he wanted, Wallace was sure he could supply it.[14] But Edison could not yet tell anyone what kind of generator he wanted — he simply didn't know.

Intensive efforts were made to get hold of other machines. A Siemens dynamo was ordered through Wallace, and when Edison had trouble getting a Gramme machine, he wired to Henry Morton and to George Barker, asking to borrow one.[15] When Barker suggested that he get hold of one at Princeton instead, Edison was a step ahead of him, Batchelor having already started experiments with the fairly small Princeton device. Efforts to get one of Charles Brush's generators were not so successful,[16] but Edison was apparently not concerned, having come rapidly to the conclusion that the Gramme machine was the most advanced one available, and hence worthy of the most intensive experimentation. A number of laboratory notebooks are full of the results of tests on the Gramme machine and others, as well as sketches of numerous possible armature windings, magnet orientations, and commutator designs. Edison, Batchelor and Upton spent most of the latter part of December engaged in this work, at the expense of all other activity, including work on the lamp. It is a significant aspect of Edison's method that even in this period of learning the fundamentals of generators, there are interspersed through all the notes possible new designs, with little or no theoretical justification.

The range of tests being made on the dynamos reflected Edison's perception that he needed to acquire a very basic understanding of how the machines worked and what principles might guide their modification. While some observations dealt with mundane considerations of friction and vibration, others were clearly attempts to deduce broadly-useful guidelines. For example, Upton noted at one point Edison's conclusion that, "When the internal resistance of the magnet equals external the best effort is obtained. Ohm's law applies to magnetism."[17] The work, combining always testing of the machines with modifications and new designs, was often intense. Batchelor noted several elaborate experiments on Christmas Day, and his drawings of new armature configurations and other modifications show that experiments continued without break through the last week 1878 and into the new year. On January 2, 1879, Batchelor wrote in his own notebook, under the heading, " 'Edison's Magneto Electric Mach.', Have begun to make a practical working machine after a few weeks hard study on Magneto electric principles."[18] Other laboratory notebooks, however, indicate no breakthrough in early January, but simply a shift in emphasis from tests of existing devices to constructing new ones. It would be several months yet before a truly satisfactory generator emerged from the Menlo Park lab.

* * * *

During late December 1878, all work on the lamp had ceased, making way for the intensive generator experiments. Despite the fact that the generator effort was still inconclusive, shortly after the beginning of the new year lamp-related work resumed. The new experiments reflected the systematic spirit now permeating the work at Menlo Park. Instead of being characterized by the construction of numerous lamp prototypes, each intended as potentially patentable models, the new experiments were carefully conceived tests and investigations of lamp materials, resulting in some remarkable observations on the behavior of materials under the conditions required for incandescence. On January 3, Upton began almost two weeks of tests on platinum-iridium and iron wires, recording the deformation of the wires when heated to incandescence and their changes in resistance.[19] At the same time, Edison himself began some similar observations on the kinds of changes platinum and platinum-iridium wires underwent when heated.[20] Batchelor soon joined in the careful testing, measuring, weighing and inspecting that marked Edison's intensive drive to learn more about what was actually happening when he put his chosen "burner" candidates under the rather extreme conditions of prolonged and intense heat which made them incandescent.[21]

The most remarkable example of the new experimental approach at Menlo Park was a series of observations which Edison recorded between January 19 and 29 under the heading, "Experiments with Platina and Platinum-Iridium alloys 20 per cent Ir — at the incandescent point with galvanic battery to determine any changes that may take place."[22] Here Edison systematically wrote down every pertinent detail about the behavior of the wires he was studying, adding additional materials to his original list as he went on. The resulting notes are distinguished by the obvious care with which Edison composed them and by the meticulous drawings which he interspersed throughout, aided by a heretofore little-used instrument, a microscope. Thus he noted not only the gross deformations of platinum wire as it was heated, but also the resulting changes in the structure of the material, the appearance of cracks and globules, and subtle differences in how the wires broke after they had been heated. Wires of platinum and different iridium alloys of platinum were compared not only on the basis of their different compositions, but also as they differed from supplier to supplier and by different gauges. Considerable effort went into determining not only physical changes in the wires, but also what chemical action might be taking place — careful weighing and flame tests being part of the procedure.

After a few days of working on platinum alloys, Edison shifted his attention to other metals, sometimes using foil strips instead of wires. Palladium behaved similarly to platinum, and microscope observations revealed not only the sorts of cracks found earlier but also what appeared to be a bubble. Gold proved impossible to bring to incandescence. Ruthenium, iridium, rhodium and iridosmine (a naturally occuring iridium-osmium alloy) were tested, with results that were more colorful than encouraging. Tests on platinum-iridium were varied by using a Gramme machine in place of the customary battery, or by heating a piece in an oxy-hydrogen flame rather than with an electric current. Small losses in weight were taken as evidence of some volatilization of the platinum, but the effect was hard to find consistently. A wide variety of metals was tested for fusibility in an oxy-hydrogen flame, and when Edison observed that nickel appeared to be as infusible as platinum, he determined to pursue further tests on the somewhat cheaper metal. On January 23, Edison wrote,

> "We take a piece of nickel and roll it out, cut a narrow strip and pass a current through it and very strange to say it becomes brilliantly incandescent <u>without fusing</u>. I think it nearly if not equal to platinum. It slowly oxidizes but we shall prevent this by sealing the burner. When it does fuse it acts like the Pt-Ir 20 pc alloy — it remains hard

> when incandescent. It is very probable that absolute chemically pure nickel will have a very much higher fusing point than the sample we have which is probably only commercial. This is a great discovery for the electric light --in the way of economy."[23]

Obviously, if nickel were equal to or better than platinum in the regulator-type lamp, then the economics of the light would indeed be greatly improved by the use of the more common metal.

So excited was Edison about his nickel experiments that word spread rapidly. A letter to Edison from Grosvenor Lowrey in New York, written January 25, quoted recent visitors to Menlo Park as reporting that Edison had already abandoned platinum for nickel. Rather than receiving this as good news, however, Lowrey admonished Edison to "be sure you are right about nickel and everything else before having anybody know about it," pointing out that the report of such a major change in the light's composition undermined investors' confidence in what had been achieved to date.[24] Even before he had received Lowrey's warning, however, Edison's enthusiasm for the cheaper metal had dissipated. Further tests on nickel on the 24th revealed considerable oxidation of the material even after a short period (ten minutes) of heating to a yellow heat. While investigations of the behavior of nickel under incandescence continued, tests of other materials resumed, and nickel was soon relegated to the long list of momentarily promising substances that did not stand further testing. The wide-ranging experiments continued for a few more days, and Edison rigged up an electric arc (powered by a Gramme generator) to heat up his test substances, only to have to cease after a day of looking at the glaringly bright arc, which caused his eyes to "suffer the pains of hell." By the end of January, however, Edison seemed to have satisfied himself that no other metal would do for a lamp element than platinum, and thus further work would have to concentrate on improving the capability of the platinum or platinum alloy to withstand the extreme conditions imposed by the lamp.

The January experiments did not reveal any obvious way to protect the platinum from the cracking and eventual disintegration that had been observed. Observations did seem to suggest, however, if only vaguely, that the platinum's problem lay less in the composition of the metal itself than in the environment in which it was heated. The sources of this inference are not clear from the laboratory notes, but there is no question that it was made. The clearest means for altering that environment and reducing whatever deleterious influences it had on the incandescing platinum was to minimize the environment itself -- in other words, to produce a vacuum. Hence, in late January Edison and his colleagues turned their attention for the first time toward creating a lamp in an evacuated glass envelope -- a "light bulb." There was nothing new about this concept, for the very earliest attempts to produce a practical incandescent light had involved efforts at preventing oxidation of the glowing element by enclosing it in a vacuum. At the outset of his work, however, Edison had rejected this approach, relying instead on a non-oxidizing element (platinum) which needed protection from melting rather than oxidation. The initial confidence at Menlo Park had been based on the belief that this sort of protection, provided by an electro-mechanical feed-back device, would be adequate and the insuperable hurdle faced by previous inventors — providing a permanent high vacuum for each light — could be entirely avoided. Now it seemed that it could not.

Edison's acceptance of the need to join the search for a vacuum lamp was, in part, a recognition of how deeply committed he had become to producing a successful lamp. Too much of his reputation and too much money was now at stake to allow him to pull back, even at the point where it might have looked as if he could only tred the same fruitless path broken by others before him. If Edison was daunted by this forced shift in direction, the notes from the laboratory do not show it. Some of Edison's confidence in entering this hitherto avoided territory may have been due to the knowledge that there were available improved vacuum pumps which would make his work easier than that of his predecessors. Most notable of these was the mercury pump first described by Hermann Sprengel in 1865. Sprengel's pump, a modification of the device of Heinrich Geissler, allowed the repeated evacuation of a space with such efficiency that previously unheard-of vacuums had been obtained in laboratory applications. On January 22, Edison cabled both Professor Barker in Philadelphia and Professor Morton in Hoboken asking to borrow a Sprengel pump "for a few days."[25] Neither man could provide one, and Edison had to do without (although sketchy notes made on January 23 suggest that an attempt was made to design a mercury pump for Kruesi to construct — with no known result).

Lack of a Sprengel pump, however, did not stop the pursuit of vacuum experiments, and on February 3 the first vacuum lamp was sketched by Batchelor and Kruesi.[26] Soon thereafter began a series of tests on the behavior of platinum in a vacuum using a mechanical pump. These tests were apparently guided by a hypothesis derived from earlier experiments and carefully recorded by Upton in a notebook on February 4: "An explanation of the changes wh(ich) occur in Pt. may be the following. The Pt. absorbs an enormous amount of H gas which is given off at high temperatures."[27] Edison confirmed this to his satisfaction in the tests that followed, writing, "I think from our experiments that the melting point is determined greatly by the amount of gas within the pores of the metal which by expansion disrupts the metal and makes it fuse easier."[28] Beyond this, Edison believed he had found a solution to the problem of absorbed gases: "By gradually increasing the heat the gas gradually comes out of the metal without disrupting or cracking it. Roughly speaking, I think that if the melting point of platina in the air by suddenly bringing to incandescence is 2000°C then its melting point is raised to at least 5000°C by subjecting it to the process of occluding the gas by heat in a vacuum."*[29] So taken was Edison by this effect that for the next few days he proceeded to investigate the effect of a vacuum on the melting of other metals under incandescence. He tested steel, iron and magnesium wires, yielding interesting results but little useful information. Upton continued the experiments, trying out not only different metals but also a variety of coatings on wire spirals.[30] A number of lamps were designed at this time with spirals of wire wrapped around bobbins of compressed lime or similar minerals, with the bobbins serving to support the tightly wound spirals on an insulated base.[31]

*Edison's use of "occluding" here is unconventional, and later the term is used with the opposite meaning of "absorbed."

During the month of February, the laboratory notebooks were filled with numerous designs for vacuum lamps, featuring spirals of wire with and without bobbins. Confidence was growing that the adoption of the vacuum represented a major breakthrough.

As February drew to a close, it did indeed seem as though an important new stage had been reached. On March 1, Edison prepared applications for an American patent that would protect not only the new vacuum techniques but also an approach he had only hinted at earlier — lamps of high resistance.[32] Later that Spring, he consolidated specifications into a wide-ranging application for a British patent that incorporated a number of other advances.[33] So clearly does the draft of the British specifications spell out what Edison believed he had accomplished, they deserve an extended look. He began by explaining his discoveries of what happened to platinum when it was heated for a period of time and then allowed to cool: "The metal is found to be ruptured and under the microscope there is revealed myriads of cracks in every direction, many of which are seen to reach nearly to the centre of the wire"(pp.31-33). He proceeded then to explain that he had also found that platinum lost weight when heated and that the combination of the cracking and weight loss made ordinary platinum unsuitable for use in an incandescent lamp. These patterns were caused, he went on, by "the gases contained both in the physical pores and also in the mass ,of the platinum."(p.41). Driving out the gases by heating the wire spirals in a vacuum was then described as the means for remedying these defects. He specified that a Sprengel pump should be used, and "if the mercury pump be worked continuously and the temperature of the spiral raised at intervals of 10 or 15 minutes until it attains to vivid incandescence and the bulb be then sealed, we then have the metallic wire in a state heretofore unknown, for it may have its temperature raised to the most dazzling incandescence, emitting a light of 25 standard candles..."(p.51). Finally, if the wire was coated with magnesium oxide, an even brighter and more durable light was obtained.

Having described fully the significantly improved behavior of platinum (or platinum-iridium alloy) in a vacuum, the specifications proceeded to give details of the lamp itself and the system in which it was to be placed. Here, for the first time, Edison clearly spelled out his other great discovery — the importance of high resistance:

> To obtain practically several hundred electric lights each equal to the ordinary gas jet upon one circuit it is essential for many reason(s) both (sic) on the score of economy, facility, and reliability to place them all in multiple arc and to prevent the combined resistances of several hundred lamps from falling to such a low point as to require a main conductor of immense dimensions with low resistance and generating machines of corresponding character. It is essential to reverse the present universal practice of having lamps which have but one or two ohms resistance and construct lamps which shall have when giving the proper light (resistance) of several hundred ohms.(pp.63-67)

He then went on to explain how the energy consumed by each lamp (for a given quantity of light) was proportional to the lamp's radiating surface, not its resistance, and thus high resistance lamps would require no more energy to operate than low resistance ones, but would allow the use of a "conductor of very moderate dimension." "In practice," he went on to say, "a resistance of 200 to 300 ohms in the burner will be sufficient"(p.69).

There were hints in some of the tests being carried out over the previous months that the men at Menlo Park were dimly aware of the significance of lamp resistance for the practicality of an electric lighting system. In late November, 1878, Batchelor remarked in notes on the system of nitrogen-filled carbon lamps recently introduced by William Sawyer and Albon Man, "If worked for quantity it would want enormous large conductors owing to the small resistance in each carbon."[34] (The Sawyer-Man carbon rods were reported to have a resistance of one ohm.) In an evaluation of the Werderman system, compiled at this time, Batchelor again noted the difficulty posed by low resistance lamps.[35] In mid-December, Upton noted the fact that the energy consumed by high resistance lamps in a multiple (parallel) circuit was the same as that of low resistance lamps in series.[36] Measurements of resistance — of lamps, of circuits, and of generators — became common features of tests during this period, but it was not until late February that the critical importance of high resistance lamps was clearly stated, as in the specifications just quoted. The recognition of this importance was a major breakthrough for Edison. Understanding that a viable "multiple-arc" system of lighting could not be built around the kind of low-resistance devices that other investors had turned out was a crucial step forward. It was one of the things that began to distinguish the work at Menlo Park from what had gone before. In the future, when Edison had to defend the patents protecting his invention, his most reliable claim to novelty was, in fact, the central place of high-resistance lamps in his system.

As important as the grasping of the high resistance principle was, it alone could not yield a workable light. Edison's patent drafts from this period follow the clear explanations of the uses of a vacuum and high resistance elements with descriptions of regulators that were nothing less than nightmarish in their complexity. The proposed British specifications described in detail an electro-mechanical regulator to accompany each vacuum bulb that was a maze of wires, springs, magnets and shafts. Edison explained that "the main object is to produce even illumination...not particularly to prevent the fusion of the incandescent conductor." [37] His insistence that the vacuum treatment of the platinum made a protective regulator unnecessary is hard to reconcile with the obvious complication that his regulator introduced into an otherwise elegantly simple lamp or with the fact that specifications for an American high resistance patent application prepared on March 1, 1879 made no such disclaimer.[38] The American application, however, described a pneumatic regulator, enclosing the vacuum bulb in a second glass container equipped with a diaphragm that would, as the temperature of the lamp climbed beyond desired limits, "disconnect the lamp from the circuit, where it remains until the temperature is reduced to the normal condition." These devices represented no real progress over those made in the Fall of 1878, and the continued need for them was perhaps the primary reason that Francis Upton wrote home to his father, "The light does not yet shine as bright as I wish it might, but I am not dispairing (sic) at all but that success will come sometime in the future."[39]

CHAPTER 3

"SOME DIFFICULT REQUIREMENTS"

Despite the complexity that continued to characterize his efforts, by the Spring of 1879 Edison believed that he finally had solved the key technical problems of the platinum lamp. To be sure, the varieties of regulators that he still employed were sources of trouble and would require further work. But the progress that he had made in improving the behavior of platinum through the vacuum treatment led him to announce that the lamp was essentially perfected and it was the remaining elements of the system that were holding up introduction of the incandescent light. This was made public knowledge in the typically flamboyant Edison fashion, as described in the New York Herald for March 27, 1879:

> The first practical illustration of Edison's light as a system has just been given. For the past two nights his entire laboratory and machine shop have been lighted up with the new light, and the result has been eminently satisfactory... Only two things, Edison says, are now necessary before the light can be given to the public. The first is the standard lamp to be used and the second a better generator than the one now in operation. Neither of these requirements is regarded by him as difficult of attainment.

The importance of seeing "Edison's light as a system" was widely apparent - to his backers, his co-workers, and the public at large. That Edison was not simply devising a workable lamp, but building a complex system of lamps, generators and transmission and control devices, was obvious to all. Too much credit has perhaps been given to him for his "systems approach" by twentieth century observers. It is true that a number of Edison's rivals seem at first glance to have been insensitive to the systems demands of a practical electric light, but there is also little question that his first months of work were hardly more sophisticated than theirs. Edison, like other inventors, perceived the real challenge of electric lighting to lie in the invention of a workable lighting element. It was Edison's overwhelming confidence in his meeting this challenge that led him to devote more attention to system components.

The model that the gas system provided for electric lighting was also obvious. The complexity that was implied by this model was readily apparent to nineteenth century observers. This is best illustrated by a Herald reporter writing on December 11, 1878:

> The various parts of the system of his electric lighting are probably as numerous and require as many patents for complete protection as did the system of lighting by gas, with its purifiers, gasometers, retorts and the hundred other appliances all going to make up the entire plan. Among the appliances of the electric light which will have to be served before the light as an entirety can be explained are the improved dynamo machines, the regulators, condensers, switches and coolers, besides the different portions of the light proper and the various forms of conductors and lamps to meet the diversity in the wants of the consumers. When all these are completed -and not a day passes without a marked advance toward their completion - the electric light of the wizard of Menlo Park will be ready for inspection, criticism and use, but not before.

To succeed in competition with gas, electric lighting would have to provide comparable service at a competitive price. Throughout his work on the light, Edison kept the competition in mind, gathering data on the size and cost of various gas systems, calculating the light output of the typical gas jet, and comparing the economics of gas and electric arc systems. The gas system also suggested components necessary for any successful lighting system, such as meters. As early as November, 1878, devices were being sketched out for measuring electricity consumed by users of the light.[1] A Herald article for December, 1878 spoke of the successful invention of a meter at Menlo Park; "one of the details that hadn't been accomplished," Edison was quoted as saying. This appears to have been typical Edison hyperbole, since the Menlo Park records show that little progress had been made toward a useful meter before mid-December. On the 15th, Edison crudely sketched out a meter, with the explanation, "I propose to shun a small quantity of the current through a decomposing cell of Ag or Cu and weight (sic) the deposit each month to determine the current consumed.[2] This was indeed the form of meter Edison eventually used - a design both simple in its construction and accurate in its measurements. It is doubtful that he had determined the final form of his meter as early as December, however, for he was still making sketches several months later.[3] The broad British specification that he drafted in the Spring of 1879 included the description of a chemical meter consisting of copper electrodes in a solution of copper sulphate, to be connected in a building's lighting circuit in much the manner of the first Edison system installations a couple of years later.[4]

Other devices Edison prescribed for his system at this early date included protective mechanisms "to provide against accidental crossing of the conductors leading from the mains" (i.e., short circuiting).[5] Once again, it is the detailed draft of British specifications that provides the best description of the means adopted toward this end. In the same box in which he indicated the chemical meter would go was to be placed a "safety magnet," which was in fact a form of circuit breaker. The principle of this novel device is clearly described:

> The object of this magnet is to disconnect the premises from the mains should the leading wires to the lamps be accidentally crossed or get in electrical connection other than through the bobbins of the lamps; the crossing of the wires will tend to draw a powerful current from the mains. The lever B is so adjusted by the retractable spring A by means of the screw C that the current will be insufficient to cause the magnet to attract the lever when all the lamps are in by any great accession of current such as would follow if the leading wires to the lamps became crossed. The magnet would then be powerful enough to attract B... (and) the circuit will be opened. [6]

Unlike the chemical meter, the safety magnet was not part of the system Edison eventually introduced commercially. Its place was instead taken by the simple wire fuse in a wood block holder.

From late 1878, the team at Menlo Park gave attention to system elements - both specific components and general considerations - with irregular frequency. The design of an incandescent lighting system was far from systematic. The laboratory notes and the occasional patent applications do not reveal any pattern to the work on the peripheral elements needed to make the lamp function. Sketches of meter designs are scattered among dynamo experiments. Proposals for rheostats and other control devices pop up in the middle of lamp notes. Sometimes these scattered efforts would bear fruit, seen perhaps as part of a caveat or patent application or occasionally lying dormant for months until practical needs highlighted by lamp demonstrations should press them into service. Later, after a practical lamp was a reality, various other component problems, hitherto unthought of or ignored, would call for an organized attack, but for the period when the workable lamp was still elusive (claims made to reporters notwithstanding), the detailed needs of the system were irregular diversions from the main task at hand.

The perception of the electric light as part of a system such as that built around gas lighting yielded concern not only about components but also about the over-all economy that would be required. Edison ordered the basic gas-lighting journals and gathered statistics on the cost and profitability of various urban gas utilities. He used available figures on total gas consumption to determine how many lamps a given locality probably had.[7] He made calculations to determine just how cheaply gas could be made and distributed, and then made numerous reckonings of the costs to be anticipated in an electrical system. These were used to convince himself that, when all was said and done, he would indeed have a competitive system. While there was nothing especially sophisticated about Edison's calculations, the exercise was actually a remarkable instance of product research. Unlike the other applications of electricity that had achieved importance - the telegraph, electroplating, the nascent telephone - the electric light was not designed to do something no other technology could do, but rather to compete directly with the well-established, largely satisfactory, technology of gas lighting. Hence, the question of whether the perfected electric light would be able to compete with gas not only technically but also economically was a very live one. In his public pronouncements, Edison never tired of repeating the claim that the electric light would be clearly cheaper than gas. While he unquestionably convinced important listeners -notably the gas men who backed the Edison Electric Light Co. - he found it necessary to repeat his calculations many times. He concentrated on the operating costs of the system and this focused attention even more sharply on the generator.

A typical set of figures was jotted in a notebook in April, 1879:

> "400,000 lights will require if 100 lights per machine, 4000 machines costing $350 per machine - 1,400,000 - requiring 68,000 horse power in 24 stations, 2833 h power in each, cost of this power for 4 hours $2,720. Total cost plant $6,000,000 interest at 10 p.c. $600,000 yearly.
>
> | | |
> |---|---|
> | Interest: | $ 600,000 |
> | Power, etc. | 992,800 |
> | | $ 1,592,800 |
>
> If gas consumers would burn in 4 hours at 4 feet per burner 6,400,000 at 2 per M $13,000 roughly or in year 4,745,000 if at one per M 2,372,500 at this price our cost $1,592,800 - our profit at $1 per 1000, $779,700.

It should be noted that Edison's "profit" consisted of the full difference between the price of gas and that of electricity - clearly the consumer was not thought to have much to say in such matters. So much was still unknown about the final shape of the Edison lighting system that such figuring was, in truth, a bit fanciful. Nevertheless, they reveal Edison's consciousness of the clear economic necessities of his promised invention. More then ever before, technical triumphs would not be enough - truly competitive solutions would be required.

While, in the Spring of 1879, the lamp was still far from satisfactory, Edison felt that it was time to tackle in earnest the problem of the generator. The capacity and efficiency of his power source, after all, would clearly be the key to the economy of his system. He was certain that, whatever lamp finally emerged from his experiments, it would be an efficient converter of energy into light. He was equally convinced that the generators he had seen and tested - Wallace's, Siemens's, Gramme's, and others - represented a primitive stage of development. With typical cockiness, he set out, more seriously than ever, to make a fundamental advance in generator technology. Behind his confidence was the feeling that after several months of work he finally did know the characteristics of the machine he needed. When he had rejected the Wallace dynamo in the Fall of 1878, he had done so more from a perception of general inefficiency than from a knowledge of its specific shortcomings as the power source for his system. Now, by February 1879, Edison had a better sense of the kind of generator he wanted and, in the newly systematic spirit he had already applied to the lamp experiments, he brought the resources of the laboratory to bear on the problem.

Edison, Batchelor, and Upton began in February to run systematic tests on the dynamos they had on hand and on modifications of their own devising. A dynamometer was rigged up to measure the amount of work going into running the generators, and measurements were made of resistances, field and current strengths and resulting electromotive forces (e.m.f.). Attention was focused on three design considerations: commutators, field magnets, and armature windings. Many references are made in laboratory notes to commutator modifications, although these were directed more at solving the practical problems all direct-current generator designers had experienced in commutation rather than making any significant departure in concept. Many pages of notebooks were filled with armature winding patterns, and the devising of new patterns almost reached the level of a popular sport at Menlo Park during February and March. At first, the armatures were tried out in modifications of Siemens or Gramme machines, but soon the entire configuration of the generator, especially the size and shape of the field magnets, became the object of experiment. By mid-March, this work produced the basic design for the dynamo that Edison successfully introduced in his first lighting systems. As in all of Edison's work in this period, the development of this design owed little to theoretical understanding and much to the ability of the Menlo Park mechanics to execute model after model, modification after modification, as ideas came popping out.

There was a theoretical foundation for Edison's generator work, but it is only dimly perceivable in the many pages of notes and work orders devoted to the problem. This can hardly be considered a peculiarity of Edison's method, for, in truth, there was only a small and unreliable body of theory available to any would-be dynamo inventor (a state of affairs that did not begin to change until the work of John Hopkinson in the mid-1880's). Edison, like most others, was still relying on Faraday and his almost half-century old conception of cutting magnetic lines-of-force with a conductor; the more lines of force crossed in the most direct manner, the more productive the generator. The most successful machines of the 1870's, those of Gramme and Siemens, worked by employing armatures with many windings and fitted as closely as possible to the poles of an electromagnet. The basic difference between the Gramme and Siemens devices was in the pattern of armature winding. The Gramme winding was adopted from the ring winding devised by Antonio Pacinotti in 1860, and consisted of a hollow cylinder in which the armature wires were laid down side-by-side around the cylinder. Siemens' approach, on the other hand, employed a drum in which the wires were wrapped length-wise around the armature, crossing near the center at each winding. Edison experimented extensively with both of these approaches, and he patented dynamos based on both types. Nonetheless, the considerable number of rough armature drawings in the February and March notebooks reflect increasing attention to the Siemens or drum approach. Page after page was filled with possible alternatives for drum winding. The reasons for settling on this approach were not spelled out, but it was an important step, for the drum armature turned out to be the basic pattern for almost all significant generator development subsequently.

The adoption of the drum armature, while important to Edison's success, was hardly a breakthrough. That came when the Menlo Park models began to incorporate changes in the field magnets of the generator. The "long-legged Mary-Ann" dynamo that was to be the prime power source for Edison's lighting system in its first years was distinguished most by the two large iron poles that were the inspiration for its nick-name. The source of the idea of placing the dynamo's armature between the poles of a powerful, over-sized magnet is not known, but the concept cannot have seemed too subtle to Edison's literal mind. The giant magnet of the generator would be a concentrated source of Faraday's lines of magnetic force, and the turning of a low-resistance armature in such a powerful field would naturally, so it may have been reasoned, be a productive source of power. The notebooks of Menlo Park do not give many clues to the reasoning behind the design, but they do document its emergence and the gradual realization that it marked the end of the search for a generator. On March 13, 1879, Charles Batchelor put instructions in the machine shop order book for yet another generator model: "58. Alter small magneto machine by taking the shell (armature) and putting it in between two powerful poles, so —" The accompanying sketch specified that the cores were to be 24 inches long and 4 inches thick.[10] Order number 58 was followed by two further orders for even larger magnets, one of them specifying, "Take the bar of iron that comes tomorrow 13 foot long and cut it in two and make a magnet of it."[11] John Kruesi noted under order 58 that he finished it on April 12th. The results were apparently so interesting that on that date Batchelor put in another order (number 127) for modifying what he called the "small Edison Faradic."[12] A week later the design was referred to as "our Dynamo."[13] Yet later, on May 1st, another version of "58" was ordered (number 150), with poles three feet long and six inches in diameter.[14] This was clearly the emerging design, even though other concepts were not yet entirely abandoned.

For all the simplistic appearance of Edison's development of the long-legged Mary-Ann generator, there was a fairly rapid comprehension of the principles behind that machine and its success. This is best revealed in the long and complex British patent specification prepared later in Spring of 1879. Here

Edison told not only the details of his design, but justification for it:

> I have ascertained by means of the Dynamometer for measuring energy applied in foot pounds and by the electrodynamometer for energy obtained in the electric form reduced to foot pounds that the practice of making the leading wires and lamps composing the extraneous resistance equal to the internal resistance of the machine, although the most effective for obtaining the maximum current, but is by no means so economical as when the extraneous resistance is many times the internal resistance of the machine, especially with machines which have a constant field magnet.[15]

The moment that Edison made this important distinction between the capacity of a generator to produce maximum current (which did require equal internal and external resistances) and the capacity of a generator for maximizing total power output (which called for considerably reduced internal resistance compared to external load) is not clearly set out in the laboratory record, but it was a great step forward in generator design. In practice, this principle was applied by reducing the amount of wire in the drum armature. Edison's significant innovations in construction of field magnets were also covered by the draft British application, claiming "that great economy is obtained by increasing the electromotive force of the current by the use of powerful field magnets in lieu of high speed of the induction cylinders or rings (armatures), such magnets being kept up by extraneous energy."[16] Finally, he also asked patent protection for his use of magnets "of great mass," but without explaining their benefit.

The recognition of the success of the new generator design was revealed in other ways as well. In a letter to his father written April 13, 1879, Francis

Upton spoke of frustration with the lamp, but "during the past week we have tried a new magneto machine and found that it was a great success."[17] And at the end of April, Edison spoke in his customarily unrestrained way to a reporter from the New York World, boasting "I have had my generator constructed and I tried it for the first time last night. It developed so much power that the coil on the bobbin was torn to pieces and I had to stop."[18] He went on to claim that shortly he would demonstrate the superiority of his machine by matching its performance with that of Gramme's and Wallace's machines, using arc lights for the load. It is a little surprising that Edison would propose such a test, given the special suitablity of his dynamo for his proposed high-resistance incandescent system. Indeed, in the same interview, Edison spells out the importance of the high-resistance approach to his system - "The resistance of my lamp is as 192 against 1 to the resistance of the carbon [arc] lamp... The point is that the more resistance your lamp offers to the passage of the current, the more light you can obtain with a given current." He then admits that he had not always considered his task as system-building.

> When I first started out on this thing, I took into consideration only the lamp, but I soon became convinced that it was necessary to have a more powerful generator and feasible plan of sub-dividing the light. The generator was the last fact accomplished, and you will soon see for yourself how it works.[19]

* * * *

At the same time that Edison was announcing the success of his generator and the importance of high resistance lamps, the U.S. Patent Office granted his patents for the regulator lamps he had devised months earlier.[21] The newspapers duly reported the details - the New York Herald filling three full columns (April 25, 1879) - and assumed that they represented the state of the art. In its editorial columns, the Herald went on to say that "no recent addition to scientific knowledge is more important." The platinum lamps, with their complex regulating mechanisms and their fragile strips or spirals of precious metal, were seen to present immediate threats to the gas industry: "It begins to look," the Herald continued, "as if the vast capital of the gas companies of all the cities of the world is to be annihilated by the new invention." When a Herald reporter hurried out to Menlo Park the next day, Edison said nothing to disabuse the industrious newsman of his incautious optimism. Consequently, the Herald editorialized further: "The success of the Edison light opens a new and vast field for enterprise, ...and it will probably rank as the most important scientific discovery of the century."[22] If in the coming months the Wizard of Menlo Park was occasionally looked upon as a humbug, it was not without some justice.

If this judgement seems a bit harsh, the evidence is clear that in the Spring of 1879, the search for a workable lamp was entering its most frustrating stage. After months, Edison felt he knew what he was looking for: a light of between eight and twenty candle-power, with a sufficiently high resistance to make it practical in a parallel circuit on an extended network (several hundred ohms, if possible), made stable by enclosing in a very good vacuum, and with a burner of a heat-resistant material, such as platinum. The basic picture of the lamp had not really changed much in Edison's mind since the prototypes of September and October, even if crucial technical details (such as the vacuum and the resistance) had been added. This is perhaps the reason that Edison did little to dampen the Herald reporter's enthusiasm for the early regulator lamps when the patents finally appeared in April. He only reminded the newspaperman that the applications had been filed months before, and remarked, "we have done some work on the subject since then."[23] In six weeks, he promised, the lamps would finally be ready for public inspection. Six weeks later, however, as summer was beginning, everything had come to a standstill, the lamp still frustratingly elusive and the pressure of other commitments pushing the electric light aside.

The work on the lamp in the Spring of 1879 may be divided into four areas of concern: 1) regulator, 2) material, 3) vacuum, and 4) insulation. The regulator was still looked upon as an inevitable feature of the electric light. Edison simply did not consider making a lamp without a thermo-mechanical or electro-mechanical feed-back device for cutting a lamp out of the circuit as its temperature rose close to the fusing point of the incandescing element. The early regulator concepts were still the ones he relied on, with both the pneumatic and the thermostatic approaches seeing use. Because the fundamental problems were thought to lie elsewhere, regulator design was not a matter of steady experimenting; instead, a flurry of ideas would emerge at intervals, often expressed only in sketches of varying finish. There was such a flurry in early April and a number of the rough notebook sketches were sent to Kruesi, along with orders for models.[24] There is no indication of how these ideas fared in the testing, and it is also not clear what sorts of departures they represented from the standard approaches. It was several months, however, before the record showed another regulator design, and the problem was never again the subject of intensive work.

The focus of lamp efforts continued to be on the "burner" - solving the problem of preventing a material heated up to unthinkable temperatures from destruction, through melting, volatilizing, burning, or cracking. The first attack on this problem was always to eliminate it or at least minimize it by finding the most suitable available substance. The long list of Winter experiments on various metals, common and rare, had been part of this effort. Those experiments eventually failed to turn up anything better than platinum or platinum-iridium. Now, in the Spring, the workers at Menlo Park generally felt there was little more to be gained by searching for alternative substances. In mid-April, spirals made of pure iron and of aluminum were put into lamps, but with such unimpressive results that the tests were not repeated.[25] As far as Edison was concerned, the electric light would be a platinum light and time would be better spent in securing good sources of the precious metal than in trying to find something cheaper.

Since platinum was the best available material for a lamp, research must then be directed to finding ways to maintain better the incandescent platinum and to make sure that it had the properties required by the system, notably, a high resistance. The vacuum and insulation experiments were aimed at these goals. The first vacuum experiments in February had convinced Edison that keeping the platinum in as good a vacuum as possible was indispensable to having a lamp that would last satisfactorily. The Menlo Park lab was equipped with the best pumps available, and in late March received a new Geissler mercury pump from the New York instrument house of Reinmann & Baetz.[26] With these instruments, getting a good and permanent vacuum in the glass containers he had adopted for the lamp was still difficult and time-consuming work. It must have been an exhausted Edison who jotted down in a notebook, "We was all night bringing up 12 lamps in vacuum. Worked all day Sunday, all night Sunday night, all day Monday."[27] A month later, Edison wrote to a correspondent that "my time is wholly taken up from 16 to 18 hours a day with vacuum pumps and time experiments."[28] Others at Menlo Park also found the work slow, Upton writing home, "It is hard to make the lamps we want though we can make very good ones. We have placed our hopes very high for we can make lamps with a few hours of life which are extremely economical and there seems to be no reason why we cannot make them last many hours in time."[29]

* * * *

By spring, the Menlo Park workers were concerned with more than simply making pieces of platinum last longer in a lamp. They had determined that their lamp required a very high resistance to work in a practical circuit, and this placed additional limits on the form of the platinum burner. Platinum is not a highly conductive metal, having a volume-resistivity of about seven times that of copper, and a 20% iridium alloy of platinum has almost twenty times the resistance of copper (for a given length and cross-section of wire). Nonetheless, the very high resistances Edison sought for his lamp would require a considerable length of platinum wire in each lamp. In attempting to calculate his requirements, Edison was entering a still murky area. For example, notebook figures probably made sometime in April begin with a measurement of resistance in a 16-inch piece of .009 inch wire of 2 ohms at room temperature (62°F). Edison estimated that the resistance of the same wire heated to incandescence would be increased five-fold, to 10 ohms. A wire with half the cross-section (.0045 in.) would have four-times this resistance; one with a quarter the original cross-section (.00225 in.), sixteen times, and so forth. Thus a 16 inch platinum wire with a .001125 inch cross-section would have a resistance of 640 ohms at incandescence; a 32-inch wire would have twice this resistance, or 1280 ohms, according to Edison's calculations. The conclusion was that "there is no difficulty in making a lamp having 2 or 3000 ohm resistance."[32] For a lamp to have an appropriately high resistance however, it would be necessary to have as a burner the longest and thinnest possible length of platinum wire, packed into the tightest possible configuration.

This conclusion, firmly based on Edison's and Upton's understanding of the physical laws governing the resistance and the energy input and output of the lamp and its circuit, drove the work at Menlo Park down paths no one had ever pursued before, paths that were in the end to prove dead-ends, but the bold pursuit of which illustrated better than anything else the extraordinary capabilities of the laboratory that Edison had at his disposal. To pack a long length of platinum wire into a tight spiral, it would be necessary to coat the wire with an insulating material, thus allowing successive winds of the coil or spiral to touch one another without short-circuiting. Much effort thus was directed toward developing a material that would: 1) adhere to the wire; 2) provide good electrical insulations; and 3) withstand the extreme heat of the incandescent platinum. Months before, Edison had concluded that an efficient lamp that gave off relatively little heat for its light would require a very compactly wound wire spiral. It was therefore already standard practice to wind the platinum wire around small spools of compressed lime, which provided a refractory support for the spirals. It was widely believed among those at Menlo Park that the discovery of a suitable "pyro-insulator" for the wire spirals was the last remaining step in the creation of a suitable lamp.

The search for an insulating material was pursued intensively during much of the spring of 1879. In late March, Batchelor directed his attention to such substances as "acetate of magnesia, acetate of silica and oxide of cerium."[33] Other candidates included barium nitrate, magnesium nitrate, sodium tungstate, calcium acetate, calcium nitrate, calcium chloride, aluminum nitrate, and zinc acetate.[34] By April the list of candidates had become extensive and sometimes bizarre: magnesium acetate mixed with rubber, an amalgam of magnesium and mercury, magnesia mixed with gutta percha in chloroform, plaster of paris, silk coated with magnesia, pipe clay mixed with magnesia, and so forth.[35] The coating experiments were in Batchelor's hands and he was clearly willing to try anything once. Among the substances he proposed in early April were compounds of cerium and zirconium, which were to emerge later as the most promising possibilities of all. The April experiments, however, ended inconclusively and the insulation problem remained a major source of concern.

Frustration with the insulation experiments combined with the press of other business - especially Edison's telephone, which was now being vigorously marketed in England - to push the electric light work aside as spring drew to a close. Even in May, few experiments were performed and the only significant light-related activity was the commissioning of an international search for sources of platinum. Late that month, Edison informed the Electric Light Co. of his plans to send a man through Canada and the western United States to check out unexploited platinum sources. A circular was prepared for wide distribution to western postmasters and Edison responded eagerly to western correspondents who thought they might have what he needed. At the same time, Edison ordered a long list of books on mineral resources in the western United States and Mexico.[36] Finally, Frank McLaughlin, a Newark acquaintance, was sent out, first to Canada and later to the West, to pursue the search. Throughout the summer of 1879, there arrived at Menlo Park ore samples from McLaughlin and from respondents to Edison's circular, and these were all dutifully assayed by John Lawson. Methods were devised for separating out platinum from "black-sand," and inquiries were made to officials ranging from the Superintendent of the U.S. Mint to the U.S. minister in St. Petersburg, Russia.[37] Since platinum was indeed to play a role in the electric light, though not the one Edison originally saw for it, these efforts were not wasted. Irrespective of their final significance, however, they were the primary light-related activities for most of May, June and July, as the Menlo Park lab was mobilized to solve urgent technical and production problems with the telephone.

This period marked the most significant lull in electric work since the challenge had been taken up the previous Fall. In May the dynamo received a little attention, and during June and July some time was taken up with dynamometer tests of the latest model "Faradic machine." A few scattered auxiliary devices show up in notebooks - a meter design, notes on conductors and conduits, and a new type of dynamo regulator. The lamp itself was untouched until late July, when laboratory resources were once again brought to bear on a variety of problems, including possible alternatives to platinum, new regulator designs, "pyro-insulation," and perfecting the vacuum pump. At this time there begins a period of dogged experimentation, characterized not by the testing of novel approaches or devices, but by a persistence in following chosen paths, a persistence remarkable in light of the limited progress that emerged to encourage it. A few individuals were given projects that occupied much of their time for weeks. Charles Batchelor continued his attack on the problem of finding a suitable insulating coating for the long platinum spirals. Francis Upton, assisted by Francis Jehl, devoted himself to testing a simplified lamp design consisting of platinum spirals in high vacuum bulbs without regulator mechanisms. The record of weeks of other disappointing results reflects, possibly, a new maturity in the Menlo Park approach; no longer was work centered around the testing of flashy new ideas in hopes of quick and easy solutions. On the other hand, there was undoubtedly a depressing air about the late summer, early fall work, weeks of hard work with barely any sign of progress.

In one area, however, a capability was being developed that would prove crucial to eventual success - the ability to produce better and better vacuums. In August, Edison added to the Menlo Park crew a full-time glass blower, Ludwig Boehm, who had apprenticed under Heinrich Geissler himself. For months, experiments had been using both Sprengel and Geissler pumps to evacuate platinum lamps, and a part-time glass blower had been engaged to keep the complex devices in order and to make modifications as required. The recruitment of Boehm, however, signified the depth of Edison's belief that a superior vacuum was indispensable to a practical lamp. Both Batchelor and Upton tried their hand at improving the pump design, seeking not only better vacuums but also, presumably, faster exhaustion, since the slow-working of the simple mercury pumps put severe limits on the pace of experimenting.[38] After several weeks of work, a complex combined Sprengel-Geissler pump was constructed, giving the Menlo Park lab what was probably the best vacuum pump in existence.[39] The new device was very difficult to keep in working order, and its use required careful attention to the sequence of operations (as well as a good deal of work lifting mercury, as Francis Jehl vividly recalled decades later), but the result was an unquestioned success. Edison's conception of the role of the vacuum in his lamp at this stage is not wholly clear. There is no evidence that the platinum lamps were troubled by oxidation, although possibly some of the insulating coatings were subject to reaction with hot gases. The most promising coatings, however, were not (being oxides themselves), and the interest in a vacuum was, in any case, independent of the coating experiments. Ridding platinum of occluded gases was the original function of the vacuum experiments, but the time-consuming tests that Upton and Jehl ran on platinum spiral vacuum bulbs during August and September suggest that purely empirical results were the basis for continuing efforts. Whatever the reason, platinum spiral lamps gave more light and lasted longer in a high vacuum.[40]

By early October, the Menlo Park lamp was a much simpler, more elegant, device than it had been a year before. It consisted of a platinum spiral, containing only a few inches of wire, mounted in the middle of a sealed glass globe, exhausted to the best vacuum ever known. Gone was the complex mechanical regulator that had so long seemed indispensable. Gone, even, was the lime bobbin thought necessary to support a long, tightly wound wire spiral. What remained looked, in fact, much like the modern light bulb.[41] Unfortunately, it still didn't work. Once or twice a bulb of this type was successfully raised to sufficient incandescence to yield eight candle-power. But none lasted more than a few hours or could tolerate more than the minimal current for incandescence. And their resistance did not exceed three or four ohms, making a mockery of Edison's carefully specified requirements for his "system." On October 8, Upton wrote in his experimental notes, "At this date the trouble is to get an insulation for the platinum wire."[42] The workers at Menlo Park were, in fact, very close to success, but the direction in which it lay still eluded them.

CHAPTER 4

THE TRIUMPH OF CARBON

Much has been written about the events at Menlo Park in October of 1879, the most pivotal month in all of Edison's electric light work. Despite the attention that the activity of these autumn weeks has received, from the contemporary newspaper descriptions to the latest Edison biographies, there remain many questions about the new turns that the research on the light took. The uncertainty still surrounding the developments of that October is due to no small degree to Edison and his colleagues, who chose to romanticize the activity in the many subsequent years of description and explanation — in large part, no doubt, to conform to popular notions of an inventor's moment of triumph. Unfortunately, biographers and other scholars have also been influenced by such notions, so that most popular accounts weave together indistinguishably the threads of simplistic reminiscences, sensational journalism, romantic suppositions, and incomplete documentary evidence. Because the written record is indeed less than satisfactory, it may not be possible to do much better than simply to make the threads of the oft-told tale of the final triumph of the incandescent light a bit more distinguishable in their varied origins and foundations, but there is unquestionably something to be said for bringing to bear on this story the critical sense the historian is traditionally pledged to maintain.

The first description of October's success was published a mere two months later, when New York Herald reporter Marshall Fox, with the cooperation of Edison and the active assistance of Upton, scored the biggest scoop of his career with his full-page story of "Edison's Light - The Great Inventor's Triumph In Electric Illumination." The appearance of the story in the Sunday Herald of December 21, 1879, was said to have dismayed Edison, who felt it was pre-mature to be put in the position of promising public demonstrations. If so, it was the first time he had shown such reticence to have the press announce a triumph, real or imagined. Nonetheless, Edison later said that Fox's account was the most accurate description published at the time. Since it was an effort to provide an informed insider's view of the "triumph," and it provided an obvious foundation for subsequent stories, it is worthwhile looking at Fox's picture of the state of affairs at Menlo Park in October.

> The lamp, after these latter improvements, was in quite a satisfactory condition, and the inventor contemplated with much gratification the near conclusions of his labors. One by one he had overcome the many difficulties that lay in his path. He had brought up platinum as a substance for illumination from a state of comparative worthlessness to one well nigh perfection. He had succeeded, by a curious combination and improvement in air pumps, in obtaining a vacuum of nearly to one millionth of an atmosphere, and he had perfected a generator or electricity producing machine (for all the time he had been working at lamps he was also experimenting in magneto-electric machines) that gave out some ninety percent in electricity of the energy it received from driving engine. In a word, all the serious obstacles toward the success of incandescent electric lighting, he believed, had melted away, and there remained but a comparative few minor details to be arranged before his laboratory was to be thrown open for public inspection and the light given to the world for better or for worse.
>
> There occured, however, at this juncture a discovery that materially changed the system

> and gave a rapid stride toward the perfect electric lamp. Sitting one night in his laboratory reflecting on some of the unfinished details, Edison began abstractedly rolling between his fingers a piece of compressed lampblack until it had become a slender filament. Happening to glance at it the idea occured to him that it might give good results as a burner if made incandescent. A few minutes later the experiment was tried, and to the inventor's gratification, satisfactory, although not surprising results were obtained. Further experiments were made, with altered forms and composition of the substance, each experiment demonstrating that at last the inventor was upon the right track.
>
> -- New York Herald, December 21, 1879

Like all previous experimenters on incandescent electric light, Edison had tried carbon very early in his work. He claimed to have tested carbonized paper as early as 1877, but found that it burned up almost immediately with even a very small current. This was the same result that experimenters had met with as far back as Humphry Davy in 1802, so Edison had not wasted much of his time with carbon, but rather went on in search of a material that resisted oxidation even at the high heat of incandescence, such as platinum. Just how and why the focus at Menlo Park should shift that October back to carbon is not completely clear, but that shift marked the final step from frustration to success.

The renewed attention to carbon possibly came about somewhat as Fox described it — the result of unthinking handling of a material very common in the Menlo Park lab those days, thanks to continued commitments involving Edison's carbon telephone transmitter. What Fox left out, and what can be pieced together only imperfectly, is the train of reasoning that should lead from a crude thin rope of lampblack in the inventor's hand to a carefully shaped incandescing filament in an evacuated glass bulb. To reconstruct this reasoning, it is necessary to bear in mind what Edison truly believed he had accomplished by the Fall of 1879, and what he knew he still lacked.

The lamp, as of the beginning of October, was certainly not "in quite a satisfactory condition." Upton, Batchelor, and others were still wrapped up in efforts to coat the platinum wire "burners" with an insulating compound that would both remain effective under the extreme heat of the lamp and also adhere easily to the wire. In truth, except for the remarkable improvement in vacuum apparatus, the lamp was little advanced from the preceding spring. Edison was surely aware of this, and this fact alone suggests why he was willing to try such an odds-on shot as his lampblack filament. But failure was not the only spur. After working for more than a year on the light, Edison firmly believed he had learned some very valuable things about the end he had in mind. One of these lessons, annunciated very early in the search, was his "electric light law," which held that the heat and the radiating surface of an incandescing element had to be maximized for an efficient light to result. The consequence of trying to maximize both of these factors very early led Edison to adopt the coiled spiral as the best shape for his light-producing element. A little later, the conviction that a practical electric lighting system required high resistance units in a parallel circuit reinforced the attention given to spirals, since this shape maximized the length of thin wire (and hence the resistance) that could be put in a single lamp. Making a spiral from metallic wire presented no problem, but making one from carbon was obviously less straightforward.

On October 7, 1879, the day before Francis Upton wrote in his laboratory notes that finding an insulation for platinum wire was the key outstanding problem, Charles Batchelor sketched in another notebook some possible approaches to making carbon spirals. The extent to which the carbon spirals were thought of as analogous to the familiar platinum spirals is clear from Batchelor's comments:

> "Made a mould for squeezing, put in some Wallace soft carbon, and squeezed it out of a hole .02 diameter getting it out a yard long if required. Could make more even sticks by rolling on glass plate with piece of very smooth wood. These sticks could be rolled down to .01 (inch diameter) and then wound in spirals. We made some and baked them at a red heat for 15 minutes in a closed tube. When taken out they were hard and solid much more so than we expected and not at all altered in shape. A spiral made of "burnt lampblack" mixed with a little tar was even better than the Wallace mixture. With a spiral having 5 inches of wire of .01]inch diameter] we can get 100 ohms. We now made a double spiral on brass so as to wind the carbon so similar to some of the first platinum spirals we made.

The two key, interrelated, considerations for any possible filament material were resistance and the capability of being wound into a spiral. Batchelor's notes of October 7 strongly suggested that lampblack could be made to qualify by these standards, but the workers at Menlo Park were in no hurry to prove that this was a path to the desired lamp. A few days later, on the 11th, Upton put a carbon stick in a Wheatstone bridge and measured its resistance as it was heated. An 8-inch rod, .06 inch in diameter, yielded a resistance of only 5.5 ohms and as it was heated by the current, the resistance decreased. This was obviously disappointing, since all pure metals increase their resistance on heating, and this was the desired effect in a lamp. Upton jotted down Edison's surmise "that pure carbon would increase its resistance on heating. That the cause of ordinary carbon decreasing is that the fine particles make better contact with each other (when heated)."[2]

He was sufficiently encouraged to note that he was "trying to mold sticks of .010 in diameter and to make them into spirals." But this was not a major priority since subsequent notes over the next few days made no reference to carbon, involving instead a silica insulation for platinum spirals and difficulties encountered with the vacuum pump.

In reconstructing the events of late October, it is important to understand the division of labor then in effect at Menlo Park. While Upton, assisted by Francis Jehl, was devoting all of his time to the incandescent light experiments, Edison, Batchelor, and others were deeply involved in a number of projects, some much more pressing than the light. Of particular importance were demands put on them by Edison's telephone enterprises. In terms of immediate applicability, the most important inventions to have yet emerged from Menlo Park were Edison's contributions to telephone technology -- the carbon-button transmitter and the chalk-drum receiver. Three years after Alexander Graham Bell had introduced his first device, the highest state of the telephonic art in 1879 was a combination of Bell's electromagnetic receiver and Edison's carbon transmitter. The superiority of the carbon transmitter over all rivals was widely recognized, and Menlo Park served as the primary source for the carbon-button that was at its heart. In the fall of 1879, not a week would pass without the receipt of requests for hundreds of the compressed carbon buttons, which were produced by a crew of men working from a shed filled with smoking kerosene lamps.[3] Menlo Park always served as not only a research laboratory but also as a small manufacturing establishment, depended upon as a source for the advanced-technology products of the 1870's.

Even more distracting that October were the demands of Edison's other telephone device — the chalk-drum receiver. Exemplifying a phenomenon that was to be common in the high-technology industries of the twentieth century, the chalk-drum device was less a real contribution to telephone technology than it was a means for avoiding patent conflicts. The Bell ownership of the basic telephone receiver patent put a major obstacle in the way of any rival efforts in the field, thus frustrating exploitation of the Edison transmitter. Western Union control of the carbon-transmitter patent in the United States removed any incentive for Edison to attack this problem, until overseas efforts began to take shape. When the Edison Telephone Company of Great Britain, Ltd. was established in 1878, the problem of the Bell receiver patent had to be met head-on. The chalk-drum receiver was Edison's remarkable answer to the problem, for this device completely avoided the electro-magnetic techniques of the Bell receiver. The "electromotograph" telephone relied on the observation that Edison had made years earlier that the friction of an electrode moving over a moist chalk surface varied with the current flowing between the two. The receiver that he constructed on this principle required the listener to turn a crank connected to the small chalk drum while using it, but for his trouble the device produced a much louder sound than the Bell telephone. The Edison interests in England took up the new receiver gratefully, and the professional community was hardly less enthusiastic at first, the journal Engineering declaring the Edison receiver and transmitter "the most perfect telephonic system that has yet been put forward."[4]

While the chalk-drum receiver did indeed give the Edison telephone a protected route to European markets, it turned out to be a difficult and bulky device in practice. The carbon transmitter was a wonderfully simple and reliable mechanism, but the new receiver was hard to use or maintain. Customers resisted having to keep a crank turning while carrying on a conversation. Worse, the receiver turned out to be delicate and tempermental, especially since it was difficult to keep the chalk-drum properly moist. Dry drums were a problem in shipping as well, often arriving in England cracked or broken.

The crew at Menlo Park found itself occupied with trying to solve the problems presented by chalk-drum manufacture, shipping, and use. During the early fall, Edison was devoting much of his own time to these problems, and Batchelor, along with most of the laboratory staff were having to divide their time between light research and demands of the telephone business. It is for this reason that laboratory notes reveal barely any electric light activity by Edison for the entire month of October and a two week lapse between the 7th and the 21st for Batchelor.

On October 19, following several days of difficulties with the vacuum pump, Upton wrote in his laboratory notes that he had returned to carbon: "A stick of carbon brought up in a vacuum to 40 candles (say). Mr. B. trying to make a spiral of carbon. Grease in the pump. Gauge broken. Trying to make carbon spirals." A couple of days later, on the 21st, Upton added to these remarks, "Stick of carbon about .020 and] inch long gave cold 4 ohms, incandescent 2.3 ohms, very good light. Pt. wires melted."[5] This same day, "Mr. B." — Batchelor -- resumed the record of his own carbon lamp experiments, proceeding toward the actual breakthrough by his customary thorough and careful steps. He first described a series of attempts at making spirals from the tar and lamp-black putty. The putty itself was of no use in a light, since it contained a number of compounds that were either volatile or fusible at high temperatures. The putty spirals had therefore to be carbonized — to be baked in an airless container until volatile compounds were driven off and only a skeleton of pure carbon remained. The carbonizing stage, however, was always the stumbling block in the forming of usable tar-lampblack spirals, and Batchelor proceeded to investigate the nature of the problem. When he tried to carbonize pieces of the putty in a glass tube he was able to observe the hot putty giving off a "yellow oily liquid" which he guessed was "benzole" (i.e. benzine) or a similar compound. This, he surmised, was a cause of the difficulty in successfully carbonizing spirals.[6]

Making spirals was still a key goal to Batchelor. Indeed, his notes at this point dwelt on the problem to such a degree as hardly to betray at all how close he was to a major breakthrough:

> "Electric Light Carbon Wire -
>
> A spiral wound round a paper cone no matter how thin always breaks, because it contracts so much. If the heating is done slowly this is modified but with the present proportion of tar and lampblack it will always break... One of the great difficulties

> is to keep the spiral in position whilst you carbonize it. This might be remedied to a great extent by using a hollow sleeve winding the spiral inside with something to hold the ends whilst they are being fastened to the leading wires."[7]

October 21st, as far as the laboratory record reveals, came to an end without the dramatic success that subsequent accounts of the electric light's invention attributed to it.

The 22nd of October, however, saw something clearly different. Batchelor's notes of that morning do not suggest great drama, but the activity of Menlo Park took a definite turn, as all the laboratory accounts make clear. In his notebook Batchelor wrote:

Carbon Spirals - 9 A.M.

> We made some very interesting experiments on straight carbons made from cotton thread so:
>
> Pt. Cotton Pt.
> *----------*------------*----------* * *
>
> We took a piece of 6 cord thread No. 24^{s} which is about 13 thousandths (of an inch) in thickness and after fastening to Pt wires we carbonized it in a closed chamber. We put in a bulb and in vacuo it gave a light equal to about] candle 18 cells carbon, it had a resistance of 113 ohms at starting and afterward went up to 140 --probably due to vibration.[8]

There is no reference here to how long this feeble light lasted. On the same day Upton referred to the same efforts, but with slightly different details:

> Carbon spirals and threads. Trying to make a lamp of a carbonized thread. 100 ohms can be made from an inch of .010 inch thread.

> A thread with 45 ohms resistance when cold was brought up in a high vacuum to 4 candles for two or three hours and then the resistance seemed to concentrate in one spot. Resistance cold 800 ohms.[9]

These observations carry no note of triumph, no inventor's "eureka!" to set them off, but they unquestionably mark the key transition of the electric light search.

Batchelor continued his experiments that day in his usual methodical fashion, constructing a series of lamps with various types of carbon filaments and listing them thus:

> 1 - of vulcanized fibre
> 2 - Thread rubbed with tarred lampblack
> 3 - Soft paper
> 4 - Fish line
> 5 - Fine thread plaited together 6 strands
> 6 - Soft paper saturated with tar
> 7 - Tar & Lampblack with half its bulk of finely divided lime work(ed) down to .020 - straight one] inch
> 8 - 200^{is} 6 cord 8 strand
> 9 - 20^{s} coats 6 cord - no coating of any kind
> 10 - Cardboard
> 11 - Cotton soaked in tar (boiling) & put on[10]

Batchelor's notes reveal that he was seeking not only the best material for a carbon filament lamp but also the best configuration for a filament; the need for putting relatively long lengths of the filament into a small space was still strongly felt. The results of his tests confirmed the significance of the behavior of the carbonized thread. Number 2 (thread rubbed with lampblack and tar) "gave an elegant light equal to about 22 candles" when powered on 18 cells. Number 3 "came up to 1] gas jets," but went out due to a short circuit in the lead-in wires. It was, in fact, number 9 — simple uncoated cotton thread -- that provided the real triumph that October day. In the middle of the night -- 1:30 by Batchelor's account -- the bulb with the simple carbonized thread was put on 18 cells and kept on. How much light it yielded is not clear, for Batchelor referred only to bringing it up initially to] candle. This, however, would have been so faint as to have excited little interest, so it is likely that the full 18 cells brought the lamp up much brighter. After burning for 13] hours, more cells were put on number 9 at 3:00 the following afternoon. It continued to burn for an hour longer, yielding a light equivalent to 3 gas jets (at least 30 candles), until the glass bulb overheated and cracked. None of Batchelor's other experiments equalled the results of this simple carbonized thread.[11]

The Menlo Park response to the success of the cotton thread lamp, however, was not to treat it as a finished invention, but rather as the beginning of a new experimental path. Edison, of course, appreciated success as quickly as anyone, but the problems posed by the incredibly fragile carbonized thread filament were large indeed, and the stubbornly held belief in the need for a spiral or coiled filament provided little encouragement for continued use of the short brittle lengths of thread such as was used in October 22nd's number 9. While Upton embarked on a series of measurements to determine the resistance and power requirements of the carbonized thread lamps,[12] Batchelor spent the last week of October carbonizing a long list of alternative materials, including celluloid, shavings from boxwood, spruce, hickory, baywood, cedar, rosewood and maple, punk, cork, flax, coconut hair and shell, and a variety of papers.[13] In addition to carbonizing experiments, Batchelor continued the series of test lamps that he had started on October 22, a series that eventually went up to number 260 with tests that were not completed until more than two months later.[14] During these two months Upton and Batchelor, with help from Kruesi, Jehl, and others, devoted an enormous amount of effort to perfecting the carbon lamp and devising means for producing and utilizing it. The transition of the Menlo Park operation from a research effort in search of a workable light to a development team dedicated to making their lamp practical and marketable was remarkably rapid and smooth, reflecting the basic Edison attitude that inventions were worth something only when they were usable and saleable.

The complete shift of the electric light work at Menlo Park to the development of the carbon lamp was rapid and thorough, and more than anything else, signified the understanding of Edison and his men that they finally had an important invention on their hands. Nonetheless, it was also clear to them that there was still some distance to go between what they had accomplished and what they envisioned as a system to successfully rival gas lighting. November was a time of alternating optimism and frustration, as most succinctly expressed in Francis Upton's regular letters home. On November 2, he wrote:

> "The electric light is coming up. We have had a fine burner made of a piece of carbonized thread which gave a light of two or three gas jets. Mr. Edison now proposes to give an exhibition of some lamps in actual operation. There is some talk if he can show a number of lamps of organizing a large company with three or five millions capital to push the matter through. I have been offered $1,000 for five shares of my stock...Edison says

> the stock is worth a thousand dollars a share or more, yet he is always sanguine and his valuations are on his hopes more than his realities."[15]

The next week, however, Upton reported, "The Electric Light seems to be a continued trouble for as yet we cannot make what we want and see the untold millions roll upon Menlo Park that my hopes want to see."[16] Finally, a week later, on November 16, Upton's letter home reflected complete confidence in their achievement:

> "Just at the present I am very much elated at the prospects of the Electric Light. During the past week Mr. Edison has succeeded in obtaining the first lamp that answers the purpose we have wished. It is cheap — much more so than we even hoped to have."[17]

He then went on to describe the cardboard filament lamp in all its elegant simplicity.

Another indicator of the attitude at Menlo Park toward the carbon lamp breakthrough was the patent application for an "electric lamp" that was filed November 4, 1879 (and eventually granted as U.S. Patent 223,898 on January 27,1880). Since this was to be the key patent in the Edison system, it merits a careful look. In the beginning, Edison spelled out clearly the distinction between his carbon lamp and all others:

> The object of this invention is to produce electric lamps giving light by incandescence, which lamps shall have high resistance, so as to allow of the practical subdivision of electric light.
> The invention consists in a light-giving body of carbon wire or sheets coiled or arranged in such a manner as to offer great resistance to the passage of the electric current, and at the same time present but a slight surface from which radiation can take place. The invention further

> consists in placing such burner of great resistance in a nearly-perfect vacuum, to prevent oxidation and injury to the conductor by the atmosphere.[18]

After the fashion of such things, the patent then detailed the making of the carbon filament (this is where the term was introduced) from a variety of materials, conceding the extreme fragility of the finished product. The final form of the filament was invariably specified as a spiral or coil, and the patent drawing hence depicts such a form. It is highly unlikely, however, that a successful lamp was ever made at the time with a carbon spiral - the carbonized materials were simply too brittle to allow such shapes. The patent also specified the joining of the carbon filament to platinum lead-in wires by using a lampblack and tar putty, rather than clamps. This, too, was apparently wishful thinking, for all lamps made in this period, and for months afterwards, required tiny platinum clamps to secure the filament. One other feature for which Edison claimed patent protection, and which was to be surprisingly significant in ensuing years, was the use of a sealed enclosure entirely of glass, dispensing with troublesome metal-glass connections, except for the tiny platinum lead-in wires. The basic incandescent lamp patent was only one of literally hundreds that Edison received for his work in electric light and power, but it was unquestionably the most significant, economically and conceptually.

The patent application that was submitted November 4 did not so much describe what had actually been made at Menlo Park as what Edison and his colleagues knew should be made. The process of learning what <u>could</u> be made occupied most of the remainder of 1879, as Edison put Menlo Park to work not only to make practical lamps but also to construct enough of a complete lighting system to convince a by-now sceptical public and an ever more wary financial community. The attitude that guided the Menlo Park workers is well reflected in another of Upton's letters home:

> The Electric Light is slowly advancing from the last big step. We now know we have something and that is what we (did) not know until last week. We can compete with gas in a great many ways now though not as completely as we wish, yet there seems to be nothing to prevent our getting a perfect burner that shall do as well as gas. Time and cost will prove what we have to be good or bad.[19]

There actually seems to have been little doubt in Edison's mind that what he had was good, and he was determined to show this to the world as quickly as possible. Yey, Edison did not do as he had so often in past, which was to talk freely to the New York reporters who had learned that a visit to Menlo Park was almost always good for some lively copy. By this time, Edison may have felt that he had been ill-served by his openness with the press, for over the past year the newspapers had been all too ready to report his successful development of the light, only to force Edison to explain to Grosvenor Lowrey and other backers that important problems still remained. This time there would be no premature announcements, no published stories forcing him into making excuses or demonstrating devices not quite ready. When Edison's London representative, Col. George Gouraud cabled to convey the London Times' request that it be given sufficient notice of any Menlo Park exhibition of the light, Edison answered, "Public demonstration takes place during holidays. It is an immense success. Say nothing."[20] As Upton wrote home in early November, Edison quickly decided to put together a full-scale demonstration of the light and its system, but until the demonstration was ready, Menlo Park was to keep silent.

No time was lost in putting together the necessary parts of a demonstration system. As the work on making the carbon lamp more dependable and durable went ahead with all speed, the details of auxiliary system elements received attention as well. On November 4, Edison cabled Norvin Green, president of the Western Union Telegraph Company, to request the services of two linemen to erect wires for a Menlo Park "light exhibition."[21] The Western Union men responded quickly, arranging to come out the next week. Upton, in addition to his continuing lamp tests, was put to work perfecting the chemical meter that Edison envisaged for measuring customer current consumption, and Upton in turn put John Lawson, one of Menlo Park's chemists, to work on the problem.[22] Correspondence went out to arrange for the purchase of steam engines for Menlo Park's generators, Edison writing to one firm on November 17, "I expect in 3 weeks from today to have the Park lighted by electricity and the prospect now is that you will soon get an order for an engine or engines."[23] The picture comes through the Menlo Park correspondence of November and December of a gathering momentum in activity as Edison mobilized his laboratory to exploit October's breakthrough.

External pressures were added to the laboratory's own enthusiasm as a spur to activity. The most important was from the financiers of the Edison Electric Light Company. In mid-November Edison received from Grosvenor Lowrey a report of the Company's latest meeting, at which the need for more money was the major topic of discussion. Lowrey once again soothed the more impatient of the investors, and the meeting resulted in a call for voluntary additional contributions to the Company at the rate of $5 per share from the cash subscribers.[24] Clearly, however, there was a need to address the anxiety of the electric light shareholders as soon as possible. By early December, Edison's secretary, Stockton Griffin, wrote to a correspondent,

> Edison is now ready for his exhibition, but will be compelled to wait 3 or 5 weeks for his patents. Upton's house was lighted last night. Edison's will be illuminated tomorrow night for Mr. Fabbri and Mr. Wright.[25]

A few days later, Upton reported to his father on the subsequent demonstration:

> The light is still prosperous; I have had six burners in my house during the past week and illuminated my parlor for the benefit of a party of visitors from New York. The exhibition was a success. Mr. Edison's and my house were the only ones illuminated.
> There will be a great sensation when the light is made known to the world for it does so much more than anyone expects can be done.[26]

Other pressures for public display of the light mounted as December wore on. The press was still being kept at arm's length, Edison allowing only Marshall Fox of the New York Herald access to the lab, and that only on condition that Fox hold his story until Edison was fully ready. Despite this, newspaper reports began appearing early in the month giving word of a breakthrough at Menlo Park and creating wide expectation of an early exhibition. Letters began coming in requesting access to any exhibition as well as further information on the invention itself. For a while Edison tried to keep his correspondents at bay, replying to one on December 9, for example, that the newspapers were wrong in predicting a showing of the light at Christmastime, but an announcement would appear in the Herald sometime before February. As the lamp tests continued, however, and other preparations were completed without major difficulty, Edison's caution began to wear off. On December 17, he cabled one of his London agents, "Exhibition ready - capitalist won't allow it until about New Years."[27] Finally, a day or so later, the silence broke and it was announced that a full-scale display of the new light would be open to the public on New Year's Eve.

It isn't clear just when or where the promise of a New Year's Eve exhibition was first made public, but when Marshall Fox's famous Herald article of December 21 appeared, it was apparently common knowledge. The article itself caught Menlo Park off-guard, as Upton reported home:

> Today has been an exciting day since this morning's Herald contained an account of the discovery of the lamp and the whole invention.
> Mr. Edison had allowed a Herald reporter to take full notes so as to prepare his account for the exhibition which was to come off in a few weeks. The reporter was Edison's friend and he thought he could keep a secret. Yet newspaper traditions were too strong and he sold out at a good price I suppose for he had the first full account. Mr. Edison is very much provoked and is working off his surplus energy today.[28]

We can take Upton's word that Edison was annoyed by the unexpected appearance of Fox's report, but it is unlikely that his displeasure lasted long. He, after all, had already told a number of people that he was ready, waiting only for the "capitalists" and the patent attorneys to allow him to go ahead. He recognized the wisdom of having the patent situation settled before explaining too much publicly, and on the 21st he cabled London to alert agents that the Herald article had appeared and to urge them to push the European patents through. On the other hand, he seems to have given Fox little difficulty over the article's appearance, for very detailed Herald reports continued out of Menlo Park for the next two weeks. Edison was probably pleased to see his backers forced by events to allow the public to see what he had accomplished. The financiers of the Edison Electric Light Company had seen first-hand too many of Edison's breakthroughs of the preceding year fizzle out when put to the test, and they were understandably nervous, as shown in a letter sent Edison on December 26 by Eggisto Fabbri, the primary representative of the J. P. Morgan interests in the Light Company:

> I suggest to you the wisdom & the business necessity of giving the whole system of indoor & outdoor lighting a full test of continuous work for a week, day & night, before inviting the public to come & look for themselves. As long as you are trying private experiments, even before 50 people, a partial failure, a mishap, would amount to nothing, but if you were to express yourself ready to give a public demonstration of what you considered a complete success, any disappointment would be extremely damaging and probably more so than may appear to you as a scientific man.[29]

Edison knew, however, that it was too late to call anything off — as Fabbri surely must have known as well. To re-assure the investors, Edison gave them a preview at Menlo Park on December 27. As Upton reported home, "several million dollars of capital were represented," and the entire show "went off splendidly."[30]

During the last ten days of 1879, the New York newspapers fed their readers regular stories from Menlo Park, detailing the comings and goings of important observers and recounting the preparations for the public showing. It is therefore the newspapers that offer the most vivid record of the electric light's introduction. On Christmas Eve, it was reported, Edison entertained a number of gas industry representatives at Menlo Park, demonstrating the virtues of his parallel circuit connections for the lights. A matter of particular interest was the number of gas-lamp light equivalents that Edison's system provided per horsepower (applied to the generator steam engine), since the economy of the electric light was a practical matter still very much open to question. In reply to inquiries and to correct some mistaken newspaper accounts, Edison reported that his system yielded "ten gas jets per horsepower." This led to some confusion still, as shown in the interview with Prof. Henry Morton of Stevens Institute of Technology that appeared first in the New York Times and later in other papers. To Morton, Edison's figures confirmed his skepticism about the incandescent light, since, he pointed out, arc light systems yielded the equivalence of about 100 gas jets per horsepower. The Edison light was, Morton concluded, only one-tenth as efficient as other forms of electric lighting, and hence hardly represented the great breakthrough that was claimed. To all this, Edison simply replied that Prof. Morton should come out to see for himself, and the professor's refusal brought scoffs from such Edison boosters as the Herald, which put Morton down as one who "believes that the world is finished and that there is no room for new inventions."[31]

As December drew to a close, the publicity rose to new heights. The Herald, especially, feeling that it had staked out a special claim to cover Edison's success, kept up the drum-beat. On the 28th, the paper reported the success of the demonstration for the Light Company investors, telling how the laboratory was lit much of the evening by forty steadily burning lamps. The next day, reports came of growing crowds at Menlo Park, of wealthy men and ordinary people alike thronging to the New Jersey village to exclaim, "Wonderful!" at every turn. On the 30th, further reports came of the visitors who went away with "no particle of doubt in any one's mind that the electric light is a success and a permanent one." And on the final day of preparations for the public exhibition, the Herald featured a lengthy description of not only the many visitors to the laboratory, but also the late evening in the lab, after all other outsiders had gone home, when the Menlo Park workers and Edison himself held forth in a good humor, apparently content that their task was near completion and that theirs was a job well done.

There is, as might be surmised, no better description of the exhibition of New Years Eve than the Herald's own, which not only conveyed some of the excitement attendant on the occasion, but also summed up well the extent to which Edison tried to have not just his light on display, but a glimpse of the whole system he envisaged:

> Edison's laboratory was tonight thrown open to the general public for the inspection of his electric light. Extra trains were run from east and west, and notwithstanding the stormy weather, hundreds of persons availed themselves of the privilege.

> The laboratory was brilliantly illuminated with twenty-five electric lamps, the office and counting room with eight, and twenty others were distributed in the street leading to the depot and in some of the adjoining houses. The entire system was explained in detail by Edison and his assistants, and the light was subjected to a variety of tests. Among others the inventor placed one of the electric lamps in a glass jar filled with water and turned on the current, the little horseshoe filament when thus submerged burned with the same bright steady illumination as it did in the air, the water not having the slightest effect upon it. The lamp was kept thus under water for four hours. Another test was turning the electric current on and off on one of the lamps with great rapidity and as many times as it was calculated the light would be turned on and off in actual household illuminations in a period of thirty years, and no perceptible variation either in the brilliancy, steadiness or durability of the lamp occured. The method of regulating the supply of electricity at the central station was explained in detail, as was also the electric motor; the latter was made to pump water and run a sewing machine with only as much electricity as was necessary to give an illumination of the brilliancy of an ordinary gas jet.[32]

The crowds that thronged into Menlo Park were made up of curiosity seekers and news hounds after the latest sensation. But they represented something more; they represented a new relationship between advanced technology and the common man. Edison's electric light was as mystifying and awe-inspiring as any invention of the age. Few things could be imagined that were more marvelous than the piece of charred paper glowing bright enough in its glass container to light up a room and yet not burning up. But instead of the fear and suspicion that such a strange device might be expected to evoke in the unscientific layman, Edison's light inspired unalloyed admiration in most of its beholders. The master of Menlo Park had already earned the sobriquet of "wizard," so the average newspaper reader might not be too surprised at the latest product of his laboratory, but the wizardry represented by scientific technology was not a source of distrust but, rather, of hope. This attitude toward the powers of science and technology is one of the nineteenth century's most important legacies, and no single instance better represents it than the enthusiasm with which the crowds ushered in the new decade at Menlo Park.

CHAPTER 5

BUSINESS AND SCIENCE

On New Year's Eve, 1879, Edison put on public display not simply his carbon lamp, but the first detailed version of a complete electric light and power system. As the newspapers reported, this was made clear to everyone who came to Menlo Park. The lamp was only the centerpiece of a display that included dynamos, switches, fuses, distribution lines, regulators, fixtures, and even a sewing machine motor. For the electric light to work at all, some kind of system like that put together at Menlo Park was necessary. For the light to work commercially, however, a whole different level of systems problems had to be confronted. Of course, the effort at Menlo Park had always been guided by economic considerations; sometimes, as in the decision to develop a high resistance lamp, such factors were critical elements in determining the path of research. But by the end of 1879, with a practical lamp a reality, all of the questions of the economy of the central-station electric light and power system came to the forefront.

There were important differences between the issues of practicality and the issue of economy. These differences, however, were largely ones of degree and not kind, for the practicality of the electric light was just as much a relative matter as the economy. The standard for both was set by gas light, itself, it should be remembered, a technology in widespread use for only a couple of generations. The questions asked by anyone viewing the electric light were whether its performance and convenience equaled that of gas and whether its cost was comparable. Edison embarked on the electric light project with a blind faith that, in the end, the answer to both of these questions would favor electricity. From time to time in the months before October 1879, Edison or one of his assistants took time to make rough calculations of the investment and operating expense that could be anticipated for an electric light system, often comparing the results with gas costs to come up with figures for possible profits (see Chapter 3, above). Now that the light was a reality, the calculations took on a much more serious character. For the first time the cost equations could be filled in with real information about the power requirements of a workable lamp and the efficiency of an appropriate generator. And, of course, now that the key technical features of the system were complete, the patience of investors could not be imposed upon too much longer without concrete steps toward commercial results.

An early effort to apply the knowledge gained from the new lamp to the question of the proposed system's economy was an extensive set of calculations recorded in December 1879 or January 1880 by Samuel Mott, Edison's draftsman. This Mott labeled "Preliminary estimate of the cost of lighting 10,000 Edison electric lamps from a Central Station each lamp giving a light equal to 16 candles or taking the place of a gas jet consuming 5 cu. ft. per hour." Assuring that the average daily use of a lamp through the year was 5 hours, or 25 cu. ft. of gas, Mott figured that the annual gas consumption of a 16 candle power source averaged 9,000 cu. ft. For convenience, the Menlo Park workers called the electrical equivalent of the light produced by burning 1,000 cu. ft. of gas **M**, so that each 16 candle power electric lamp could be said to consume

9 M of electricity per year. A system for 10,000 lamps would thus have to supply 90,000 M annually (the equivalent of a gas supply of 90 million cu. ft.). Tests with the carbon horseshoe lamp showed that 8 lamps could be lit for each horsepower applied to the generator, meaning a station supplied with 1,250 h.p. would be required for 10,000 lamps. Initial investment for such a station was estimated at $170,900 - $1.90 per M, in Mott's terms. Annual depreciation was figured at 7.14 cents per M ($6,425), labor costs at 13.2 cents per M, fuel at 11.7 cents per M, water at 3.9 cents per M, and rent, taxes and insurance at 11.1 cents per M. The total of 47 cents per M was then figured as the actual cost of supplying consumers with electricity (giving annual costs for the 10,000 lamp central station of $42,300). If power could also be sold by the station during the day, additional investment and operating costs would be very small, but profitability would be much enhanced. Mott estimated that a 10,000-lamp station should be able to market 400 horsepower for about 10 hours a day for "small shops, elevators, leather sewing machines, pumping &c." The dividends or investment that could be expected from such an establishment were quite respectable, ranging from a 11% return for light and power sold at 50 cents per M to 90% if charges were $1.50 per M (with some power at a lower rate). Mott concluded by comparing his figures with the average gas company investment of $9.00 for each 1,000 cu. ft. of capacity (vs. $1.90 per M of electricity) - operating costs of 85 cents per 1000 cu. ft. supplied to the consumer (vs. 47 cents per M. of electricity). The economic calculations painted a rosy picture indeed for Edison's electrical system.[1]

With typical brashness Edison gave assurances to his investors that such calculations left no room for doubt about how his system would fare in competition with gas. At the end of December, for example, the secretary of the Edison Electric Light Company, Calvin Goddard, reported that the friend of a stockholder had taken figures from newspaper accounts of the light and found gas still cheaper than electricity.[2] Edison took time from the hectic preparations for the New Year's Eve demonstration to reply to Goddard:

> Your favor of the 27th was duly received. I am preparing full statistics, etc. as to cost and I cannot now give time to refuting the statements of your gas friend, but briefly I would mention that no company in New York or in America can make and put 1,000 feet of gas in the holder for 35¢, that there is 15 pc leakage chargeable to the 1,000 feet before it is delivered. That it does not cost 1¢ per hour per h.p. if I do not charge it to depreciation and interest, but only] cent per h.p. That I give a jet equal to 5 foot of gas burnt in Sugs Standard Argand. That if I run a 250 h.p. engine all night it will supply lights all night or if there is not enough lights to absorb 250 h.p., but say 100, then the Corliss cut-off works and there is just so much less coal burned. If you go into the delivery of gas then we have] the plant or interest 4 pc depreciation to 12 pc gas - no leakage to 15 pc gas and a chance to use our immense plant 10 hours of the day for selling power which is then sufficient in New York to pay interest on the plant and make the light for night for nothing. There are many other things which I could mention but I cannot at the present spare time.[3]

As so often in the past, Edison's pronouncements to both his backers and the public were wildly over-optimistic, but they once again served to keep investors' faith up and the public interest strong.

The obvious usefulness of this public optimism did not mean that it was guileful — in those months following October's breakthrough, the faith of the men at Menlo Park was very strong that the light they had discovered was all they had hoped for, and thus was competitive with any other. Even Francis Upton, who tried to be less cavalier about the difficulties of their undertaking was full of confidence that the Edison system would be a profitable reality in a matter of months. He wrote to a friend in late January, 1880:

> I have been figuring (sic) during the past week on some estimates and they all show that we are going to make enormous profits at the present prices of gas, and fair profits at the present cost of gas. The lamps are durable as far as we can judge and no new troubles show themselves. I should say it is a good time to buy stock. There is no doubt of our going into New York in the course of six months. The patents are going to be excessively strong.[4]

The calculations Upton made in December were almost identical to Mott's yielding a daily cost per "M" of 43.7 cents (as compared to Mott's 47¢).[5] In January, however, it began to be clear that much more needed to be known about the dimensions of the task they were setting for themselves before Edison and his co-workers could move ahead. In particular, the problem of the extent and cost of the conductors supplying electricity from the central station to lamps and motors was beginning to loom as a crucial concern.

Charles L. Clarke was one of the many young men who were spurred by the excitement of Menlo Park in late 1879 and early 1880 to discover for themselves what was happening in the inventor's wonderful workshop. Clarke's major distinction from the others was that he was a good friend of Francis

Upton, a classmate from Bowdoin College and, like Upton, had studied in Germany. Thus when Clarke joined the ranks of the Menlo Park workers, he was given the task, under Upton's guidance, of calculating the dimensions of conductors needed for a central station system. He filled several notebooks, beginning in early 1880, with figures and tables relating the sizes of conductors, the area to be served, and the cost.[6] These calculations were guided by the principles that Upton laid out for him. In one of his own laboratory notebooks, Upton spelled out "general laws" for figuring the cost of conductors; such as:

> - The cost increases as the square of the distance from the central station.
> - 1 Ohm may be taken as a fair estimate of the resistance of a conductor for 10 lamps.
> - 1/10 of the energy will be lost in the conductor when all the lamps are on.
> - If a 200 Ohm lamp can be made in place of a 100 Ohm lamp the cost in a district will be] for conductors or the distance from the station may be 1.4 times as great so that the station will supply 2 times as many lamps with the same average cost for conductors....
> - The cost per lamp in a given area is proportional to the size of the area.[7]

The principles and assumptions that guided these calculations favored from the beginning the relatively localized system that the first New York station at Pearl Street was to exemplify. The close relationship perceived between the costs of the system and the size of the area served discouraged any notions of service areas extending beyond a mile from the generating station. The variables considered by Upton, Clarke, and everyone else at Menlo Park --lamp resistance, conductor length, conductor resistance --could not have yielded any other conclusion.

Because the success of their system seemed to depend so much on a high level of usage in a relatively small area, Edison and his colleagues always framed their development work in terms of concentrated urban use -specifically, in terms of serving a portion of New York City. To be sure, there were other reasons for this as well. From the beginning, the Edison Electric Light Company was a New York City enterprise backed by New York money, led by New York men, and coupled to New York interests. In addition, the press that favored Edison with such lavish attention was largely a New York press, and, as always, the only way to hold their serious and sustained interest was to develop a New York system. Finally, from the time of Edison's Horatio Alger-like adventures in New York as a youth of 22, Edison had identified himself with the metropolis and had perceived it as the key testing-ground for the exciting new technologies of the day. The questions and calculations that he and his co-workers occupied themselves with in early 1880 were therefore uestions about and calculations for New York.

When Francis Upton set down in his notebook the questions that had to be answered to plan the central station system, he therefore asked about New York, wanting to know:

How many feet of gas are consumed in various parts of N.Y. per consumer and an estimate of the average time of burning.

How much horsepower is taken and the price paid per horsepower up to 10 horsepower.

Cost of pipes laid in the street and depreciation.

Cost of management.

Cost of building lots or rent of same.

Cost of water for H.P.

Houses estimated cost of introducing.

Cost of condensing as compared to high pressure engines.

Cost of laying pipes or wires in the street.[8]

He then filled much of the remainder of his notebook (58 pages worth) with figures acquired through inquiries concerning the costs of gas and other forms of lighting in the city and the kind of expenses that could be expected for an electric central station and distribution network.[9] The results never differed greatly from the early calculations recorded by Mott; indeed, one set of figures was identical to Mott's, suggesting that Upton may in fact have been responsible for all of the estimates made in this period. The calculations for system size and cost made in early 1880 were the first serious efforts of what turned out to be a long series of attempts to work out clearly the expenses and the profitability of the Edison system.

As the Menlo Park workers turned their attention to the complex task ahead of them, following the heady success of the New Year's Eve demonstration, the key components of the system were carefully scrutinized in the search for improvements. One system element that had been largely left alone for the preceeding few months but which now came in for intensive work was the generator. Since the "long-legged Mary Ann" emerged from the Menlo Park shops in mid-1879, Edison felt that he had met the challenge of providing an appropriate generator for his system in its essentials. As questions of long term practicality and economy came to the fore, however, particular elements of the generator came in for careful scrutiny. As early as Jan. 2, 1880, Batchelor began sketching new commutator designs and new commutator brush arrangements.[10] The spur for this may have been the task given John Kruesi and his machine shop crew to construct at least six new machines of several different sizes.[11] The new construction provided the opportunity to experiment with possible refinements: the original design, and the need for different size machines required the re-working of a number of elements, particularly brushes and armatures. Batchelor took on the commutator and brush work, Upton was responsible for armature experiments, Kruesi assisted both men and Edison kept his hand active in all the generator work.[12]

A typical example of the cut-and-try approach that characterized all of Edison's generator work was a series of experiments carried out on brush arrangements in early February, 1880. A key problem with the Edison generator, as with all generators, was sparking at the brushes. A notebook entry of February 8 described one search for a solution:

> We found by turning the brush at right angles to commutator the spark disappeared, which led to the following experiments.

The next few pages were then taken up with drawings of various brush-commutator arrangements, involving different angles for the brushes, different widths of brushes, and different contact points between the brushes and the commutator. Each variation elicited a judgement, ranging from a bold "NG" (for "no good") to "very good and durable" and finally, "OK -very good-Standard, Can at this angle (32°) be placed in any position all over the commutator." The extent of satisfaction with his solution can be measured by Edison's care to initial and date this final design, for possible patent documentation.[13] It is not clear from these experiments the extent to which Edison appreciated the fact that a far more critical consideration in sparking at the commutator brushes was the placement of the brush contacts at the "neutral point" of the commutator. Since such placement was largely a matter of the fine adjustment of brush positions, it may have simply been an obvious procedure for the Menlo Park experimenter, even if there was no theoretical basis.

The efforts to improve the armature design of the generator were not as straightforward, since the deficiencies of the original design were not so clear. Upton was given the responsibility to devise armature experiments and to formulate the general considerations for armatures and generator design as a whole. In early February he recorded a number of experiments with armatures treated in a number of ways, paying particular attention to the heat generated at the armature surface. With the assistance of Kruesi's machine shop, various armatures with cores of painted (laminated) iron plates were constructed and tested. While the concept of eddy currents in the armature cores was never mentioned in the laboratory records, the Menlo Park experimenters had clearly required some understanding of the need to localize internal currents in the cores, while at the same time keeping the internal armature resistance as low as possible. The limited understanding of the theory behind their machines was underscored by the occasionally bizarre approaches that Edison and his colleagues experimented with. Upton, for example, recorded Edison's design for an armature made of a long strip of iron, .032 in. thick, wound in a spiral with paper to insulate the layers of iron.[14] Kruesi did construct such an armature, made of 80 feet of iron and recorded the result of tests as "very bad."[15] Upton's results with an armature made of iron plates .037 in. thick and oxidized on the surface for insulation were much better - testing on a load of 75 lights for three hours at 95 volts and producing only 100°C. He noted that "this is the best ever done in the world and brings us home with this size of machine."[16]

Upton's contribution to generator development in this period went beyond executing Edison's experiments. As he was inclined to do, he tried to spell out the "laws" that should govern generator construction. His basic formulation was,

> "The best machine is that which with the least amount of energy consumed on the magnets will give the greatest E.M.F. on the smallest resistance in the armature so long as the spark on the commutator may be kept under. Interest on investment, friction and magnetic friction being made as small as possible."[17]

Upton elaborated on these considerations in subsequent notes:

- The minimum cost of the magnets is when the interest on the amount invested is equal to the cost of the energy consumed in them.
- The friction of the bearings must be made as small as possible.
- Magnetic retardation may be largely avoided using very soft iron.
- Local action [eddy currents?] is in the Edison machine of no consequence.
- Spark on the commutator may be made very small by placing the brushes endways and widening the commutator.[18]

Additional calculations followed to show examples of how reducing the armature resistance or increasing the size of the magnets could be justified as long as the additional investment was balanced by increased output or lower heat loss. It was a firmly established part of Upton's outlook - and Edison's - to specify clearly the relationship between technical considerations and economic ones. The eventual success of the Edison system was in no small measure a product of the clarity with which the men at Menlo Park understood this relationship, in individual instances as well as in the general scheme of things.

* * * *

Working out the myriad of details of the full-scale Edison system was to be the major pre-occupation at Menlo Park during 1880, but in the beginning of the year the greatest single object of attention was still the lamp itself.

The displays of the last days of 1879 had truly been great public successes. They had also, however, been intense field tests for the carbon paper horseshoe lamp, and the results made clear to Edison that the lamp was still not all he wanted it to be. The correspondence and laboratory notes of that winter do not include a systematic critique of the lamp's performance, but its problems were apparent from the tests and experiments that continued to pre-occupy the laboratory without a break from the moment work resumed after New Year's Eve.

Hardly any feature of the lamp escaped Edison's critical scrutiny in this period. The chief concern was the lamp's longevity, and life tests begun in late October continued. By late January, one lamp had burned for more than 550 hours, and several others were approaching 500 hours.[19] As gratifying as this was, the occasional long-lived lamp did not represent the kind of dependability that Edison felt the system required. Too many other lamps were breaking after much shorter periods and the influences determining lamp life were simply not well understood. Some problems were in fact obvious; the cracking of the glass bulb at the point where it was closed around the lead-in-wires was a continual headache, for example. Other difficulties were harder to pin down, such as the clouding of the inside surface of some bulbs after a short period of use, or the undependability of the filaments themselves - some of them lasting for days and weeks and others, identical in preparation and appearance, breaking at the slightest shock or giving out quickly while burning. The attack on these problems differed little in character from the months of work that preceded the carbon filament lamp, consisting of a broad range of experiments dictated by empirical considerations and guided by the occasional, sometimes crucial, insight.

There were, however, some differences in the environment in which the Menlo Park laboratory workers carried out their experiments. The new blood that had been attracted by the success of the carbon lamp was one source of change, for it allowed Edison to assign some kinds of experiments to an individual who could then devote himself entirely to the task at hand, without being directed to other problems, momentarily more urgent. Young Albert Herrick for example, was given the task of keeping records of the test lamps installed around Menlo Park, and Wilson S. Howell was set to the job of improving the operation of the vacuum pumps, now kept going at all hours evacuating experimental bulbs.[20] The widely-publicized triumph at Menlo Park not only attracted ambitious young men seeking exciting new paths to success, but it also attracted the attention of a variety of experts in one field or another who wrote in to let Edison know what they could do for him. Edison's concern over some of the lamp's problems was reflected in the care with which he sometimes responded to these unsolicited letters. One Albert Taylor, for instance, wrote on January 3, 1880 to recommend a variety of bristol board for lamp filaments made with the finest kaolin. Edison replied that he wanted board with no kaolin or other non-fibrous fillers.[22] This contrasted with his reply to a suggestion sent in by G. Haines on January 6 that Edison might find useful and a bristol board made from linen. Edison instructed that he be asked to see about getting 100 pounds of linen bristol board.[23]

An interview with Edison that appeared in newspapers across the country on January 16 quoted him as saying that one source of difficulty in perfecting the light was the ease with which the glass of his bulbs was breaking, especially at the point where the glass closedaround the lead-in wires. This brought a rash of letters offering solutions and personal assistance, Edison's responses showed his worry about the glass problem. While a couple of correspondents were brushed off with polite explanations of why their suggestions were not useful, others were asked for more information on their suggestions, and when one Philadelphia writer, describing himself as "a practical glass blower," said that he thought he could help out if he were sent a sample bulb or given train fare to Menlo Park, Edison instructed his secretary, "Grif, send a return ticket."[24] Laboratory records do not show whether any of this volunteered help produced useful results. In other instances, Edison's responses to suggestions indicated his satisfaction with particular features of the lamp. Several letters were received in January, for instance, with advice on improving the vacuum in his bulbs. Edison's response was generally polite, but rarely invited any further correspondence on the matter. While Edison did not answer every letter he received, and the replies that did go out were usually prepared by Stockton Griffin, the Menlo Park secretary, based on a few noted by Edison, the apparent care with which he read the large amount of unsolicited mail, even at this busy time, was still remarkable.

One letter received in mid-January that Edison did not pass on to Griffin for a reply was from the mathematician and astronomer, Simon Newcomb, head of the National Almanac Office at the U.S. Naval Observatory in Washington.

Newcomb, one of America's most distinguished scientists, suggested that the light output of the carbon-filament might be considerably improved if Edison were to find a form of carbon more homogeneous and solid than that provided by the carbonized paper. Whether Edison had already come to this conclusion is not clear, but the search for a better filament material in the months ahead was in fact eventually guided by the perception that carbon with a more homogeneous structure was necessary. Newcomb touched on another subject in his letter and thereby gave a clue to how the American scientific community regarded Menlo Park and Edison's accomplishments there. Newcomb and Albert A. Michelson, then teaching physics at the U.S. Naval Academy, were in the midst of plans for making new measurements of the speed of light, one of the key physical problems of the nineteenth century. In response to Edison's invitation to set up their apparatus at Menlo Park, Newcomb wrote to say that the lack of hotel facilities in the village posed an obstacle to their working there. "Otherwise," he wrote, "I should like very much to accept your kind offer, as I think the advantages of your laboratory would be very great."[26] The image of Prof. Michelson, who made the precise measurement of physical phenomena his life-long work, rubbing shoulders at Menlo Park with the ever-practical Edison is an incongruous one, but the fact that it was even considered attests to the status that the Edison laboratory had achieved in the highest circles of American science.[27]

The mail that came into Menlo Park was of little practical help to Edison. He knew that the problems of his light would have to be attacked just as they had always been attacked - through mobilizing the great resources at his command and concentrating them on what he saw as the most critical areas. In early 1880, the problem to which Newcomb had referred, that of devising a better filament, was a chief priority, and much of the laboratory's effort was brought to bear on it. In mid-January, for example, Edison put his chemist, John ("Basic") Lawson, to work carbonizing a wide range of materials to see how they emerged from the furnace. It was work like this, occupying only a few days, that was to form the basis of the image of Edison's research as a haphazard cut-and-dry activity. Indeed, Lawson's list of tried substances included its share of peculiar samples, such as flour paste, leather, macaroni, sassafras, pith, cinnamon bark, eucalyptus, turnip, ginger root, and a variety of gums, barks, and other plant parts or derivatives.[28] This list is reminiscent of that compiled by Batchelor in late October, 1879, when he carbonized a variety of woods as well as such materials as coconut hair, cork and celluloid (chap. 4). Edison himself recorded experiments with a variety of woods during that winter, noting the effects of different methods of carbonization as well as the differences in the different materials.[29] The tradition of wide-ranging, loosely-directed experimentation was firmly established at Menlo Park, and the search for an improved filament was clearly in that tradition.

Just how important this kind of activity was relative to the other work that went on at Menlo Park is open to question, however. The list of plant materials tested for suitability as a source of filaments consisted of perhaps several dozen substances, a few of which, like macaroni or leather, were bizarre, but most of which were raw plant fibers of one sort or another, clearly the result of a well-worked-out logic for search and discovery. Furthermore, the time spent by Edison, Batchelor and others on the haphazard testing of materials was rather small when compared to the efforts made in the other directions. For example, Batchelor spent much of his time during January and February making filaments from paper and a few varieties of plant fibers, particularly manila hemp, in various sizes and with various modifications of the carbonizing process.[30] Both Batchelor and Edison carried out numerous experiments aimed at improving the performance of paper horseshoe filaments by treatments of the paper (such as boiling in sugar) or coating the filaments (with metal oxide solution much like those tried out on platinum months before).[31] The image sometimes conjured up of a laboratory plunged into a wild search through Nature's storehouse for a better material does not reflect the true character of Menlo Park in early 1880. Instead, Edison and co-workers were seeking solutions to the deficiencies of their lamp in a number of directions, guided sometimes by a clear perception of where the problems lay and sometimes by intuition, hope, or chance.

The attention given to the search for a better filament material was matched by efforts to improve other weak points in the lamp. The original carbon lamp connected the filament with the lead-in-wires by tiny screw-clamps made of platinum. These were expensive, time-consuming to make, and not wholly satisfactory in their performance. Hence, considerable time was spent in trying to devise alternatives that would be relatively cheap and still reliable. The clamps had to meet very straightforward standards: they had to join the platinum lead-in wires securely to the carbon filament and they had to withstand the high temperatures of the glowing filament. In the course of his lamp work, Edison had encountered only two substances that he could rely on to work at such high heats - platinum and carbon. Naturally, therefore, in the effort to minimize the use of platinum, the experimenters at Menlo Park turned to finding a form of carbon that could hold both wires and filament while tolerating heat. Batchelor spent a good deal of time during February and March making carbon "clamps" (often just plugs or rings rather than the true clamps) from various substances. The early results were inauspicious; for example, on February 1 Batchelor recorded:

> Made hemp fibres with clamps of plumbago, graphite such as used in lead pencils - they have got too much stuff mixed with them for us -seem to swell up and form gases or arcs which bust up the lamps. Clamps made for these were just a cylinder of graphite with hole to push a wire and holes in top for carbon loop.[32]

Batchelor subsequently noted experiments on clamps made of "Wallace carbons," lignum vitae, ironwood, and coconut shell. The wood and shell clamps were designed to be carbonized along with the filaments and were the subject of extensive experimentation.[33] For a while, Edison was convinced that the carbon clamps would prove an effective inexpensive substitute for platinum, hence the extended description he gave of their construction in a caveat filed with the U.S. Patent Office on March 20. But by the end of March, Edison had to acknowledge that he had not found a truly satisfactory replacement for the clamps made of platinum or platinum-iridium.[34]

Besides tackling the practical problems of the carbon filament lamp, the Menlo Park workers felt a genuine need to understand better the general principles governing the behavior of the lamp. This effort was closely linked both with the lamp research and with the plans and calculations for the full-scale lighting system. Once again, it was the scientific Upton who took up the task of laying out the key physical relationships that determined lamp behavior and efficiency. He sought to define the link between the surface area of a filament, its resistance, the energy it consumed and the light it produced. Upton's concern for the surface area presented by the filament was a hold-over from Edison's very early conclusion that he wanted to minimize the surface area of the incandescing element in his lamp -primarily to reduce heat loss. As a practical matter, later lamp makers did not find it useful or necessary to make the surface area of filaments a major consideration. Thus Upton's conclusion that "the light from the same energy is inversely as the surface from which it is given off" was not to be of practical importance. Other relationships, however, were, as exemplified by this illustration:

> A 200 Ohm lamp to give off the same light as a 100 Ohm lamp with the same surface will require 1.4 times the E.M.F. of a 100 Ohm lamp. That is, if a 100 Ohm lamp requires 87 volts a 200 Ohm lamp will require 121.8 volts. A 400 Ohm lamp will require 2 times the E.M.F. or 174 volts.[35]

This is actually Upton's statement of the basic relationship between the power consumed by a lamp (W or wattage), the voltage (V) of the circuit, and the resistance (R), which, when expressed in terms of watts, volts, and ohms, can be put as $W = V^2/R$. This is the relationship determined by James Prescott Joule in 1840, with W expressed in the form of heat. It is curious that Upton, possessed of graduate training in physics, should have expressed

Joule's Law in such primitive terms. It may be that the implications of these basic physical principles for the electric light were still being worked out even at this late stage.

A key consideration in Upton's work; as shown both in his studies of the lamp and in his calculations for the generating station, was the efficiency of the carbon lamp. The question of how much light Edison was getting for the energy put into his generators was not only a question of great practical concern at Menlo Park, but it was also a question of general scientific and technical interest. In March, Professors C. F. Brackett and Charles Young of Princeton visited Menlo Park to run tests on the generators and lamps, paying particular attention to careful measurements of the steam horsepower put into the generator, the electrical power made available by the generator, the number of lamps hit by one machine, and the light output of the lamps. Their results were compiled in a detailed report submitted to Edison at the end of March. They must have been gratifying to the Menlo Park researchers, for Brackett and Young provided confirmation of the results of the results Edison himself had been reporting. The generator was judged to convert 86.7 percent of the mechanical work put into it to electrical work. When armature losses were subtracted, 82 percent was available for use. The energy consumed by the lamp was calculated by careful measurements of the basic parameters, yielding a resistance of 99.722 Ohms, a circuit voltage of 76.526 V and a current that was measured (by electrolytic deposition) at 0.766 Webers (= Amperes). The current in the lamp had a corrected value of 0.7578 Webers, which corresponded closely with the value given by Ohm's

Law. The mean value of the horsepower consumed in a single lamp was .0777 h.p. (equivalent to 58 watts); determined by Joule's Law in the form $W = I^2R$. This result meant that 12.87 lamps could be operated per horsepower and that, given an output of 4.717 h.p. for the Edison generator, 60 lamps could be lit by one machine. To make their tests comprehensive, Brackett and Young also ran photometric tests on the lamps, measuring peak illumination at 14.6 candle-power - well within the range of the gas light standard. Edison could not have hoped for a fuller confirmation of his own claims for the light.[36]

Hard on the heels of Brackett and Young came two even more distinguished scientists to run very similar tests - Professors Henry Rowland of Johns Hopkins and George Barker of the University of Pennsylvania. Barker was a close friend of Edison and had followed with interest the work on the electric light from the beginning. Rowland, at 31 already one of America's most accomplished physicists, had always had an avid interest in electricity and at this point in his career was especially concerned with calorimetry. It is therefore not surprising that the measurements that he and Barker carried out "on the efficiency of Edison's electric light" (the title of the article in the April 1880 American Journal of Science reporting their results) used calorimetric measurements of lamps to determine directly power consumption. The most significant conclusion of Rowland and Barker's experiments was not confirmation of Edison's claims for his lamp's efficiency but rather the observation that efficiency, expressed in terms of candlepower of illumination produced per horsepower, was directly related to the temperature at which the filament operated - the hotter the filament, the more light it gave off, in obsolute terms and in terms relative to energy consumption. Thus two bulbs lit to a mean brightness of 11.6 candlepower gave an output of 109.0 c.p. per h.p.; the same bulbs at a mean brightness of 31.2 c.p. yielded 204.3 c.p. per h.p. The physicists concluded with this statement:

> The increased efficiency, with rise in temperature, is clearly shown by the table, and there is no reason, provided the carbons can be made to stand, why the number of candles per horsepower might not be greatly increased, seeing that the amount which can be obtained from the arc is from 1000 to 1500 candles per horse power. Provided the lamp can be made either cheap enough or durable enough, there is no reasonable doubt of the practical success of the light, but this point will evidently require much further experiment before the light can be pronounced practicable.[37]

Edison was anxious to have the approbation of the scientists, for the apparent unsuitability of the light for commercial use after all the publicity in December gave rise to considerable skepticism in the press and elsewhere. Criticism in the newspapers struck a sensitive nerve and the scientific confirmations were ammunition that Edison did not hesitate to fire back at writers and publishers. To the famous Chicago publisher, Joseph Medill, Edison got off a copy of Rowland and Barker's results and accompanied it with a letter that let loose the anxiety and annoyance that public skepticism was arousing in him:

> I send you tests made by Professor B. & R. Other tests are being made [by the] best scientific men. Your correspondent named Hall of N.Y. Tribune [Medill published the Chicago Tribune] came here and stood about 20 minutes and then writes his long article, from inferences based on

> ignorance & misunderstandings. It is true that January 1st we put up about 80 lamps the first made, to ascertain the life of the lamps. They have all gone out. Their average life was 792 hours. The shortest 26 hours, the longest 1383 hours, a very satisfactory result for a 1st experiment. I have never concealed this fact when a lamp busted I let it remain where people could see it. My laboratory is open & free to sneaks, ignoramus detectives as well as gentlemen. I could have easily have made new lamps and replaced those destroyed had I wished to deceive the public.[38]

Edison pointed to the Rowland and Barker tests as proof of the economy of his system, but his exasperation as well as the stubborness that was driving him finally burst out as he finished the draft of this letter:

> After all these scientific tests are over, they will probably acknowledge the cheapness over gas, but they will say that the lamps won't last or that I cannot make them cheaply. [The rest of the draft is crossed out, but legible] In fact I am sorely puzzled to understand the motives of these attacks since I haven't cheated anybody but I am going to do all I said I would and more, too. Please don't publish this.[39]

The scientific community was for far from being a unified ally of Edison, for shortly after the Rowland and Barker tests were sent off to Medill, there appeared in Scientific American the results of unauthorized tests by Professor Henry Morton and his colleagues at Stevens Institute in Hoboken. Using only one lamp, supplied by Scientific American, for Edison had refused cooperation, Morton confirmed the basic parameters of the lamp's operation. His test lamp yielded 16 candle-power when put on 48 Grove cells (which would mean a voltage of 85 to 90 V) with a resistance of 75 Ohms (compared to 123 Ohms cold). The current was measured at 10.9 Webers (= Amperes), so that Morton also calculated an efficiency of about 12 lamps per horsepower. He then went on, however, to calculate over all efficiency on the basis of the performance of well-known generators such as those of Brush and Siemens, which required 1-2/3 mechanical horsepower to yield one horsepower of electricity. Morton compared the cost of this in coal consumption, about 5 lbs per hour, with gas yield of the same amount of coal, 25 cu. ft., which he estimated would produce some 110 candlepower. Claiming that the effective output of an Edison lamp was only about 10 c.p., Morton thus asserted that the electric light cost about the same to operate as gas. To him, this was, over all, a negative conclusion for the Edison lamp:

> If each apparatus and system could be worked with equal facility and economy, this would of course show something in favor of electric light; but when in fact everything in this regard is against the electric light, which demands vastly more machinery, and that of a more delicate kind, requires more skillful management, shows more liability to disarrangement and waste, and presents an utter lack of the storage capacity which secures such a vast efficiency, convenience, and economy in gas, then we see that this relatively trifling economy disappears or ceases to have any controlling importance in the practical relations of the subject.[40]

While Edison could hardly have been pleased by Morton's statement and the negative attitude it reflected, he must have taken some satisfaction from the fact that Morton had reached his conclusions using generators with an efficiency of no more than 60%. The application of Edison generators to the same calculations, given their better than 80% efficiency, would thus yield a far more positive picture of the Edison lamp's economy.

Even as the public debate over economy was raging, Edison's men were hard at work putting the finishing touches on the first installation of the Edison system outside Menlo Park. During March and April, 1880 the new steamship _Columbia_ was docked in New York for outfitting, including installation of the first commercial Edison electric lighting plant. Henry Villard, head of the Oregon Railway and Navigation Company, the _Columbia's_ owner and operator, saw the December demonstrations at Menlo Park and instantly became an enthusiast. In a matter of weeks, Villard (who, ironically, had at one time been a correspondent for Medill's Chicago _Tribune_) approached Edison with a proposal for installing the new light on the _Columbia_, then under construction at John Roach's shipyard in Chester, Pennsylvania. The correspondence that set up the arrangements for this installation is not to be found in the Edison archives, but the consequences for activity at Menlo Park are nonetheless clear. The _Columbia_ afforded Edison the opportunity to put his light into commercial operation in short order under carefully managed conditions. The _Columbia_ would also show off the electric lights real advantages over all alternative forms of shipboard illumination. Edison resisted any other requests for lighting installations that he felt would distract from the development of the full-scale urban system that he envisaged, but Villard's enthusiasm and the belief that the _Columbia_ offered a chance for a well-publicized effort with special popular appeal made it an opportunity that Edison could not turn down.

The _Columbia_ installation was a spur to development of many auxiliary features of the system during the first months of 1880. The first lamp sockets, complete with key switch, were the product of this period, since some means for securing lamps while in use was imperative for shipboard fixtures. The resulting design did not incorporate the screw socket, but it was a perfectly satisfactory approach that reflected sensitivity to the need for developing the lamp for easy use by everyone.[41] Another item that had to be completed for use on the Columbia were the "Safety wires," or fuses, that were to be very protective elements of the system. In mid-April, Upton recorded a short series of tests on various gauges of lead/tin wire to determine how they heated in a circuit.[42] The ship was fitted with four "long-legged Mary Ann" dynamos - the standard Menlo Park type that was rated at 60 sixteen-candle-power lamps each (with one supplying current to the field coils of all four). The lamps with which the ship was supplied were also the Menlo Park standard of the day, made with paper horseshoe filaments. Lamp production, however, was still very experimental, thus each lamp had to be tested and the variation in their resistance and light outputs were recorded.[43] The whole job, while done as well as Edison could manage, was necessarily a bit of a chancy proposition, with a number of crude expediencies resorted to, such as rough cotton insulation for the ship's wiring. Francis Upton spent much of his time that April overseeing the electrical installation, and when it was done, he was anxious but hopeful, as shown in a letter home written May 9:

> I am now through with the steamer Columbia, as it sailed yesterday for San Francisco with the lights aboard. I hope that everything will go well and see no reason to anticipate trouble. It will please the Californians when it arrives and be of use to the vessel. There will be in future a great many steamers to fit with the light and this will be quite a profitable business in itself.[44]

The outfitting of the Columbia was described in some detail in Scientific American, which observed of the Edison installation, "Certainly there is no place where a lamp of this character would be more desirable than on shipboard, where the apartments are necessarily limited in size and pure air is a matter of great consequence."[45] The Columbia, while a project undertaken essentially as a favor for Villard, brought home an economic message that Edison was not quite ready to hear: The incandescent light would have an appeal and applicability in specialized, limited markets well before its place as the universal illuminant was established.

Indeed, as the development work was organized and pushed forward at Menlo Park in those first months of 1880, the economic messages were coming to Edison with increasing insistence. By spring, the technical problems that the lamp still presented were well-defined and the dimensions of the envisaged urban system were being calculated with care. The measurements of the systems were being used as confirmations of the rougher tests of the Menlo Park workers, providing assurances that the power needs and the operating costs of the carbon horseshoe lamp were well understood. But as time went on, the need for moving the economic considerations out of the notebooks and calculations and into factories and actual installations became more obvious. In a sense, the development work at Menlo Park up to this point was still laboratory-oriented. To satisfy the public, investors, and himself, Edison would now have to move development out into the open, into the creation of operating systems and a manufacturing infrastructure to support them. It was to escape the distractions of installation and manufacturing that Edison had removed himself to the fields of Menlo Park in 1876, but the accomplishment of the electric light would drive him back into the activities, and in so doing, would lead to the abandonment of Menlo Park itself.

CHAPTER 6

A SYSTEM COMPLETE

In the first months of 1880, the laboratory at Menlo Park completed the transition from a research establishment, devoted to discovering how to construct a practical incandescent lamp, to a development center, driven by the economic and technical requisites of a marketable system. In some ways, the activities were little different than they had been: a myriad projects were being pursued at once, with a dozen or so workers taking charge of their particular responsibilities, all under the general guidance of Edison himself. The problems being wrestled with and the methods used for their solution also resembled those of years before; they usually were approached in an unremittingly practical way, broken down into discrete tasks that appeared to present a limited and manageable range of options. The laboratory's swollen staff, however, was now less the personal staff of a mercurial inventor than it was an organization serving the interests of an enterprise that was as much commercial as it was technological -- the electric lighting system.

The changes at Menlo Park were not sudden or simple. It was still Edison's laboratory, and as such it reflected the liveliness and imagination of the man who promised "a minor invention every ten days and a big thing every six months or so." Throughout 1880, the change in spirit and orientation was a steady process, driven by the technical demands of the lighting system. To understand what was happening, it is more important than ever to comprehend the entire complexity of the laboratory's operations, rather than simply to focus on the records of electric light experiments. Fortunately, it is just at this time that there appears a remarkable record of the day-to-day work of the people at Menlo Park. In March, Charles Mott, who had joined Edison's office staff at the beginning of the year, began to keep a detailed account of all the work going on around him. This account, part diary and part log-book, was apparently an effort to keep track of all the laboratory's projects and the activities of all of its most important staff. Mott does not tell why he kept this record, but it was clearly not just for personal reasons. In the beginning, he was careful to cross-reference many of his notes with indications of pertinent laboratory notebook entries. While this practice became less consistent as time went on, Mott's journal still provided a summary of the activities and ideas often recorded in more detail elsewhere. This careful record of daily activities may have been a task assigned to Mott as both a means of retrieving notebook data (a kind of narrative index) and as additional ammunition for patent problems that might arise.

Whatever the reason for the journal, Mott's record provides a picture of Menlo Park's activities that is far more comprehensive than can be derived from any other source. For about a year, from mid-March 1880 to mid-March 1881, he jotted down in small pocket notebooks his observations of what people were doing, of who was absent (and for what reason), and of what the laboratory notebook entries for any particular day covered. Supplementing his rough notes with conversations with laboratory workers, Mott then put his observations in a journal narrative. An extended look at this narrative gives some flavor of Menlo Park's hectic pace as well as an occasional glimpse of the less serious side of life in what was to many the world's most exciting workshop.[1]

When Mott began his journal, the men at Menlo Park were involved in not only the electric light but a number of additional projects, some of them old and some new. The telephone work that had occupied Edison's attention previously and which was closely tied to commercial efforts in Britain was still a source of concern, and in March, 1880 a few workers were set to improving the chalk-drum receiver that Edison had devised to get around Alexander Graham Bell's patents. In a curious conjunction of efforts, one of the possible improvements under investigation was the application of an electric motor to the chalk-drum, which had to be continuously rotated when in use as a receiver. Another project that was diverting some attention from the electric light was the continuation of the study of ore samples that were being sent into Menlo Park from all over North America. This effort had begun in 1878 with the attempt to locate new and cheaper supplies of platinum at a time when Edison was convinced that that expensive metal would be the basic incandescent element. Despite the fact that this was no longer the case, ore samples continued to come in and Edison continued to have them tested. The tests, however, were less concerned with the platinum content of samples than with the gold, and Edison's interest derived less from the needs of the light than the attraction that a possible new source of gold has always had for ambitious men. Closely related to this were the efforts that were being made to devise and perfect a magnetic ore separator — a device that would use a powerful magnetic field to separate and concentrate various useful metals in low-grade ores. Mott's journal includes a description of ideas for such a device in its entry for March 25 — the first details of a project that was to come back to Edison often in the next years, until, in the 1890's, he was to pour himself and his fortune into a futile effort to revolutionize iron production in America. The magnetic ore separator, like almost all other side projects that surfaced in this period, owed its origins to the development of the electric light, and it was of course the requirements of the lighting system that ultimately governed the pace and direction of activity at Menlo Park.

Mott's first journal entries described some of the details of work that have already been dealt with here. He recounted the visits of Professors Barker, Brackett, and Rowland and gave his own description of the calorimetric measurements of the light's energy consumption (March 14, 1880). His description of the construction of the laminated armature spells out clearly its purpose:

> Cunningham finishing the first armature made from exceedingly thin sheets of iron (the thickness of tin) insulated with tissue paper, the last one put at work about a week ago was constructed on the same principle but with rather thicker discs say 1/32 inches thick, those of the present make will contain about 600 discs of tin thickness and insulated as stated. It is found that this construction produces vastly better results than the thick uninsulated plates and does not heat to any injurious degree. (March 15, 1880)

Mott also followed the work on experimental filaments in some detail, describing the devices that were made to cut and shape them from wood and the various approaches that were taken to improve methods of anchoring them to clamps. The basic research elements covered by Mott were, by and large, just the ones we would expect to find, except that they were now set in a much more precise chronological context.

Unlike many of the technical matters that he covered, the observations that Mott made on the procedures and personalities of the laboratory are unique. Shortly after beginning his journal, for example, Mott described a basic change in the laboratory's operations:

> Sunday Mch. 21
> Dean continuing work on new mould, but otherwise nothing doing in Shop or Laboratory.
> To night is the first Sunday night since I have been here and I believe for months before I came, that the Engine has not been running and work in the Laboratory proceeding the same as at other times, and it is now understood that night work for the present shall be discontinued. Mr. Batchelor's complaining of his eyes is the present inducement for making this change, which will undoubtedly prove advantageous to all who have from choice or necessity worked nights and slept and rested during the day - and a saving of considerable expense in night meals which have heretofore cost from $120 to $140 per month during the winter.

Even when dealing with the technical work in his more typical observations, Mott gives us a much more intimate sense of a day at Menlo Park than we can get from other sources. The day following the above entry, for example, finds this record:

> Monday Mch. 22
> Dean finished mould for Plumbago ends for fibers and this evening Mr. Batchelor made two unsuccessful attempts to get the fibers out in tack (sic). The mould however does its work very nicely and he will probably be able to get out some during tomorrow. Mr. Edison sketched another design for mold for same purpose and gave to Dean to make.

> Have been running large armature all day for heat test - find it heats some but could not learn from Mr. Upton the number of degrees increase, not so much however I believe but what it will be able to stand.
>
> Reported here that on Friday last Mr. Edison in New York City disposed of his relay to Western Union Tel. Co. for $100,000.
>
> Profs. Upton and Jehl at work on Photometric and calorimeter tests probably for their own edification and practice as it is entirely useless to make any enquiries of them in regard to their investigations. Prof. Barker here a short time in afternoon.
>
> Wilber here and said that during last week he filed for Mr. Edison six applications for Patents (one a day). I coppied [sic] applications for two weeks stay in Interference cases Edison vs. Dolbear & Edison vs. Dolbear vs. [sic]

It is through Mott's images of the busy patent lawyer, the frustrated technician and the slightly snobbish academic that the Menlo Park laboratory truly begins to come to life.

* * * *

Despite the continuation of older projects and the persistent intrusion of new ones, the laboratory in 1880 revolved around the electric light and its support system. By late spring, the most important problems had defined themselves clearly: (1) how to make the light bulb sturdier and more reliable; (2) how to make bulb production cheaper and suitable for factory operations; (3) how to determine the parameters of anticipated system installations; and (4) how to make the generator more reliable and more efficient, especially with large loads. Efforts to perfect the bulb continued to focus on finding an improved filament material. Mott's journal relates the progress of the Menlo Park experimenters as they attempted approach after approach in search for the ideal carbon form:

> (April 8) "Those at work on the lamp and on carbons (Batchelor, Force, Mr. Edison, Flammer and some of the men in Shop) greatly interested in the efforts to devise suitable means and devices for reducing woods to sufficient small dimensions for carbonizing, and have been trying several different devices, Ott being of the opinion that a very fine keen saw will leave the wood smoother and in better shape for the carbons." (April 29) "Wood loop cut from the thin worked holly milled by Force and cut after manner and in same former used for cardboard, carbonized by Van Cleve, were measured and put in lamps ready for pump, resistence 125 and 194 ohms." (May 14) "Carbonization. Several moulds of Bast fibers were carefully prepared and formed around wood for carbonization, but the wood proved very detrimental, every one having been broken in the moulds during the process. Van Cleve is preparing some more for trial." (May 20) "Carbonization. Van Cleve carbonized three moulds of bent wooden loops by securing the strips in slotted nickel plates; he got them out very nicely and in good shape. Bast fiber. Four of the Bast fiber lamps were measured and tested with current of 103 volts they gave from 30 to 32 candles and about six per horse power. They were connected to main wires in Laboratory and during the first hour three of them broke in the clamps and glass but the fiber in each instance remained in globe unbroken. Showing the fiber to make strong carbon but difficult to form good contact with."

These are only samplings of the day-by-day record Mott kept on the often frustrating hunt for a more durable and more reliable filament material.

Besides giving a continuous record of the search for a better filament material, Mott's journal also provides a much clearer picture of the different kinds of activities that were pursued as part of the quest. For example, as each general kind of material was considered and tested for suitability as a filament source, special tools had to be devised to properly shape it. For weeks, Mott recorded work done to devise a wood milling machine for preparing wooden loops. On May 21, he noted the result:

> Wood Milling. Dean is jubilant over his success today in working the cam milling machine with complete success and getting out about 100 loops of box & holly in excellent shape and in several cases sawing them so perfectly that the whole five loops were left joined at the thick ends, although the machine have been worked for some time with indifferent success. Today is the first Dean has felt satisfied with its working.

Other work related to the filament search involved developing better molds for the carbonization process, methods for extracting gum and resin from wood prior to carbonization, and devising other shaping tools. Mott confirmed that the number of different materials given tests as filaments was not very large. By late spring, tests were limited to a few kinds of woods and bast fibers. While the experiments on woods continued through the spring, the usefulness of the material with a natural fibrous structure became clearer as time went on, and bast and other fibrous substances were the subject of the bulk of the lamp experiments by summer. One of the primary advantages of the fibers was their superior stability after carbonization. According to Mott (June 12): "Mr. Edison observed that the Bast fibers shrink in carbonizing about 17 per cent, against 33% shrinkage in paper, woods, &c." It was natural, therefore, that further experiments should focus on finding other fibrous materials.

Bast fiber received most of the laboratory's attention during June, but persistent problems were encountered in the connection between the carbonized fibers and the clamps. On June 25 Mott reported that some loops were cut out of osier willow and palm leaf samples, but that they turned out to be very fragile after carbonizing. A few days later some palm leaf loops were carbonized successfully, but the first lamps made from "palmetto" were not very promising. More were tried over the next week, but without markedly greater success. Finally, upon returning from a short Fourth of July vacation, Mott reported that "A collection of Bamboo Reed and choice Bast have been obtained and some loops cut out but none yet put in the lamps to test (July 8)." On July 10, Mott reported the first tests of bamboo, and there was nothing spectacular in the results: "Bamboo cut from top or outside edge of fan. Resistance cold 188 ohms at 16 C. 114 ohms and gave 8.6 per horsepower." Performance of the bamboo in a lamp was somewhat like that of the bast fiber: (July 12) "A bamboo lamp tested Saturday (July 10) was put at 44 candles this morning, got very blue at clamp and lasted 1 hour 15 minutes." Bamboo was, of course, to be the solution to the search for a sturdier, more reliable filament material for commercial use, but its debut in the Menlo Park lab, while promising, was no more spectacular than that of dozens of materials before it.

It actually required only a few weeks of additional experiments to determine that bamboo was indeed the material sought after. It is instructive to follow Mott's recounting of how this conclusion was reached. Soon after the initial tests, Batchelor, who was in charge of the carbonization experiments, figured out the shrinkage of the bamboo after carbonization (20%) and gave instructions for making a former for bamboo loops.[2] By this time, the laboratory had devised a means for speeding up the crucial life tests for new filament materials. Instead of running lamps at standard operating voltage to yield around 16 candle power (the desired light output for commerical use), lamps were put at higher voltages and tested at outputs of forty candles or more. This procedure reduced testing time from hours and days to minutes. Thus Mott describes one early bamboo test: "(July 17) Bamboo. Carbon of Bamboo with slight notch cut in one side set burning at about forty candles; in about five minutes the clamp on one side melted down forming a globule on the end of the wire and destroying the carbon. Lamp Number 1277 Book No. 57 Page 159." Further tests indicated the real superiority of bamboo: "(July 21) Average test on Lamps: From the lamps so far tested at 44 candles, the average life was taken and found to be, for Bast 6 Minutes, Calcutta Bamboo 17 Minutes and paper about three minutes. The Bamboo carbons were in many cases imperfect which has probably reduced the average for them, but which will be undoubtedly raised when proper precaution and care is used in selecting only perfectly cut and prepared carbons." At about this same time efforts were made to acquire a better quality of bamboo, with further gratifying results: "(July 19) Bamboo Pure. Some Pure Bamboo (genuine) was obtained and given to Bradley from which to cut some loops. [The Bamboo previously used was Calcutta Bamboo.] The genuine is very fine grained and works nicer than the other." This "genuine" bamboo was later referred to as "Japanese Bamboo," and it did indeed prove to be a superior material. By August, it was clear that they had what they wanted, Mott reporting: "(August 2) 6in. Bamboo. Lamp burned 3 hrs. 24 mins. at 71 candles and gave nearly 7 per h.p. - the best lamp ever yet made here from vegetable carbon." From this day on, Mott made no more references to experiments on filament materials; "carbons," "fibers," and "loops" always refer to bamboo, and the tools devised for shaping them are made with that material in mind.

* * * *

At the same time as efforts went forward to improve the performance and durability of the light, much of the work at Menlo Park was directed toward designing the means for producing the light bulb for large-scale commercial use. While the problems of the electric light's operational economy — the cost of the power it consumed — and of its capital requirements — primarily the cost of generators and conductors — were recognized early by Edison as key elements in the design of the system, the basic cost of the lighting unit itself did not become a major consideration until it became an immediate practical problem in the Spring of 1880. Until six months before, after all, most efforts were directed to designing a lamp that not only depended on a complex mechanism for maintaining its filament, but also used appreciable amounts of expensive metals like platinum and iridium. The unit costs of any of Edison's platinum lamps would have been horrendous, and his faith in their ultimate commercial possibilities rested on the belief that platinum could be had much more cheaply, that a properly designed lamp would last indefinitely, and that quantity production of any device would be accompanied by significant economies. Edison was fortunate in never having to test these beliefs, for the carbon lamp that emerged in the Fall of 1879 was a marvelously simple device, made largely of very common and cheap substances.

This good fortune did not mean, however, that commercial production of the lamp lacked significant challenges. The search for a better filament material was, after all, spurred by the difficulty of handling the cardboard carbons while making lamps. But the filament was only part of the production problems that the lamp posed, and Edison wasted little time in trying to disprove skeptics who claimed that his fragile glass globes with the unbelievably high vacuum could never be more than laboratory devices. The installation aboard the Columbia provided the first real spur for the development of a lamp manufacturing capability. Only a few days after work began on making lamps for the Columbia, Edison began to tackle the most critical lamp production problem, evacuation. Mott recorded this start:

> (April 1) Mr. Edison tonight commenced experiment on pumps with the view of using single instead of double pumps as at present also of combining or arranging a large number in small space has on two lamps of fiber carbon, globes made tube shape.

The extremely high vacuums achieved in the carbon lamps by the Sprengle pumps were their most extraordinary feature, and adapting evacuation into a factory process posed a unique challenge. Making lamps in the laboratory required hours of close attention to the modified Sprengle pumps, which were themselves prone to breakage and faulty operation. To adapt the pumps to a factory, the workers at Menlo Park sought to simplify the construction of the pump, to simplify its operation, and to mechanize its action as much as possible.

The efforts to simplify the pump, making it more reliable and quicker acting, were important ones, as shown both by the amount of attention they received that spring and by the litigation that followed a number of years later between Edison and his chief glass-worker, Ludwig Boehm. Mott's description of this work gives some flavor of how the Menlo Park laboratory attacked this kind of problem:

> (April 9) Boehm made glass cyphon for experiment on the new single Sprengle principle pump....
> (April 10) Pump. Dr. Moses trying the new Sprengle drop pump with syphon attachment, as a whole finds it does not give results entirely satisfactory. Mr. Edison with much good reason attributes the partial failure to the cyphon attachment rather than to the pump itself.
> (April 12) Pump. It was noticed that in pouring the mercury in the globe reservoir, that the force carried more or less air into the globe from whence it found its way into the cyphon and thence to the pump to obviate which Dr. Moses had tubes made closed on bottom with apertures on sides near the bottom so as to break the fall of the mercury and distribute it in the bottom of the reservoir with less force; found it to remove the difficulty of air in the cyphon but still the pump did not work as completely as desired.

Over the next week, Mott's journal describes work on the pump by Boehm, Moses, Upton, and Jehl. One aspect of the Menlo Park approach that comes through clearly from Mott's description is the free, competitive spirit that sometimes reigned when several workers tackled the same task; another is the opportunity for invention that was sometimes seized by even the youngest of Menlo Park's workers (in this case, Francis Jehl):

> (April 18) Pump. Francis had Holzier make pump after his design, which is very simple, free

of stop cocks, takes but little room, and comparatively little mercury, tried in evening and pump vacuum up to one half of gauge tube obtained in little over an hour. He had also made a rubber stopper cup or socket in which to make the lamp connection without the necessity of using ground glass stoppers.

(April 19) Pumps. Francis put one wooden loop lamp on his pump in Dark room and got vacuum and heated up in two hours.

Dr. Moses with two paper loop lamps got good vacuum in five hours but had not heated. From these first efforts it would be difficult to say which of the pumps were best and quickest for getting vacuum, but the pump in use by Francis is much the simpler, cheaper, and occupies less room. Boehm making a new pump slightly different from either just mentioned.

(April 22) Pump. The single tube pump made by Boehm yesterday was started by Dr. Moses and he has succeeded in getting a good pump vacuum in 17 minutes and the pump appears to work quite satisfactorily. Francis also at work with his pump but so far as known has not timed it or obtained any data as to its merits.

...

(April 24) Pump by Francis again up and running with lamp on, and got vacuum in two hours. He had attached a device for flooding and removing the Mercury from the lamp cup or holder, made with small piece glass tubing attached to side of cup about one third down from top, to which is attached a short piece of rubber tubing running and attached to a small reservoir, bottle or other receptacle. By raising or lowering of which the mercury is forced in or drawn out of the cup, the rubber cork or stopper in the cup is cut sloping so as to deposit the mercury on the low side at the point of connection between cup and tube. (drawing)

(April 25) Pumps. Holzier made six additional pumps of same pattern as one in use in dark room by Francis with new cup flooding device and put on frames with long slots in bottom and wooden slide fitted therein moveable up and down and to which is attached the tube receptacle of the gauge mercury. (drawing)

...
(April 27) Pump. Francis claims good pump vacuum on his pumps in six minutes.
...
(May 3) Pump. John Ott taking one of the pumps from dark room apart and carefully taking dimensions of the tubing and all parts of the pump and making full sized diagram of same for use by glass blowers that they may make a number more of precisely the same size, caliber, &c. to ascertain whether they will give equally good results, and will be put in old factory and thoroughly tested as the pump.

It is perhaps not coincidence that on the same day that Mott spoke of tests of "the pump," May 3, he also recorded that the first concrete steps were being taken to set up the lamp factory:

> (May 3) Old factory. Along Rail road is being cleaned up and repaired preparatory to putting in pumps and lamp manufacturing apparatus.

Over the next few months Mott made periodic references to the work going on to prepare the old factory building on the other side of the Pennsylvania Railroad tracks from the laboratory complex for the installation of bulb making equipment. The manufacture of that equipment would, of course, be largely the work of the laboratory, thus these same months were filled with that task as well. Here, as might be expected, pump construction was the greatest chore, even after Jehl's design had been adopted. Edison planned to install hundreds of the modified Sprengel pumps in the factory, and this necessitated the design of further machinery to keep them going, one of which was described by Mott:

> (May 4) Mr. Hornig making diagram of power pump to be set up and used in old factory for handling the mercury for the 476 pumps to be

> put up there, in which they are putting down floor.
> ...
> (May 10) Mercury Pump. Mr. Hornig calculates 1000 lbs of mercury will be necessary to fill pipes and pump of capacity sufficient to 200 vacuum pumps. Mr. Edison decides to run the large Pump with electromotor instead of steam.

This "mercury pump" was one of the remarkable pieces of equipment designed at Menlo Park to put light bulb manufacture on a factory scale. The operation of the laboratory vacuum pumps required constant attendence by someone whose responsibility it was to keep the mercury reservoir at the top filled with the liquid metal. This was just the job that had occupied Francis Jehl for so many months, and it was a slow, laborious, dull task. It was thus proposed that the factory be equipped with a large pump that would keep the mercury reservoirs of the vacuum pumps filled mechanically. Edison's decision to power this pump by an electric motor driven by current from the generators that would be providing light to the factory and surrounding buildings was the first step toward the industrial application of electric power.

Other pieces of equipment and machines had to be designed for the lamp factory. These included an annealing oven to strengthen the finished bulbs, carbonization ovens to bake quantities of filaments, and various shaping and milling tools for the preparation of filaments. One other device deserves a closer look, for it reveals the sensitivity of Edison and his colleagues to the important differences between the construction of experimental devices in a laboratory and the manufacture of consumer items on a large scale. The Menlo Park laboratory had for some time relied heavily on the services of skilled glass-blowers, who were not only responsible for the often intricate glass work that the making and modifying of vacuum pumps and other laboratory apparatus required, but also were ultimately responsible for the blowing of the light bulbs themselves. The cheapening of bulb making would clearly require an alternative to the skilled craftsmanship of the glass-blowers. Mott described this development:

> (May 4) Lamp Mould. The metallic mould for lamp bulbs was secured on a permanent iron base and arranged with spring to open and void(?) and pully treadle for closing & works very completely. Pelzer here with two samples of lead glass tubing, and took with him one of the globes blown by Boehm as model from which to make wooden mould.
> (May 9) Globe Mould. Holzier blowed about one half dozen globes in the metallic mould and treated them with the acid solution. It may not require so much skill to blow in mould as off hand and therefore with cheaper labor, but as for appearance and time I think there is no advantage whatever in the mould.

The trials with molds continued for a brief period, but in the end bulbs continued to be "free-blown." William Holzer (Mott's "Holzier") joined the staff in January, 1880, leaving work in Philadelphia (see above, chap. 5), where he had lived for many years. Holzer may have been responsible for urging Edison to contact the Corning Glass Works, which sent a representative to Menlo Park, according to Mott, on June 21. Not long after, arrangements were made with Corning to supply blown bulb blanks (made for "pot glass"), although it was November before the first shipment of 307 dozen blanks arrived at the Menlo Park factory (at a cost of $5.00 per gross).[3] The bulb blanks remained the principle sub-contracted component of the Edison light bulbs.

The preparation of the lamp factory, the construction of machinery for it, and the installation and testing of equipment occupied workers at Menlo Park through the summer. The construction of the more than 500 vacuum pumps was a considerable job itself, requiring the full-time attention of a number of glass-blowers for several months. The large mercury pump turned out to be a very difficult machine to design and build for reliable, continuous operation, and in these early days of electric motors, considerable time and energy were lost in fixing crossed wiring and burnt-out armatures. Even seemingly trivial problems often took weeks to solve, requiring those who would otherwise be supervising the factory installations to return to laboratory work. For example, it was early discovered that repeated use of mercury in the vacuum pumps tended to foul it with impurities that soon impaired the pumps. Thus the Menlo Park chemists, Lawson and Moses, had to devise methods of cleaning the mercury in the course of its use in the factory. In another instance, soon after the adoption of bamboo as the basic filament material, it was observed that many bamboo loops emerged from the carbonization process badly bent over. At first, Batchelor devised a clever means of the straightening them after they had been put into the bulbs; Mott described it this way:

> (Aug. 4) Straightening carbons. Some of the longer carbons have at time bent over to one side vary [very] much after they had been placed in the lamps and heated. To straighten them the lamp is placed between the poles of an electric magnet and the current turned on on the lamp. One pole attracts while the other repels the charged carbon and the lamp is placed between the poles in such relation that the polar action is

> utilized to straighten the carbon through the glass globe. I find that this "little dodge" has been worked for some time but today is the first I have caught them at it.

This expedient was, however, clearly not suitable for the needs of the factory. Batchelor continued attacking the problem, and Mott's description of how the solution finally emerged gives another revealing glimpse of the Menlo Park style:

> (Aug. 12) Carbonization. Mr. Batchelor's experiments with different heats did not solve the problem or reveal the cause of the loops bending over. A thorough discussion to night suggested the theory that it might be due to the fact that the way the present loops are cut and carbonized the pith and outside of the Bamboo always comes on the side of the loop, and to test the theory whether the pith side, being more loose and porous than the outside did not shrink more from the effects of the heat, than the more firm and compact outside. It was determined to change a carbon forming mould so that the widened ends might stand at right angles with the face and thus bring the pith either on inside or outside of the loop. The mould was then arranged and between twelve o'clock and morning Mr. Batchelor got out three or four, had them put in lamps exhausted and heated very high and to the gratification of all the loops remained erect and they justly feel that the problem is solved and that carbonization is now worked to a fine art.

Batchelor's own laboratory notes give another perspective on how this problem was attacked:

> The cause of the bending over of the loop after it is heated in vacuo I thought was due to insufficient heating in carbonization but after a series of experiments to determine that point we came to the conclusion that whether heated slightly or to a high temperature some of each bent whilst others kept straight.

> We then remembered that some bamboo fibres which were 4" long and of which we made a great number almost all kept straight. We also remembered that almost all of these were put in the clamps edgeways instead of flatways. This led us to see that the way Bradley cut them from the cane, and the bending them flatways afterwards, would have the "pith side" on one face and the "hardshell" side on the other face(;) unequal shrinkage of course must occur on two such faces and cause the bending.
>
> We now made a mould for carbonizing that would hold the fibre edgeways so: [drawing]...From this mould we tried some on the pumps and they not only were perfectly flat themselves but did not change their upright position with the most intense heat we could get on them.[4]

The problem of the bent bamboo loops was just one of many small (yet often crucial) details that had to be worked out as lamp manufacture was systematized. Mott's reference to the "thorough discussion" that followed Batchelor's initial difficulties provides a good instance of the cooperative team effort that was as much a part of the laboratory's working as the independent and friendly competition that was illustrated by the work of Jehl, Boehm and others on vacuum pump design. It is well to note that Edison's name is mentioned by neither Mott nor Batchelor (indeed, Mott records that Edison was absent all day), for in dealing with such details, the laboratory could function very well without Edison, particularly when they were being handled by Batchelor, Upton, or another of the team with substantial responsibilities. Batchelor's own notes offer a more detailed picture of the kind of reasoning at work in laboratory discussions -- an empirical and yet clearly deductive sort of approach that is the mainstay of any establishment devoted to solving technical problems. The "perspiration" that Edison said was 99% of inventive genius was effective because it was always guided by the kind of alert and perceptive thinking exemplified here.

In a similar manner other obvious deficiencies of the lamp were attacked. The design of the clamps that connected the filaments to the lead-in wires presented very difficult problems that took many months to solve. The original platinum screw-clamps were not only expensive and time-consuming to make, but their performance was often unsatisfactory, and Mott recorded with some frequency the appearance of a blue glow at the foot of many filaments in test lamps - a glow due to an imperfect connection between filament and clamp. In the summer of 1880, nickel was found to be a suitable substitute for platinum in the construction of screw clamps, but clamp manufacture was still difficult and performance no more reliable. After lamp manufacture began in the factory in the fall, the clamp problem became critical. Finally, in December, the chemist Lawson was called in to see what he could do to eliminate the need for clamps altogether.[5] His approach was to plate the ends of the carbon filaments with copper and then to join the plated filament ends directly to the lead-in wires by further plating.[6] Surviving artifacts from the Menlo Park lamp factory testify to the success of this approach.

Less urgent, perhaps, than the clamp, but still presenting a challenge to Menlo Park ingenuity, was the problem of designing a base and socket for the commercial lamp. The laboratory method of connecting operating lamps — simply holding the lamp upright and attaching the lead-in wires to standard terminal screws — was clearly not satisfactory for general use. The Columbia installation stimulated the first efforts to devise a method of connecting lamps that was both convenient and safe. Thus in early 1880 the first lamp sockets were made, consisting simply of wooden recepticles outfitted with copper strips on the inside. Lamps were provided with similar strips at the end of the two lead-in wires, and when they were inserted into the sockets, the copper strips would press against the socket strips and complete the electrical connection.[7] This was good for upright installations, but was obviously not as stable and secure as might be desired. The final solution was, of course, the screw base and socket, which made its first appearance in the fall of 1880.[8] The evolution of this design in the commercial bulb can be followed through surviving artifacts. The first screw base was of wood, with plaster of Paris used to attach the bulb to the base. Later, in 1881, the bulky wood was dropped in favor of more plaster of Paris, and still later that year the design was modified to place less stress on the base-bulb connection and the modern socket form was complete (even if the materials continued to change over the years).

* * * *

Ever since he had introduced his "long-legged Mary Ann" the year before, Edison had been content that his dynamo design left nothing to be desired. The Columbia installation showed that the laboratory could produce any number of generators as needed for any particular system. The development of a new form of dynamo was not a task of the highest priority during early 1880, as the difficulties of perfecting the lamp and devising means for factory production were the focus of attention. Despite this, it is clear that during that year Edison's conception of the commercial central-station power plant changed and his ultimate goal in dynamo design was the most significant part of that change. The best statement of his new goal was contained in an article on "The Success of the Electric Light" that he prepared for the North American Review and published in October. Therein, after describing the improved bamboo lamp, he went on to outline how he envisioned his power plant:

> Another important modification of the system, introduced since the latest authorized account of the light was published, is the substitution of dynamo-machines for magneto-machines in the stations from which the electricity is to be supplied to the several districts of a city. Here, again, the change is entirely in the direction of simplicity and economy. Where before it was proposed to furnish a station with one hundred magneto-machines with a multiplicity of belts and shafting, we now make ten dynamos of 120-horse power, each worked directly by a 120-horse-power engine. We thus do away with a very considerable loss of power, and at the same time the outlay for machinery is very much lessened.

Like so many of Edison's public statements, this one cannot be taken at face value. From the time two years before that he had experimented with the machines made by Wallace and Gramme, Edison had always used dynamos - generators supplied with electromagnets - and not magnetos - generators dependent on permanent magnets. Neither his "long-legged Mary Ann" nor any other machine that he had considered seriously for use in his system had been magnetos, and yet he announced here his progressive step in adopting the dynamo principle. As for the talk of a 120 horse-power machine, however, there Edison spoke more of plans than realities. Such a machine would be able to power more than 1000 lights, but no device built at Menlo Park up to this time could power more than fifty or sixty lights. In August, 1880, Upton jotted down some "calculations for 100 H.P. machine," but he was clearly making plans for something far greater than had yet been built.[9] Most of the dynamo work taking place during 1880 was directed toward building a sufficient number of reliable machines of the standard bi-polar design to supply the needs of the Columbia installation and then of the larger Menlo Park system, supplying the demonstration lighting system being erected around the village and the light and power needs of the factory. These installations were precisely of the pattern that Edison disavowed in his North American Review article, that is, made up of whatever number of 50 or 60 lamp machines was required to meet total power needs.

By the end of the summer, however, the vision of a larger, more effective dynamo as a key element of the full-scale commercial system had taken hold. Given the pressures of other projects, work on realizing this vision went ahead slowly. On September 7, Mott recorded, "Forgings of soft iron for the magnet arms or poles and top pieces for the large 100 horse power dynamo were (received)," and on the 11th he noted, "Large Dynamo. Mr. Clarke finished the details and drawings for the large armature, and the heavy castings for bases of magnets were received." From that time until January, 1881 work was pressed forward on the construction of Edison's first large dynamo -- the prototype of the "Jumbo" dynamo that was to emerge from the Edison shops about a year later. The design and construction of this machine posed considerable challenges to the Menlo Park crew, for it was the first thing they had ever attempted that far surpassed a laboratory scale of construction. Mott's journal entries for the Fall and Winter of 1880-81 hardly allowed a week to go by without some reference to the large dynamo project. Special tools and machine tools had to be built to work on the large parts, particularly the armature and the commutator, of the large machine. Extensive discussions took place with steam engine makers, especially Charles T. Porter, whose Porter-Allen engines represented the state of the art of steam engine design in the 1880's. One of the key features of the machine that Edison envisaged was its direct connection with the driving steam engine, instead of the belt and pulley connection that had always been used with the smaller dynamos. This required, however, that the characteristics of the steam engine be taken into account at every stage of the dynamo's design and construction. It turned out that the challenge of building dynamos to work in such intimate unison with steam engines was never completely overcome by Edison, as evidenced by the difficulties he experienced with the Jumbo dynamos installed in the 1882 Pearl Street station. As remarkable as Edison's large dynamos were, sight should not be lost of the fact that most of the early Edison power stations, after Pearl Street, were operated with smaller dynamos powered by belts and shafts from independently operated steam engines. Direct shafting between dynamo and prime mover would for the most part have to wait until reciprocating steam engines were replaced by giant steam turbines a couple of decades later.

Despite the limited long-term significance of Edison's large dynamos, the engineering approach and logic that their construction reflected were key elements of the Edisonian method as practiced at Menlo Park and therefore deserve careful scrutiny. The rationale for the large dynamo was straightforward, as suggested by Edison's American Review statement that the new machine would "do away with a very considerable loss of power, and at the same time the outlay for machinery is very much lessened." As Edison saw it, the use of a large number of small, belt-driven dynamos multiplied the mechanical losses that were inherent in any sort of linkage between steam engines and machinery. The simplicity of this logic, however, did not mean that it was deemed unnecessary to measure the actual inefficiencies involved. While tests were carried out periodically to determine the efficiency of the Menlo Park dynamos, it was on the eve of the completion of the prototype large machine that definitive tests were performed. The design of these tests and their results were carefully recorded by Charles Clarke, who by the end of 1880 had clearly assumed the position of Menlo Park's chief expert on power engineering. Clarke compiled his observations of the test of January 28-29, 1881 into a report entitled, "Economy Test of the Edison Electric Light," which represented the most extensive technical statement of the performance of the Edison system after its first full year of development.

The test that Clarke reported was carried out on the completed Menlo Park light and power system, which had been first shown to the public the month before. This system incorporated the key elements of the commercial central station installations that Edison envisioned, including underground conductors linking the lamps with the dynamos in a "multiple-arc" (or parallel) system of distribution. Clarke's test reflected the technical precision that was typical of all that he did. On the evening of January 28, a new fire was started under the steam boiler at 9:07, the engine itself was started at 9:22, the full load of lamps was on at 9:26], and the engine was stopped at 9:21 the next morning. Careful measurements were made of the boiler dimensions and fuel consumption, the steam-engine performance, the dynamo circuits, and the lamp behavior. The number of lamps in the circuit included 399 full-size "A" lamps, rated at 16 candle-power, with a resistance of 110 ohms, and 54 "B" lamps, half the size and resistance of the "A" lamps. The "B" lamps were used in series-connected pairs, thus offering the equivalent load of 27 "A" lamps, for a total load equivalent to 426 standard "A" lamps. Three lamps failed at different times during the 12-hour test, thus Clarke calculated the test load at 424-2/3 standard "A" lamps. Clarke's precision extended to his calculations of the total power produced during the test, which he summarized in his report, "While the engine was running 27,674 lbs. of water were evaporated, the engine developing 20.054 horse-power for 4.5 minutes, and 83.67 horse-power for 11 hours and 54.5 minutes." Using these figures, Clarke noted that the number of lamps per gross horse-power equaled 5.08 (= 424.66 ÷ 83.67). Further calculations were used to determine the energy losses in tranmission and in the mechanical systems, and when these losses were all subtracted from the gross horse-power, and the other corrections introduced to the effective number of lamps on the circuit, the resulting efficiency was 7.25 lamps per horse-power. This did not compare unfavorably with the measured energy consumption of the lamps of 8 per horse-power. The 0.75 horse-power discrepancy was charged by Clarke to "the increased friction of the engine and system of driving pulleys and belts," which, he noted later, would be largely eliminated by the proposed directly-connected high-speed engine and large dynamo combination. The report concluded with Clarke's statement that "the approaching completion of the large dynamo, it is hoped, will soon place it within Mr. Edison's power to give to the engineering public complete and reliable data showing even a greater increase in the economy of lighting by electricity."[10]

Three weeks after Clarke's careful tests, the large dynamo was nearing completion. On February 20, 1881, Mott jotted down in his pocket notebook (where he scribbled notes for later elaboration in his journals) that "all (is) in readiness" with the "Porter dynamo." The machine was run for a few minutes on the 24th, but problems appeared in the bearings. On the 26th Mott recorded that the "Porter-Allen run all day at about 300 (rpm) empty to smoothe her up." The next evening the giant machine was ready for a full-scale test, and Edison came down from New York to observe it. Mott's notes of the time indicate that the machine powered about 600 lamps to an average of 18 candle-power running at 600 rpm -- suggesting that it was capable of powering 800 lamps at a lower, standard voltage. Francis Jehl's Menlo Park Reminiscences includes a particularly detailed description of this dynamo's first test, and his account differs from Mott's in some details.[11] Both suggest, however, that while the high-speed machine produced the power it was designed for, the difficulties of operating such a large engine at such high speeds over extended periods manifested themselves quickly. At full speed, the machine tended to heat badly at the bearings, so it was generally operated at under

500 rpm. According to Jehl, it continued to run satisfactorily for some weeks. In the process of shifting his operations to New York, Edison ordered a number of the smaller dynamos shipped to the city and allowed the large machine to assume to burden of lighting the Menlo Park lighting system. Finally, toward the end of May, while Edison was at Menlo Park, he ordered further experiments with the dynamo, and in the course of these the machine burned out through a cross in the armature and was not re-built. The large dynamo, for all its mechanical difficulties, did what it was designed to do, and it proved to Edison's satisfaction that he could indeed build the giant machines that he envisioned for his central station system.[12]

* * * *

From the beginning of his work on the electric light, Edison made no secret of his conception of a light system patterned after gas. Both before and after the invention of the carbon filament lamp he sought to learn more about gas systems, and especially about the economic parameters of such systems. The statistics that were collected about gas lighting in various cities and towns were used to determine the parameters of the central station electric lighting system. This was in part due to the obvious fact that gas lighting represented the competition for any system of centrally distributed electric light. But gas represented more in Edison's mind than the competition -- it was a guiding analogy at every step of the way. The entire concept of "subdivision" of the current was to a degree a product of the gas analogy, and certainly the insistence on independently controlled lights, necessitating the parallel circuit mode of distribution and consequently requiring high-resistance lamps, was directly modelled on a key feature of gas lighting. The model went beyond even these considerations, however, and determined other aspects of the Edison system -- aspects that in retrospect were unnecessary for a complete and successful system. The best example of this extreme influence of gas is in the pursuit of underground distribution. The system of gas distribution from pressurized reservoirs through under-street mains into buildings through smaller conduits was itself modeled on urban water distribution systems, and for both gas and water such an approach seemed (and still seems) the only practical one. For electricity, however, underground distribution presented itself as an expensive and complex alternative to overhead wires, already so familiar in telegraph systems.

No one, of course, was more familiar with telegraph systems than Edison, and the possibility of overhead distribution of electricity was obvious. That large amounts of current could be distributed by overhead wires had been demonstrated by existing arc lighting installations, although for very limited distances and to relatively few lamps in each case. Edison's familiarity with the telegraph also included knowledge of the drawbacks of overhead wiring -- the frequent breakdown of lines due to storms and snows and to the constant exposure of primitive insulation to normal weather and to city atmospheres and the unsightliness of the central districts of large cities cluttered with a maze of telegraph, fire alarm, stock ticker, and the first telephone lines. Edison was aware that one of the great attractions of gas lighting was its reliability, and he correctly sensed that this was in large part due to underground distribution. For electric lighting to attain a comparable reliability, Edison saw no alternative to underground systems, despite their vastly greater cost and technical difficulty. There is no evidence that he was ever challenged in this logic by his colleagues, his backers, the press, or the public.

What did challenge the creation of an underground system was the inadequacy of contemporary insulation technology. This manifested itself with frustrating persistence through 1880. The New Year's Eve demonstration had been an exhibit rushed into being by the scepticism of the New York press and the anxiety of heavily committed financial backers. Edison never considered it, however, a true exhibition of his system and he was anxious that the full extent of his system be demonstrated as soon as possible, lest his vision be inadequately appreciated by the public and by capitalists. In the Spring of 1880, therefore, as soon as the New Jersey clay was fully thawed, workers at Menlo Park began tackling the task of building the first true model of the Edison system. Once again, Mott's journal provides the best view of the frustrating job of installing an underground distribution network around the laboratory complex and, to made the model more persuasive, into the surrounding fields. On April 21, Mott recorded that "with plough and shovells the ditches for conductors to the Park Street lamps were commenced...." The ditches posed little problem, so a couple of days later Mott described a device rigged up to play out the conductors as they were laid into the ditches, and he made the first reference to the use of tar for coating the conductor boxes "to enable them better to reject moisture and as a preventive against decay." All seemed to go smoothly, and on May 4 Mott recorded that another line was begun from the generating station. To save time and labor, Mott noted, this line and all others were to be put down in untarred boxes and covered with tar only after completely laid (May 5). Another line was begun the following week, and Mott described the five lines that the completed system would consist of: the newly begun line of four strands of No. 10 wire to the station of the electric railway, "one of six wires North, one of 25 wires South, one of 18 wires west and one of 16 wires east"(May 10). The number of wires in each main line was determined by the anticipated load: as the line made its way from the generating station, one or two wires were dropped out every hundred feet or so, so that the line tapered as it reached the end. This approach ws to reduce the voltage drop along the length of the conductors by minimizing the circuit's resistance at its origin. There remained a measurable voltage drop nonetheless, so the Menlo Park system required carefully tested and sorted lamps — those requiring higher voltages to achieve the rated candle power being placed nearer the generators, those needing lower voltages being installed further down the line. The design of the Menlo Park system required consideration of such factors, but it was still not a complex operation.

On July 15, Mott noted in his journal:

> Conductors. The gang that have been at work on laying the conductors to the Street lamps since May 1 got them all down today, but there is still a large amount of it to tar, cover, and fill trenches. This job has taken two & one half months, with an average I should judge of six men on the work.

The next day, according to Mott, Upton began testing the insulation of those lines that had been covered. The results were that "some of the circuits are very badly insulated and all more or less defective." Mott allowed himself one of his rare commentaries:

> It seems a little strange that unexperienced men should be permitted to put down nearly five miles of wire and cover it without being required to test a single circuit or wire until the entire work is finished, and it will now require considerable extra labor and delay in putting the circuits in working order.

Mott could not have guessed the extent of the impending delay, but over the next two months numerous experiments and tests were carried out on possible insulating compounds and their behavior in the Menlo Park soil. Tests in rain-soaked ground were of special importance, and once Edison himself cabled to Grosvenor Lowrey to say that he could not leave the lab due to the fact that he had been waiting for "a wet morning."[13] Developing adequate insulation for the underground lines arose as yet another one of the unanticipated challenges for the Edison system.

Menlo Park's most scientific minds -- Upton, Jehl, and Clarke -- found themselves assigned to the insulation problem, since careful testing of the resistance between the lines was required. Wilson S. Howell, who had charge of the installation work from the beginning, supervised the efforts to develop a suitable combination of insulators. These followed the familiar Menlo Park pattern of determining a promising direction, devising variations, and testing each variation under standard conditions.[14] Mott dutifully recorded the various combinations of cloth, rubber, wax, and so forth that Howell and his crew put to the test (see, for example, Mott's entry for Sept. 8 - Appendix). As summer gave way to autumn, Edison was getting anxious about his goal of a system in place by year's end.

When work began (for the fourth time) on laying down the lines in late September, fifteen men and boys were put to the task. The final insulating compound consisted, in Mott's words, of "two thicknesses of muslin [unintelligible] with composition of Paraffine, tar, Linseed oil and Asphaltum." According to Howell's account of many years later, three layers of muslin were wrapped around the wires before they were returned to the trenches.[15] Mott reported that the first street lights of the new system were lit on Monday, November 1, and the following night, "the entire line along Turnpike from Carmans to Factory was supplied with lamps and burned till nearly 12 o'clock." The story was told later that Tuesday's illumination was in celebration of the election that day of James Garfield as President. The new lines were a success, and one week later Edison's own house was put on the system. Finally, on November 20 Mott reported that the work was essentially complete, having "employed an average of about twelve men" for almost two months. The trials of the Menlo Park underground installation were a foretaste of the difficult work that lay ahead in the street of lower Manhattan. Edison's success, however, in the last weeks of 1880, convinced him and equipped him to convince others that whatever obstacles were to come could, with persistence and effort, be surmounted.

* * * *

The last month of 1880 was largely given over to the job of convincing those that needed to be convinced of the completeness and usefulness of the Edison system. This had been the purpose of the Menlo Park system, and once the system was in place, little time was lost in putting it to the task. By the beginning of December all of the elements desired for a full-scale demonstration were in place save one. Edison had very much wanted to use his large, direct-connected dynamo in any widely-publicized exhibition of his system, but difficulties in the machine's design and, more importantly, delays in the delivery of the large Porter-Allen steam engine prevented this. Consideration was given to getting a suitable engine from some other manufacturer, but finally Edison had simply to swallow his disappointment and plan his demonstrations around the series of smaller "long-legged Mary Ann" generators that had been providing power at Menlo Park for most of the year. These were at least well-tested and reliable, and Lowrey and others from the Light Company reminded Edison that reliability was of utmost importance at this stage of wooing public acceptance. Pressures from the Light Company were building in the Fall of 1880, since public opinion and financial confidence were clearly getting restless as the first anniversary of the light's public debut approached. In early November, Edison received a letter from G.W. Soren, one of Lowrey's law partners and secretary of the Light Company, advising him "of a resolution... to the effect that the Executive Committee is requested to visit Mr. Edison at Menlo Park early next week for the purpose of consulting with him as to measures to be taken for bringing the Company light before the public."[16] Edison may have rankled at the reference to the "Company light," but, after all, the "Company" had paid for it and, after more than two years of paying, the financiers were clearly anxious to see some returns.

To move things forward in that direction, Lowrey and others in New York City began to plan the legal steps that would be necessary for installing a lighting system in the city. Despite all the calculations and estimates that the Menlo Park workers had been making regarding the size and capital requirements of such a system, Edison still seemed to be only dimly aware of the complexity of the task before him. In response to an overseas inquiry in October, he stated that he could "safely say that the Edison Electric Light Company of America will have one station established and in full working order lighting the lower portion of the City of New York before the first of May 1881."[17] Not only did this attitude ignore the technical difficulties before him, but the Light Company officials exerted some effort in making Edison aware of the political and economic hurdles standing in the way. After Edison sent him some rough plans for laying wires in New York City streets, Tracy Edson wrote back to explain some of the steps to be taken:

> ...I have today called upon the Commissioner of Public Works, Allan Campbell Esq., with whom I am acquainted, and stated my desire that he should visit Menlo Park with me as soon as you are ready and see you and the Light as I saw it the other evening, in a private and quiet way, before any public exhibition or announcement is made, as he could have a better opportunity, in that way, to examine into and judge of the merits of the system.
> ...Now as I think it would be a great assistance to us in getting the rights we desire if these Gentlemen should be favorably impressed in regard to our Light, I would like it very much if you would make arrangements to exhibit it to them in the manner above indicated, as soon as you conveniently can....[18]

As Edson had undoubtedly foreseen, the problem of getting the city's permission for the lighting system's installation under the streets required more than quiet demonstrations for the benefit of one or two officials directly involved; the City Fathers themselves had to be wooed.

In mid-December Edison himself was called into the act. When the President of the New York City Board of Aldermen, John S. Morris, voiced reservations about the Light Company's application for a franchise, a letter was prepared for Edison's signature that explained the care and extent of the work at Menlo Park, and it ended with an invitation to come out for a full-scale demonstration. A few days later, formal invitations were sent out from Menlo Park to all members of the Board to come to the laboratory on Monday evening, December 20.[19] This occasion was far from the "private and quiet" showing that Edson had envisioned, for it was, in late twentieth-century jargon, a "media event" of the first order, and the newspapers made the most of it. The reporter from Truth found it all great fun. After describing the impression that the Menlo Park lights had on the politicians, he went on to detail the full extent of the lobbying effort:

> The City Fathers had begun to look quite dry and hungry and as though refreshments would have looked much more palatable to them than the display of inventions they had been wondering at for two hours without a great deal of comprehension although with a wonderful exhibition of understanding and appreciation. Their hopes were quickly realized by the announcement that the collation, served by Delmonico, was ready. For half an hour only the clatter of dishes and the popping of champagne corks could be heard and then the wine began to work and the Aldermen, true to their political instincts, began to howl, "Speech, Speech." One of the witnesses of this visit said that the City Fathers were amazed at the appearance of the man they called "Professor" Edison. "Why," whispered one City Father to another, "he looks like a regular fellow. See how he handles his cigar — just like the boys in the Wigwam (Tammany Hall)."

More negotiations followed in the ensuing days concerning the terms under which the Edison interests would be allowed to work in the streets, but the demonstration at Menlo Park clearly left no doubt of the workability of the Edison system.

Other exhibitions through the month of December broadcast the message that the Edison light was finally ready. On December 5 Menlo Park played host to Sarah Bernhardt, then in the midst of an American tour. The visit was the "divine Sarah's" idea, for the actress was dazzled by the reports she had read of Edison's phonograph -- clearly an intriguing invention to a performer famous for her voice. The tour of Menlo Park, however, provided yet another opportunity for putting the light before the public, and Edison did not hesitate to take advantage of it.[20] Other distinguished individuals made their way to Menlo Park that month. Lizzie Upton wrote to her sister Sadie, "The Electric Light is lovely now. I do wish you could see it. We are to have it in here tonight. All the streets are lighted and all over the fields. Jay Gould is coming out to see it tonight and Dudley Sargent is coming out here tomorrow night with his lady."[21] Just like the previous year, a trip to Menlo Park was a fashionable holiday sojourn during the last week of 1880. Large numbers made their way to the New Jersey village on Christmas Eve, while others came out to observe the second New Year's Eve display. The more than 400 lamps spread through the laboratory buildings, homes, streets and fields provided dazzling testimony to the arrival of the electrical age.

CHAPTER 7

PROMISES FULFILLED

In 1880, Edison's establishment at Menlo Park changed its character from a laboratory primarily devoted to invention to a site for the development and manufacture of the components of the Edison lighting system. The little New Jersey village was not as well suited for the more mundane role of manufacturing center, especially when most of its products were intended for the system's great inaugural installation in New York City, some twenty-five miles away. The abandonment of Menlo Park, therefore, began as soon as the demonstration system had served its purpose. 1881 saw the gradual diminution of the laboratory's role and the scattering of much of the crew of assistants that had been so much a part of Edison's work there. Charles Mott's records of the laboratory's activity reflected the changes at Menlo Park. Throughout January Mott's daily record generally included a reference to Edison's presence in New York, frequently adding that others, such as Clarke or Kruesi, were accompanying him. In February the move accelerated: Charles Batchelor sailed for Europe to make arrangements for the electrical exhibitions in Paris and London, and Edison settled on a permanent location for his New York offices at 65 Fifth Avenue.[1] On February 7, Mott noted that his brother Sam had received orders to move his draughting operations to New York, and a month later, on March 10, Mott wrote that he was "Ordered by Mr. E. to go to N.Y. office with Elec. Light Patents & caveats, so my records must cease from this date."*[2]

*Mott, in fact, continued to keep a daily record in New York for some time.

As the electric light moved from the laboratory into the working world, and as Edison moved himself from Menlo Park to New York, the kind of records that chronicle their story changes. Whatever eccentricities the Menlo Park laboratory had in its mode of operation, it followed a basic rule that Edison learned early in his career -- whatever happens, write it down. Despite problems in dating, disjointed sequences of notes, haphazard organization, or cryptic references, the laboratory notebooks still stand as a remarkably full record of activity. The focus of work in one or two buildings and the close supervision that this allowed permitted to exist in the often hectic atmosphere of Menlo Park a recording system which, while imperfect, was of such obvious value that its products were carefully kept, with little attrition, until they passed into the hands of archivists. Edison's New York years (1881 to 1886, when he moved to West Orange, N.J.) produced a written legacy of a very different quality, characterized much more by the demands of business and bureaucracy than by the procedures of a laboratory and the possibilities of patents. The insight that we have into the inner workings of the laboratory and the thinking of the men working there is not available to us once the scene shifts to New York. The records from 65 Fifth Avenue and the half-dozen other centers of Edison enterprise are largely the correspondence of business and finance plus whatever technical notes were deemed significant enough to keep. The story of Edison in New York is therefore changed in tone as well as substance from that of the Wizard of Menlo Park.

The ground for the move in early 1881 was well prepared. The most important step had been the incorporation on December 17, 1880 of the Edison Electric Illuminating Company of New York by a number of the same investors who had formed the Edison Electric Light Company two years before. Like the 1878 incorporation, this one was organized by the indefatiguable Grosvenor Lowrey, who still saw himself as a protector of Edison's personal interests in the ever-more complex financial and political dealings surrounding the Edison enterprises. As a matter of fact, Lowrey's loyalties were already shifting more and more to the Wall Street interests that he had served so long, but this was perhaps not yet obvious to Edison. On the date of the Illuminating Company's incorporation, Lowrey wrote to report the fact to Edison and to soothe, yet once again, the inventor's prickly ego:

> My dear Edison:
> I shall not present your letter of resignation as Mr. Fabbri very strongly objects to your leaving the Board. His impression was that "Edison's name is a tower of strength to us, and if he never attended a meeting, it would be a great loss if his name should not appear at all times among the names of the Directors."....
> We yesterday organized and filed the articles of association of the "Edison Electric Illuminating Company of New York," under the general gas company acts of this state, stating the object of the organization to be to illuminate the streets, &c. by gas. We have to state this as the object in order to perfect a legal incorporation, but every gas company has by law, after it is organized, the right to turn itself into an Electric Light Company, and we have prepared a long ordinance to be submitted to the Common Council if we are so advised, granting us the franchise to lay down wires over the entire city.[3]

The formation of the Illuminating Company was part of Lowrey's carefully orchestrated plan to clear away all conceivable legal obstacles to the installation of the Edison system in New York. As was explained in the 1881 annual report of the Light Company, the new organization was required by New York state law restricting use of the streets for lighting distribution to firms incorporated under the Gas Statutes, as opposed to the general corporation laws. This necessary following of the gas industry pattern in the formative years of electric lighting accounts in part for the clear separation in America between the electric utilities and the electrical manufacturers (as distinguished from the pattern that developed in the communications industry, for example). In real terms of finance and management, however, the separation was (as in the case of many early electric utilities) initially slight, for of the thirteen members of the Illuminating Company's first Board of Directors, nine were from the Light Company's Board. The first president, Norvin Green, was also president of Western Union, and the Drexel, Morgan interests were well represented, most visibly by Egisto Fabbri, who served as first treasurer of the company.

The visit of New York's Board of Aldermen to Menlo Park followed the incorporation by only three days, as Lowrey lost no time in pursuing the required franchise for the Illuminating Company. Lowrey's haste was due not only to the financier's impatience over getting the light into money-making operation, but also to highly visible competition that was now emerging. On December 18, the first public electric lighting system in New York City went into operation as the Brush Electric Light Company started up its three dynamos at 133-135 West 25th Street to supply a series of arc lights on Broadway between 14th and 34th Streets. While a year before the New York newspapers had been filled with news of the miracle wrought with carbonized thread at Menlo Park, this December they devoted their fanfare to the spectacle of the glaringly bright Brush arc lamps that were giving birth to Broadway's "Great White Way." The Brush system was based on the best arc lighting technology of the time, applying generators of Brush's own design (each sufficient to power 16 lamps of 2,000 candle-power each) and using overhead transmission lines on telegraph poles. The Brush Company operated the Broadway lamps as a free demonstration for almost six months, after which it (now the Brush Electric Illuminating Company) was rewarded with a city contract to light not only the original Broadway stretch, but also nearby portions of 14th Street, 34th Street, and Fifth Avenue, as well as Union and Madison Squares. By the end of 1881, there were 55 Brush arc lamps as part of New York's public lighting system. In addition, the Brush light quickly made its way into nearby hotels and theaters in what was then the established shopping and entertainment district of the city. While the Brush are light represented, to Edison at least, no major technological achievement nor a direct challenge to the incandescent light, its highly visible appearance and ready public acceptance at precisely the time that the public was growing vocally weary of the failure of the Edison system to make its long heralded commercial appearance must have provided a special incentive to move further activity from the laboratory into the streets.[4]

In the same article of December 21, 1880 in which it reported the aldermen's visit to Edison's laboratory and the new arc lights on Broadway, the New York Post commented, "There are now six different companies at work introducing electric lights in this city, the lights being known as the Brush, Maxim, Edison, Jablochhoff, Sawyer and Fuller (Gramme patents) lights." While most of the activity represented by rival interests was limited to arc lighting, the public did not always discriminate in its perception of electric lighting, and this accounted somewhat for the diminished spotlight on Edison's efforts during the busy New York years. In addition, the competition was not exclusively from arc lighting, as the same Post article went on to describe the success of Hiram Maxim's incandescent lights "in the vaults and reading rooms of the Mercantile Safe Deposit Company," where they had been "working admirably" for almost two months. At this time there were still no Edison installations outside of Menlo Park (except for the steamer Columbia). Edison had no doubt in his mind that the Maxim lamp was nothing more than a bald copy of his own cardboard filament lamp, distinguished only by the M-shaped filament. Nonetheless, Maxim's success in the installation at the Equitable Building (where the Mercantile's offices were located) was a technical achievement of some note, and served notice on Edison and the Electric Light Company that they could wait no longer to commercialize their product.[5]

Lowrey's push to organize the Illuminating Company and clear away the legal obstacles to the New York central station was one response to the new presures to get the system into operation. An even broader response was Edison's own organizing of the manufacturing capability that the central station system would require. The first part of this effort had been the establishment of the lamp factory at Menlo Park, which by the end of 1880 was turning out several hundred bulbs daily. The lamp factory established a precedent for the organization of manufacturing for the Edison system, for it was independent of the Edison Electric Light Company, dependent on it only for the license to manufacture and supply lamps under the Edison patents. The financiers behind the original company had no intention of putting more of their money into the electric light before they could realize some return on the patents for which they had already supported Edison for more than two years. Edison, for his part, was apparently quite willing to put his own money into an establishment over which he could expect to retain control. The Light Company, while happy to see Edison's money financing lamp production, was nonetheless careful not to give too much away. When, for example, a contract was drafted in January, 1881 between it and the "Edison Electric Lamp Company," the Light Company directors balked not only at the 5 cent per lamp profit that was proposed, but they also objected to the proposed company, to be made up of Edison, Batchelor, Upton, and E.H. Johnson. The contract that eventually emerged in March was between the Light Company and Thomas Edison alone, and it reduced the undivided profit to be allowed per lamp to 3 cents, after which the 35-cent price that the Company paid for each lamp was to be reduced by the half the excess profit.[6] This episode illustrated the extent to which the Light Company managed to exercise ultimate control over the Edison light, even in opposition to the inventor himself.

Another pattern that emerged with the organization of the lamp works was the disbanding of the once close-knit crew that surrounded Edison at Menlo Park. As the new manufacturing concerns continued to be formed in 1881, men like Upton, Kruesi, Dean and others found themselves in management roles, often at some distance from Edison himself. The lamp factory had at first been closely supervised from the laboratory, with Batchelor taking a leading hand in getting everything under way. The factory began turning out bulbs in mid-Summer, 1880, but the official beginning of factory production was designated as October 1, 1880, and the first regular payroll began on November 11. When, in January, 1881 it was decided to send Batchelor to Europe to organize the electric light interests there, Upton was placed in charge of the lamp works. This was to mark a permanent change in Upton's career, for he was for the rest of his working life to be primarily concerned with light bulb production. He was never again to work closely at Edison's side, with the exception of a short period in late 1881 when Edison went to Menlo Park because, as he wrote Johnson, "Upton had got away off his base & was trying to get back without informing me."[7] By early 1881, in fact, Charles Clarke had clearly become the one Edison leaned on for the kind of mathematical and technical assistance he had once sought from Upton. Other key Menlo Park figures soon found themselves scattered among the proliferating Edison enterprises. John Kruesi was put in charge of the Edison Electric Tube Company, set up at 65 Washington Street in New York in February, 1881, for the purpose of organizing the installation of the underground distribution system for the

Other important folders:

Exhibitions - Paris Electrical Exhibition (1880-1881)
These folders contain material related to the electrical exhibition of 1881 held in Paris, France. There is extensive correspondence by Batchelor, Bailey, and Otto Moses, one of Edison's chemists from Menlo Park who assisted Batchelor in running the exhibition. Some of the correspondence also relates to the establishment of European lighting companies and the promotion and manufacture of the light in Europe.

Mining - Platinum Search (1879)
This folder contains correspondence related to Edison's search for a source of platinum to be used as the burner in his lamp. A large number of these contain marginal notes by Edison.

Railroad - Electric (1880-1882)
These folders contain material related to Edison's electric railroad and the development of electric motors. See also Mining - General and Cat. 2174.

Prior to 1882, the letterbooks were used very sporadically to record outgoing correspondence. Often the only record of a response is the marginal notation on the incoming letter in the Document File. That file also contains occasional drafts of outgoing letters. Fortunately, the letterbooks are well indexed and correspondence to the important individuals mentioned in the discussion of electric light materials found in the Document File is easily found. Of special note are letters written in 1882 to Johnson and Batchelor which detail much of the work on the development of the system. The letterbooks have been assigned "LB" numbers. There are fifteen letterbooks dealing with the period 1878-1882 in the main collection, LB-003 to LB-017. There is also a letterbook kept by Samuel Insull, Edison's secretary, between January 1882 and November 1883 (Cat. 290). Much of the material in that letterbook concerns the electric light. Another book, E-4395, contains copies of foreign cable messages from March 1881 to July 1883, most of which deal with the electric light.

Other Documents

There are a few other types of documents that provide information about the development of Edison's electric light system. These include agreements, financial records, memoranda and reports. Agreements provide useful information about Edison's relationship to the various electric light companies. The financial records provide information about Edison's finances, monies expended on experiments, and the operation of the companies, particularly the manufacturing companies. Memoranda and reports provide information of varying importance about Edison's research and about the various companies.

Agreements are found in the Document File in folders related to the companies and in the foreign folders. There is another collection, the Harry F. Miller File, which consists primarily of agreements, including a number related to the electric light. Photocopies of a few agreements from other collections are found in a file of photocopies from outside collections. This file is currently being organized by the Edison Papers Project.

Financial records occur in the Document File in folders related to particular companies and in special folders. The special folders include:

> Edison, T.A. - Accounts
> These folders contain rough accounts and trial balances and there are occasionally summary statements related to Edison's personal finances and to the operation of the laboratory.
>
> Edison, T.A. - Bills and Receipts
> These folders contain loose bills and receipts. Most of the bills from this period are found in invoice books (see below). These bills relate primarily to purchases for the laboratory. Company bills are found in folders related to those companies. Bills related to book and journal orders are found in the invoice books and in Edison, T.A. - Book and Journal Orders folders. Bills for patent expenses are found in the Patents folders.

The most important account books are the ledgers used from 1878-1882. These are Cat. 1185-1187 and an uncatalogued book from March-December 1880 and another from January 1881 - December 1887. The books from 1878-1880 include accounts for the various experiments. Also important is a book with weekly statements of money spent on electric lighting from October 1878 -January 1880. These were written on individual sheets and pasted into the book, Cat. 1224. The invoice books, Cat. 1161-1162, contain bills from 1878-1882. The bills have been annotated to indicate what account they were paid from, sometimes the accounts were for specific experiments and sometimes merely for general laboratory expenses. These accounts correspond to those set up in the account books.

Memoranda, reports, and occasional other documents such as circulars are found in the Document File in the folders noted above in the discussion of correspondence.

Clippings

There are two sets of clippings from newspapers and technical journals which provide useful information about the work of Edison and his rivals on electric lighting. Newspaper clippings, in particular, are useful in providing information about Edison's work which is not easily discerned from the notebooks and other materials. For example, they help us to better understand his work on generators. Edison, who often made announcements about his work through the press, began his work on electric lighting with the assumption that he could use William Wallace's generator (New York **Sun**, September 16, 1878). By December, he began to work in earnest on generators and it was in that month that he announced that Wallace's generator was inadequate for his purposes and that he was now designing his own generator

(New York Sun, December 19, 1878). This helps to modify the work of scholars who have argued that Edison envisioned "the essence of components and their interactions before he began intensive research and experimentation."[10] The newspaper interviews, when used in conjunction with the notebooks show that Edison's decision to design his own generator was, in fact, the product of his experimental research and not the result of earlier theoretical analysis of the "essence of components and their interaction." The clippings are also useful in reconstructing the way in which the laboratory operated (see pp. 32-4 above).

The most useful set of clippings for Edison's work is a volume put together by Charles Batchelor, Cat. 1241, which contains primarily newspaper clippings from 1878-1881. Also useful are Batchelor clipping books, Cat. 1242-1243, from 1881-1882. All the Batchelor clipping books are found in the Charles Batchelor Collection (see below).

Another set of clippings was kept in the laboratory. Menlo Park Scrapbooks, Volumes 1-40, are a set of fifty-seven technical scrapbooks (many of the volumes are sub-numbered), plus an index volume. They are the first in a series of scrapbooks begun by William Carman and Francis Upton in 1878-1879. New books were added and old ones updated by the laboratory staff. The first forty volumes deal primarily with technologies and subsequent volumes added through 1889 are largely concerned with scientific matters. There are approximately 150 scrapbooks still extant in the entire series and there may have been over 200 books at one time. Most of the clippings are from technical and scientific journals, although some are from popular magazines and newspapers. The books on electric lighting include Cat. 1011-1019, labeled "Electric Light, which contain many clippings dealing directly with Edison's work;" Cat. 1025-1027, labeled "Magneto Electric Generators;" Cat. 1051, labeled "Electric Lamp;" and Cat. 1052, labeled "Radiometer and Vacum Pump." There are also a few other volumes which contain material about electricity and magnetism which may be useful for understanding the state of the art. Also see Cat. 1002, "Combustion of Coal; Theoretical Heat from Boilers and Steam Engine Cost."

Primary Printed

There are a number of primary printed materials which were useful in the study of the electric light. These include the Edison Electric Light Company **Bulletins**, company printed materials such as advertising brochures and catalogs, printed patents, and printed patent litigation records.

The Edison Electric Light Company **Bulletins** were begun in January 1882 to answer questions of the company's agents. Later these bulletins were also sent to the company's stockholders. Twenty-one were published between January 1882 and December 1883. They include information about the various electric light companies and the annual reports of the Edison Electric Light Company, the Edison Illuminating Company of New York, and the Edison Company for Isolated Lighting. They are a particularly good source for the progress being made between January and September 1882 on the installation of the Pearl Street central station in New York. There are also accounts of other central and isolated plants in the United States and abroad. The bulletins also provide other items of interest related to the Edison and rival systems of electric lighting, gas companies, and general information about electric lighting, including the reprinting of newspaper and journal articles. Bound sets of these volumes are located at West Orange.

The various Edison electric light companies published advertising circulars, catalogs, and brochures for their agents to use in selling the system. These have been collected together in a collection of Primary Printed Material for Edison Companies. There is a similar collection which contains material from non-Edison companies, although there is little material there from the 1880s. These collections have been indexed by the Edison Papers Project. There is also a bound volume of some of the Edison companies' pamphlets which is currently uncatalogued.

All of the Edison printed patents have been bound into a series of seven volumes, in order by patent number. Most of the electric light patents from 1878 to 1882 are found in Volumes 1-3. The Edison Electric Light Company also kept records of the patents Edison applied for between 1878 and 1885. The claims and drawings of these patent applications wre copied into uncatalogued volumes E-2534-2535, E-2537-2538, and E-4398-4400.

Bound volumes of printed patent litigation are found in the library at the Edison National Historic Site. An inventory of these litigation records has been prepared by the Edison Papers Project. Included are a number of electric light cases. Of particular note are Edison Electric Light Co. vs. United States Electric Lighting Co. (7 volumes) on the carbon filament patent 223,898 and the testimony from patent interferences, Sawyer and Man vs. Edison (filament), Keith vs. Edison vs. Brush (dynamo electric machines), and Mather vs. Edison vs. Scribner (dynamo electric machines). Exhibits from patent litigation often provide the only extant copies of certain documents. The testimony is particularly useful for fleshing out what was going on in the laboratory but should be used in conjunction with other materials which substantiate the testimony. Robert Conot, in his biography of

Edison, noted that the inventor was a poor witness when asked to recall the sequence of events and that "they blended and telescoped into each other, and he misplaced even fairly recent happenings by as much as three months."[11] While this statement was made about Edison's testimony in the complex series of court cases arising out of his work on the quadruplex telegraph, similar problems appear in his testimony in the electric light cases and his still later reminiscences about his work on electric lighting.

Reminiscences

The reminiscences most widely used by other researchers studying the development of the electric light have been those of Edison, which were extensively quoted in the Dyer and Martin official biography, Edison: His Life and Inventions, and of Francis Jehl, a laboratory assistant who wrote the three volume Menlo Park Reminiscences. There are also less well-known and shorter reminiscences by Edison and his associates, a number of which were written for the Dyer and Martin biography.

Edison wrote an extensive set of notes and answers to questions for his secretary, William H. Meadowcroft, which were used in the Dyer and Martin biography. Meadowcroft is cited as collaborator but was very likely the principle author. Some of this material was also used for a short article which Edison authored with Meadowcroft probably acting as ghostwriter. This short piece was written in 1926 for Henry Ford.[12] As noted above, in the discussion of notebooks, Edison incorrectly remembered investigating the gas industry before he began work on the light. This same story appears in the Ford article. It is typical of the failure of Edison to remember when and in what order certain events took place. This same problem appears in his testimony which was usually much sooner after the actual event than his reminiscences.

Another problem with the reminiscences of Edison and his associates is the tendency to remember events which have somehow become part of the "official" story, even when it is likely they did not happen as remembered. An example of this is the famous story of the "forty hour" lamp of October 21, 1879. In the article Edison wrote for Ford, he notes that the laboratory notebook from this date records a lamp made of cotton thread. However, he then goes on to say that it lasted about forty-five hours when, in fact, it lasted thirteen and a half. This same story has been told by all those who were present in October.

Among those present was Francis Jehl, who joined Edison as an eighteen year old laboratory assistant in 1879. In his Menlo Park Reminiscences, Jehl claimed to have been there in November 1878 and even describes the arrival of Francis Upton to the laboratory. The employment records, including a letter of recommendation from Grovesnor P. Lowrey, all show that he was not there until at least February 1879. Jehl also gives himself a more prominent role in the early electric light research than is indicated by the laboratory records. He does not enter the laboratory notebooks until September 1879 when he assisted Francis Upton with vacum pump experiments. Later that year and in 1880, Jehl seems to have been primarily engaged in making tests of lamps. He also assisted in the development of the vacum pump and the chemical meter during 1880 and 1881.

Jehl's work does have its merits. Parts of the Reminiscences are based on a diary which he kept. Unfortunately, this diary is missing from the Tannahill Library at the Edison Institute in Dearborn, Michigan. From internal evidence in the Reminiscences however, it appears that he kept it only from February to May 1881, when he was at the Edison Machine Works Testing Room. In his discussion of this period, Jehl quotes directly from his diary. Jehl also made use of various documents and contemporary articles to refresh his memory and, in that respect, the Reminiscences take on something of the character of a secondary work. Finally, his discussion of the roles of various members of the laboratory staff is quite useful and he contacted a number of them to provide brief reminiscences of their own. Of particular note are the lengthier reminiscecences of Charle L. Clarke and John W. Lieb which are quoted in their entirety by Jehl. These are "Menlo Park in 1880," by Clarke, pp. 855-63 and Clarke and Lieb's "The Historic Pearl Street New York Edison Station," pp. 1041-55.

There are also a number of short reminiscences which were written as part of the application process of the Edison Pioneers and that organization also collected other reminiscences. These are filed at the archive in the Edison Pioneers Biographical Collection. The material in this collection is filed under an individual's name and the file contains useful information about those who worked with Edison.

Other reminiscences were used in the Dyer and Martin biography and some of those sent by Edison associates to William H. Meadowcroft when he was compiling material for the biography are found in the Meadowcroft Box Collection. This collection also contains Edison's reminiscences compiled for the biography.

There is a short account by Charles Batchelor about Edison's return from Wyoming and visit to William Wallace's shop in the summer of 1878 and a short analysis of Edison's method of invention by Francis Upton which are useful in looking at Edison's work on electric lighting. These are housed in special collections containing materials by these two principal Edison assistants. See the discussion of these special collections below.

Special Collections

There are two special collections which are particularly useful for research on Edison's work in electric lighting. These are the Charles Batchelor Collection and the Francis R. Upton Collection.

The Batchelor Collection was given to the Edison National Historic Site between 1957 and 1961 by his daughter, Emma Batchelor. Much of the material relates to work on electric lighting between 1878 and 1882. Of particular note are the following items:

Cat. #	
1237	Notebook 1880-1899
1239	Notebook 1881-1883
1241	Clippings 1878-1881 (see discussion under clippings above)
1242	Clippings 1881
1243	Clippings 1881-1882
1301-3	Set of three notebooks containing notes of lamps ordered and tested between September 1880 and October 1882. The entries are numbered 1-1301.
1304	Notebook 1878-1879, 1884-1891. A very important early notebook.
1308	Order Book 1879. This book was kept by Batchelor and John Kruesi to record orders of experimental devices made by the laboratory machine shop in 1879. These correspond to notebook which mention order numbers.
1321	Bound volume of Edison's British Patents 1872-1880.

There are also other materials in this collection which are useful for research on the marketing of the electric light in Europe during the years 1881-1883. See the inventory of the collection created by the archive staff. There are also two card indexes to this collection at the archive.

The Upton Collection was given to the Edison National Historic Site by Upton's daughter, Eleanor Upton via Paul J. Kruesi, son of John Kruesi, in 1963. Most of the material in this collections is later than 1882. However, there are some very important materials related to research on the electric light. Of particular note are the following items:

E-6285-1	Notebook used by Upton in November 1878 for his literature search.
E-6285-2	Notebook used by Upton in November 1878 for his literature search.
E-6285-5	Five letters from Upton to Charles Farley, 1878-1880.
E-6124	Series of letters from Upton to his family, 1878-188?
E-6298	Includes folder of letters from Upton to others concerning the electric light. Folder labeled "Electric Light History." Also a memorandum by Upton of notebook references from 1879-1882 dealing with the electric light.

The Upton Collection may undergo reorganization in preparation for the microfilm edition of the Edison Papers. However, the small size of this collection makes the material easily accessible.

Other Collections

While the archive at the Edison National Historic Site contains most of the important material related to Edison's work on the electric light, other manuscript collections were also searched. The most important were the Edisonia Collection at the Tannahill Library at the Edison Institute in Dearborn, Michigan, the Records of the Patent Office at the National Archives, the Hammer Collection at the Smithsonian Institution, and the Swan Papers in Newcastle-on-Tyne, England.

The Edisonia Collection houses the second largest collection of Edison materials. Some of these relate to work on the electric light. They proved to be only supplemental to the material at West Orange. Among the materials are miscellaneous agreements, correspondence, notes and sketches, and company brochures. There is also a Pioneers Collection which provides some biographical information, reminiscences, and miscellaneous manuscripts. At the time this collection was used it was being reorganized.

The Records of the Patent Office (National Archives Reocord Group 241) contain a number of items which are useful. Of particular importance are:

> Patent Application File
> Those related to Edison's allowed patents have been microfilmed and a set is located at the Edison Papers Office at Rutges University, New Brunswick, New Jersey. These include the original application, any changes in the application, and çorrespondence between Edison's patent attorneys and the patent office. There are also abandoned patent application files but most of these were destroyed by Congressional approval and no early Edison applications were kept.
>
> Interefence Case Files
> These are not easily accessible and the National Archives does not have a complete set of all interference proceedings. They are accessible by a partial inventory prepared by the Archives staff and by the historic Register of Interferences kept by the Patent Office and part of Record Group 241. Among the interferences in the collection is one between Edison and Ludwig Boehm, his glassblower in 1879 and 1880, concerning the design of Edison's vacum pump.

The Hammer Collection at the Smithsonian Institution contains a large body of material relating to the career of William J. Hammer, who became associated with Edison in the development of the electric lighting system in 1880. Of immediate importance to those interested in the work on electric lighting in the period 1880-1882, are some notebooks from Menlo Park, Box 12 which contains material on the installation and operation of the Holborn Viaduct central station, and Box 13 which contains material on the planning of the Pearl Street central station. The collection also contains miscellaneous correspondence and clippings from this period.

(1) Edison testimony, Telephone Interferences, pp. 10-11

(2) Christopher Derganc, "Thomas Edison and His Electric Lighting System," IEEE Spectrum 16 (February 1979), p. 54

(3) Kruesi testimony, Edison vs. Siemens vs. Field, p. 52

(4) N-79-07-12

(5) Mott, PN-80-09-23; Memorandum of February 16 and February 17, 1881

(6) Josephson, p. 181

(7) Dyer and Martin, p. 247

(8) Mott, N-80-07-10

(9) Edison testimony, Edison vs. Siemens vs. Field, p. 113; Charles L. Dean testimony, Ibid., p. 150; John F. Ott testimony, Mather vs. Edison vs. Scribner, pp. 11, 15

(10) Hughes, "Edison's Method," in Technology at the Turning Point, ed. William B. Pickett (San Francisco: San Francisco Press, 1977), p. 10

(11) Conot, p. 91

(12) Thomas A. Edison, The Beginning of the Incandescent Lamp and Lighting System: An Autobiographical Account (Dearborn, Michigan: Edison Institute, 1976); typescript at the Edison National Historic Site is dated 1926

INDEX

FOOTNOTES FOR CHAPTER 7

(1) PN 81-01-19, 5 Feb 81

(2) Ibid., 10 March 81

(3) Lowrey to TAE, 17 Dec 1881

(4) Payson Jones, pp. 111-119

(5) Ibid., pp. 350-351

(6) These agreements are found in Electric Light - Edison Electric Light Co., 1881

(7) TAE to Johnson, 27 Nov 81

(8) Francis Jehl, Reminiscences, vol. 2, p. 848

(9) Mott, PN 81-01-19

(10) Kruesi to TAE, 11 June 1882

(11) This story is told in Josephson, p. 231

(12) New York Tribune, 14 August 1882, quoted in Payson Jones, p. 140

(13) TAE to Owen Gill, 29 Jan 1881, in LB-006, p. 874

(14) TAE to L. Prang & Co., 11 Feb 1881, in LB-006, p. 919

(15) S.B. Eaton to TAE, 23 Nov 1881

(16) Electric Light - Edison Company for Isolated Lighting, 1882

(17) TAE to Louis de Bebian, 5 Feb 1881

(18) Edison Electric Light Co., Bulletin, no. 4, 24 Feb 1882, p. 3

(19) Electric Light - Bergmann, 1881

(20) Jehl, vol. 2, p. 563

(21) Edison Electric Light Co., Bulletin, no. 15, 20 Dec 1882, p. 44

(22) TAE to Batchelor, 31 Dec 1881, LB-007, pp. 489-95

(23) Clarke to TAE, 11 Nov 1881

(24) Hammer to Frank W. Smith, 31 Aug 1932, Edison Pioneers

(25) TAE to Edison Electric Light Co., 2 Dec 1880, in LB-006, p. 610,

(26) N 80-08-13

(27) N 80-11-25, pp. 27-141; N 80-08-13, pp. 49-255

(28) Edward H. Johnson, "Edison Electric Light Stock considered as a speculative holding for the ensuing quarter," 15 Sep 1881

(29) Electric Light - Edison Electric Illuminating Co. of New York 1881

(30) C.L. Clarke to TAE, 3 June 1882

(31) C.L. Clarke to TAE, 1 Aug 1882

(32) Contract, April 1881, Electric Light - Edison Machine Works, 1881

(33) Insull(?) to Batchelor, 28 Sep 1882

(34) N 81-04-06, pp. 37-41, 15 July 1881

(35) TAE to S.B. Eaton, 13 Sep 1881

(36) Edison Electric Light Co., Bulletin, no. 9, 15 May 1882, pp. 7-11

(37) TAE to Johnson, 31 Dec 1881

Bibliographic Essay

This study has relied primarily on the large body of material in the archive at the Edison National Historic Site in West Orange, New Jersey. This extraordinarily complete collection of the inventor's records has allowed us to study, in great detail, the creative process of invention. The most important source for this study has been the collection of laboratory notes and drawings made by Edison and his staff. Because of their central role in our study and the relative infrequency with which these kinds of materials have been used for historical analysis, this essay will focus on these records. Correspondence was also of great value and the complexity of the collection at West Orange requires that this material be explained in some detail. Somewhat less detail is used in describing the other sorts of documents which helped to shed light on Edison's work. Some attempt has been made to evaluate this material and to provide the necessary information to gain access to them in the colllection at West Orange. Included are discussions of miscellaneous manuscript materials such as agreements and financial records, collections of clippings from newspapers and journals, primary printed material such as company publications, patents and litigation records, and reminiscences, both manuscript and published.

Other collections were looked at for this study and those that proved of some value have also been discussed. These are the Edisonia Collection in the Tannahill Library at the Edison Institute in Dearborn, Michigan, the Records of the Patent Office at the National Archives, and the Hammer Collection at the Smithsonian Institution.

Notebooks

Laboratory notes and drawings have not been widely used in writing the history of technology. These sources have often not been preserved, forcing historians to rely on published papers and patents. Even when they have been available for use, they have generally served only to supplement more traditional documents. A detailed discussion of the laboratory records can aid in understanding the problems encountered in their use and also address some of the problems raised by the work of others who have made use of this material in looking at Edison's work on the electric light.

The complexity of the records made it best to begin by discussing how laboratory notebooks were kept by Edison and his assistants. Fortunately, testimony from patent interference proceedings sometimes addressed this question and is useful in reconstructing the system of record-keeping. Testifying in 1880, Edison summarized the evolution of his record-keeping system prior to the period when he began to work on electric lighting.

> I commenced in a small way, some time in 1873, to have my sketches witnessed, but very few sketches were made compared to those made in 1877, when I commenced the practice of placing note books all over my laboratory, with orders to my assistants to draw out and sign every experiment; previous to 1877 drawings were made on all sorts of scraps of paper and thrown in a drawer.[1]

The notebooks which Edison began using in 1877 were 9 x 11. inch tablets from which individual sheets were later removed and collected together according to the specific invention for which they were made. In this way, Edison was able to provide a record of his experiments for purposes of patent litigation. This system was the one being used in September 1878 when Edison began his electric light experiments.

At that time, he also began to have his bookkeeper, William Carman, copy important notes and drawings into large ledger volumes. The earliest notes on the electric light, from September and October, were copied into one of these volumes. These and other loose pages of notes and drawings on the electric light were then organized and given identifying numbers. The practice of collecting together individual sheets taken out of tablets seems to have become unwieldy with the large number of notes and drawings resulting from the electric light experiments and Edison modified his system. He began, in late November, to use standard size, 6 x 9 inch, hardbound notebooks of about 280 pages each. These notebooks were numbered to identify them and left intact as a permanent record. The existing notebooks used from 1878 to 1882 number from 1 to 249. Of these, 74 are missing, although there are a few notebooks which appear to have labels that have been damaged, obscuring the numbers. The first missing notebook is number 35 and, of the first fifty, only five are missing. [See Table 1] Thus, the records of the earliest electric light experiments are remarkably complete.

The complexity of the various systems of record-keeping being used in the fall of 1878 confused one scholar who speculated that "since the surviving notebooks from September 1878 indicate no success with subdivision...they are incomplete, and it is certainly possible that a book with such an entry has been lost."[2] While there may be missing notes and drawings, they were not ones identified by Edison as important to his conception of the problem. The most important notes from this time were copied by Carman into a ledger volume. These are largely concerned with the design of regulators to control the temperature of the burner which is also the subject of the earliest electric light caveats which were copied into another of these ledger volumes. Unfortunately, the reminiscences of Edison and his associates have at times led reseachers to look for what they expect to find and not what is actually in the record.

Other problems have appeared in the attribution of dates. According to John Kruesi, superintendent of the laboratory machine shop,

> ...the order was in general to date all sketches and all drawings that were made on the day they were made, or in case it was neglected...to put down the date of the day when they were dated.[3]

Unfortunately, while this practice was adhered to during the early work on the electric light, Edison and his associates often neglected to date later entries. This seems to have been due to the press of work and to more members of the staff being involved in making entries in the notebooks.

There are a number of ways of solving dating problems. Often two members of the staff would make entries in separate books to record the same set of experiments. When this occurred, it is possible to supply dates if one set is dated and the other is not. Other entries can be dated to within a certain time period if there are dated entries which occur in the notebook on either side of the undated entry. Finally, it is possible to ascertain at least the earliest probable date that a particular book was used. The covers of the hardbound books are not uniform. Their coloring allows the books to be grouped together, as books of similar color appear to have been bought together and when they are grouped according to color, they tend to fall into distinct periods. [See Table 2]

Two notebooks which have played important roles in major biographies of Edison help to demonstrate some of these dating problems. In his recent biography

TABLE 1

MISSING NOTEBOOKS

35	69	101	162	181	202	221	246
43	81	109	163	182	205	222	247
44	90	118	164	183	207	232	248
49	91	122	166	185	208	234	
54	92	141	169	193	209	237	
61	93	144	170	194	211	239	
62	94	147	173	195	216	241	
63	97	154	175	196	217	242	
64	98	156	178	199	218	243	
65	99	159	180	200	219		

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3 books have labels but the numbers are obscured.

4 books have no labels.

1 book is in the Batchelor Collection and, although it has been recovered, there is no evidence of a label on the original cover.

2 notebooks were used by Francis Upton for his literature search and are unlabeled.

Notebook 36 is in Tannahill Library at the Edison Institute.

There may be additional Menlo Park Notebooks in the Hammer Collection at the Smithsonian Institution.

TABLE 2

NOTEBOOK DATING

Color	#	Nov 1878– Apr 1879	May 1879– Dec 1879	Jan 1880– Mar 1880	Apr 1880– Jun 1880	Jul 1880– Sep 1880	Oct 1880– Dec 1880	Jan 1881– Mar 1881	Apr 1881– Dec 1881	Jan 1882– Aug 1882	Oct 1882– Dec 1882	Undated
Blue-Green	1-47, 192	36	4	1								2
Dark Red	48-96		12	9	2		2					5
Blue-Green w/Red	67-73			5								1
Light Blue-Black	100-125				6	10	4					1
Green w/Orange	126-191			2	2	12	11	7	1		3	7
Dark Blue-Black	197-249							12	11	6		1

of Edison, A Streak of Luck Robert Conot claims that an entry in Notebook 190 proves that Edison turned to experiments with carbon filaments in October 1879 because of a Scientific American article of July 12, 1879 about which Edison made the following notation:

> In Scientific Amn July 12/79 I notice piece taken from Newcastle on Tyne -Chemical Society's Journal Speaks of Swans having lamp on incandescent principle with "Cylinder" carbon = get original paper - "Carbon pencil" spoken of[4]

While this is proof that Edison did read the article and probably tried to get the original Newcastle Chemical Society article, it is not sufficient to claim that he had read it by October 1879. This undated notebook is probably one of a number of books which were used in January 1881 for notes to be used in the preparation of a proposed "Practical treatise on Elec....for Publication in Book Form." Books 184, 186, 187, 188, 189, 190, and 191 all contain notes on electricity and gas gathered from various published sources. Some also contain draft essays. A number of these books, including 190 are also mentioned in a memo of materials sent to the New York office in February 1881, all of which appear to be related to the proposed treatise.[5] Furthermore, these books all have the same color cover, which was probably not used until 1880; the earliest entry for any of the books with these covers is January and most are from June or later. not only does the evidence about dates weaken Conot's argument, but so does a careful reading of the entry. Edison has underlined the word "Cylinder" and not the word carbon, indicating that his primary concern was probably the form of the carbon used and not the substance itself. Edison seems to be underlining the difference between his burner and Swan's.

Notebook 184, mentioned above as one of the books used in the preparation of the proposed treatise, was used by Matthew Josephson, in his 1959 biography of Edison, to support the inventor's claim that be began by studying the gas industry to determine the relative merits of "Elecricity versus Gas as General Illuminant."[6] In the authorized Dyer and Martin biography of 1910, Edison claims that

> On my return home [from William Wallace's shop in September 1878] I started my usual course of collecting every kind of data about gas; bought all the transactions of the gas-engineering socities, etc., all the back volumes of gas journals, etc. Having obtained all the data, and investigated gas-jet distribution in New York by actual observations, I made up my mind that the problem of the subdivision of the electric current could be solved and made commercial.[7]

This account has been repeated by all subsequent Edison biographers, but the notebooks and other documents show us a quite different time frame for Edison's investigation of the gas industry. While Edison claimed from the beginning that he would replace gas lighting with electric lighting, there is no evidence of any extensive investigation of the gas industry until the spring of 1879. Previous to this there had been only occasional notes on the gas industry, apparently the result of scattered newspaper and journal articles which came to Edison's attention. Books on the gas industry did not begin to be ordered until November 1878 and journals were not received until 1879. The systematic study of gas lighting in New York did not occur until 1880 when surveys were made of the Pearl Street central station district and tests were conducted of the gas lights at Sigmund Begmann's shop in New York.[8]

As evidenced in the foregoing discussion, the dating of notebooks can be extremely complicated. It requires a certain degree of connoisseurship in the treating of notebooks as artifacts which can be "read" much the same as an archaeological artifact. It also requires a careful comparison of dated and undated notebook entries and a comparison with other materials. Among these other materials is a set of six pocket sized notebooks (PN-80-04-09, PN-80-05-03, PN-80-06-08, PN-80-07-14, PN-80-09-23, and PN-81-01-19) and two standard notebooks (N-80-03-14 and N-80-07-10) used by Charles P. Mott, a member of the Menlo Park office staff, to record the daily activities of the laboratory from March 1880 to March 1881. Mott often gave references to specific notebooks and also detailed who was working on what project, alllowing both names and dates to be attributed to entries that could otherwise only be guessed at.

Besides the Mott journals, there are other ways of determining authorship. Again a certain connoisseurship is required to distinguish handwriting and drawing styles. The frequency of entries by Edison, Charles Batchelor, and Francis Upton allow the careful researcher to become familiar with their styles and to distinguish between them with relative ease, although there are entries which are not easily distinguished. Most of the material from 1878 and 1879 is by these three men. Entries by other members of the laboratory staff are less frequent and, if they did not sign the entry, it can present problems. Again it is possible to distinguish handwriting, especially among those whose hand appears a number of times or who write other documents which can be compared. In 1880, many more individuals kept lab records and it is more difficult to distinguish between them, but the Mott journal can be used to determine the authorship of some entries and allow the researcher to become familiar with the styles of different staff members.

Another problem presented by the notebooks is the rough character of many of the entries. Frequently, there are rough sketches or calculations without any identification as to what they represent. While there are complete notes on experiments such as those Edison performed on various metals in January 1879 [see pp. 40-44 above], the inventor frequently sketched out his ideas while explaining them orally to his assistants.[9] This resulted in many rough sketches without a clear statement of the ideas they represent. Other members of the staff also varied in the completeness with which they kept their records. Francis Upton, perhaps because of his university training, often was more thorough than others in recording in detail the experiments he performed, although he also produced page after page of unexplained calculations. One important piece of evidence which is often missing from the notebooks is the reasoning behind a particular set of experiments or the direction of the research at any one time. For example, in the design of the generator, the notebooks do not provide a clear idea of why the ring armature and large field magenets were adopted. Knowing of Edison's familiarity with Faraday and his work on fields of force, which are often sketched out in the notebooks, it is possible to infer some of the thinking which took place. Or, again, the reasons for the critical decision to turn to carbon in October 1879 are never made clear and must be inferred from a newspaper account, a knowledge of the requirements Edison had for his filament, the notebook entries themselves, and a general knowledge of Edison's work with carbon for other purposes.

Another aid to understanding cryptic notebook entries are the patents and caveats which describe Edison's specific devices. Drafts of these are found in the notebooks, often providing more detail than the official document filed with the patent office. British patents are also very useful because the inventor could be more inclusive in his claims and describe a whole system rather than individual components.

Finally, a word should be said about the archival arrangement of the notebooks. All of the hardbound, standard notebooks used by Edison at Menlo Park and in his later laboratories were assigned "N" numbers by the archive. This number was based on the earliest date in the book, but these are often incorrect or have been conjectured incorrectly. The N-number should never be used as the basis for dating a notebook. However, these are important for retrieval as they are used as shelf numbers for storage. Thus, Notebook 1, which is assigned N-78-11-28, is stored on the shelf following Notebook 2, which is assigned N-78-11-22. We have always cited N-numbers rather than Menlo Park Laboratory numbers.

Other notes and drawings related to electric lighting are to be found in four other groups of notebook materials. Most are in "Volume 16," which is the number assigned by Edison to the loose pages of notes and drawings related to the electric light. This number, along with a unique page number was assigned each page. Some of this material, from September and October 1878, was also copied into "Experimental Researches," Volume 1, Cat. 994. Some electric light draft caveats were written into "Experimental Researches," Volume 5, Cat. 997. A small group of loose pages of notes and drawings, which was not included in Volume 16, has been filed, year by year, in a collection called "Miscellaneous Notes and Drawings." Finally, there are eight scrapbooks which have notes and drawings pasted into them. These are Cat. 1146 to 1153, containing materials from 1878 to 1888, which are primarily related to the electric light. Most of these notes and drawings were made by Edison to be used in the preparation of patent and caveats.

Correspondence

The most fruitful way to discuss the correspondence is to look first at the archival organization and then at the type of material available within that organization. The loose correspondence, most of it incoming, is organized in a series known as the "Document File." This file also contains some other types of material, such as agreements and account records, but is primarily a correspondence file. It is organized by year and within each year there are main subject categories, related to inventions. These subject categories are further subdivided by company or by foreign countries. There is also, for each year, a file known as "Edison, T.A. - General," which contains miscellaneous correspondence and correspondence that deals with more than one subject. This file is being reorganized in preparation of the filming of the microfilm edition of the Edison Papers. All years up to 1881 have been reorganized and most of the material related to the electric light in 1882 has also been reorganized. A unique identifying number is assigned to each folder in the file as it is reorganized. Below is list of the folder titles which relate to the electric light and a brief summary of the type of information found in them.

The following folders are to be found in all years from 1878-1882:

Electric Light - General
These folders contain general inquiries about Edison's work on the light. Many of the letters deal with technical questions and Edison often wrote marginal comments which were to be used in answering the correspondent; often these marginal notes are the only record of an answer. Other letters relate to the business arrangements for the light. Of particular note in these folders are letters by George F. Barker, professor of physics at the University of Pennsylvania.

Electric Light - Edison Electric Light Company
These folders contain material related to the formation of the company and to its operation. Especially important for the years 1878 and 1879 are letters by Grosvenor P. Lowrey, the Western Union lawyer who was instrumental in organizing the company. Between 1880 and 1882, the most important member of the company was Sherbourne V. Eaton, who was vice-president and chief operating officer. In 1882, there is a folder under the general heading of the company which contains reports sent by Eaton to Edison. In that year, there is also a folder containing correspondence from Charles L. Clarke, the company's chief engineer, which pertain to technical matters. In 1882, the company folder also contains material related to the various manufacturing and service companies established for the commercial introduction of the light. There are also individual folders for these companies.

Electric Light - Foreign
These folders contain material related to the foreign business arrangements for the light. In 1878 and 1879, letters by Lowrey are very important. For all years, see especially letters by George E. Gouraud, Edison's agent in England; Theodore Puskas and Joshua F. Bailey, his agents in France; Egisto Fabbri, the Drexel, Morgan & Co. partner; and Edward H. Johnson, who was in England for a time in connection with Edison's light and telephone and who was in charge of the establishment of the Holborn Viaduct station. In the years 1880-1882, the foreign folder is further subdivided into Europe and United Kingdom. Beginning in 1880, there is also an Edison Electric Light Company of Europe folder.

Edison, T.A. - General
These folders contain letters which deal with more than one subject. Often found in this folder are letters by Barker, Gouraud, Johnson, and Puskas.

Patents
These folders contain material related to Edison's American and foreign patents. Most of the correspondence is from Edison's chief patent attorney, Lemuel W. Serrell. There are also occasionally letters from other attorneys or Edison associates concerning his patents. The Electric Light - Foreign - United Kingdom folders also contain material related to Edison's British patents.

Menlo Park Laboratory
These folders contain correspondence related to the purchase of supplies and equipment for the laboratory. Also see Edison, T.A. - Bills and Reciepts folders and Invoice Books, Cat. 1161-1162 In 1881, there is a folder containing reports to Edison by Thomas Logan, superintendent of hte scaled down laboratory.

Edison, T.A. - Book and Journal Orders
These folders contain material related to the purchase of books and journals by Edsion. Many of them are related to his work on the electric light.

Folders related to various electric light manufacturing and service companies established between 1880 and 1882:

Bergmann & Company (1881-1882)
This company was formed by Edison, Sigmund Bergmann, and Edward H. Johnson to manufacture fixtures and small components for the electric light system. Most of the material in these folders deal with orders. Previously, Bergmann had his own company and material related to this company are in folder titled Bergmann, S.

Electric Light - Edison Lamp Company (1880-1882)
These folders contain much correspondence from Francis Upton, superintendent of the lamp company, related to continuing experiments on the lamp and the problems of production. There is also material related to orders and the operation of the company.

Electric Light - Edison Machine Works (1881-1882)
These folders contain material related to the production of generators and meters. Of special note is the 1882 folder for the Testing Room, which contains correspondence from William S. Andrews, head of the room, about experiments and tests of meters and dynamos. See the Clarke correspondence in the Edison Electric Light Company folder of 1882 for similar material about experiments and tests. There is also material related to orders and the operation of the company.

Electric Light - Electric Tube Company (1881-1882)
These folders contain primarily correspondence from John Kruesi, superintendent of the company. Most of the material deals with orders and the operation of the company.

Electric Light - Edison Electric Illuminating Company of New York (1880-1882)
This company was formed, in December 1880, to install the first central station in New York. There is some information about the Pearl Street station found in these folders.

Electric Light - Edison Company for Isolated Lighting (1881-1882)
This company was formed to install isolated plants. In 1882, there are reports sent to Edison containing excerpted material from the company's defect books, which were used to record complaints. There is much technical information contained in these reports.

FOOTNOTES FOR CHAPTER 4

(1) N 79-07-31, pp. 85-91

(2) N 79-08-22, p. 135

(3) Telephone - Carbon Button Orders, 1879

(4) March 21, 1879, quoted in Jehl, Reminiscences, vo.1, p. 277

(5) N 79-08-22, p. 169

(6) N 79-07-31, pp. 93-97

(7) Ibid., pp. 99-103

(8) Ibid., p. 105

(9) N 79-08-22, p. 171

(10) N 79-07-31, p. 107

(11) Ibid., pp. 111-115

(12) N 79-08-22, pp. 173-175

(13) N 79-07-31, p. 117

(14) Ibid., pp. 119-257

(15) Upton to his father, 2 November 1879

(16) Ibid., 9 November 1879

(17) Ibid., 16 November 1879

(18) U.S. Patent 223,898 (issued January 27, 1880)

(19) Upton to his father, 22 November 1879

(20) Telegrams between TAE and Gouraud, December 1879

(21) TAE to Norvin Green, 4 November 1879

(22) N 79-04-03, pp. 174-282

(23) TAE to C.G. Wildreth, LB-005, p. 359

(24) Lowrey to TAE; 13 Nov 79; E.L. - Edison Elec. Light Co. 1879

(25) Griffin to Bailey, 2 December 1879, LB-005, p. 389

(26) Upton to his father, 7 December 1879,

(27) TAE to Phonos, 17 December 1879

(28) Upton to his father, 21 December 1879

(29) E.P. Fabbri to TAE, 26 December 1879

(30) Upton to his father, 28 December 1879

(31) Herald (in Jehl, p. 400)

(32) Herald, 1 Jan 1880

FOOTNOTES FOR CHAPTER 5

(1) N 79-12-(00), pp. 1-11

(2) C. Goddard to TAE 27 Dec. 1879

(3) TAE to C. Goddard; 29 Dec. 79; E-3408, p. 475

(4) Francis Upton to Charles B. Farley, 25 Jan. 1880

(5) From Upton Collection document listed as E-6285-7

(6) N 80-01-30; 80-01-31; 80-02-08.2

(7) N 80-01-26, pp. 25-29; Jan. 26, 1880

(8) N 80-01-26, pp. 31-33

(9) N 80-01-26, pp. 70-128

(10) N 80-01-02, pp. 1-3, 13-15

(11) N 79-06-16.2, pp. 215-220; 5 Jan. 1880

(12) N 79-01-14, pp. 150-151

(13) N 79-06-12, pp. 98-101

(14) N 79-10-18, p. 221-222

(15) N 79-06-12, p. 107; 10 Feb. 80

(16) N 79-10-18, p. 234

(17) N 80-01-26, p. 45

(18) N 80-01-26, p. 49

(19) Upton to his father, 25 Jan. 80

(20) Herrick: N-79-08-28, pp. 1-37

(21) Howell; Edison Pioneers

(22) Albert Taylor to TAE, Jan. 3, 1880

(23) G. Haines to TAE, Jan. 6, 1880

(24) All letters in E.L. General 1880

(25) Austin-Kenny to TAE, Jan. 18, 1880

(26) S. Newcomb to TAE Jan. 19, 1880

(27) See David Hounshell, "Edison and the Scientists," Science 207 (8 Feb. 1980), pp. 612-617

(28) N 79-03-10-2, pp. 91-103

(29) N 79-02, pp. 77-79

(30) N 80-01-02.2, pp. 26-57; 91 to end

(31) Ibid., pp. 94-168; N 80-02-16, pp. 1-7

(32) N 80-01-02.2, p.59 (drawing), also p. 73

(33) Ibid. pp. 63, pp. 71-79 see also N 80-03-29 entire

(34) N 80-02-16, p. 83, 25 March 80

(35) N 80-01-26, pp. 35-43

(36) Upton note, dated 27 Mar. 1880

(37) H.A. Rowland and G.F. Barker, American J. of Sci. v. 19, April 1880.

(38) Draft of letter TAE to Jos. Medill April 8, 1880

(39) Ibid.

(40) Henry Morton, et.al., "Some Electrical Measurements of One of Mr. Edison's Horseshoe Lamps," Scientific American, v. 42 (17 April 1880), p. 241.

(41) N 78-06-12, pp. 173-174; N 78-11-21, pp. 136-141

(42) N 80-03-15, pp. 207, 217

(43) Ibid., pp. 209-213

(44) Upton to his father; May 9, 1880

(45) "The Columbia," Sci. American, v. 42 (22 May 1880) p. 326

FOOTNOTES FOR CHAPTER 6

(1) The Mott journals are notebooks N-80-03-14 and N-80-07-10; the Mott pocket notebooks are PN-80-04-09, PN-80-05-03, PN-80-06-08, PN-80-07-14, PN-80-09-23, and PN-81-01-19. These are cited in this chapter by the journal date entry only.

(2) Mott: July 15; also N-80-06-02, pp. 23-31; N-80-06-28, pp. 37-43

(3) Some of this information is from "Thomas Alva Edison Lighting Timeline," unpublished ms. from the Corning Glass Works Corporate Archives.

(4) N-80-06-02, pp. 73-77, 13 Aug 80

(5) See Edison's notes; N-80-10-01, p. 51 of Oct 10, 1880

(6) Lawson: N-80-12-13, pp. 3-7, Dec. 13-29, 1880; Mott: Dec 15, 17, and 21, 1880; Edison: N-80-11-16, pp. 149, 163

(7) N-78-11-21, pp. 136-141; N-79-06-12, pp. 196-197, 18 Apr. 1880

(8) N-80-09-11, pp. 18-19

(9) N-80-08-10, pp. 53-77

(10) Clarke's report was dated Feb. 7, 1881 and, he explained later, Edison was so pleased with the results that he initially planned to publish it. Commercial considerations prevented this, and the copy of the report used here was one given by Clarke to the library of the American Institute of Electrical Engineers in 1904. It is now in the Engineering Societies Library, New York.

(11) Jehl, Reminiscences, vol.2, pp. 876-878

(12) Ibid., pp. 878-887

(13) TAE to Lowrey, 20 July 1880

(14) See N-80-06-29, pp. 145-155; N-80-07-16, pp. 3-139; N-80-07-05, pp. 59-120

(15) Jehl, Reminiscences, vol. 2, pp. 723-724

(16) G.W. Soren to TAE, 5 Nov 1880

(17) TAE to Bermeire Magis, 19 Oct 1880

(18) Tracy R. Edson to TAE, 20 Nov 1880

(19) Draft prepared by C. Goddard, 15 Dec 1880; draft TAE to Aldermen, 18 Dec 1880

(20) Jehl, Reminiscences, vol. 2, pp. 770-777

(21) Lizzie Upton to her sister, Sadie, 27 Dec 1880

Palace. There they received the second Jumbo dynamo from Goerck Street, this one a bit larger than the Paris machine, being provided with an Armington & Sims engine with a maximum rating of 200 horsepower. The large dynamo, however, was not intended for the Crystal Palace display, which was powered by twelve Z dynamos, but for installation in a model central station - far less ambitious than the Pearl Street effort, to be sure, but no less strategically situated for gaining the attention of influential individuals and institutions. Since the legal obstacles to installing a system of underground mains in London were even more formidable than in New York, and since it was desired to install the London system quickly and at minimal cost, the station was located on the Holborn Viaduct, which crossed over Faringdon Road at the western boundary of London's "City," financial and communications center of the British Empire. The Viaduct allowed electrical conduits to be installed underneath without necessitating underground excavation, and obviating the need for permits under the gas statutes. On January 12, 1882, the generator installed at 57 Holborn Viaduct began operating. In April, it was joined by a second C dynamo and the two were operated together in much the fashion envisioned for the Pearl Street station. The demonstration was an immediate success, and the combined impact of the impressive display that Hammer designed for the Crystal Palace and the highly visible demonstration of both street and domestic lighting provided by the Holborn Viaduct station was considerable. The London press reacted favorably, despite initial scepticism. Reporting on the Crystal Palace display, the Daily News wrote,

> There are two questions to solve besides the production of a lamp, viz.: the proper distribution of electricity throughout a town, and its economy relative to gas. Mr. Edison is far and away in advance of all rivals in the solution of these problems. His exhibition is the wonder of the show, and his representative is certainly the prince of all showmen. There is but one Edison and Johnson is his prophet. One feels after an hour with Mr. Johnson that there is nothing left to be done, that one's gas shares must be sold at once, that there is only one system, and that is Edison's and that every question has been solved.

The Holborn Viaduct system was indeed a full-scale demonstration of the Edison light. The installation stretched a half-mile along the Viaduct, from Holborn Circus to the General Post Office. By April, a total of 938 lamps were wired up, including 164 street lamps of 32 candle-power, a new product of the lamp factory that allowed Edison to demonstrate further the versatility of his system. Customers included hotels, restaurants, shops, offices, and the City Temple, in addition to a portion of the General Post Office itself.[36] The newspapers of Fleet Street were nearby, allowing the press a favorable vantage point from which to report on all the details of the system. The Holborn Viaduct station was a testing ground for a number of key elements of the Pearl Street system, especially the safety devices and the regulating mechanisms. It was always intended as a temporary demonstration and not as the basis of a permanent commericial station. Installation of a permanent, Pearl Street-like system in London was in fact contemplated even before the Holborn Viaduct station was operating. Edison wrote to Johnson at the end of December, 1881, to suggest that he "keep your eye out on some square mile of London in which there is a slum near the center in which we could obtain a building cheap."[37] Not long after the Edison demonstration had proven itself, however, Parliament passed the first Electric Lighting Act, with franchise terms so strict that not a single full-scale urban system was installed in Britain until the law was changed in 1888. Numerous isolated plants were installed in London and the provinces in the following years, but, due to legislation, Britain was retarded for years in the development of an electricity supply system.

Meanwhile, work went ahead steadily in New York toward the completion of the First District. The best record of the progress of this work in 1882 is from the Bulletins that the Edison Electric Light Company began issuing in January, at first only for the use of its agents, but shortly distributed to stockholders and other interested parties. Since all but the first Bulletins were intended for public consumption, they were not completely reliable regarding problems encountered in the last stages of the work, but the First District activity really allowed little room for dissembling in any case. The first Bulletin, dated January 26, reported on "Lighting up New York City" as follows:

> Between six and seven miles of street mains have thus far been laid in the down town district. The bad weather has caused a suspension of laying mains for nearly a month. About six miles more mains must be laid. The third mammoth dynamo has been completed... Mr. Edison is satisfied with the improvements in these dynamos and will now hasten the work on the uncompleted dynamos for the First District in this city. Six will be finished first, and after they are started in the Pearl Street building, another six will be finished to be placed in the adjoining building, which also belongs to our company. The meter to be used in the first district is completed and satisfactory. It registers with almost absolute

> exactness. This gives still another advantage over the existing gas system, where the meter question is one of looseness and uncertainty. No time for lighting up the Down Town District can be fixed. The work is being pushed forward with the utmost vigor, but the undertaking is so great, probably a few months must yet elapse before the district is actually lighted.

The meter had, in fact, posed difficult problems, and it is not clear that these had been successfully dealt with by January 1882. By the late spring, however, the months of experiment had produced a chemical meter using pure zinc plates in a solution of zinc sulphate. A shunt of german silver (a copper-zinc-nickel alloy) with a carefully calibrated resistance led current from the circuit into the meter, where it caused zinc from the solution to be added to the plates. The total current consumed by the customer was determined by periodic collection and weighing of the zinc plates. Where meters were exposed to the cold, a light bulb was installed in the meter box, where a thermostatic switch would turn it on to keep the solution from freezing in the coldest weather. Edison was quite proud of his meter and was very defensive about its accuracy. The meters for Pearl Street were manufactured by Bergmann & Company and were installed in houses as they were wired into the system. They were not, however, actually used as the basis for billing until the Pearl Street station had been operating for almost six months since, as the Electric Light Company's 1883 Annual Report stated, "Mr. Edison was continually making changes and improvements...and the Illuminating Company wished to avoid being tied up by contracts to furnish light, until after Mr. Edison had entirely completed his observation."

In March, the fourth and fifth Bulletins reported that, with the spring thaw, Kruesi had resumed the laying of the underground conductors and was moving ahead at a rate of a thousand feet a day. By mid-April it could be reported that the building at 257 Pearl Street had been fitted with the boilers and auxiliary equipment, that six Porter-Allen engines had been received and that work on the dynamos was nearing completion. The next couple of months brought word of steady progress on the largest outstanding task, completion of the street mains - 12,500 feet were laid in April, another 7,923 feet in May. The twelfth Bulletin, dated July 27, reported, "the entire network of underground conductors finished, aggregating over 80,000 feet." Further work consisted largely of completing connections between mains and houses and installing meters and fixtures. Of special significance was the report that the New York Board of Fire Underwriters had given its approval to the Edison installations and indicated that their presence would have no adverse affect on insurance rates, provided they were properly insulated. Finally, the completion of the work at the station itself was noted:

> The equipment of the central station in Pearl Street is also finished. Fire was built under the boilers for the first time on June 29th, and on the next day the small engine used for the coal conveyors, blowers, etc., was started and all that portion of the equipment was found to work well. The first steam dynamo was started July 5th; and, July 8th, a satisfactory experiment was made on 1,000 lamps arranged on an upper floor. Since that date, some of the other engines and dynamos have been carefully tested with the 1,000 lamps, and the details of their adjustment perfected. The field regulating apparatus has also been tested, and the electrical indicator, the first ever used on so large a scale, has also been found satisfactory.

Only a few final tests of the electrical system remained. A month later, in the thirteenth Bulletin, dated August 28, all was said to be ready, and, indeed, "a number of buildings in various parts of the district have already been lighted." Connections to houses continued, 226 having been put on the system as of August 26. "No serious obstacles" were anticipated before "the early lighting up of the entire district."

Every effort was made to test the installation before any publicly announced start-up was undertaken. The system was too complex and too much was at stake to allow the debut of Pearl Street to be left to chance. The feeders and the mains were tested with one of the Jumbos connected to a small portion of the system at a time. There were, John Lieb pointed out later, no proper meters in the entire station, but indications of a rough sort were devised to show when loads were high (or low), and resistances were plugged in and out of the feeder circuits to control voltage levels. Most of the last-minute worry revolved around the integrity of the underground conducters. No serious problem was encountered, but one incident received a bit of press coverage, somewhat to Edison's dismay. On a day in late August when the Jumbo was being tested and a considerable portion of the mains were in the circuit, word came of a leakage of current near the corner of Nassau and Ann Streets. There a crowd gathered around a wet spot in the road, for whenever a horse passed over it, the current from Pearl Street gave the animal a very surprising shock, startling a number of innocent cart drivers. It was concluded that some worker had driven a spike through a mains tube and the ground was soaked enough to bring the current to the surface. This resulted in little more than mildly embarrassing publicity, but it kept Edison and the Illuminating Company on their guard.

* * * *

By September, enough testing had been completed to give Edison the confidence to begin service at Pearl Street, although all connections in the system had not yet been completed. On September 4, Edison coordinated his watch with station engineer John Lieb's and, accompanied by Kruesi, Bergmann, and others, made his way to the offices of J. Pierpont Morgan in the Drexel building at Broad and Wall streets, at one edge of the First District. There, he supervised the installation of the safety catches and at 3 o'clock in the afternoon, turned on the office lamps. It was an understandably dramatic moment, and, as so often in the story of the electric light, it was caught most eloquently by the press. The best description of the general impression that the lights gave in that portion of the District thus served (bounded by Nassau, Wall, Pearl, and Spruce Streets) is from the Herald:

> In stores and business places throughout the lower quarters of the city there was a strange glow last night. The dim flicker of gas, often subdued and debilitated by grim and uncleanly globes, was supplanted by a steady glare, bright and mellow, which illuminated interiors and shone through windows fixed and unwavering. From the outer darkness these points of light looked like drops of flame suspended from jets and ready to fall at every moment. Many scurrying by in preoccupation of the moment failed to see them, but the attention of those who chanced to glance that way was at once arrested. It was the glowing incandescent lamps of Edison, used last evening for the first time in the practical illumination of the first of the districts into which the city had been divided. The lighting, which this time was less an

> experiment than the regular inauguration of the work, was eminently satisfactory. Albeit there had been doubters at home and abroad who showed a disposition to scoff at the work of the Wizard of Menlo Park and insinuate that the practical application of his invention would fall far short of what was expected of it, the test was fairly stood and the luminous horseshoes did their work well...

To a Sun reporter, Edison remarked simply, "I have accomplished all I promised."

FOOTNOTES FOR CHAPTER 1

(1) Daily Graphic: Conot, p.113.

(2) Josephson, p.175, Conot, p.115.

(3) Batchelor memoir, p.2, Batchelor Collection

(4) Cat. 994, p.117, 27 Aug 1878.

(5) The Mail (10 September 1878), fr. ENHS scrapbook.

(6) Sun (20 October 1878)

(7) TAE to William Wallace, 13 Sep 1881 (Material from the Document File has been indexed by the Edison Papers project and is accessible by date, author, and recipient; individual folders will not generally be cited for individual items.)

(8) Caveat, 13 September 1878

(9) Ibid.

(10) Sun (16 September 1878)

(11) George Barker to TAE, Sep 1878

(12) Grosvenor P. Lowrey to TAE, 17 Sep 1878

(13) Cat. 994, pp. 127-134

(14) TAE to Theodore Puskas, 22 September 1878

(15) George Bliss to TAE, 24 September 1878

(16) Cat. 994, p. 143

(17) Cat. 994, p. 139

(18) Cat. 994, p. 142

(19) Barker to TAE

(20) Moses G. Farmer to TAE, 7 Oct 1878DF 1-78-034

(21) Electric Light, Volume 16

(22) TAE to Lowrey, 3 Oct 1878

(23) TAE to Puskas, 5 Oct 1878

(24) TAE to George E. Gouraud, 8 Oct 1878

(25) Electric Light - General, 1878

(26) ibid.; LB-003, p. 400

(27) TAE to Gouraud, 16 October 1878,

(28) Gouraud to TAE, 24 October 1878,

(29) Sun (20 October 1878)

(30) Lowrey to TAE,20 October 1878,

(31) Griffin to Lowrey, 1 November 1878,

(32) Lowrey to TAE, 2 November 1878,

(33) Lowrey to TAE, 31 October 1878,

(34) TAE to Lemuel W. Serrell, 31 October 1878

(35) Electric Light - Edison Electric Light Company, 1878

(36) Upton to his mother, 7 November 1878 (Upton correspondence unless otherwise noted is in the Upton Collection)

(37) TAE to Howard Butler, 12 November 1878

(38) TAE to Puskas, 13 November 1878

(39) ibid.

(40) Upton to TAE, 2 November 1878, Electric Light - Edison Electric Light Company, 1878

(41) TAE to William & Rogers, 29 November 1878, in LB-004, p. 20

FOOTNOTES FOR CHAPTER 2

(1) The first volume of Francis Jehl's Reminiscences of Menlo Park is a generally reliable source on the background of the men at Edison's laboratory.

(2) From a clipping in a Menlo Park scrapbook.

(3) G. Lowrey to TAE, Nov. 25, 1978.

(4) G. Lowrey to S. Griffin, Dec. 5, 1878.

(5) G. Lowrey to TAE, Dec. 10, 1878.

(6) G. Lowrey to TAE, Dec. 23, 1878.

(7) TAE to T. Puskas, Jan. 3, 1879.

(8) G. Lowrey to TAE, Jan. 25, 1879.

(9) M. Josephson makes this point in Edison, p. 190.

(10) N 78-11-22

(11) Batchelor notebook (Cat. 1304), p. 13 (Dec. 19, 1878).

(12) N 78-11-22, pp. 11-15; N 78-11-28, pp. 31-33.

(13) New York Sun, Dec. 17, 1878.

(14) W. Wallace to TAE, Dec. 21, 1878.

(15) Wallace and Sons to TAE, Dec. 11, 1878; TAE to G. Barker, Dec. 19, 1878; G. Barker to TAE, Dec. 21, 1878; H. Morton to TAE, Dec. 26, 1878.

(16) Chas. H. T. Collis to TAE, Dec. 21, 1878.

(17) N 78-11-22, p. 21.

(18) Batchelor notebook (Cat. 1304), p. 25; C. Batchelor to James Adams, Jan. 2, 1879.

(19) N 78-12-31, pp. 30-96 (Jan. 3 - 15, 1879); N 78-12-20.1, pp. 70-106.

(20) N 78-12-31, pp. 45-47.

(21) N 78-12-15.1, p. 121; N 78-12-20.1, pp. 266-280.

(22) N 79-01-19, pp. 27-68.

(23) Ibid., pp. 61-62.

(24) G. Lowrey to TAE, Jan. 25, 1879.

(25) TAE to G. Barker, Jan. 22, 1879; TAE to H. Morton, Jan. 22, 1879.

(26) Volume 16, Electric Light Sketches.

(27) N 79-01-21, p.41.

(28) N 78-12-31, pp. 99-101 (Feb. 6, 7, 8, and 9, 1879)

(29) Ibid., pp. 101-103.

(30) Ibid., pp. 105-163.

(31) N 79-02-20.1

(32) N 79-02-24.1, pp. 51-87.

(33) N 79-02-15.2, pp. 31-161; patent issued June 17, 1879 as British Patent 2402 of 1879.

(34) Batchelor notebook (Cat. 1304), p. 2 (Nov. 28, 1878).

(35) Ibid., p. 5 (Nov. 30, 1878).

(36) N 78-12-20.3, p. 3; N 78-12-16, pp. 1-16.

(37) N 79-02-15.2, p. 105.

(38) N 79-02-24.1, pp. 79-81.

(39) F. Upton to his father, Feb. 23, 1879.

FOOTNOTES FOR CHAPTER 3

(1) N 78-11-28, pp. 7-9

(2) N 78-12-15.2

(3) N 79-02-15.2, pp. 27-41

(4) N 79-02-15.2, pp. 135-145

(5) N 79-02-15.2, pp. 133

(6) N 79-02-15.2, pp. 147-151

(7) N 78-11-28, pp. 1-5

(8) See Chap. II, pp. 11-12

(10) Cat 1308, p. 119

(11) Cat 1308, p. 121

(12) Cat 1308, p. 137

(13) Cat 1308, p. 141

(14) Cat 1308, p. 143

(15) N 79-02.15.2, pp. 151-153

(16) N 79-02.15.2, pp. 155

(17) Upton to his father, 13 Apr 1879

(18) New York World, 30 Apr 1879

(19) ibid.

(20) ibid.

(21) U.S. Patents 214,636; 214,637

(22) New York Herald, 27 Apr. 79

(23) Ibid.

(24) N 79-03-10.1, pp. 41-56; 79-01-14, pp. 63-83; 79-04-03, pp. 47-61; 79-01-21, pp. 129-133, 141-149 — 1308; Order book pp. 135-135.

(25) N 79-03-10.1, pp. 37-39

(26) Letters from Reinmann & Baetz of Mar. 25, 26, and 27, 1879

(27) N 78-11-21, pp. 119, 16 Mar. 79

(28) TAE to J.O. Green, 18 Apr. 78

(29) Upton to his father, 4 Apr. 1879

(30) Encyclopaedia Britannica (11th edition),v. 6, pp. 856-857

(32) N 78-12-11, pp. 280-282

(33) Cat 1304, pp. 44-45, 23 Mar. 79

(34) N 79-03-25, pp. 1-9, 25 Mar. 79

(36) Mining - Platinum Search, 1879; LB-004, p. 277; LB-004, p. 358.

(37) LB-005, p. 4

(38) N 79-07-25, p. 3; N 79-07-31, pp. 264-278; N 79-08-22, pp. 31, 45, 54

(39) N 79-08-22, 96-103

(40) N 79-08-22, pp. 3-134

(41) N 79-09-20

(42) N 79-08-22, p. 129

central station. Charles Dean, orginally Kruesi's assistant in the Menlo Park machine shop, was soon afterwards designated superintendant of the Edison Machine Works, located in the former Aetna Iron Works at 104 Goerck Street, on New York's lower East Side. These three enterprises, the lamp works, the Tube Company, and the Machine Works, were to be the manufacturing infrastructure of the Edison system, and thus were the foundations of the corporate culmination of that system, first as elements of the Edison General Electric Company, organized by Henry Villard in 1889, and then within the even larger General Electric Company, created by merger with Thomson-Houston interests in 1892.

It was with the immediate future in mind, however, that Edison began organizing the manufacturing companies in the winter of 1881. The lamps were the most novel of the system components and the challenge of placing their manufacture on a sound commercial footing had been the most obvious one. This can be seen as one of the reasons for the close link, both geographically and administratively, between the lamp works and the Menlo Park laboratory. With lamp production under control by the end of 1880, it was clearly time to develop the means for supplying the remaining elements of the system. These, however, required less radical departures from ordinary machine shop practice, hence the relative ease with which the two key mechanics from Menlo Park were able to establish their New York works. Charles Mott's daily record of Menlo Park activity noted Kruesi's absence (in the company of Edison and others) in the first part of February, 1881, when presumably a search was being made for a suitable New York building for the Tube Works. The Works began operation formally on Febraury 14,[8] but Mott noted on the 18th that Kruesi was at the laboratory "making exp. with (insulating) compound No. 7 varying proportions of Parafin, preparatory to commencing operation at building in Washington St."[9] The Menlo Park lab served all of the New York shops, as well as the lamp works, as an experiment and testing center, serving in a role much closer to the twentieth-century industrial laboratory than is often recognized. The new factories, however, soon developed testing facilities of their own, and gradually during 1881, even the more experimental work, such as the search for a better meter, was transferred to New York.

Kruesi worked closely with Edison in his management of the Tube Works, as he quickly strove to organize the creation of an underground distribution network. The model underground system at Menlo Park had taught them much about the requirements for a reliable installation. The insulating compound of asphalt, linseed oil, paraffin, and beeswax that Wilson Howell had so laboriously developed was adopted with little change. Kruesi soon devised a standard two-wire conduit that consisted of copper conductors of semi-circular section separated by appropriately shaped pasteboard washers and covered by the insulating compound inside a protective iron pipe. Further work was required to develop different forms of junction boxes, fuse holders, and other elements of a full-scale underground installation. In addition, the performance of the conduits and connections had to be constantly tested as they were put down under New York streets — another valuable lesson from the Menlo Park experience. All of this required close coordination between the Tube Works and Edison's headquarters on Fifth Avenue, and Edison and Clarke spent many hours either in the shops or in the streets with Kruesi, working out problems caused by unreliable suppliers, careless laborers, or unpleasant surprises. An example of the last was reported to Edison by Kruesi in June, 1882:

> We have observed a very unexpected phenomena in our Junction Safety Catch boxes. Friday night we opened one which was put in long ago, when the inside cover was taken off a lot of gas escaped, and when one of the men came near with a light it blazed up and burned for about 5 minutes (singed a man's hair) and was put out with a pair of bellows. Today again we had to open one in daytime - the escape of gas was the same only was not ignited.
>
> It may cause trouble if a man had to breake a connection when the current was on - the spark may ignite it. I suppose it comes from the compound. We may have to put two plugs in the inside cover & blow out the gas occasionaly - what do you think of it?[10]

The solution of problems of this sort became almost routine, and none of them presented long-term difficulties. Indeed, the basic underground distribution technology was spelled out by Edison in a patent filed April 22, 1881 (U.S. Patent 251,552, issued December 27, 1881), just as the work in the New York streets was getting under way, and only one notable change was made before the two-wire system was superceded by three-wire distribution in late 1882. This change was the replacement of the cardboard spacers in the conduits by ordinary rope, which could be easily wound around the conductors to provide the needed spacing. In terms of sheer toil, nothing in the building of Edison's "First District" matched the effort of Kruesi and his Electric Tube Works, and the former Swiss mechanic was given ample credit for his labors.

The construction of the conduits and junction boxes was not the only technical challenge presented by the distribution system. The fundamental problem of transmission losses through long lengths of conductors had long been a concern of Edison, and the New York system was the first time that a solution was critical to success. A year before moving to New York, in January, 1880, Edison filed a patent application for a system of "multiple-arc distribution," which was the most fundamental statement of the principles of power distribution on a parallel circuit. Indeed, the claims of this patent were so broad that it was not actually granted until 1887 (U.S. Patent 369,280), by which time its claims were rapidly being superceded by the advancing state of the electrical art. Of greater practical value was Edison's invention in the summer of 1880 of the "feeder-and-main" principle of distribution, which he covered in a number of patents (especially U.S. Patents 239,147 and 264,642). Without the ingenious feeder-and-main approach, the Edison system might still have been stopped dead by the enormous costs of copper that would have been required by a "tree" circuit such as that used at Menlo Park. In this form of distribution the drop in voltage between the generator end of the circuit and the farthest consumption end was managed by the use of larger, lower-resistance conductors near the generators that gradually tapered as they led out to the edge of the system. For a system such as that envisaged in New York, with service as much as a half-mile from the central station, this would have required enormous and costly mains. The feeder system by-passed this problem by supplying power to the service mains through a number of smaller conductors - the feeders - each of which served only a portion of the service mains. A relatively large drop in voltage, say 10%, could be permitted in the feeders, for the drop in the local circuits - the service mains and the house circuits - would be negligible and would thus be unaffected by periodic changes in load. The feeder-and-main system was simple and ingenious, as well as vital to the success of the Edison system. When Lord Kelvin was asked why no one had ever thought of such a straightforward solution to such a fundamental problem before, he was quoted as replying, "The only answer I can think of is that no one else is Edison."[11]

Most of Edison's time in New York was divided between work on the underground distribution system, under the auspices of Kruesi's Tube Works, and the development of key system elements - primarily the large dynamos - in the Goerck Street shops of the Edison Machine Works. The Machine Works were initially a much expanded version of the Menlo Park machine shop, but the combination of specialization in the construction of dynamos and the steadily expanding commercial demand for its products soon made the New York shops a very different operation. The move to 104 Goerck Street, supervised by Charles Dean, began on March 2, after arrangements for the use of the buildings had been completed with the shipbuilder John Roach. Like the other new Edison enterprises, the Machine Works belonged to Edison and his colleagues and operated on a license from the Edison Electric Light Company. The scale of the Machine Works, however, quickly outstripped all the others; less than 18 months after it began operations, the New York Tribune published this glowing report:

> The manufacture of the dynamo machines and engines for working the same is controlled by a company having works at No. 104 Goerck-St., New-York, and the energy with which this part of the enterprise is conducted may be appreciated when it is stated that within three weeks after the shops were rented the first Edison steam dynamo, capable of supplying over 1,200 sixteen-candle lamps, was tested. Until recently 300 skilled mechanics were employed, but the business has so increased that 500 additional men have been taken on, thus increasing the payroll to 800. Still more men are needed, but it has been found a difficult task to select competent men for the work. Not less than 1,000 men have been specially trained at these works since the start, a special and careful training being of absolute necessity. Since the time of testing the first steam dynamo, eight others of still larger size (1,400 lights) have been completed, and work on twelve others of the same size commenced, and during the last twelve months 355 dynamo machines of lesser capacity, varying from 15 to 250 lights, but chiefly for 60 full lights each, aggregating 75,000 lights in all, have been turned out.[12]

The Machine Works' expansion was due not so much to the needs of the New York system as it was to the requirements of the large number of smaller installations that Edison began selling in 1881. The large capacity of the Goerck Street factory, along with that of the Lamp Works, enabled the Edison interests in 1881 to respond at last to the demand for small systems that had been put off for so long.

Ever since the announcement of the carbon lamp breakthrough in late 1879, Edison had consistently turned aside the many requests he received for the immediate installation of his light in factories, stores, public buildings, streets, and the like. The one "isolated" system that he installed in 1880 was on the Columbia, and that was clearly as a special favor to Henry Villard. If other backers had had Villard's enthusiasm and eagerness, it is possible that Edison would have found it difficult to refuse to install more small systems, but they refrained, and Edison found it easy to put off others with the explanation that his central station system took priority. By the beginning of 1881, however, the resistance to getting into the isolated plant business diminished, and the building of Edison plants gained an enormous momentum in the following months. The change in Edison's attitude can be seen in his reply to an inquiry from Owen A. Gill, who was interested in lighting the Maryland State Penitentiary in Baltimore:

> Menlo Park, Jany. 29, 1881
> You perhaps know that all my efforts have been and all my appliances are devised especially for the general distribution of electricity throughout a city to be sold by meter, and not for the lighting up of a single building hence I am at the present moment at a slight disadvantage when asked to light up a single building. I could very much easier light up a square mile with 1500 to 2000 houses than I could a single building although that may seem a paradox to you.
> We are getting our offices in New York and I expect very soon to accomodate my system for isolated lighting....[13]

The next week, Edison was situated in offices at 65 Fifth Avenue, and one of the first accomplishments in New York was the installation of a lighting plant at the lithography shop of Hinds, Ketcham & Company at 213 Water Street. As in the case of many of the early isolated plants, the choice of customer was not entirely fortuitous, as evidenced by the letter that Edison sent to the paint maker Louis Prang on February 11: "Last week we lighted up the Lithograph establishment of Messrs. Hinds and Ketcham in New York. They were unable to work at night until they put in the electric light. Now I learn they have no difficulty in distinguishing colors."[14] In the following months, lighting plants were installed in steamships, hotels, railroad shops, newspaper offices, and a variety of mills and factories.

For almost a year this was done largely under the direction of the Electric Light Company itself, until in November, 1881, the Edison Company for Isolated Lighting was organized by a number of the Light Company officials, who continued to manage the new firm from their Fifth Avenue offices.[16] By the time the dynamos were turned on in New York's First District, in September, 1882, there were 99 isolated plants installed across the United States and many others overseas. They ranged in size from two plants in Fall River, Massachusetts, that each lit 750 16-candle-power lamps in cotton mills, to a few miniature installations powering only fifteen lamps, as, for example, in Henry Draper's laboratory at New York University or in a part of George Eastman's photographic supply house in Rochester.[16] The isolated plants were not cheap - Edison quoted to a steamship owner a price of $2,800 simply to install generators and auxiliary equipment[17] - but the Isolated Lighting Company identified rapidly some specialized markets for whom the new technology had particular attractions. Fully one-quarter of the first hundred plants, for example, were in textile mills, for the superiority of electric lighting over gas in such fire-prone places was readily apparent. One mill owner in Newburg, N.Y., for example, wrote to tell the Company, "I expect the difference in insurance rates will pay the whole expense inside of two years."[18] The Edison Electric Light Company regularly put stories of fires caused by gas systems in its Bulletins, and salesmen were encouraged to make use of them and then to explain the virtues of Edison's "safety catch" (fuse) in practically eliminating the potential for fire with electricity. The effectiveness of this appeal is apparent in the adoption of isolated plants for sugar refineries, newspapers and other printing establishments, and dry goods manufacturers.

The rapid growth of the isolated plants business provided important support to the Lamp and Machine Works, which for years remained dependent on isolated systems for much of their market. The proliferating small installations also fostered the growth of the third manufacturing establishment serving the Edison system, that of S. Bergmann at 108-118 Wooster Street in lower Manhattan. The German-born mechanic, Johann Sigmund Bergmann, had worked with Edison for six years in Newark before leaving to set up his Wooster Street shops for the manufacture of "Hotel and House Annunciators and Electrical Apparatus of all Kinds" (according to his letterhead). Due to Edison's high regard for Bergmann's work and his reluctance for most of the Menlo Park years to get too deeply into manufacturing, he had turned to Bergmann from time to time to produce his inventions - the phonograph being the most notable example. By early 1881, Bergmann's shops had expanded considerably and he possessed just the sort of capability Edison required for the production of the smaller elements of the lighting system. Therefore, in April Edison approached Bergmann with a proposition - he would provide Bergmann with additional capital for expansion and would endeavor to devise appropriate products, if Bergmann and E.H. Johnson (who had earlier bought into the firm) would agree to form a partnership devoted to the manufacture of "special appliances connected with Electric Lighting."[19] Examples of such appliances were specified as "small fixtures, lamp sockets, switches, safety catches, shades, etc., etc." Bergmann agreed, and the Wooster Street factory became the works of "Messrs. Bergmann and Company," which over the following years developed most of the visible consumer goods that accompanied the spread of electric lighting. Bergmann and Company, like the other Edison firms, expanded rapidly and moved into larger quarters at 17th Street and Avenue B on Manhattan's lower East Side in the summer of 1882 (which buildings had formerly been used by the Maxim lighting company). In 1889, it became part of the newly formed Edison General Electric Company and thus provided the foundation for the enormous electrical consumer products industry.

The commercialization of the Edison system through isolated plants provided not only needed markets for the new manufacturers, but also an important stimulus to broader innovation. The technology being developed for central stations could not be transferred to smaller installations unchanged, thus alongside the efforts to solve problems of the urban central station were important modifications devised for the wide range of small systems. The most obvious difference between the central station and the isolated system was in the size of the power plant. Edison was unwavering in his belief that central stations would require large direct-connected dynamos of the type that took so much time and effort to build at Menlo Park in 1880. He saw the primary product of the Goerck Street works as a series of large dynamos, rated at 100 horse-power or more and capable of powering as many as 1200 full-size lamps. Isolated plants, however, would not require such large, expensive machines, and so arrangements for producing smaller dynamos would be required. There existed, of course, a well-tested and reliable small dynamo design with which Kruesi and his associates at the Machine Works were very familiar - the "long-legged Mary Ann." This original Edison bi-polar generator had been slightly modified since its invention in mid-1879, and it had proven itself not only at Menlo Park, but aboard the Columbia as well, where the original four generators continued to operate for over fifteen years.[20] The long-legged Mary Ann thus provided the basic design for the most popular Edison generator, the "Z" dynamo. The Z, rated at 60 A (16 candle-power) or 120 B (8 candle-power) lamps, was installed in 71 of the first 99 isolated plants. In early 1882, the Isolated Company called upon Edison to produce larger models, for more efficient operation in extensive installations, and the L (150 A lamps) and K (250 A lamps) dynamos began coming out of the Goerck Street shops.[21] In addition, a smaller, 15-lamp, dynamo (called the E) was installed in a few instances where only one or two rooms were to be lit. All of these models were derived from the long-legged Mary Ann - the increased capacity of the L and K coming from the addition of one or two more pairs of field magnets. Their production did not require the extensive creative effort that went into the central station machines, but they did reflect the Machine Works' capability to adapt its products to changing needs.

The isolated systems spurred innovation in other ways. The fact that such systems, especially the smaller ones, were often operated by mechanics or engineers with little or no training in electrical equipment presented a challenge, for the new technology was liable to provoke considerable complaint when it did not perform as promised, due not to faulty equipment but to improper handling. Edison responded by devising simplified controls, meters, and indicators. He described one example in a letter to Batchelor dated December 31, 1881:

> In putting out a great number of plants as we are now doing we have found it necessary to have a Regulator for the candle power of our lamps as the parties using the light are apt to run the lamps up very high and thus cause a great many breakages. Plus the average life would be shortened; great dissatisfaction caused people to get the impression that our statements as to life were not true. So I have devised an Indicator which works beautifully and I advise that hereafter all Isolated Plants shall be accompanied by one of them.[22]

The marketing of isolated plants also drove Edison and his colleagues to sharpen their commercial instincts and to adopt a more entrepreneurial attitude toward their work. Through the first few months of 1881, the Menlo Park demonstration system was kept aglow many evenings, and the Menlo Park staff were required to play host to both curiosity seekers and potential purchasers or franchisees. Soon after offices were established at 65 Fifth Avenue, Edison ordered a couple of the Menlo Park generators sent up to New York, and the light was prominently displayed there. And subtler commercial touches were expressed from time to time, as shown by Clarke's suggestion to Edison (dated November 11, 1881):

> It would be well - as soon as the patterns can be spared - to round all the edges of the base and field for Z dynamo and introduce any features in the way of graceful curves which certainly will add much to the appearance and nothing to the cost of the machine.[23]

It is important to remember that while in the midst of the bold undertaking of the New York central station, the technical and commercial soundness of the Edison system was being demonstrated far and wide (in Europe and Latin America as well as the United States) by isolated plants, and that such plants for years remained the most important and common providers of the Edison light.

* * * *

Edison's dreams, however, were wrapped up in the central station system, and it was to its creation that he devoted himself upon moving to New York. The manufacturing concerns that were in operation by the spring of 1881 made the isolated systems possible, but they were brought into being to serve the central station effort. In the early spring, the last legal obstacles were cleared away. On March 23 a contract was signed formalizing the relationship between the Edison Electric Light Company and the Illuminating Company. The contract gave the new company a license to construct and operate an electric lighting system based on the Edison patents in two sections of New York City. The first of these was identified as a section:

> ...located in the lower part of the City of New York, bounded on the East by the East River, on the West by the middle line of Nassau Street, on the North by the middle line of Spruce Street, and on the South by the middle line of Wall Street.

The second district was simply defined as an "uptown" area to be designated in the future. Accounts differ as to how the First District was initially determined. William Hammer recalled many years later that he had, in the spring of 1880, gathered at Edison's request a number of large maps of New York City, on which Edison shortly outlined the area for his first station.[24] By the time he moved to New York, certainly, the boundaries of the First District were set. During 1880, in fact, Edison had had men surveying a number of streets in lower Manhattan to determine not only the amount of gas used for lighting in each building, but also the power consumed in operating hoists (often mule-power) and other equipment. By the time the legal and financial details had been worked out for the Illuminating Company, the knowledge of the First District and the kind of light and power market it represented was extensive.

The acquisition of this knowledge was consistent with the pains that Edison took to understand thoroughly the task facing him in New York. The surveys that began in late 1880 were logical extensions of the careful calculations with which Upton and others had occupied themselves earlier in the year. In December, Edison wrote to the Light Company's Executive Committee to request the services of Herman Claudius for the purpose of "arranging, mapping and figuring out the main and subsidiary conductors for our first district in New York."[25] Using the information brought back from canvassers of the district and additional figures gleaned from gas company records, Claudius came up with block-by-block and house-by-house figures for the amount of gas potential customers consumed yearly, the number of lights they burned, and the amount of power they consumed for various purposes.[26] The information included in the district survey went into far more detail than this, however, for potential customers were asked about such things as the globes and shades they used on their lights, the use of gas for heating or engines, damage caused by gas impurities, complaints about leakages or excessive heat, various forms and uses of motive power, personnel required for tending engines, insurance rates, winter and summer hours, and so forth.[27] It is not clear how much use this detailed information proved to be in the long run, but it probably armed the Edison salesmen with some of their better pitches and it may have guided Bergmann and Company in its development of auxiliary equipment. The key facts of the First District were straightforward - it contained about 1500 gas customers, who used 20,000 gas jets, and, with the promise of free wiring and lighting costs in line with gas, most of them were found ready and willing to receive the new light.[28]

* * * *

On April 19, 1881, the New York City Board of Aldermen granted a franchise to the Edison Electric Illuminating Company to "lay tubes, wires, conductors and insulators, and to erect lamp-posts within the lines of the streets and avenues, parks and public places of the City of New York, for conveying and using electricity or electrical currents for purposes of illumination...."[29] The two-page franchise resolution included appropriate clauses for insuring that the Illuminating Company repaired all damage to streets and pavements, that it did not allow its work to disturb other underground facilities and that it assumed full liability for all damage to private or public property. The good-will that had been won from the aldermen during their visit to Menlo Park may have accounted for the fact that the city asked for only five cents per linear foot of trench as the fee for the street work. Mayor William Grace objected to the council's generosity, but his veto was easily over-ridden, and Kruesi was able to begin laying his tubes by the end of April. The only other payment that arrangements with the city required were to the inspectors who were to assure that the work and the restoration of the streets following it posed no public hazard. Edison remarked many years later that these gentlemen presented no obstacles to their work, since they simply showed up each week to collect their fees and then promptly disappeared.

The laying of the mains in the First District took from the spring of 1881 through the summer of 1882, and while it went forward without significant technical difficulties, the sheer amount of work that was involved in laying more than 80,000 feet of under-street conductors and the myriad of small problems that required rapid and careful attention made this the most exhausting of the tasks involved in completing the Edison system. In a matter of only a few months, Kruesi had the routine of the Tube Works and the street crews well established, and much of his energy was devoted to maintaining the work to the desired standards. Kruesi was given considerable responsibility for the day-to-day work and for the mechanical details of the underground system. Clarke, who was appointed the Illuminating Company's chief engineer, was responsible for many of the more technical aspects of the mains installation, particularly where questions arose about the electrical connections or capacities. Edison himself, however, kept a close eye on things, and Clarke was careful to keep him informed and to involve him directly when changes were proposed, as in the case of deciding to reduce the number of fuses in house installations. Clarke wrote him:

> You have verbally agreed to the abolition of a safety catch in the sockets and fixtures. Will you please state your agreement in writing so that should the matter come up later I can shew that you have been consulted, although the change is to be made on my authority.[30]

A little later Clarke wrote in more general terms:

> It is well to have all steps involving a departure from the old system properly stated in writing, so that the responsibility can be placed, and it can be ascertained if due discretion has been used and proper parties consulted.
>
> I wish you however to bear witness if you can to the fact that I am painstaking with reference to the system generally and in detail, that I take particular attention to consult you on all points pertaining to your system and never take or have taken the initiative without your assent. Can you do this?[31]

While men with more of an engineering mentality, like Clarke or Kruesi or central station engineer John W. Lieb, assumed a greater role in the development of the Edison system as it grew more and more complex, it was still Edison who had the ultimate responsibility for the new technology.

At the same time that work was starting on the street mains in the First District, the locating of a site for the generating station became a major priority. In later recollections, Edison spoke of his frustration over high Manhattan real estate prices, even in an area that had been selected because it accomodated industry. In truth, once the boundaries of the district had been set, Edison did not have a wide range of options in locating his generators. The distribution system he was planning had a range that was limited to about one-half mile from generators to the farthest lights. In a system depending on street mains, this required location of the generating station as close as possible to the center of the system area. The choice of the buildings at 255 and 257 Pearl Street, therefore, was probably not simply on the basis of their relative cheapness (as Edison claimed) but was determined somewhat by the geographical requirements of the system. In early May 1881, the Illuminating Company completed the purchase of the Pearl Street buildings, for which it paid $65,000. The property had originally been used for commercial activity, thus the building that would house the generators, steam engines, and boilers, number 257, had to be substantially strengthened before any machinery could be installed. There was initially some concern about the ability of the second floor to carry the load of the enormously heavy dynamos, but Clarke had the best wrought-iron structure put into the interior of the building, and only a few weeks before the station began operating he had the loading certified by engineers. Number 257 Pearl Street was 25 feet wide and 100 feet deep, with four stories and a basement - far from Edison's ideal for his model station, but, as it turned out, perfectly adaptable for his needs. The basement was used for storage of coal and the removal of ashes. A conveyor was installed to carry coal up to the first floor, where four Babcock & Wilcox boilers provided steam at 120 pounds per square inch pressure to the generators on the next floor up. Above them, on the top floor, was a large bank of lamps, which were used for testing dynamos and otherwise measuring the station's load. The building at 255 Pearl Street was kept for equipment storage, offices, sleeping quarters for station attendants, and testing and measuring facilities. The station of the Edison Electric Illuminating Company did little to improve the ambience of its dilapidated neighborhood, but it proved a very functional structure in its almost twelve years of service.

In the spring of 1881, Edison was still driven by the challenge of developing a generator suitable for the kind of central station he envisaged. The winter's test of the large Menlo Park 100 horse-power machine was considered a success, although modifications in the machine's design were necessary. The first task, in Edison's mind, of the Machine Works on Goerck Street was to build the new large dynamos that would be the mainstay of central stations. The Menlo Park machine had been directly driven by a Poter-Allen steam engine, but Edison was not fully satisfied with its performance, especially its speed regulation. He thus approached the Armington & Sims company with a proposal that they provide a 125 horse-power engine capable of running at 350 revolutions per minute for $2000.[32] Meanwhile, tests continued to be made of the suitability of other engines, and Charles Porter was also contacted for possible further work. Edison considered the behavior of the engine linked to his dynamo to be a critical factor and he continued to be less than fully satisfied with the machines he could get. He thus kept his options open even as he found it necessary to commit himself as the large dynamos near completion. This proved fortunate, for supply difficulties kept Gardiner Sims from doing all the work Edison needed for Pearl Street. When, however, the Porter-Allen engines were put into operation at the station, the deficiencies of the governors made it impossible to run more than one engine at a time without setting up horrendous vibrations in the dynamo room. For four weeks, the Pearl Street station operated on only one generator, until Edison devised a mechanical linkage between the steam engines.[33] Shortly afterwards the Armington & Sims engines were installed and multiple running of the engines was much easier. The operation of direct-connected steam engine-dynamos did not, in fact, turn out to be the most satisfactory form of power plant for the early central stations, and most stations after Pearl Street returned to the use of smaller belt-driven dynamos such as had been used at Menlo Park.

The design and construction of the large dynamo's steam engine, while a matter of great concern to Edison, was not something he could manage directly. The building of the dynamo itself, however, was clearly in his hands, and much of his creative efforts in 1881 were bent toward improving the large dynamo that had been tested at Menlo Park early in the year. Even at this point Edison experimented with some radical design changes, such as a disk armature that could be operated at very high speeds (1,200 revolutions per minute and higher) and would eliminate the need for an iron core as was used with the drum-wound armatures of other machines. The copper disk dynamo that he had built at Menlo Park early in 1881 worked and was patented (U.S. Patent 263,150), but it did not represent a practical point of departure for the central station machine. Soon after the Goerck Street shops were set up, work began on building a second large dynamo, intended for use in the Edison exhibits at the upcoming Paris International Electrical Exposition. This machine was soon designated the "C" model dynamo and was the first of 23 such machines built at Goerck Street. The Paris machine (as it was called at the time) differed from the experimental Menlo Park dynamo primarily in the construction of its armature. One of the sought-after advantages of the large dynamos was the lowering of the resistance in the armature due to its size, but the Menlo Park machine had not been satisfactory in this regard. The C dynamo was built after months of experimentation on the armature construction, Francis Jehl being called up from Menlo Park in May to set up a testing room at Goerck Street to measure armature performance. All summer the Machine Works mechanics struggled to build a machine that minimized armature resistance and yet did not burn out or spark while running at speeds of over 300 revolutions per minute. Working on such a large and complex machine presented new and difficult problems and required considerable toil. Jehl noted once, for example, that it took 55 men working eight days and nights to change the construction of the armature when one of its parts had to be re-shaped.[34] By the end of the summer, however, the armature had been constructed with a resistance of less than 0.01 ohm and most of the problems of keeping the machine cool enough (using an air blast) and regulating its operation had been solved. In September, the giant dynamo was broken down and packed into 137 crates and loaded aboard the ship that had recently brought P.T. Barnum's famous elephant Jumbo to America, giving the machine the name by which it was known familiarly ever after. The cost of the work must have dismayed even Edison (who could be quite cavalier about such things), for he lost little time in writing to the Light Company seeking compensation - $6,171.31 for experimental costs alone.[35]

The machine that emerged from this labor was a technical triumph. It far surpassed in size any electrical machine that had ever been attempted before. The Jumbo measured 168 inches by 105 inches at the base and weighed just over 30 tons. Armington & Sims provided the engine for the machine that went to Paris. When operated with the air blast at 350 revolutions per minute, it produced a current of about 500 amperes at 103 volts (= 51,500 watts) and could power as many as 700 A lamps. At the Paris Exposition a smaller load, about 500 lamps, was used and the air blast was not required. The reception at Paris was everything that could have been hoped for; Batchelor cabled home that Edison's generator and light had carried away the highest honors, whereas rivals such as Hiram Maxim and Joseph Swan had received lesser prizes. The Exposition succeeded in elevating the standing of the Edison system in the eyes of European scientists, engineers, and businessmen, and the Paris awards carried much prestige on the other side of the Atlantic as well. A considerable boost was given to the commercial enterprises on the continent which Batchelor had been chosen to organize, and when the Exposition was over, the dynamo was installed in the factory at Ivry-sur-Seine of the Societe Continentale Edison. Contracts for isolated plants in showcase locations, such as the Opera Houses in Paris, Berlin, and Milan, were quickly arranged, and the Edison system in Europe was off to a spectacular start.

The European success continued into 1882, for as Batchelor worked in France to get manufacturing under way, Edward Johnson and William Hammer went on to London for an electrical exhibition at the Crystal

APPENDIX TO CHAPTER 6

On Saturday, May 22, Mott began the practice of summarizing the past week's work in his journal. These brief summaries, reviewed week after week, constitute the best source for getting a sense of the variety of activities under way at Menlo Park. They are thus reproduced here.

> (May 22) Work general. Glass blowers pushing work on pumps. Gang laying conductors to Street lamps. Three men at old factory preparing building for lamp manufacturing. Mr. Batchelor on Machine for making small clamps, occasionally stopping to discuss gear question for Magnetic locomotive. Men changing counter shaft and pulleys on electric locomotive.
>
> (May 29) Work general for the closing week and to day - two men preparing the sleepers for extension of R.R. Four ballasting and shapening up old track. Gang putting sown conductors to street lamps(,) 2 carpenters at work in old factory. Mr. Batchelor & Force making and preparing to put up clamp machine, Cunningham & Bradley on Small Dynamos. Glass blowers on pumps. Laboratory very quiet.
>
> (June 5) Work general. During the week Mr. Batchelor & Martin Force on clamp machine. Ott on turning Bast Fibers. Andrews on circular annealer for outside globes. Bradley and Andrews on apparatus to try the power of magnetic traction. Glass Blowers on Pumps. Two or three on extending track of electric R.R. Gang on laying conductors. Three mounting pumps. Cunningham on Small Dynamos.
>
> (June 12) Work general. During the past week Dr. Moses continuing experiments on the reduction of Alumina and on making carbonized box wood crucibles with which to conduct the exp. but has

had no further success in reducing it. Glass Blowers at work on pumps. Bradley on machine for making Bast fibers. Batchelor, Force, Ott & Andrews on different parts of clamp machine. Cunningham on small field Dynamos. Hornig on gear for elec. locomotive, Clarke on means of most economically maintaining the electro motive force in large circuits and systems. Carpenters on New cars and gang on laying conductors and a few on Rail Road extension.

(June 19) Absent fishing - Mr. Edison and about all the men except some in the shop, left here about four o'clock p.m. to take a schooner (hired for the purpose) at Woodbridge for an excursion and fish, expecting to remain away until Monday night. Work general of the week. Several in shop at work on patterns for motor gear. Men & Ayers team on Rail Road extension. Mr. E. interested and experimenting on Bast fiber lamps. Batchelor still absent. Cunningham on small field dynamos.

(June 26) Work general of week. Mr. Batchelor still absent. Ott on former for and getting out slotted plates in which to carbonize Bast fibers. Most of the men in shop on preparing the gear castings for putting on the electric locomotive. Three men during day on R.R. extension and Martey (?) with five men from 6 o'clock till dark. Mr. Edison and Upton testing and experimenting with Bast fiber lamps. Glass blower on pumps.

(July 3) Work general of week. Mr. Batchelor, Ott & Force on clamp machine. Mr. Edison & Upton, testing lamps and experimenting on carbons. Pump power put up in lamp Factory. Men on R.R. extension, several in Shop on Gear of electric locomotive. Glass blowers on pumps. Carpenters on Cars & elevated messenger exp.

(July 10) Work general for past week. Mr. Batchelor, Force and Ott principally on clamp machine, the former a little on captive baloon (sic). Smith and one or two assistants on Magnetic brake. Logan and Martin on gear of electric locomotive. Several at Lamp Factory. Gang on R.R. and on Conductors. Dean finishing up wood miller. Glass blowers on 5th hundred pumps. Bradley, Flammer & Van Cleve on experimental carbons. Upton & Clarke still absent.

(July 17) Work general for past week. Men at work at Gas and Air works and fixtures at Lamp Factory. Men finished the preliminary laying of the conductors to Street Lamps. Dean finished wood miller, took it apart and put away. Gear of electric locomotive about finished. Mr. Batchelor again interesting himself in experimental carbonization. Messrs. Edison and Upton experimenting with and testing lamps.

(July 24) Work general. Men preparing the gas carbonizing furnaces by putting in the gas and blast pipes and fixtures. Clarke on Electric Locomotives. Mr. Batchelor on carbons and apparatus for carbonizing. Conductor gang uncovering street lamp circuits. Men finishing up gear for electric locomotive.

(July 31) Work general for past week. Messrs. Edison and Batchelor making some interesting experiments with carbons and hydrocarbons and means of carbonizing. Andrews making carbon formers of different devices for us in large 30 carbon moulds of gas furnace. Dean making fiber clamps and formers for four, six, and eight inch loops. Mr. Clarke on electric locomotive, insulated car wheels and roller creepers (?). Wilber here three or four days drawing specifications. Cunningham making glass heater or the device for holding tubes for heating over gas flames (described under date May 28). Several tables fitted for glass blowers at Lamp factory. Hammer making the rubber connections between pumps and mercury pipes. Conductor gang wrapping and tarring the 25 wire circuit. Carpenters building the large magnetic separator.

(Aug. 7) Work general for past week. Team drawing coal dust from ten cars of which are laying on the switch for Mr. Edison. Men continuing work cleaning out the Pond. Ott remoddling and putting screw gear in telephone receivers. Dean making former in which to cut Bamboo fibers. Mr. Batchelor carbonizing and experimenting on apparatus for that purpose and has worked it down "fine". Mr. Wilber here most of the week getting up specifications. Men preparing lamp factory for occupancy by putting in the final trimmings. Chalk motograph receiver tried O.K. to noisy & armature to be constructed differently.

(Aug. 14) Work general for past week. Mr. Batchelor experimenting to determine the cause and devise means to prevent the long carbons from bending over side-ways in the lamps, found the cause and remedied the defect by removing the cause. Men under Logan putting the cast gear on the electric locomotive. Trying the experiments with the coal dust furnace and experienced great delay and annoyance by it. N.G. Testing the blower and Gas supply at Lamp Factory, the former efficient but the latter has neither capacity nor simplicity for practical use there. Men wrapping conductors with muslin tarred and then wound with marlin and again tarred. Mr. Wilber here several days at work on Patent Specifications.

(Aug. 21) Work general for past week. Men putting the gear in the electric locomotive. Dean making cutting clamps & former for Bamboo strips. Andrews making carbon formers. Ott & McKenzie on call box for Pond indicator. Upton making calculations of the power, conductors, &c. necessary for a lighting station in New York. Clarke working on Dynamo (illegible) Book No. 116. Mr. Batchelor superintending starting the Lamp Factory.

(Aug. 28) Work general of past week. Mr. Batchelor on the drawings and details of clamp machine. Dean with several assistants at work on same and on Bamboo cutters & splitters. Upton and Hammer on size, length, &c. of conductors for lighting station in New York. Clarke still on New form of armature adapted for large machines. Smith working to improve the clutch of friction wheel of electric locomotive.

(Sept. 4) Work general. Mr. Batchelor on detailed drawings of clamp Machine and Dean and assistants at work on same and on clamp former for Bamboo. Smith remoddling the friction clutch wheel for electric locomotive. Men digging foundations &c. for building and gas works at Lamp Factory and pumps there prepared for starting.

(Sept. 11) Work general of past week. Mr. Batchelor making efforts to get the Factory started. Messrs. Edison, Upton and Hammer at work on conductors for central Station and plans for laying them. Joh Ott making McKenzie call boxes for Pond indicator. Dean working several men on Fiber cutting moulds and on clamp machine. Carpenters splitting old glass house for Draughting room. Other carpenters at work on preliminary work of Supplemental Factory building. Johnson commenced on Chandelier.

(Sept. 18) Work general past week. Experiments continued in insulating compounds. Mr. Batchelor working at Power Mercury Pump at Factory, but unsuccessful in getting it to work reliably. Mr. Upton at work on Station conductors. Smith on wooden facsimile of large armature commutator connections. Logan on casting of Large Dynamo. Dean and assistants on Clamp Machine and fiber formers.

(Sept. 25) Work general past week. Carpenters at work on building supplemental to Lamp Factory. Gang commenced third laying of Street Lamp conductors, insulating with composition. Large planer running on castings etc. of Large Dynamo. John Ott finished three call boxes for Pond indicator and continued work on wooden facsimile of commutator for Large Armature. Dean on Clamp Machine and Bamboo clamp formers.

(Oct. 2) Work general for past week. Logan & some of shop men working on Large Dynamo. Dean and assistants on Bamboo clamps and on clamp machine. Painters finishing up new drawing office. Factory turning out quite a number of lamps and Francis testing them. Upton and Hammer on Station conductors. Mr. Batchelor at Factory. Johnson at work on chandeliers.

(Oct. 9) Work General for past week. Factory has been turning out and Francis testing a considerable number of lamps. Work progressing nicely on the large dynamo. Dean and assistants still on Clamp machine and fiber cutting clamps. Gang on insulating the Street conductors. Carpenters on inside work of Factory supplemental building. Man.(Moore) left for China and Japan.

(Oct. 16) Work general. Testing lamps by the quantity. Men on Large Dynamo. Gang of about twelve on Street conductors. Dean and assistants on clamp Machine and clamps for cutting bamboo. Rotary engine received and partially tried.

(Oct. 23) Work general for past week. Carpenters finished Black (illegible) Shop. Dean made a start on the large armature. Mr. Batchelor experimenting on pumps. Gang on insulating cables. John Ott at work on Meters. Draughtsmen all in new room.

(Oct. 30) Work general past week experiments conducted on heating carbons in gasses. Dean with assistants working on large armature and on mould for cutting bast fiber. Gang still on insulating conductors. John Ott finished wheel meter. Gas fitters running steam piping at factory for heating purposes. Mr. Batchelor experimenting on and having pumps changed to bent one tube with dryer and spark gauge attachment. Men at work preparing to pump water from gulley.

(Nov. 6) Work general for past week. Upton & Hammer tabulating the statistics obtained by Mr. Russell's canvass. Edison & Francis treating carbons in gasses. Commenced putting out the Street lamps. Dean & assistants on Armature. Cunningham on commutators for same. Ott on Meters. Several men in shop on Magnets &c of large dynamo.

(Nov. 13) Work general of past week. Messrs. Batchelor & Edison engaged principally on Interference case. Little doing at Factory in consequence of delay in getting the screw pump. Men in shop pushing work on large dynamo & armature. Ott at work on an Electric dynamometer.

(Nov. 20) Work general past week. Bed plate for Dynamo Engine placed in shop and some preliminary fitting of the parts effected. Discs secured on the Armature shaft, and work on the commutator &c. progressing satisfactorily under Dean. Messrs. Edison & Batchelor experimenting at factory on times for subjecting fibers to process of carbonization, on length of time and heat to apply to lamp on pumps, and on heating mercury and pumps. Mr. Clarke working on the relation and laws of motors to machine &c. Acheson on (illegible) carbon by Electrolysis.

(Nov. 27) Work general of past week. Mr. Batchelor and assistants preparing the pumps and pipes for the power pump and clean mercury. Mr. Edison with two or three assistants making experiments on high vacuum on pumps in Laboratory. Dean and several assistants pushing work on the large armature. Logan and other on Magnets, base, etc. of large dynamo.

(Dec. 4) Work general past week. Work on large dynamo, Glass blowers making pumps. Mr. Batchelor preparing for power pump. Mr. Edison experimenting on high vac(uum) and lamps.

(Dec. 11) Work general of past week. Screw Mercury pump put up and prepared ready for work. Work in shop progressing on large dynamo. Logan winding cores of magnets. John Ott on a meter with four Mercury cups for contacts. McKenzie trying to work call box with magneto current generated by the magneto call box of Johnson. Mr. Clarke making measurements to determine the loss in dynamo by local cutting. Nichols determining the constants for the low resistance Electric dynamometer.

(Dec. 18) Work general for the past week. In the shop work has been pushed forward on the large dynamo, and Ott finishing up lamp sockets. At the Factory the glass blowers on pumps and lamps, and Moffett mounting and putting up new device for securing the pumps adopted, and the castings ordered. Lawson working on plating the ends of carbons and Herrig experimenting on plating carbon and wires together. Second experiment on burning dust coal direct under boilers tried and so far with fair success. Lamps being tested and put on the lines preparatory to illumination on Sunday and Monday nights.

(Mott returned from a four-day Christmas vacation on Tuesday, Dec. 28 and recorded this report of the Christmas Eve demonstration.)

(Dec. 28) 400 lamp test. 400 lamps were burned on Friday evening, Christmas eve, and Economical test made of the Engine by Mr. Clarke, boilers forced to 90 lbs. pressure, engine to 75 Rev., gave 6.9 lamps per horse power, but I believe this result is obtained after deducting the power consumed in friction of shafting etc.

(Jan. 1, 1881) Illumination & Economic test. In the evening 408 lamps were burned and a number of visitors were here to see the display. Mr. Clarke made a test of the engine while running for the lamps and developing 82.3 horse power and got perfect diagrams. Boiler pressure 110 lbs. Revo 75, total H.P. 82.3 less frictional diagram left net of 61.95 H.P. or on 408 lamps gave 6.59 per H.P. less field gave net 7.88 per h.p. on 22.58 pounds steam per H.P. per hour. Proving the Brown engine first class for economy etc.

INSERT A

The Search For a Vacuum

Air is removed from an incandescent light bulb for two principal reasons: to prevent oxidation of the filament material, and to reduce heat loss. Edison understood these reasons, and virtually all of his experiments were done with some degree of evacuation.

He had a manually-activated piston pump as early as 1874. With it he performed the preliminary experiments of January 1877. This is the same pump, apparently, that was used in the effort that began in the Fall of 1878. With it he could achieve a vacuum on the order of 2½ mm of mercury or about .003 atmospheres.

On January 19, 1879, he became aware that occluded gases were present in platinum and suspected they might play a major role in its mechanical and electrical properties. He found similar "bubbles" in other materials. The need for a higher degree of vacuum was immediately apparent, and he sent out a call for one of the relatively new Sprengel mercury pumps — which Edison later said he had known about since 1875 but obviously had not felt worth obtaining.

Edison's telegram barrage was unsuccessful and he was limited during the next two months to his old mechanical pump. Why he did not show more concern for this failure is unclear. Also uncertain is exactly when the new era finally began. Surviving correspondence indicates that he first contacted the New York glass-blowing firm of Reinmann & Baetz in March of 1879, and that they delivered the first (Geissler) pump on March 26. At the same time they advised him that the mercury should be very clear in order not to coat the inside of the pump with contaminents. Reinmann himself was to follow to help with the installation which he described as a bit tricky.

Another Geissler pump was obtained about the same time from Princeton, through Upton's former professor Brackett. When it arrived is unclear, but both Upton and Edison later recalled it as after the one from Reinmann & Baetz. In any case, it apparently was not in working condition and had to be repaired.

As it turned out, it was William Baetz who came to Menlo Park to help develop vacuum apparatus. Starting at the very end of March or early April, he came over from New York as often as three days a week to repair existing pumps or create new ones. Between then and mid-August he assembled at least eight different arrangements of Geissler pumps, Sprengel pumps and combinations of the two. The last were produced after Edison saw an article by De la Rue and Muller. Examination of the original article reveals not only a combination of two pumps, but also a McLeod gauge, which Edison added to his arrangement later in the year.

A few words might be included here about these two basic forms of mercury pumps. Geissler's device was essentially an improvement on the approach of the Academia del Cimento in the 17th century which created an enlarged Torricelian vacuum. Geissler took a tube full of mercury that was just short of the barometric length of 30 inches. At the top a two-way valve connected either to the chamber to be evacuated or to the open air. The bottom of the tube was connected by a flexible hose (or other equivalent arrangement) to a container with mercury. By lowering and raising this container the effective height of the mercury column could be made more or less than the barometric height. In the former case the stop cock would be opened to evacuate the chamber, in the latter case it would be turned to allow residue air to be exhausted to the atmosphere. In a Sprengel pump a long vertical tube split near the top, one path leading to the chamber to be evacuated and the other to a vessel of mercury. By proper arrangements mercury was dropped past the opening, carrying residue air in the lower part of the tube before it in-to a trough at the bottom where it could escape. The Geissler arrangement was quicker, the Sprengel system could achieve a higher degree of vacuum; hence the advantage of combining the two.

In any event, working with mercury and glass was tedious and frustrating, and the need for a glass blower was virtually constant. Edison tried to persuade Baetz to move out to Menlo Park, but was unsuccessful. So an ad was placed in the newspaper and as a result Ludwig Bohm joined the select group of Edison pioneers. Bohm had worked with Geissler and then emigrated to the United States in 1878 at age 19. He brought to the New Jersey rural laboratory a much-needed skill (earlier in the year Edison had unsuccessfully tried to persuade Upton to learn the techniques of glass blowing), not just for the pumps but for producing a variety of glassware items including experimental light bulbs. He stayed a little over a year and was clearly a critical factor in Edison's success.

New efforts in August 1879, produced a pump capable of reducing the pressure in a bulb to 1/100,000 atmosphere. Edison called this "the first pump by which a partially satisfactory vacuum was obtained". He also testified that while Bohm executed first class workmanship, his pumps were no more efficient than those preceding. To reconcile these two statements one would conclude that Baetz's final efforts, in early August, produced the first "satisfactory vacuum". However one must also take into account uncertainties in recollection (even though the above remarks were made in 1881) and the fact that Edison's testimony was given in a case where he was attempting to discredit Bohm's originality.

The improved pumps helped clear up another mystery. Part of the metallic filament was apparently volatilized at incandescent temperatures and became deposited on the glass envelope — with implications both for the life of the filament and for the transparency of the glass. Upon further evacuation, however, the effect disappeared, showing, as Edison surmised in his paper given to the AAAS meeting at Saratoga at the end of August, that it was due to gas molecules bombarding the filament (and also that it was not — as some have surmised — an early manifestation of the Edison effect).

Pumps continued to provide difficulties — breaking or sticking or otherwise failing to function — but the presence of Bohm assured that experimentation could continue. In any case, it is clear that by mid-August, with a good four months of experience behind them, that they had solved the basic problem. A bulb could be evacuated to an acceptable level — a millionth of an atmosphere by the end of the year (though compare to De la Rue's reported $.066 \times 10^{-6}$ atmospheres) -- in twenty minutes. This piece of experimental apparatus was therefore ready for the final assault.

Bernard S. Finn
4/26/82

INSERT B

The Menlo Park Mystique

Although Menlo Park has, with considerable justification, been called the world's first industrial research laboratory, it was not -- in its essential organization -- a prototype for those to follow. Later laboratories would provide an environment within which a number of separate creative minds could work, stimulating each other and making common use of the facilities. For Edison the laboratory was structured to serve only one creative mind, his own. As he said, "I am not in the habit of asking my assistants for ideas. I generally have all the ideas I want. The difficulty lies in judging which is the best idea to carry out." This is not to say that others were completely stifled, but the rule in the lab was to carry out Edison's specific instructions first, with other work to follow if there was time. And without the master to provide direction, as would occur from time to time, the pace of action dropped precipitously. Thus Upton reported in a letter home, "one thing is quite noticeable here that the work is only a few days behind Mr. Edison, for when he was sick the shop was shut evenings as the work was wanting to keep the men busy."

To keep an enterprise going under such circumstances was no mean feat. The small, intimate laboratory of phonograph days expanded substantially in late 1878 for the electric lamp enterprise. Three new buildings were constructed (the office-library, the engine house, and the photographic studio which soon became a glass blower's shed) and more people were hired. In

1883 Edison recalled, "the place was crowded with people; I had thirty or forty assistants, and sadly neglected my usual care in dating exhibits and recording all experiments...I really had not the time." He went on to compare the activity with an only slightly earlier time when he was working on the telephone and when "I only had two or three assistants. We had more time, and I did a great portion of the work myself, whereas with the electric light I had 20 or 30 (sic. The larger numbers mentioned above are probably closer to being right during the period late 1878 - early 1881.) assistants and things were going on with a great rush, and I could not make the records myself."

The method of record-keeping (to which Edison refers in this testimony) reflected the new level of activity. In 1878 Edison adopted a system using standardized hard-covered note books. "A couple of dozen were always scattered around the laboratory among the assistant", with as many as forty in use at any one time.

Edison, as is well known, worked long hours, preferring those after dark, and he expected his men to be with him. They were, late into the night and frequently all night. As John Ott put it, "my children grew up without knowing their father. When I did get home at night, which was seldom, they were in bed."

Charles Flammer had a room in the laboratory where he worked putting carbons in lamps. He "slept there nights, or whenever I got a chance, but it was very seldom I slept at night." There was compensation, in the form of overtime pay (at the regular rate) but clearly there was a higher degree of motivation at work, creating an enthusiasm that George Bernard Shaw -- who was briefly employed to promote Edison's London telephone operation -- noted in his prefact to The Irrational Knot. The American technicians who had come to London "adored Mr. Edison as the greatest man of all time in every possible department of science, art and philosphy".

Those who came to Menlo Park to engage in the light bulb adventure did so with a variety of backgrounds and for a variety of reasons. Upton, Griffin and Jehl came because Lowrey sent them. Charles Mott came to join his brother Samuel, who came because he wanted to learn the electrical business. Albert Herrick first visited the laboratory with his mother who was doing an article for Century magazine. He was only seventeen at the time, a student, but at Upton's suggestion he began work just before Christmas in 1879 and stayed for what must have been a very educational year. Boehm came in answer to an advertisement for a glass-blower.

Wages were generally in accord with the market, though there was considerable flexibility. Some began by working for free. And some negotiated. Typical, perhaps was Samuel Mott, who had studied drafting and electricity briefly at the Princeton School of Science and arrived at Menlo Park with a letter of introduction to Upton from Upton's former teacher. He later said he would have accepted anything, that he even would have paid Edison for the privilege of working. He was offered $5.00 a week, which he negotiated upwards to a respectable $7.00. Boehm, who came in response to a desperate need for glass-blowing talent in August 1879, talked the Wizard out of $20.00 a week, raised to $30.00 at the first of the year. Edison testified that he subsequently was able to pay much less to others of equal competence.

The glue that held all of this together was clearly Edison himself. A loner who was uncomfortable in normal circumstances, he had developed during his years as an itinerant telegrapher a talent for easy rapport with working men. Motivation for the men came from several sources. There was respect; Edison clearly worked harder, longer and more effectively than the rest. At the same time he was a peer. When John Ott first saw Edison he "was as dirty as any of the other workmen, and not much better dressed than a tramp. But I immediately felt there was a great deal to him."

Also, the operation was structured so that he worked with the others. Because everything flowed from his inventiveness, he was naturally interested in everything that was being done and pursued all activities with a watchful eye and pertinent suggestions. He knew when to take a break. Often this was at midnight, with coffee, pie, a cigar, loud music on the organ and a round of jokes. Edison once said, "I was very fond of stories and had a choice lot...with which I could usually throw a man into convulsions." And he was an impossible prankster able to liven up proceedings when necessary, and encouraging others to do likewise.

In a word, the laboratory was not just a work place. It was a home away from home. For the bachelors in particular, living at Mrs. Jordan's boarding home, it was the center of their lives, to which they turned for a variety of home needs. It was not uncommon that a man, through for the day, would stick around in the evening to watch what they were doing and when it came time for a midnight snack the working crew would be augmented by a number of extras who would disappear again when work resumed. Upton experienced the mood in a letter to his father, about four months after he moved to Menlo Park: "I find my work very pleasant here and not much different from the times I was a student. The strangest thing to me is the $12.00 I get each Saturday, for my labor does not seem like work, but like study and I enjoy it."

On can only speculate how long the spirit of Menlo Park could have survived, or how many people it could tolerate. The numbers during the lamp days were apparently still tolerable. But when Edison recreated the laboratory on a much larger scale in a more ? area, at West Orange, it is clear that the essential character was no longer present.

Bernard S. Finn
4/21/82

INSERT C

Carbon and the Incandescent Lamp

Because of its resistance and high-temperature qualities, carbon was a natural choice for use in an incandescent lamp. Precautions had to be taken, of course, to prevent it from oxidizing -- by containing it either in an inert-gas atmosphere or in a vacuum. But, still, a majority of the early serious experimenters in incandescent lighting concentrated on it, and we should not be surprised to find Edison starting out the same way.(1)

Our evidence for Edison's interest in lighting prior to the fall of 1878 is unfortunately largely limited to court testimony, which can be suspect because of its self-serving nature. However, the activities described are consistent with other things we know, and the tesitmony was in many cases supported by documents which, if no longer extant, were at the time subjected to court scrutiny. What follows is a reasoned description of what seems to have happened.

No specific motivation for Edison's original interest is provided by the record. It is not hard to believe, however, that notice of work being done by others in the early 1870s piqued his curiosity. Additionally, publicity being given to arc lighting -- including the problem of its being too bright and hence the need for "subdivision" -- may have stimulated him.

Although Edison claimed that he had "experimented more or less since 1864 with the electric light"(2), and with incandescent carbon as early as 1869, the first specific reference to any lighting experiments is provided by Kruesi, who presented a personal memo book (apparently since lost) in court with notations to the effect that such work was done in Newark on January 5 and 6, 1877.(3) There is no mention of carbon, but, since vacuum apparatus was apparently used, this was probably the incandescent material. Further deatails are lacking, and in 1881 neither he nor Edison could recall anything beyond what was recorded.(4)

Carbon was certainly not an unknown material in electrical laboratories. At Menlo Park in the summer and fall of 1876 paper and cardboard were being carbonized in bulk quantities, not only for use there, but also for the production of wires, resistances, battery electrodes, and other items to be sold to the American Novelty Company, which had recently been founded in New York by Edward Johnson, who came into Edison's employ at Menlo Park in 1880.(5) In 1877 further amounts of carbon were needed for Edison's telephone transmitters.

Batchelor testified, and Edison confirmed, that in August or September of 1877 he cut strips from one (or perhaps several) of these carbonized sheets and brought them up to incandescence in a vacuum. This time, as Edison recalled, the carbon oxidized, a result they tried to alter by coating it with molten glass. The apparatus used was also described, and produced for the court (but, as far as is known, has since disappeared). It was a Gassiot Cascade, a relatively common piece of vacuum demonstration apparatus which had been purchased some time previous and which was now modified to fit their needs. What they had in the end was an arrangement of two brass rods, supporting the incandescing material under a glass cover. This artifact was found and presented in evidence to the court; it is not known to exist today.(6)

Batchelor described arrangments for the experiment in some detail.(7) He added binding posts and clamps to the rods. Edison wanted to use hard carbon for the incandescing element, but it proved impossible to get a piece small enough to fit, so they tried the carbonized paper instead. Still, it was a difficult, tedious task to fit the elements in place.

> I did it by unscrewing the ball from the top of the rod and also unscrewing the globe from the holder above the cock; also unscrewing the packing cap. When these are all apart the top rod will drop out and the bottom rod can be left in the part having the cock. The carbon was now screwed to the clamp of the bottom rod whilst lying on the table. The other clamp was then screwed to the other end of the carbon, and all three together lifted and turned, so that the part having the cock would be topmost. The lamp also was turned upside down, and the rods and carbon carefully dropped through it. The top rod was then held until the packing and packing cap were put on, when the whole was screwed together again, and the ball replaced. The binding posts were put on the lamp to hold the connection wires from the battery.

The apparatus was then placed on an air pump plate, evacuated, and brought to incandescence. This was done at least four times (according to Batchelor), or two or three times (according to Edison). Recollections about the size of the carbon element were 3/4 to one inch long by 1/16 inch by .007 to .008 inch (Edison), and one inch by 3/16 inch (or less) by .008 inch (Batchelor). Resistance was not measured.(8) Eight years later in 1889 Edison recalled that these experiments included one with a loop of carbon. He claimed that they cut a strip of cardboard, bent it and then carbonized it (9) -- which is not in accord with the earlier recollections and appears very much to be retrospective wishful thinking.

Further lighting activity in 1877 was documented by papers presented in evidence. Two, dated November 1 and December 3, indicated the use of silica, boron and other substances in place of carbon.(10) Another sheet, dated October 5, indicated an early understanding of the value of parallel circuits.(11) As Edison noted in his testimony, they -

> tried boron, ruthenium, chromium, and the almost infusible metals for separators in my electric light devices. Boron is very high resistance, and would do if arranged thus (diagrammed in parallel)...silicon, on the other hand, is of very low resistance, and would have to be arranged thus (in series).

Edison apparently did not return actively to the subject of lighting until the fall of 1878, when, as he prepared for an intensified effort, these last-mentioned papers were assembled with others and copied into the newly-formed Experimental Researches series of notebooks.(12) Interest in carbon was revived, according to Edison, at the same time. This was confirmed by Batchelor, who testified that he coated tissue paper with lamp black and tar and rolled it up into rods and tested for incandescence by heating in a vacuum. Slivers of wood and broom corn were also tried.(13)

According to Batchelor, early in 1879 in a discussion with Edison centering on the need for a high resistance element "he remarked how easy it would be to get this resistance if carbon were only stable."(14) Then the subject was dropped.

The next mention of carbon for a lamp in available documents is in a letter to Edison from an Aaron Solomon in California, postmarked July 25.(15) Solomon wrote that he had assisted a gentleman in England (presumably Joseph Swan) in an exhibition of electric lights with incandescing elements of carbon, platinum, and something said to be better than platinum. Edison's response indicated interest only in platinum, going on to ask if Solomon knew of any sources for it in California.

A brief account of Swan's experiments appeared in an article by J. S. Proctor, as taken from the Newcastle Chemical Society Journal. It began:

> At our meeting in December, 1878, Mr. J. W. Swan exhibited an electric lamp, on the incandescent principle, which had broken down in consequence of the electric force being too great for the cylinder of carbon through which it had to pass. One of the points of interest noted was the appearance of a sooty deposit on the inside of the glass. The flask which contained the carbon pencil and its platinum conductors, having been filled with nitrogen and exhausted with a Sprengel pump, was supposed to convey by chemical means any carbon from the incandescent pencil to the cooler surface in its neighborhood.(16)

The rest of the account was concerned with Proctor's examination of the deposit.

Edison refers to this article in an undated notebook entry which -- from circumstantial evidence -- was probably not made before January, 1880 (see Bibliographical Note). In the meantime, of course, he had himself turned irrevocably back to carbon which, with the help of the high-vacuum Sprengel pump, provided a splendid solution to his problem.

References

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James Dredge, Electric Illumination (London: Engineering, 1882), vol. 1, pp. 572-578.

John W. Howell and Henry Schroeder, History of the Incandescent Lamp (Schenectady: The Maqua Co., 1927), pp. 29-41.

2. National Archives and Records Service, Record Group 491, Interference 8195: Edison vs. Maxim vs. Swan. No. 73, testimony on behalf of Edison, p.196.

3. National Archives and Records Service, Record Group 491, Interference 7768: Sawyer and Mann vs. Edison. No. 35, testimony on behalf of Edison, P.132.

4. Ibid., pp. 134-135.

5. Ibid., pp. 34, 142.

6. Ibid., p. 144.

7. Ibid., pp. 145-146.

8. Ibid., pp. 49, 51, 58.

9. Interference 8195, p. 2.

10. Interference 7768, p. 17.

11. Ibid., p. 136.

12. Ibid., p. 46.

13. Ibid., p. 155.

14. N 79-02-12, p. 5.

15. Aaron Solomon to TAE, July 25, 1879.

16. B.S. Proctor, "The Smoke of an Electric Lamp," Scientific American 41 (July 12, 1879), p.20.

ARTIFACTS

In addition to notebooks, letters, patents, books and other written sources, a large number of objects--both experimental and manufactured--have survived from the period covered by this report. Included are generators from the steamship Columbia and the Pearl Street station, fuses and lighting fixtures from the Hinds, Ketcham plant, underground mains from New York streets, chemical meters, small motors, and light bulbs. Most are preserved at the Edison Institute at Dearborn, the Edison Historic Site at West Orange, and the National Museum of American History in Washington; an undetermined number are scattered through private collections. These, too, are documents from the past, confirming the reality of what has been and suggesting ways of interpretation. They are intriguing documents, not always easily read--in large part because we have not been as clever as we might have been in posing questions to them.

Objects have played a modest but significant role in the preparation of this manuscript. They have provided a touchstone against which we have been able to judge the meaning of documents, enabling us to understand instinctively the context of an abbreviated sketch of armature connections or to sense the frustrations associated with a balky Sprengel pump. Surviving filaments have given a sense both of the fragility of carbonized materials and of their remarkable resiliance. Fuses, switches, and other early components which appear in words and drawings as finished products are revealed in actuality to have been somewhat tentative and jury-rigged.

In recent years some experiments have been performed by John Bowditch with machines preserved at the Henry Ford Museum and Greenfield Village of the Edison Institute. He has observed that inadequacies in the design of bases and brush holders of early generators at Menlo Park which suggest that attention to detail was not uniformly applied. On the other hand, experiments performed on a later dynamo have indicated that performance (in this case voltage output at speeds much lower than specified) can often substantially exceed expectations. Separate work with reproductions of apparatus used at Menlo Park has confirmed the considerable amount of time and effort that went into the fabrication of even a single light bulb—a significant factor in determining the advantage Edison's laboratory gave him over his less well-endowed rivals.

Examination of light bulbs in the Smithsonian's collections (in the National Museum of American History) has shown that developments did not always follow a linear pattern. For instance, if the bulbs are arranged in order of the sequence of bases, anomolies appear in the sequence of filament attachments. This may be evidence that parts were re-used, or it may indicate a breakdown in the normal developmental process. In either case it suggests there might be value in taking a closer look at Edison's laboratory procedures, both for lighting and for other activities.

Resistance measurements made at the Smithsonian on a limited number of light bulbs where filaments have survived intact give substance to what we already know from other sources—that Edison had to tolerate fairly wide variations in his product. This is easily understood in the case of bamboo filaments, which were to be copper-plated and which therefore had broad ends (to dissipate the heat at the junction) and could not be altered in length. Evidence of the measurements indicates that these variations could easily run as high as 20%. Of further interest are indications that even later in the decade, when carbon paste had replaced copper plating and flared ends were no longer needed, wide variations persisted. The nature of this problem has been known, since luminosity measurements were made on individual lamps on the production line until the advent of the drawn tungsten wire lamp in 1911; they were then batched according to different voltage ratings which would give them the proper candle power. The results of our tests would suggest that a closer look at a wider sample from the almost three decades of commercial production prior to 1911 (which, of course, is outside the scope of this study) might prove revealing, since if variations were as great as seem to be indicated there should have been significant impact on research, power station and marketing activities.

It is of utmost importance to realize that although examination of an object may help to answer a question posed by the documentary record, there is at least equal liklihood that answers may be provided to questions which we had not previously known to ask. Or new questions may be raised for which answers have to be found, either from objects or from documents. This simply means that, as with all historical research, the subject matter should be approached with an open and flexible mind. If this is done, we may expect to continue to learn new things about the early history of Edison's incandescent electric light from further probing of the surviving relics.

LIGHT BULBS AND SOCKETS

Bases.

1. Base I. 1879. Smithsonian Institution Catalog 320,504; 181,797; 310,578. Lead wires were folded up along the outside of the neck of the bulb; in some cases copper strips were used instead to provide a larger contact surface. String held the wire or strips in place.

2. Base II. 1880. SI 180,933; 303,843. Early in 1880 (according to Jehl, p. 741) Edison got the notion of a screw base from a kerosene oil can. This first version of the screw base was employed in the public demonstration at the end of that year. It was made of wood and was fastened to the glass bulb with plaster of Paris.

3. Base IIIa. 1881. SI 181,799; 320,735. E. H. Johnson, who was a partner with Edison and Sigmund Bergmann in Bergmann & Co., applied for a patent on this version on May 27, 1881. The screw shell has been reduced in size and the second contact is provided by a beveled ring. This model was made of wood and may not have been available commercially.

4. Base IIIb. 1881. SI 180,934. A light bulb with the Johnson ring and made with plaster of Paris was offered for

sale sometime during the year (Hinds, Ketcham lamps were of this type, for instance). There was a problem with the design, however; if the bulb was screwed in too hard the plaster between the contacts was placed in tension and often broke.

5. Base IV. 1881. SI 318,664. Bergmann, with help from Edison (see Jehl pp. 745-746) designed a base with a slightly larger screw shell and a small cap on the end, which replaced the beveled ring as the second contact. The patent application was made February 25, 1882. He kept the plaster lip around the top so that the bulb could be screwed in without twisting the glass bulb, which might break loose from the base. This base will fit a modern socket.

6. Base V. 1884. SI 318,638. The seal between bulb and base was now strong enough so that the lip could be omitted.

7. Base VI. 1888. SI 318,686. The number of threads on the screw shell was increased. This was made possible by the introduction of moulds in the production of the glass bulbs; the necks of the bulbs were then uniformly long enough to accommodate the lengthened shell.

Filament Attachments.

8. A. Clamp. 1879. SI 181,797; 181,799; 180,931. Platinum clamps were welded to the platinum lead wires. In 1880 the ends of the filament were plated with copper to provide a better contact. Clamps were also made of other materials, including nickel and German silver (The clamp for SI 180,931 is recorded as made of German silver).

9. B. Copper Plating. 1881. SI 318,677 Starting early in the year lamps were manufactured with short copper wires fused to the platinum lead wires. These copper wires were flattened at the end, bent over, and plated to the filaments.

10. C. Carbon Paste. 1886. SI 318,686. A paste, in the first instance made of graphite and India ink, made the process even simpler.

Light Bulbs.

11. I-A. SI 181,797; 310,578; 320,504.

12. II-A. SI 181,798; 180,931.

13. II-B. SI 180,933.

14. IIIa-A. SI 181,799. Use of the more primitive clamp with a later base design suggests that this version—made of wood—was an experimental model.

15. IIIb-C. SI 180,934.

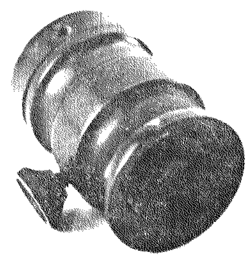
16. IV-A. SI 318,653. An anomoly in the progression, since clamps had long since been abandonned by the time this form of base was being manufactured.

17. IV-B. SI 318,664.

18. V-B. SI 318,638.

19. VI-C. SI 318,686.

1a



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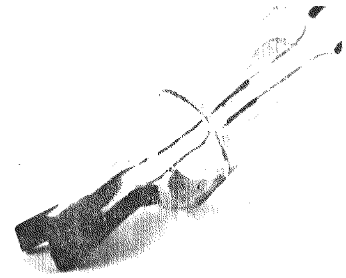

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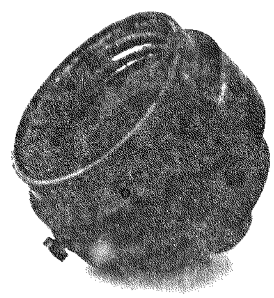

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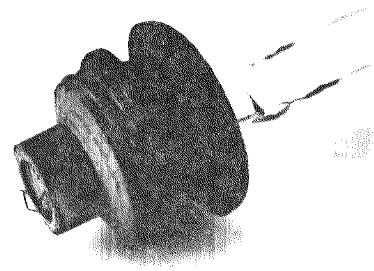

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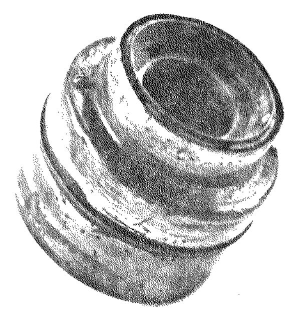

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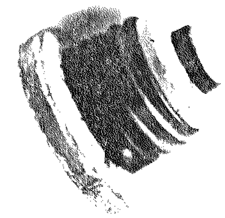

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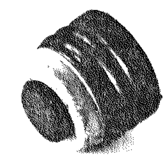

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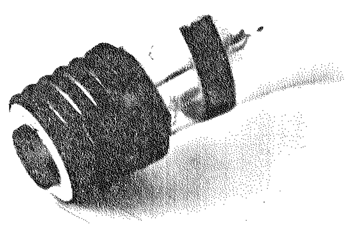

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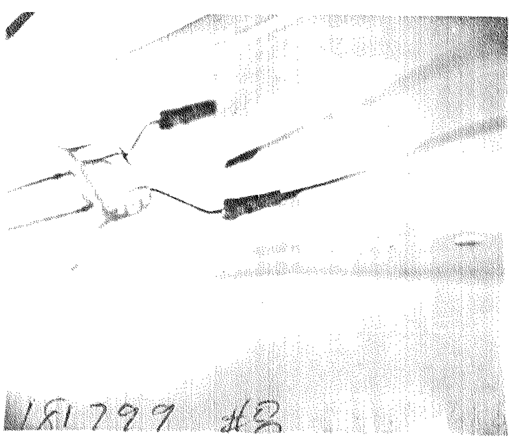

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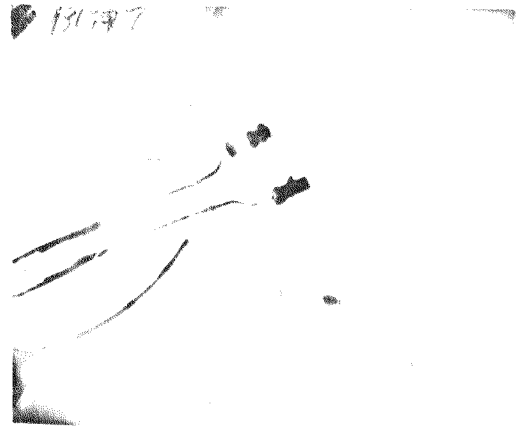

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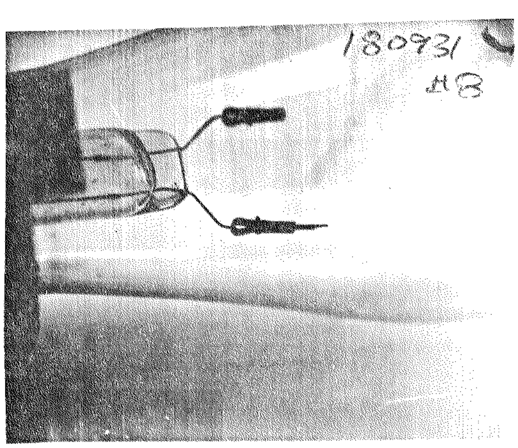

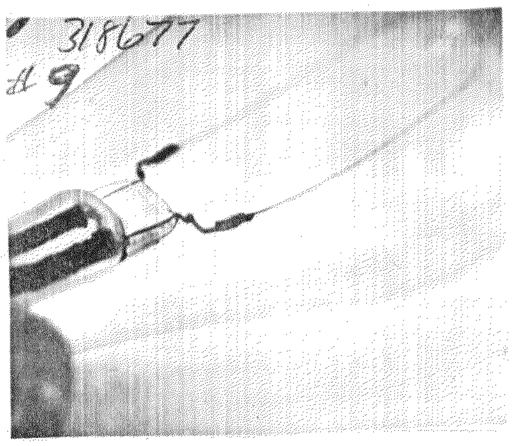

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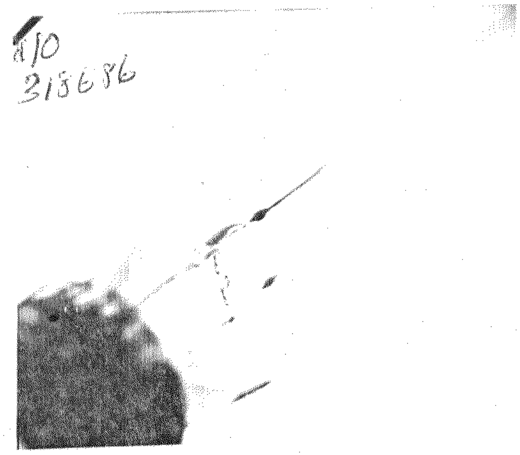

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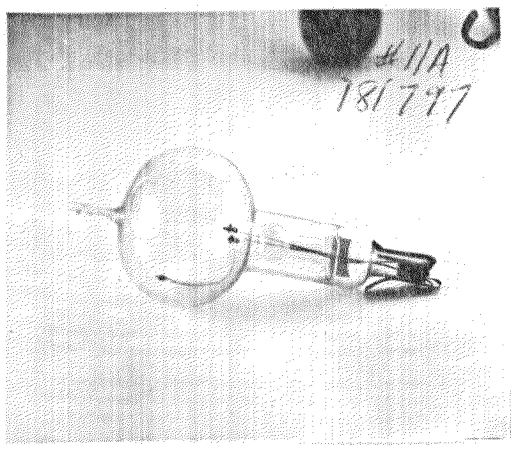

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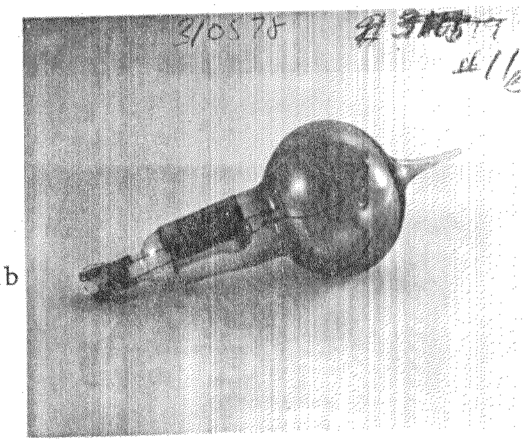

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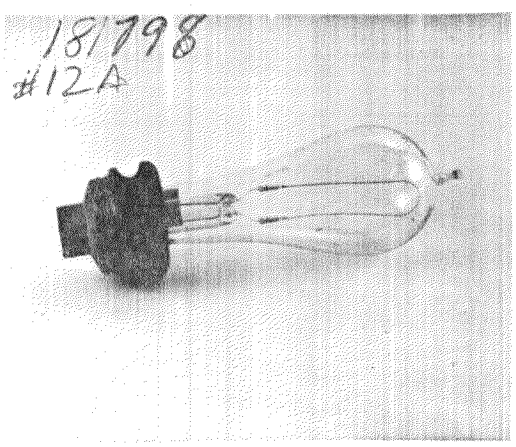

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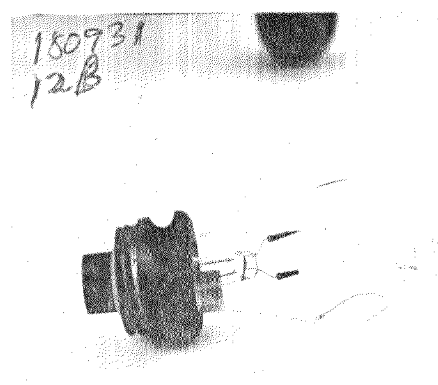

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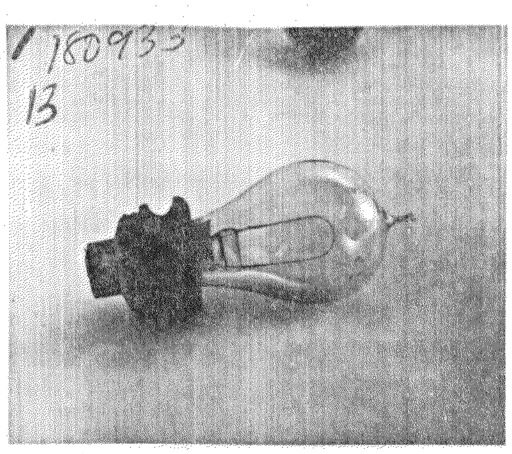

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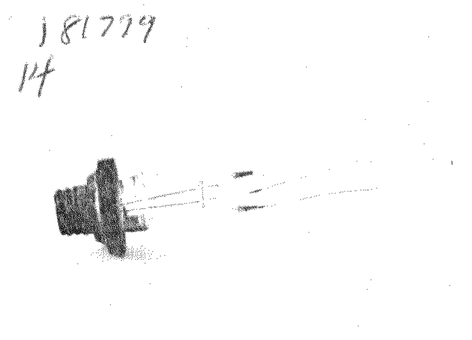

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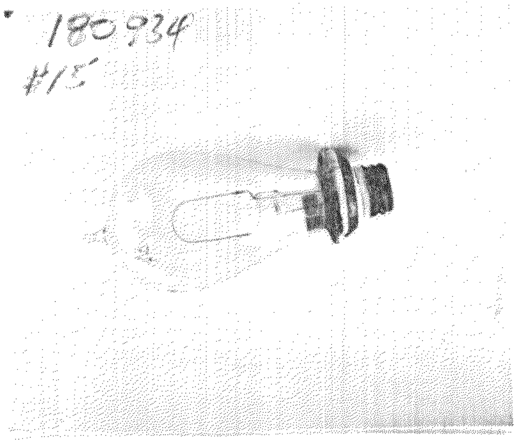

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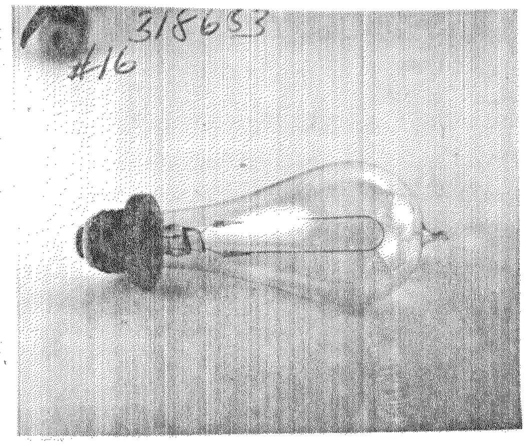

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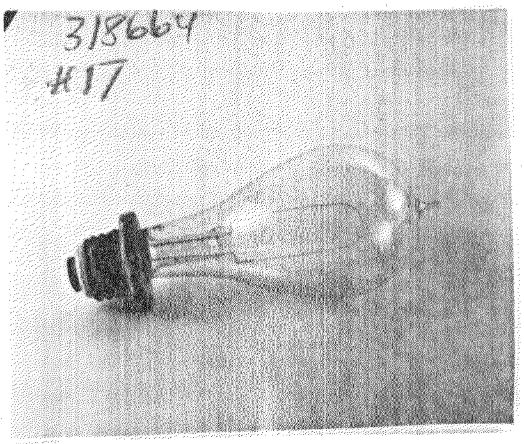

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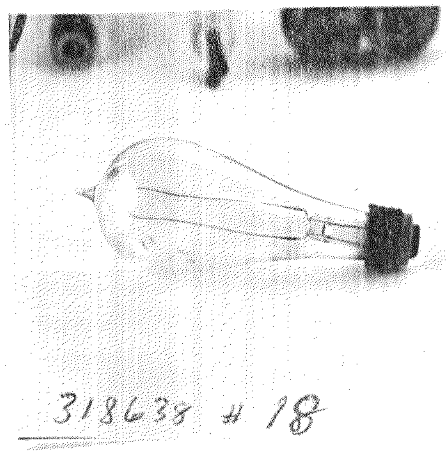

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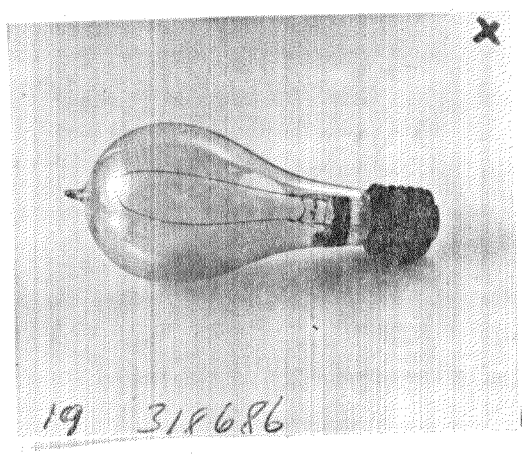

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Borrower	Inst	Date	Returned
Louis Hutchins	NMSC	11/09/2006	