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Papers 19–30
On Science and
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CONTRIBUTIONS FROM THE MUSEUM OF HISTORY AND TECHNOLOGY

SMITHSONIAN INSTITUTION WASHINGTON, D.C. 1963

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FRANK A. TAYLOR
Director, United States National Museum

In acknowledgment of the many contributions of the Burndy Library to the advancement and encouragement of studies of the history of science and technology, these papers are dedicated to

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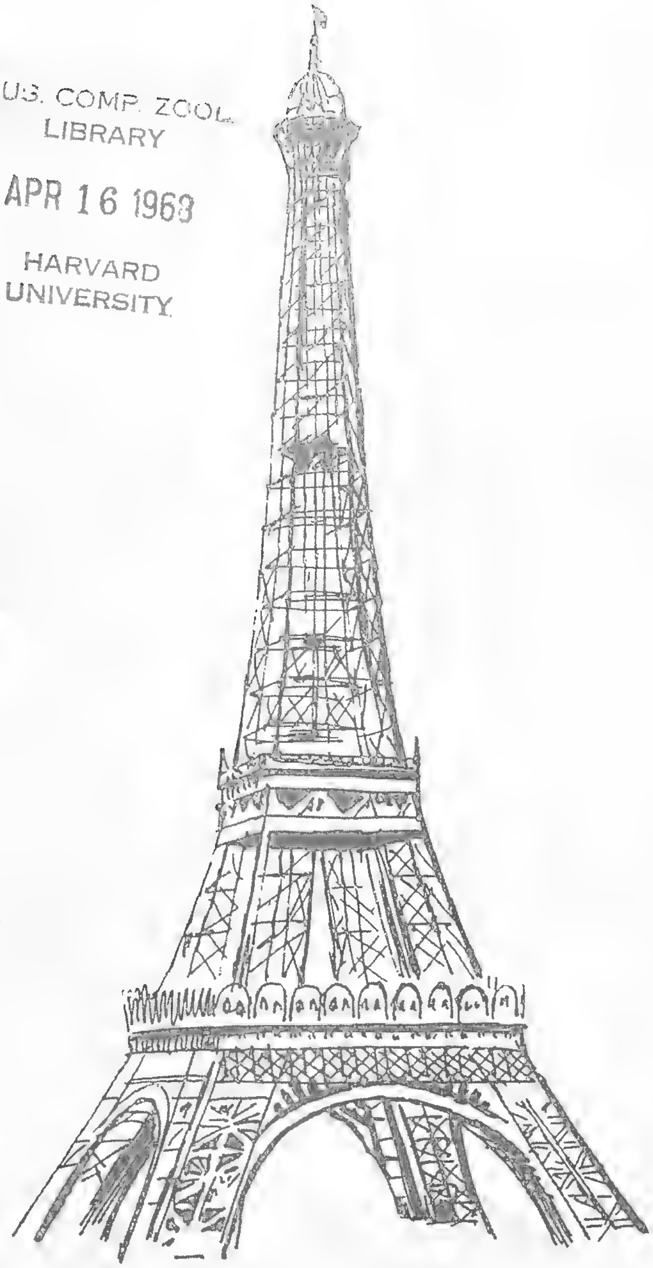
Elevator Systems of the Eiffel Tower 1889



by Robert M. Vogel

Paper 19, pages 1–40, from

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CONTRIBUTIONS FROM
THE MUSEUM OF HISTORY AND TECHNOLOGY:
PAPER 19

ELEVATOR SYSTEMS OF THE EIFFEL TOWER, 1889

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ELEVATOR SYSTEMS of the EIFFEL TOWER, 1889

By Robert M. Vogel

This article traces the evolution of the powered passenger elevator from its initial development in the mid-19th century to the installation of the three separate elevator systems in the Eiffel Tower in 1889. The design of the Tower's elevators involved problems of capacity, length of rise, and safety far greater than any previously encountered in the field; and the equipment that resulted was the first capable of meeting the conditions of vertical transportation found in the just emerging skyscraper.

THE AUTHOR: *Robert M. Vogel is associate curator of mechanical and civil engineering, United States National Museum, Smithsonian Institution.*

THE 1,000-FOOT TOWER that formed the focal point and central feature of the Universal Exposition of 1889 at Paris has become one of the best known of man's works. It was among the most outstanding technological achievements of an age which was itself remarkable for such achievements.

Second to the interest shown in the tower's structural aspects was the interest in its mechanical organs. Of these, the most exceptional were the three separate elevator systems by which the upper levels were made accessible to the Exposition visitors. The design of these systems involved problems far greater than had been encountered in previous elevator work anywhere in the world. The basis of these difficulties was the amplification of the two conditions that were the normal determinants in elevator design—passenger capacity and height of rise. In addition, there was the problem, totally new, of fitting elevator shafts to the curvature of the Tower's legs. The study of the various solutions to these problems presents a concise view of the capabilities of the elevator art just prior to the beginning of the most recent phase of its development, marked by the entry of electricity into the field.

The great confidence of the Tower's builder in his own engineering ability can be fully appreciated, however, only when notice is taken of one exceptional way in which the project differed from works of earlier periods as well as from contemporary ones. In almost every case, these other works had evolved, in a natural and progressive way, from a fundamental concept firmly based upon precedent. This was true of such notable structures of the time as the Brooklyn Bridge and, to a lesser extent, the Forth Bridge. For the design of his tower, there was virtually no experience in structural history from which Eiffel could draw other than a series of high piers that his own firm had designed earlier for railway bridges. It was these designs that led Eiffel to consider the practicality of iron structures of extreme height.

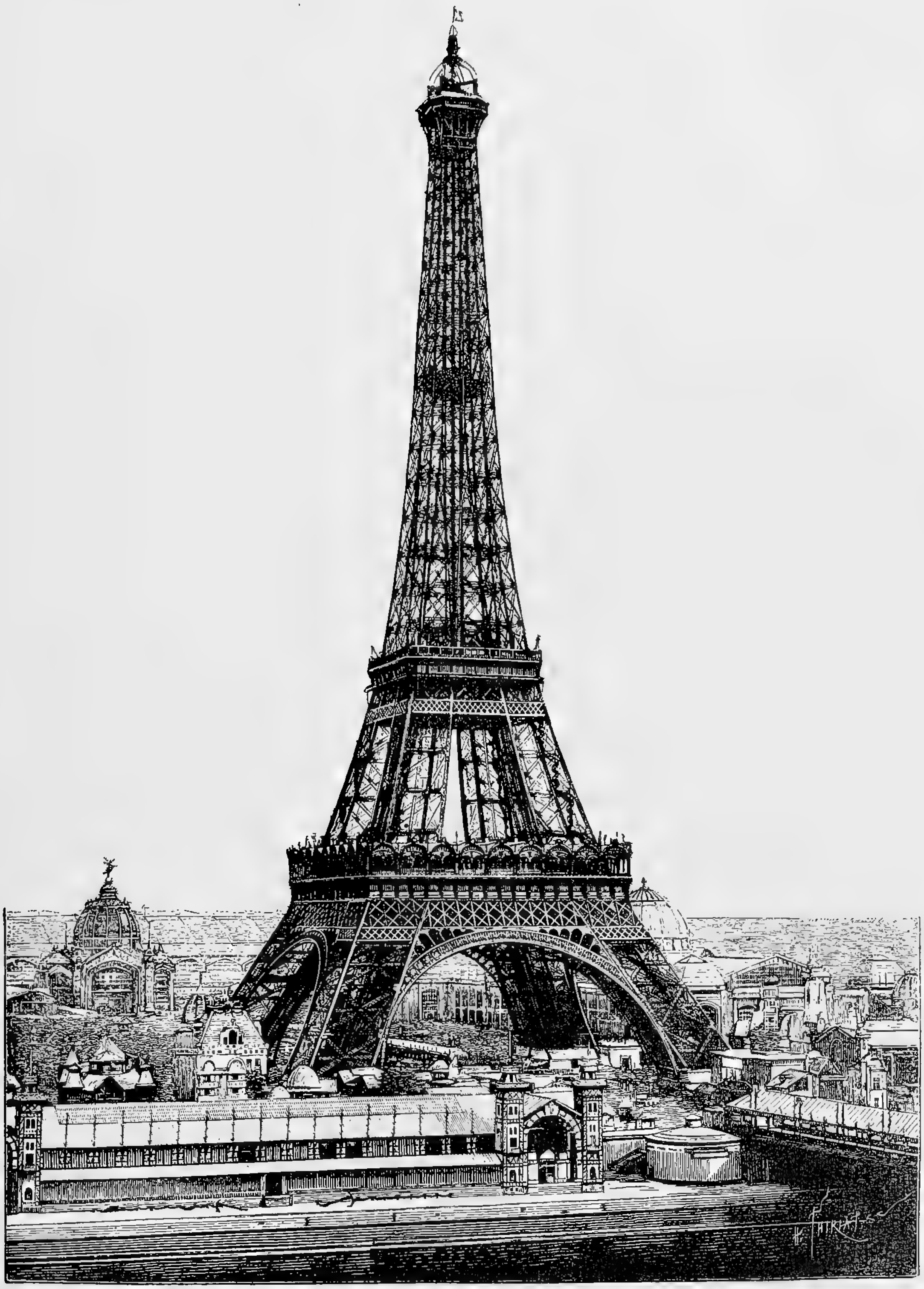

Figure 1.—The Eiffel Tower at the time of the Universal Exposition of 1889 at Paris. (From *La Nature*, June 29, 1889, vol. 17, p. 73.)

G Eiffel

Figure 2.—Gustave Eiffel (1832–1923). (From Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, frontispiece.)

There was, it is true, some inspiration to be found in the paper projects of several earlier designers—themselves inspired by that compulsion which throughout history seems to have driven men to attempt the erection of magnificently high structures.

One such inspiration was a proposal made in 1832 by the celebrated but eccentric Welsh engineer Richard Trevithick to erect a 1,000-foot, conical, cast-iron tower (fig. 3) to celebrate the passing of the Reform Bill. Of particular interest in light of the present discussion was Trevithick's plan to raise visitors to the summit on a piston, driven upward within the structure's hollow central tube by compressed air. It probably is fortunate for Trevithick's reputation that his plan died shortly after this and the project was forgotten.

One project of genuine promise was a tower proposed by the eminent American engineering firm of Clarke, Reeves & Company to be erected at the Centennial Exhibition at Philadelphia in 1876. At the time, this firm was perhaps the leading designer and erector of iron structures in the United States, having executed such works as the Girard Avenue Bridge over the Schuylkill at Fairmount Park, and most of New York's early elevated railway system. The company's proposal (fig. 4) for a 1,000-foot shaft of wrought-iron columns braced by a continuous web of diagonals was based upon sound theoretical knowledge and practical experience. Nevertheless, the natural hesitation that the fair's sponsors apparently felt in the face of so heroic a scheme could not be overcome, and this project also remained a vision.

Preparatory Work for the Tower

In the year 1885, the Eiffel firm, which also had an extensive background of experience in structural engineering, undertook a series of investigations of tall metallic piers based upon its recent experiences with several lofty railway viaducts and bridges. The most spectacular of these was the famous Garabit Viaduct (1880–1884), which carries a railroad some 400 feet above the valley of the Truyere in southern France. While the 200-foot height of the viaduct's two greatest piers was not startling even at that period, the studies proved that piers of far greater height were entirely feasible in iron construction. This led to the design of a 395-foot pier, which, although never incorporated into a bridge, may be said to have been the direct basis for the Eiffel Tower.

Preliminary studies for a 300-meter tower were made with the 1889 fair immediately in mind. With an assurance born of positive knowledge, Eiffel in June of 1886 approached the Exposition commissioners with the project. There can be no doubt that only the singular respect with which Eiffel was regarded not only by his profession but by the entire nation motivated the Commission to approve a plan which, in the hands of a figure of less stature, would have been considered grossly impractical.

Between this time and commencement of the Tower's construction at the end of January 1887, there arose one of the most persistently annoying of the numerous difficulties, both structural and social, which confronted Eiffel as the project advanced. In the wake of the initial enthusiasm—on the part of the fair's Commission inspired by the desire to create a monument to French technological achievement, and on the part of the majority of Frenchmen by the stirring of their imagination at the magnitude of the structure—there grew a rising movement of disfavor. The nucleus was, not surprisingly, formed mainly of the intelligentsia, but objections were made by prominent Frenchmen in all walks of life. The most interesting point to be noted in a retrospection of this often violent opposition was that, although the Tower's every aspect was attacked, there was remarkably little criticism of its structural feasibility, either by the engineering profession or, as seems traditionally to be the case with bold and unprecedented undertakings, by large numbers of the technically uninformed laity. True, there was an undercurrent of what might be characterized as unease by many property owners in the structure's shadow, but the most obstinate element of resistance was that which deplored the Tower as a mechanistic intrusion upon the architectural and natural beauties of Paris. This resistance voiced its fury in a flood of special newspaper editions, petitions, and manifestos signed by such lights of the fine and literary arts as De Maupassant, Gounod, Dumas *fils*, and others. The eloquence of one article, which appeared in several Paris papers in February 1887, was typical:

> We protest in the name of French taste and the national art culture against the erection of a staggering Tower, like a gigantic kitchen chimney dominating Paris, eclipsing by its barbarous mass Notre Dame, the Sainte-Chapelle, the tower of St. Jacques, the Dôme des Invalides, the Arc de Triomphe, humiliating these monuments by an act of madness.[1]

Further, a prediction was made that the entire city would become dishonored by the odious shadow of the odious column of bolted sheet iron.

It is impossible to determine what influence these outcries might have had on the project had they been organized sooner. But inasmuch as the Commission had, in November 1886, provided 1,500,000 francs for its commencement, the work had been fairly launched by the time the protestations became loud enough to threaten and they were ineffectual.

Upon completion, many of the most vigorous protestants became as vigorous in their praise of the Tower, but a hard core of critics continued for several years to circulate petitions advocating its demolition by the government. One of these critics, it was said—probably apocryphally—took an office on the first platform, that being the only place in Paris from which the Tower could not be seen.

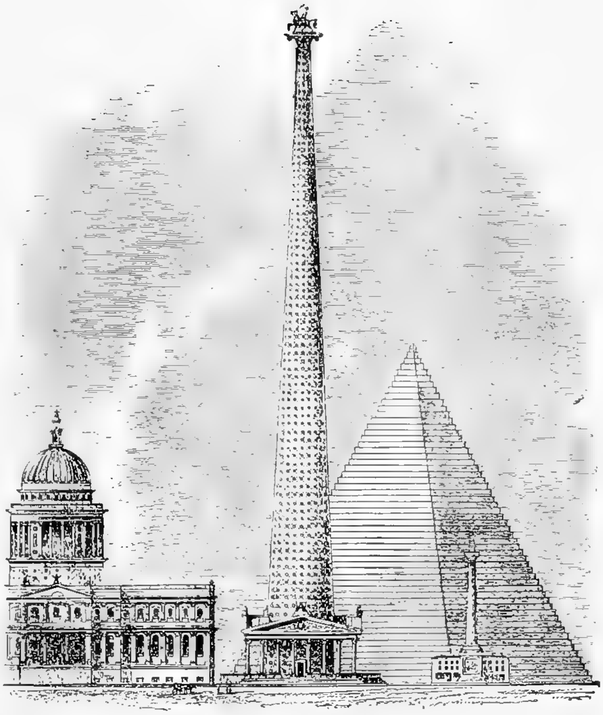

Figure 3.—Trevethick's proposed cast-iron tower (1832) would have been 1,000 feet high, 100 feet in diameter at the base, 12 feet at the top, and surmounted by a colossal statue. (From F. Dye, *Popular Engineering*, London, 1895, p. 205.)

The Tower's Structural Rationale

During the previously mentioned studies of high piers undertaken by the Eiffel firm, it was established that as the base width of these piers increased in proportion to their height, the diagonal bracing connecting the vertical members, necessary for rigidity, became so long as to be subject to high flexural stresses from wind and columnar loading. To resist these stresses, the bracing required extremely large sections which greatly increased the surface of the structure exposed to the wind, and was, moreover, decidedly uneconomical. To overcome this difficulty, the principle which became the basic design concept of the Tower was developed.

The material which would otherwise have been used for the continuous lattice of diagonal bracing was concentrated in the four corner columns of the Tower, and these verticals were connected only at

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[1] Translated from Jean A. Keim, *La Tour Eiffel*, Paris, 1950.

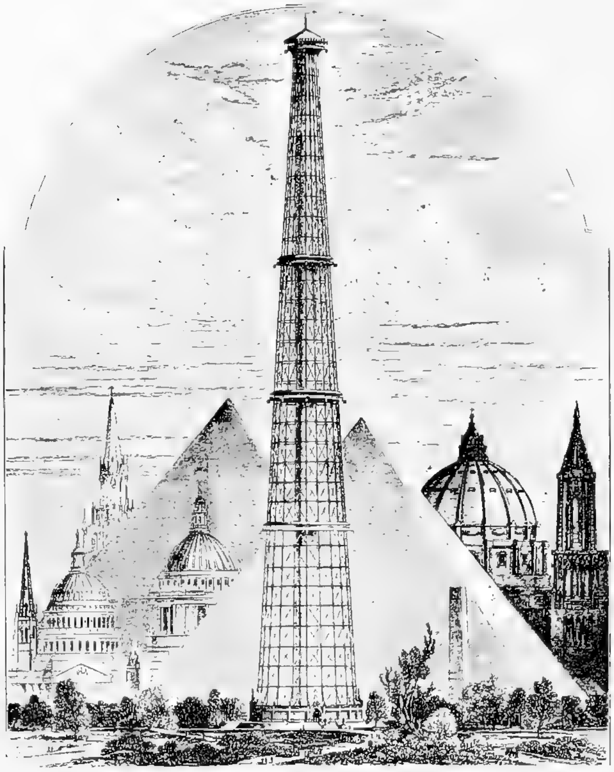

Figure 4.—The proposed 1,000-foot iron tower designed by Clarke, Reeves & Co. for the Centennial Exhibition of 1876 at Philadelphia. (From *Scientific American*, Jan. 24, 1874, vol. 30, p. 47.)

two widely separated points by the deep bands of trussing which formed the first and second platforms. A slight curvature inward was given to the main piers to further widen the base and increase the stability of the structure. At a point slightly above the second platform, the four members converged to the extent that conventional bracing became more economical, and they were joined.

That this theory was successful not only practically, but visually, is evident from the resulting work. The curve of the legs and the openings beneath the two lower platforms are primarily responsible for the Tower's graceful beauty as well as for its structural soundness.

The design of the Tower was not actually the work of Eiffel himself but of two of his chief engineers, Emile Nouguier (1840–?) and Maurice Kœchlin (1856–1946)—the men who had conducted the high pier studies—and the architect Stéphen Sauvestre (1847–?).

In the planning of the foundations, extreme care was used to ensure adequate footing, but in spite of the Tower's light weight in proportion to its bulk, and the low earth pressure it exerted, uneven pier settlement with resultant leaning of the Tower was considered a dangerous possibility.[2] To compensate for this eventuality, a device was used whose ingenious directness justifies a brief description. In the base of each of the 16 columns forming the four main legs was incorporated an opening into which an 800-ton hydraulic press could be placed, capable of raising the member slightly. A thin steel shim could then be inserted to make the necessary correction (fig. 5). The system was used only during construction to overcome minor erection discrepancies.

In order to appreciate fully the problem which confronted the Tower's designers and sponsors when they turned to the problem of making its observation areas accessible to the fair's visitors, it is first necessary to investigate briefly the contemporary state of elevator art.

Elevator Development before the Tower

While power-driven hoists and elevators in many forms had been used since the early years of the 19th century, the ever-present possibility of breakage of the hoisting rope restricted their use almost entirely to the handling of goods in mills and warehouses.[3] Not until the invention of a device which would positively prevent this was there much basis for work on other elements of the system. The first workable mechanism to prevent the car from dropping to the bottom of the hoistway in event of rope failure was the product of Elisha G. Otis (1811–1861), a mechanic of Yonkers, New York. The invention was made more or less as a matter of course along with the other machinery for a new mattress factory of which Otis was master mechanic.

The importance of this invention soon became evident to Otis, and he introduced his device to the

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[2] The foundation footings exerted a pressure on the earth of about 200 pounds per square foot, roughly one-sixth that of the Washington Monument, then the highest structure in the world.

[3] A type of elevator known as the "teagle" was in use in some multistory English factories by about 1835. From its description, this elevator appears to have been primarily for the use of passengers, but it unquestionably carried freight as well. The machine shown in figure 7 had, with the exception of a car safety, all the features of later systems driven from line shafting—counterweight, control from the car, and reversal by straight and crossed belts.

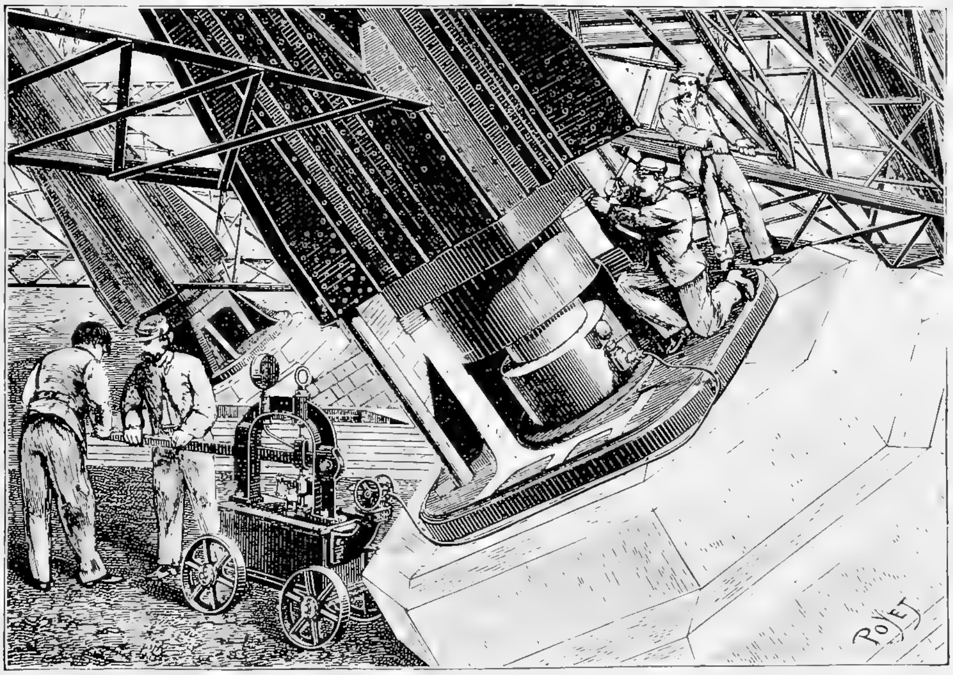

Figure 5.—Correcting erection discrepancies by raising pier member—with hydraulic press and hand pump—and inserting shims. (From *La Nature*, Feb. 18, 1888, vol. 16, p. 184.)

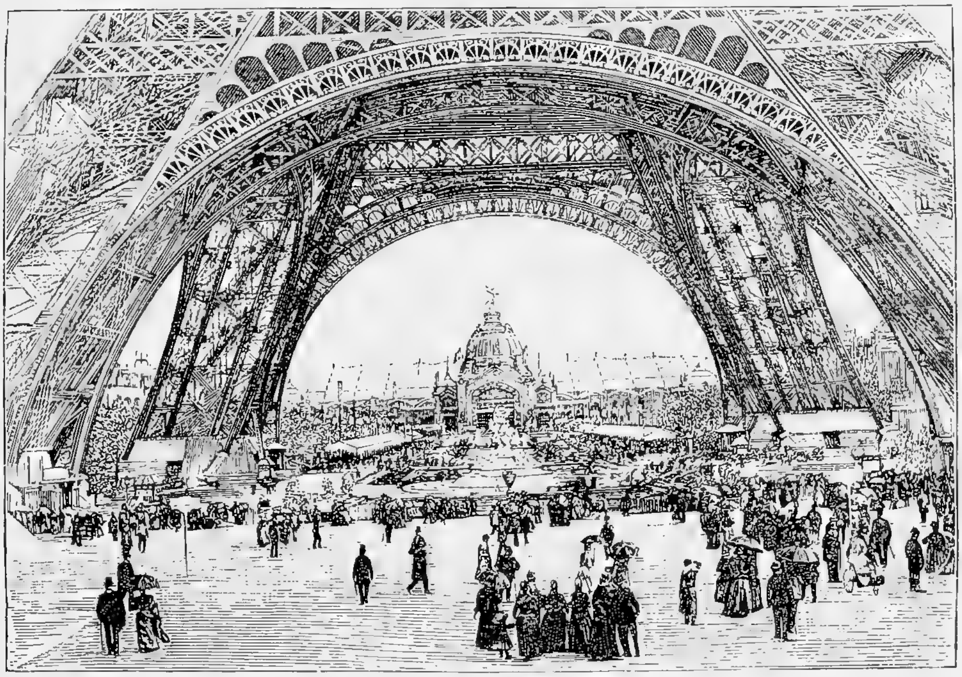

Figure 6.—The promenade beneath the Eiffel Tower, 1889. (From *La Nature*, Nov. 30, 1889, vol. 17, p. 425.)

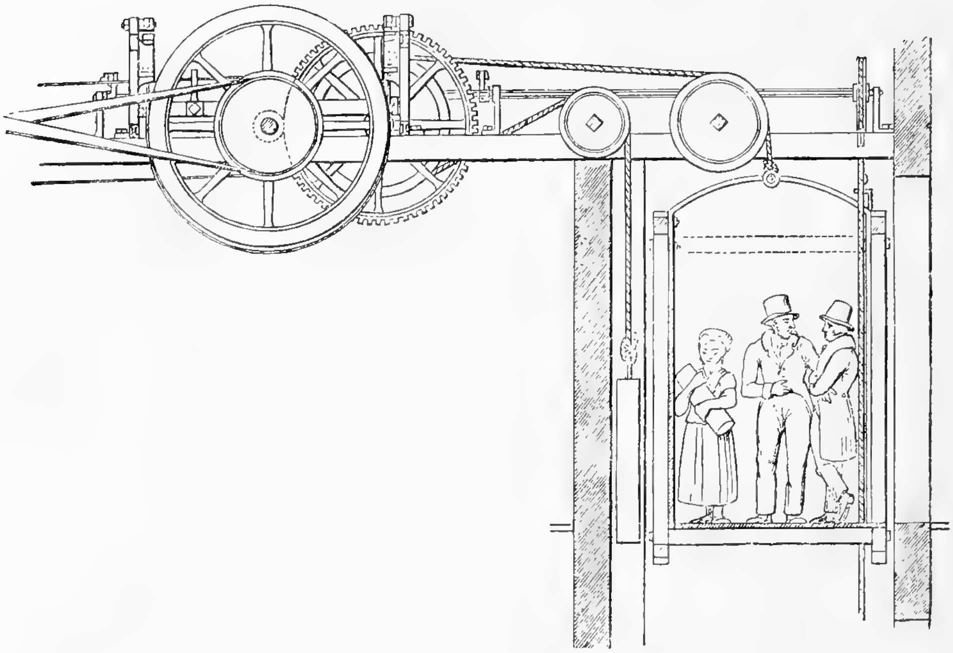

Figure 7.—Teagle elevator in an English mill about 1845. Power was taken from the line shafting. (From *Pictorial Gallery of Arts*, Volume of Useful Arts, London, n.d. [ca. 1845].)

public three years later during the second season of the New York Crystal Palace Exhibition, in 1854. Here he would demonstrate dramatically the perfect safety of his elevator by cutting the hoisting rope of a suspended platform on which he himself stood, uttering the immortal words which have come to be inseparably associated with the history of the elevator—"All safe, gentlemen!"[4]

The invention achieved popularity slowly, but did find increasing favor in manufactories throughout the eastern United States. The significance of Otis' early work in this field lay strictly in the safety features of his elevators rather than in the hoisting equipment. His earliest systems were operated by machinery similar to that of the teagle elevator in which the hoisting drum was driven from the mill shafting by simple fast and loose pulleys with crossed and straight belts to raise, lower, and stop. This scheme, already common at the time, was itself a direct improvement on the ancient hand-powered drum hoist.

The first complete elevator machine in the United States, constructed in 1855, was a complex and inefficient contrivance built around an oscillating-cylinder steam engine. The advantages of an elevator system independent of the mill drive quickly became apparent, and by 1860 improved steam elevator machines were being produced in some quantity, but almost exclusively for freight service. It is not clear when the first elevator was installed explicitly for passenger service, but it was probably in 1857, when Otis placed one in a store on Broadway at Broome Street in New York.

In the decade following the Civil War, tall buildings had just begun to emerge; and, although the skylines of the world's great cities were still dominated by church spires, there was increasing activity in the development of elevator apparatus adapted to the transportation of people as well as of merchandise. Operators of hotels and stores gradually became aware of the commercial advantages to be gained by elevating their patrons even one or two floors above the ground, by machinery. The steam engine formed the foundation of the early elevator industry, but as building heights increased it was gradually replaced by hydraulic, and ultimately by electrical, systems.

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[4] The Otis safety, of which a modified form is still used, consisted essentially of a leaf wagon spring, on the car frame, kept strained by the tension of the hoisting cables. If these gave way, the spring, released, drove dogs into continuous racks on the vertical guides, holding the car or platform in place.

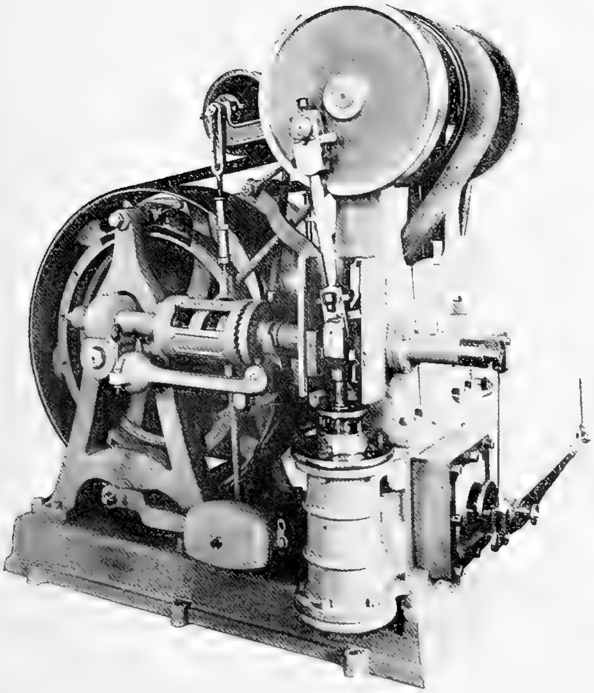

Figure 8.—In the typical steam elevator machine two vertical cylinders were situated either above or below the crankshaft, and a small pulley was keyed to the crankshaft. In a light-duty machine, the power was transmitted by flatbelt from the small pulley to a larger one mounted directly on the drum. In heavy-duty machines, spur gearing was interposed between the large secondary pulley and the winding drum. (Photo courtesy of Otis Elevator Company.)

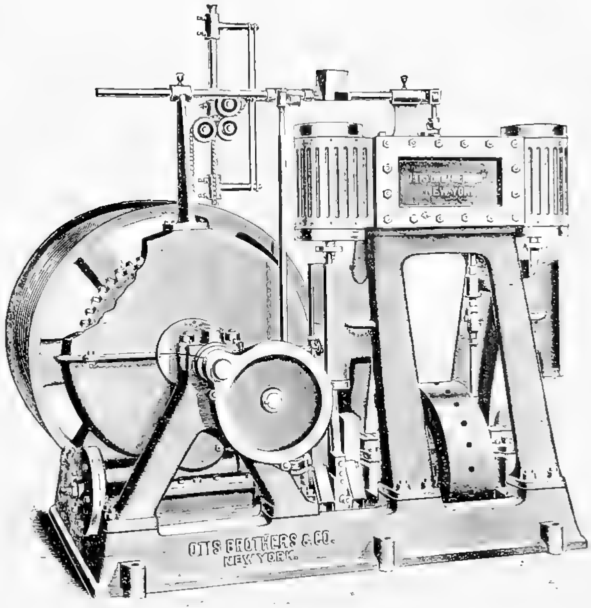

Figure 9.—Several manufacturers built steam machines in which a gear on the drum shaft meshed directly with a worm on the crankshaft. This arrangement eliminated the belt, and, since the drum could not drive the engine through the worm gearing, no brake was necessary for holding the load. (Courtesy of Otis Elevator Company.)

THE STEAM ELEVATOR

The progression from an elevator machine powered by the line shafting of a mill to one in which the power source was independent would appear a simple and direct one. Nevertheless, it was about 40 years after the introduction of the powered elevator before it became common to couple elevator machines directly to separate engines. The multiple belt and pulley transmission system was at first retained, but it soon became evident that a more satisfactory service resulted from stopping and reversing the engine itself, using a single fixed belt to connect the engine and winding mechanism. Interestingly, the same pattern was followed 40 years later when the first attempts were made to apply the electric motor to elevator drive.

By 1870 the steam elevator machine had attained its ultimate form, which, except for a number of minor refinements, was to remain unchanged until the type became completely obsolete toward the end of the century.

By the last quarter of the century, a continuous series of improvements in the valving, control systems, and safety features of the steam machine had made possible an elevator able to compete with the subsequently appearing hydraulic systems for freight and low-rise passenger service insofar as smoothness, control, and lifting power were concerned. However, steam machinery began to fail in this competition as the increasing height of buildings rapidly extended the demands of speed and length of rise.

The limitation in rise constituted the most serious shortcoming of the steam elevator (figs. 8–10), an inherent defect that did not exist in the various hydraulic systems.

Since the only practical way in which the power of a steam engine could be applied to the haulage of elevator cables was through a rotational system, the

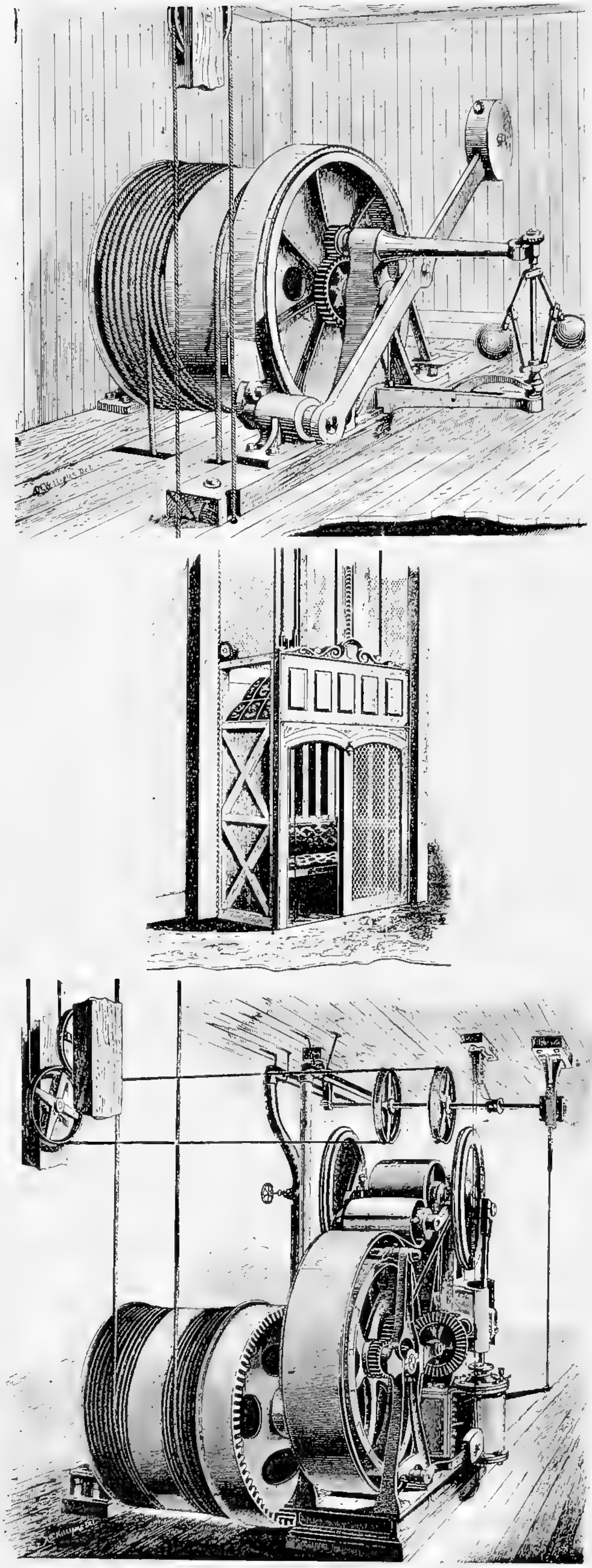

Figure 10.—Components of the steam passenger elevator at the time of its peak development and use (1876). (From *The First One Hundred Years*, Otis Elevator Company, 1953.)

cables invariably were wound on a drum. The travel or rise of the car was therefore limited by the cable capacity of the winding drum. As building heights increased, drums became necessarily longer and larger until they grew so cumbersome as to impose a serious limitation upon further upward growth. A drum machine rarely could be used for a lift of more than 150 feet.[5]

Another organic difficulty existing in drum machines was the dangerous possibility of the car—or the counterweight, whose cables often wound on the drum—being drawn past the normal top limit and into the upper supporting works. Only safety stops could prevent such an occurrence if the operator failed to stop the car at the top or bottom of the shaft, and even these were not always effective. Hydraulic machines were not susceptible to this danger, the piston or plunger being arrested by the ends of the cylinder at the extremes of travel.

THE HYDRAULIC ELEVATOR

The rope-geared hydraulic elevator, which was eventually to become known as the "standard of the industry," is generally thought to have evolved directly from an invention of the English engineer Sir William Armstrong (1810–1900) of ordnance fame. In 1846 he developed a water-powered crane, utilizing the hydraulic head available from a reservoir on a hill 200 feet above.

The system was not basically different from the simple hydraulic press so well known at the time. Water, admitted to a horizontal cylinder, displaced a piston and rod to which a sheave was attached. Around the sheave passed a loop of chain, one end of which was fixed, the other running over guide sheaves and terminating at the crane arm with a lifting hook. As the piston was pressed into the cylinder, the free end of the chain was drawn up at triple the piston speed, raising the load. The effect was simply that

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[5] A notable exception was the elevator in the Washington Monument. Installed in 1880 for raising materials during the structure's final period of erection and afterwards converted to passenger service, it was for many years the highest-rise elevator in the world (about 500 feet), and was certainly among the slowest, having a speed of 50 feet per minute.

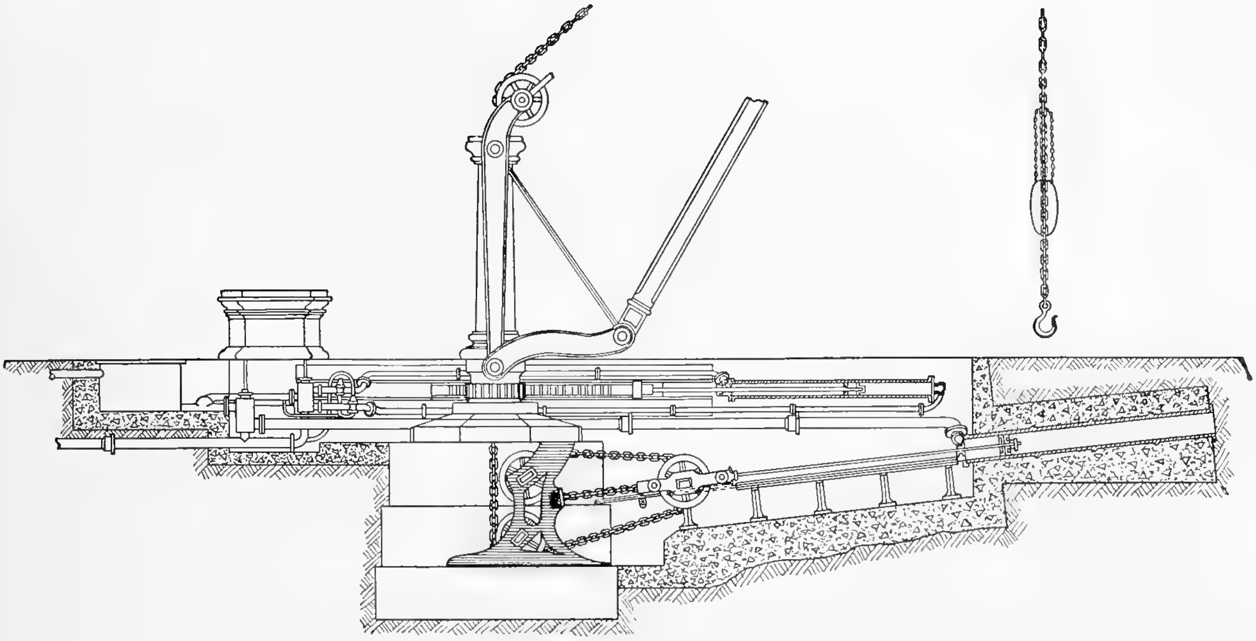


Figure 11.—Armstrong's hydraulic crane. The main cylinder was inclined, permitting gravity to assist in overhauling the hook. The small cylinder rotated the crane. (From John H. Jallings, *Elevators*, Chicago, 1916, p. 82.)

of a 3-to-1 tackle, with the effort and load elements reversed. Simple valves controlled admission and exhaust of the water. (See fig. 11.)

The success of this system initiated a sizable industry in England, and the hydraulic crane, with many modifications, was in common use there for many years. Such cranes were introduced in the United States in about 1867 but never became popular; they did, however, have a profound influence on the elevator art, forming the basis of the third generic type to achieve widespread use in this country.

The ease of translation from the Armstrong crane to an elevator system could hardly have been more evident, only two alterations of consequence being necessary in the passage. A guided platform or car was substituted for the hook; and the control valves were connected to a stationary endless rope that was accessible to an operator on the car.

The rope-geared hydraulic system (fig. 13) appeared in mature form in about 1876. However, before it had become the "standard elevator" through a process of refinement, another system was introduced which merits notice if for no other reason than that its popularity for some years seems remarkable in view of its preposterously unsafe design. Patented by Cyrus W. Baldwin of Boston in January 1870, this system was termed the Hydro-Atmospheric Elevator, but more commonly known as the water-balance elevator (fig. 12). It employed water not under pressure but simply as mass under the influence of gravity. The elevator car's supporting cables ran over sheaves at the top of the shaft to a large iron bucket, which traveled in a closed tube or well adjacent to and the same length as the shaft. To raise the car, the operator caused a valve to open, filling the bucket with water from a roof tank. When the weight of water was sufficient to overbalance the loaded car, the bucket descended, raising the car. On its ascent the car was stopped at intermediate floors by a strong brake that gripped the guides. Upon reaching the top, the operator was able to open a valve in the bucket, now at the bottom of its travel, and discharge its contents into a basement tank, to be pumped back to the roof. No longer counterbalanced, the car could descend, its speed controlled solely by the brake.

The great popularity of this novel system apparently was due to its smooth operation, high speed, simplicity, and economy of operation. Managed by a skillful

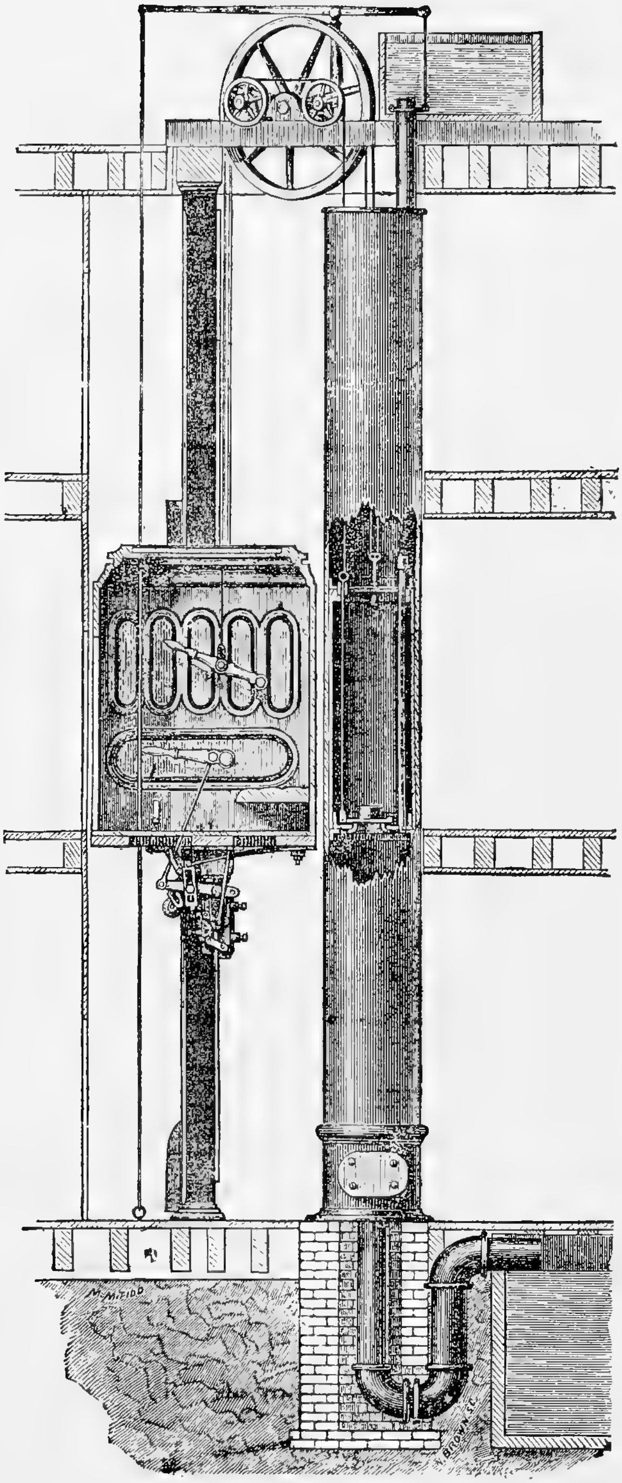


Figure 12.—Final development of the Baldwin-Hale water balance elevator, 1873. The brake, kept applied by powerful springs, was released only by steady pressure on a lever. There were two additional controls—the continuous rope that opened the cistern valve to fill the bucket, and a second lever to open the valve of the bucket to empty it. (From *United States Railroad and Mining Register*, Apr. 12, 1873, vol. 17, p. 3.)

operator, it was capable of speeds far greater than other systems could then achieve—up to a frightening 1,800 feet per minute.[6]

In addition to the element of potential danger from careless operation or failure of the brake, the Baldwin system was extremely expensive to install as a result of the second shaft, which of course was required to be more or less watertight.

Much of the water-balance elevator's development and refinement was done by William E. Hale of Chicago, who also made most of the installations. The system has, therefore, come to bear his name more commonly than Baldwin's.

The popularity of the water-balance system waned after only a few years, being eclipsed by more rational systems. Hale eventually abandoned it and became the western agent for Otis—by this time prominent in the field—and subsequently was influential in development of the hydraulic elevator.

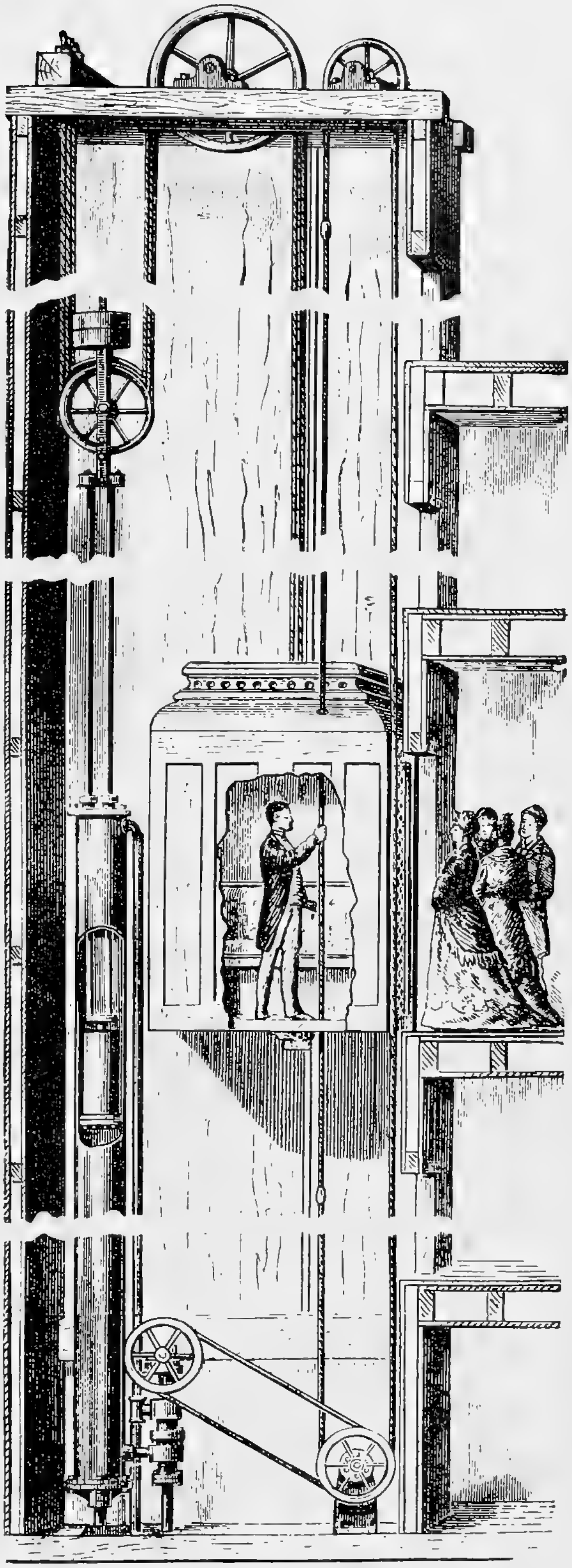
The rope-geared system of hydraulic elevator operation was so basically simple that by 1880 it had been embraced by virtually all manufacturers. However, for years most builders continued to maintain a line of steam and belt driven machines for freight service. Inspired by the rapid increase of taller and taller buildings, there was a concentrated effort, heightened by severe competition, to refine the basic system.

By the late 1880's a vast number of improvements in detail had appeared, and this form of elevator was considered to be almost without defect. It was safe. Absence of a drum enabled the car to be carried by a number of cables rather than by one or two, and rendered overtravel impossible. It was fast. Control devices had received probably the most attention by engineers and were as perfect and sensitive as was

---

[6] Today, although not limited by the machinery, speeds are set at a maximum of about 1,400 feet per minute. If higher speeds were used, an impractically long express run would be necessary for starting and stopping in order to prevent an acceleration so rapid as to be uncomfortable to passengers and a strain on the equipment.

Figure 13.—Vertical cylinder, rope-geared hydraulic elevator with 2:1 gear ratio and rope control (about 1880). For higher rises and speeds, ratios of up to 10:1 were used, and the endless rope was replaced by a lever. (Courtesy of Otis Elevator Company.)



possible with mechanical means. Cars with lever control could be run at the high speeds required for high buildings, yet they could be stopped with a smoothness and precision unattainable earlier with systems in which the valves were controlled by an endless rope, worked by the operator. It was almost completely silent, and when the cylinder was placed vertically in a well near the shaft, practically no valuable floor space was occupied. But most important, the length of rise was unlimited because no drum was used. As greater rises were required, the multiplication of the ropes and sheaves was simply increased, raising the piston-car travel ratio and permitting the cylinder to remain of manageable length. The ratio was often as high as 10 or 12 to 1, the car moving 10 or 12 feet to the piston's 1.

In addition to its principal advantages, the hydraulic elevator could be operated directly from municipal water mains in the many cities where there was sufficient pressure, thus eliminating a large investment in tanks, pumps and boilers (fig. 14).

By far the greatest development in this specialized branch of mechanical engineering occurred in the United States. The comparative position of American practice, which will be demonstrated farther on, is indicated by the fact that Otis Brothers and other large elevator concerns in the United States were able to establish offices in many of the major cities of Europe and compete very successfully with local firms in spite of the higher costs due to shipment. This also demonstrates the extent of error in the oft-heard statement that the skyscraper was the direct result of the elevator's invention. There is no question that continued elevator improvement was an essential factor in the rapid increase of building heights. However, consideration of the situation in European cities, where buildings of over 10 stories were (and still are) rare in spite of the availability of similar elevator techniques, points to the fundamental matter of tradition. The European city simply did not develop with the lack of judicial restraint which characterized metropolitan growth in the United States. The American tendency to confine mercantile activity to the smallest possible area resulted in excessive land values, which drove buildings skyward.

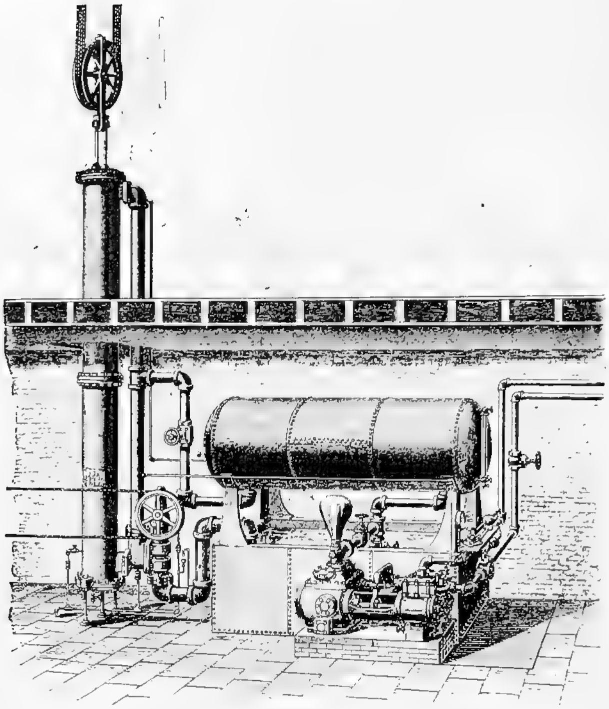


Figure 14.—In the various hydraulic systems, a pump was required if pressure from water mains was insufficient to operate the elevator directly. There was either a gravity tank on the roof or a pressure tank in the basement. (From Thomas E. Brown, Jr., "The American Passenger Elevator," *Engineering Magazine* (New York), June 1893, vol. 5, p. 340.)

The elevator followed, or, at most, kept pace with, the development of higher buildings.

European elevator development—notwithstanding the number of American rope-geared hydraulic machines sold in Europe in the 10 years or so preceding the Paris fair of 1889—was confined mainly to variations on the direct plunger type, which was first used in English factories in the 1830's. The plunger elevator (fig. 16), an even closer derivative of the hydraulic press then Armstrong's crane, was nothing more than a platform on the upper end of a vertical plunger that rose from a cylinder as water was forced in.

There were two reasons for this European practice. The first and most apparent was the rarity of tall buildings. The drilling of a well to receive the cylinder was thus a matter of little difficulty. This well had to be equivalent in depth to the elevator rise. The second reason was an innate European distrust of cable-hung elevator systems in any form, an attitude that will be discussed more fully farther on.

At the time the Eiffel Tower elevators were under consideration, water under pressure was, from a practical standpoint, the only agent capable of fulfilling the power and control requirements of this particularly severe service. Steam, as previously mentioned, had already been found wanting in several respects. Electricity, on the other hand, seemed to hold promise for almost every field of human endeavor. By 1888 the electric motor had behind it a 10- or 15-year history of active development. Frank J. Sprague had already placed in successful operation a sizable electric trolley-car system, and was manufacturing motors of up to 20 horsepower in commercial quantity. Lighting generators were being produced in sizes far greater. There were, nevertheless, many obstacles preventing the translation of this progress into machinery capable of hauling large groups of people a vertical distance of 1,000 feet with unquestionable dependability.

The first application of electricity to elevator propulsion was an experiment of the distinguished German electrician Werner von Siemens, who, in 1880, constructed a car that successfully climbed a rack by means of a motor and worm gearing beneath its deck (figs. 17, 18)—again, the characteristic European distrust of cable suspension. However, the effect of this success on subsequent development was negligible. Significant use of electricity in this field occurred somewhat later, and in a manner parallel to that by which steam was first applied to the elevator—the driving of mechanical (belt driven) elevator machines by individual motors. Slightly later came another application of the "conversion" type. This was the simple substitution of electrically driven pumps (fig. 21) for steam pumps in hydraulic installations. It will be recalled that pumps were necessary in cases where water main pressure was insufficient to operate the elevator directly.

In both of these cases the operational demands on the motor were of course identical to those on the prime movers which they replaced; no reversal of direction was necessary, the speed was constant, and the load was nearly constant. Furthermore, the load could be applied to the motor gradually through automatic relief valves on the pump and in the mechanical machines by slippage as the belt was shifted from the loose to the fast pulleys. The ultimate simplicity in control resulted from permitting the motor to run continuously, drawing current only

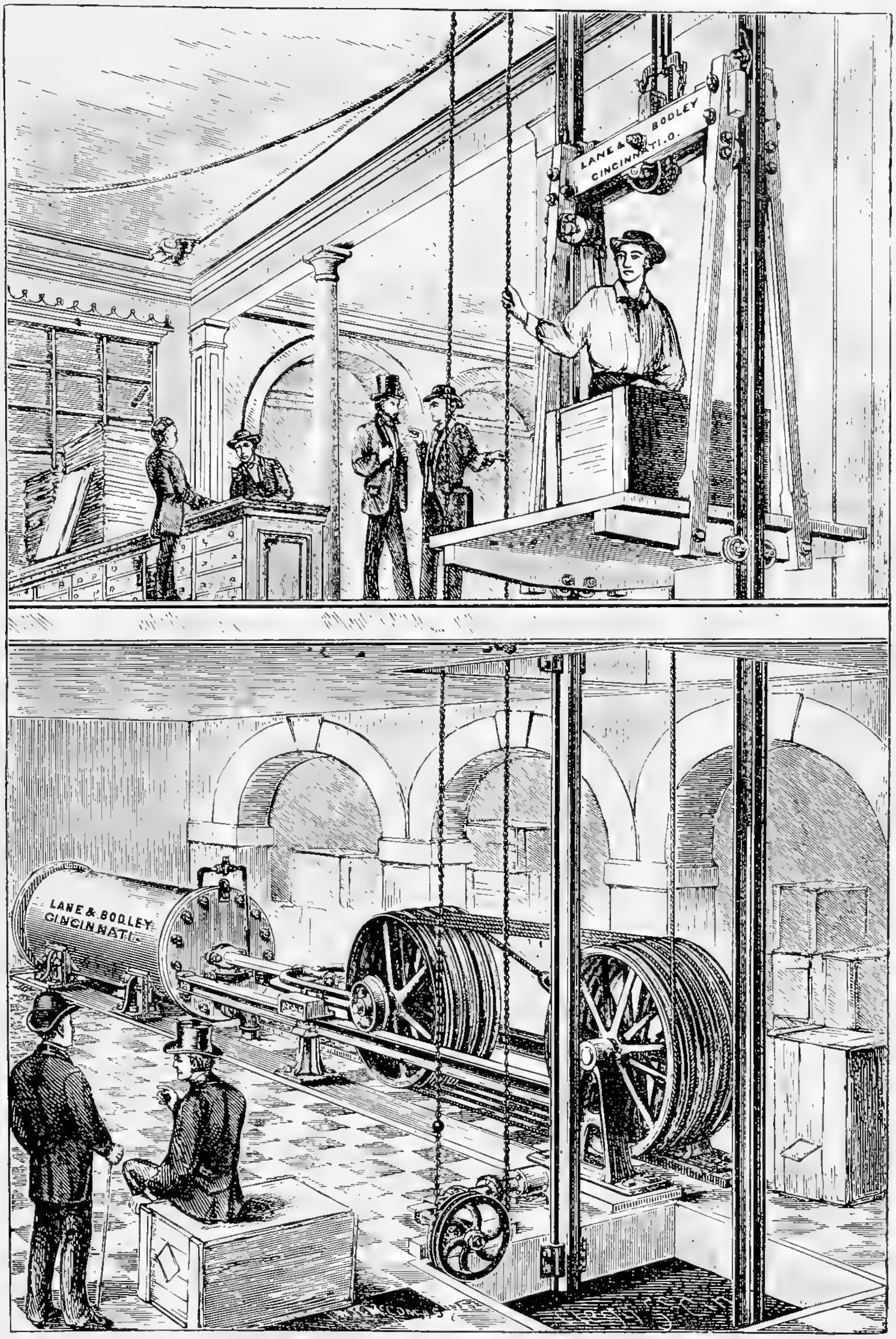

LANE & BODLEY
CINCINNATI, O.
LANE & BODLEY
CINCINNATI.

Figure 15.—Rope-geared hydraulic freight elevator using a horizontal cylinder (about 1883). (From a Lane & Bodley illustrated catalog of hydraulic elevators, Cincinnati, n.d.)

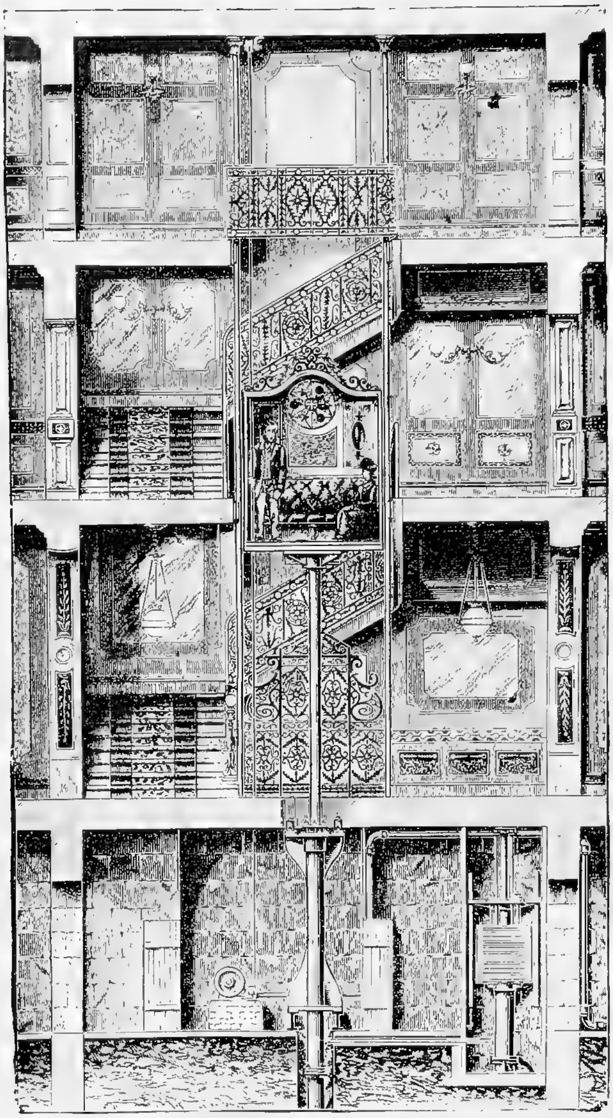


Figure 16.—English direct plunger hydraulic elevator (about 1895). (From F. Dye, *Popular Engineering*, London, 1895, p. 280.)

in proportion to its loading. The direct-current motor of the 1880's was easily capable of such service, and it was widely used in this way.

Adaptation of the motor to the direct drive of an elevator machine was quite another matter, the difficulties being largely those of control. At this time the only practical means of starting a motor under load was by introducing resistance into the circuit and cutting it out in a series of steps as the speed picked up; precisely the method used to start traction motors. In the early attempts to couple the motor directly to the winding drum through worm gearing, this "notching up" was transmitted to the car as a jerking motion, disagreeable to passengers and hard on machinery. Furthermore, the controller contacts had a short life because of the arcing which resulted from heavy starting currents. In all, such systems were unsatisfactory and generally unreliable, and were held in disfavor by both elevator experts and owners.

There was, moreover, little inducement to overcome the problem of control and other minor problems because of a more serious difficulty which had

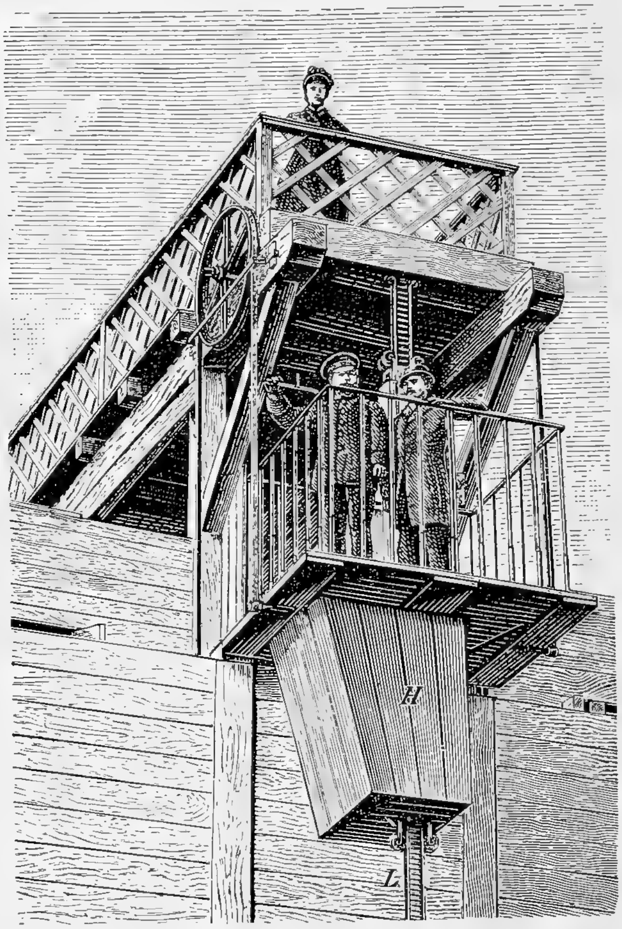


Figure 17.—Siemens' electric rack-climbing elevator of 1880. (From Werner von Siemens, *Gesammelte Abhandlungen und Vorträge*, Berlin, 1881, pl. 5.)

persisted since the days of steam. This was the matter of the drum and its attendant limitations. The motor's action being rotatory, the winding drum was the only practical way in which to apply its motive power to hoisting. This single fact shut electricity almost completely out of any large-scale elevator business until after the turn of the century. True, there was a certain amount of development, after about 1887, of the electric worm-drive drum machine for slow-speed, low-rise service (fig. 19). But the first installation of this type that was considered practically successful—in that it was in continuous use for a long period—was not made until 1889,[7] the year in which the Eiffel Tower was completed.

Pertinent is the one nearly successful attempt which was made to approach the high-rise problem electrically. In 1888, Charles R. Pratt, an elevator engineer of Montclair, New Jersey, invented a machine based on the horizontal cylinder rope-geared hydraulic elevator, in which the two sets of sheaves were drawn apart by a screw and traveling nut. The screw was revolved directly by a Sprague motor, the system being known as the Sprague-Pratt. While a number of installations were made, the machine was subject to several serious mechanical faults and passed out of use around 1900. Generally, electricity as a practical workable power for elevators seemed to hold little promise in 1888.[8]

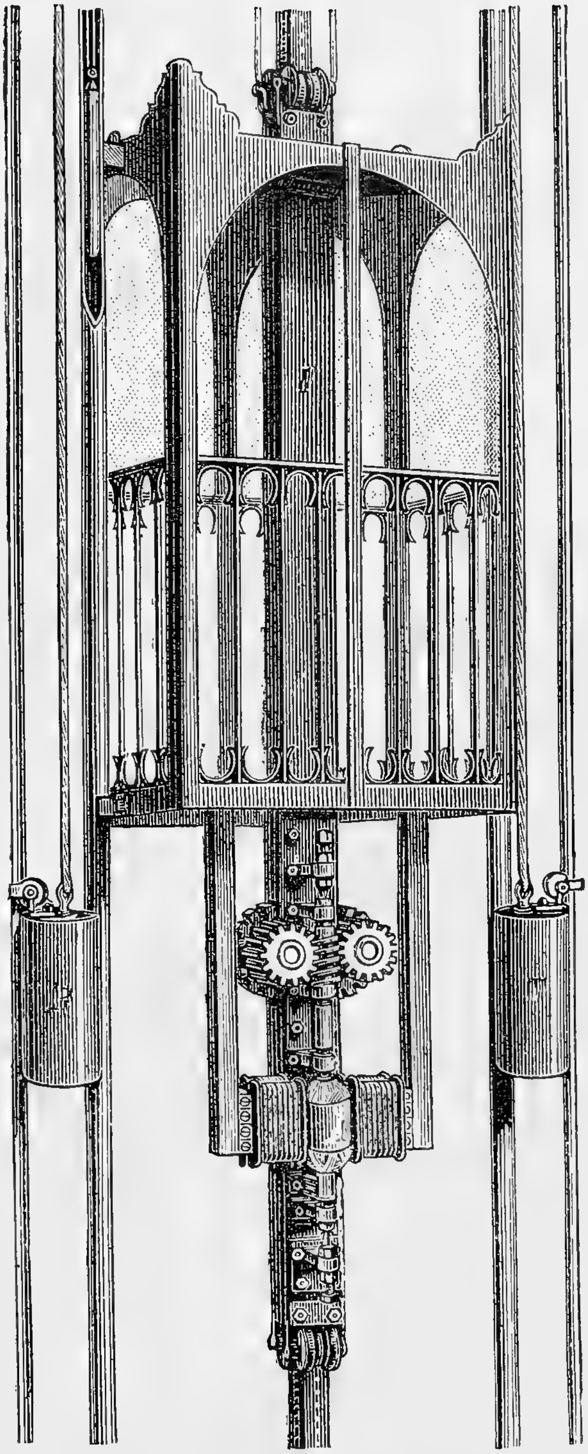


Figure 18.—Motor and drive mechanism of Siemens' elevator. (From Alfred R. Urbanitzky, *Electricity in the Service of Man*, London, 1886, p. 646.)

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[7] Two machines, by Otis, in the Demarest Building, Fifth Avenue and 33d Street, New York. They were in use for over 30 years.

[8] Although the eventually successful application of electric power to the elevator did not occur until 1904, and therefore goes beyond the chronological scope of this discussion, it was of such importance insofar as current practice is concerned as to be worthy of brief mention. In that year the first gearless traction machine was installed by Otis in a Chicago theatre. As the name implies, the cables were not wrapped on a drum but passed, from the car, over a grooved sheave directly on the motor shaft, the other ends being attached to the counterweights. The result was a system of beautiful simplicity, capable of any rise and speed with no proportionate increase in the number or size of its parts, and free from any possibility of car or weights being drawn into the machinery. This system is still the only one used for rises of over 100 feet or so. By the time of its introduction, motor controls had been improved to the point of complete practicability.

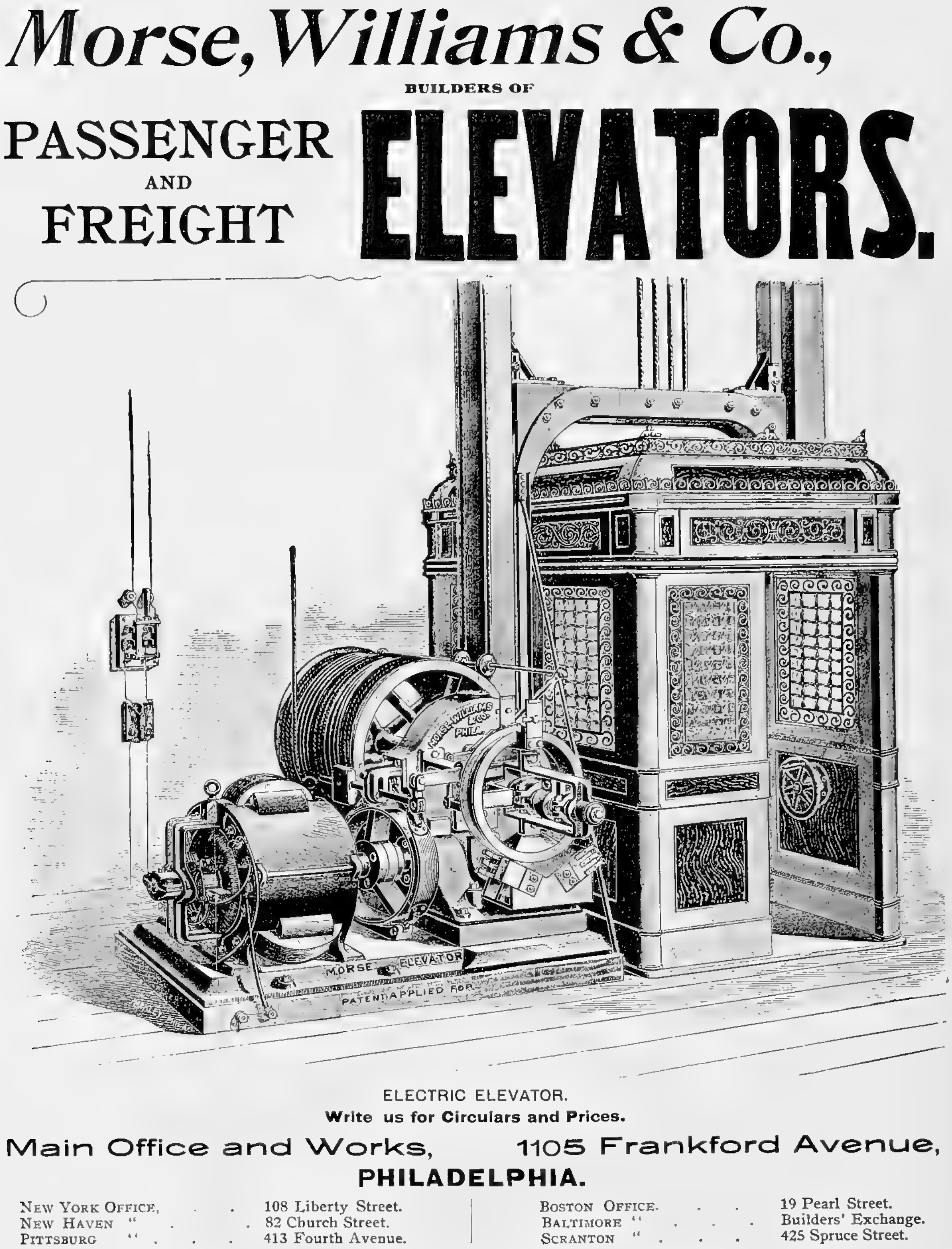

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Figure 19.—The electric elevator in its earliest commercial form (1891), with the motor connected directly to the load. By this time, incandescent lighting circuits in large cities were sufficiently extensive to make such installations practical. However, capacity and lift were severely limited by weaknesses of the control system and the necessity of using a drum. (From *Electrical World*, Jan. 2, 1897, vol. 20, p. xcvii.)

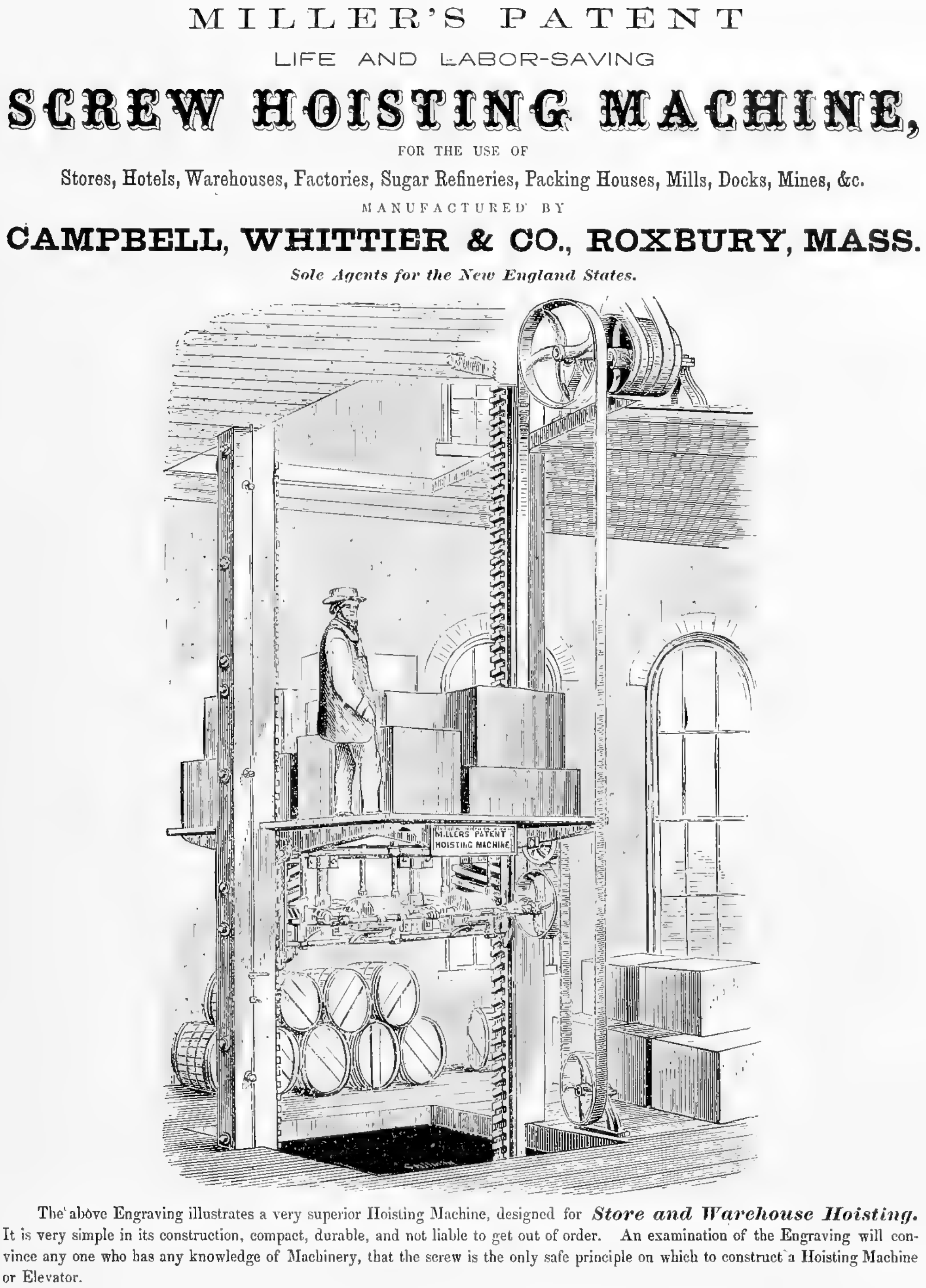

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Figure 20.—Advertisement for the Miller screw-hoisting machine, about 1867 (see p. 23). From flyer in the United States National Museum.

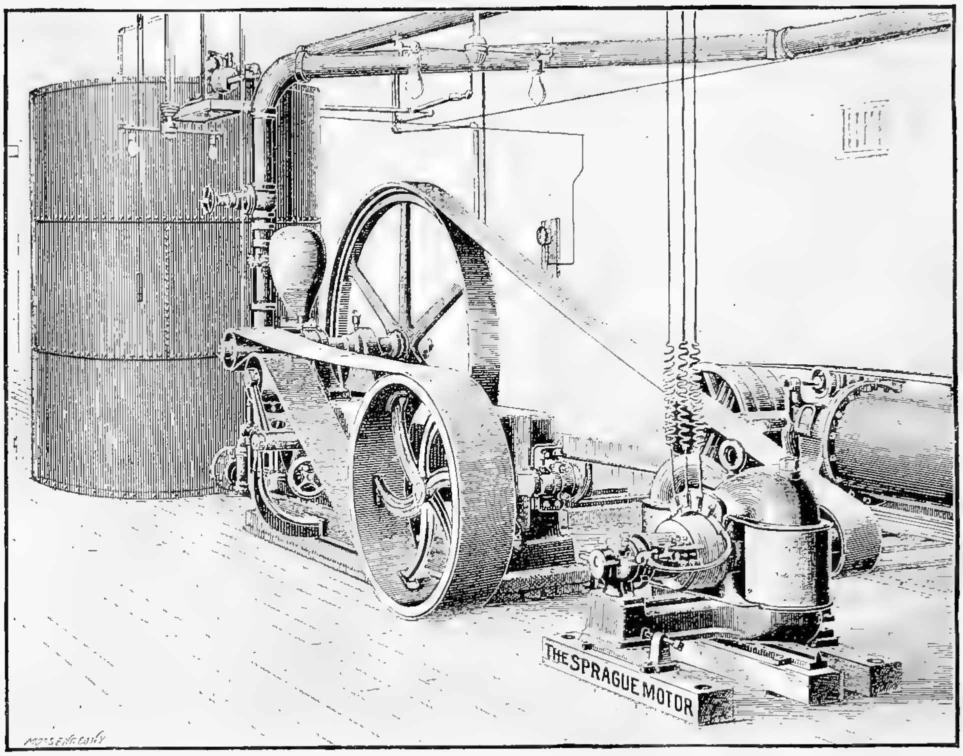

Figure 21.—The first widespread use of electricity in the elevator field was to drive belt-type mechanical machines and the pumps of hydraulic systems (see p. 14) as shown here. (From *Electrical World*, Jan. 4, 1890, vol. 15, p. 4.)

The Tower's Elevators

A great part of the Eiffel Tower's worth and its *raison d'être* lay in the overwhelming visual power by which it was to symbolize to a world audience the scientific, artistic, and, above all, the technical achievements of the French Republic. Another consideration, in Eiffel's opinion, was its great potential value as a scientific observatory. At its summit grand experiments and observations would be possible in such fields as meteorology and astronomy. In this respect it was welcomed as a tremendous improvement over the balloon and steam winch that had been featured in this service at the 1878 Paris exposition. Experiments were also to be conducted on the electrical illumination of cities from great heights. The great strategic value of the Tower as an observation post also was recognized. But from the beginning, sight was never lost of the structure's great value as an unprecedented public attraction, and its systematic exploitation in this manner played a part in its planning, second perhaps only to the basic design.

The conveyance of multitudes of visitors to the Tower's first or main platform and a somewhat lesser number to the summit was a technical problem whose seriousness Eiffel must certainly have been aware of at the project's onset. While a few visitors could be expected to walk to the first or possibly second stage, 377 feet above the ground, the main means of transport obviously had to be elevators. Indeed, the two aspects of the Tower with which the Exposition commissioners were most deeply concerned were the adequate grounding of lightning and the provision of a reliable system of elevators, which they insisted be unconditionally safe.

To study the elevator problem, Eiffel retained a man named Backmann who was considered an expert on the subject. Apparently Backmann originally was to design the complete system, but he was to prove inadequate to the task. As his few schemes are studied it becomes increasingly difficult to imagine by what qualifications he was regarded as either an elevator expert or designer by Eiffel and the Commission. His proposals appear, with one exception, to have been decidedly retrogressive, and, further, to incorporate the most undesirable features of those earlier systems he chose to borrow from. Nothing has been discovered regarding his work, if any, on elevators for the lower section of the Tower. Realizing the difficulty of this aspect of the problem, he may not have attempted its solution, and confined his work to the upper half where the structure permitted a straight, vertical run.

The Backmann design for the upper elevators was based upon a principle which had been attractive to many inventors in the mid-19th century period of elevator development—that of "screwing the car up" by means of a threaded element and a nut, either of which might be rotated and the other remain stationary. The analogy to a nut and bolt made the scheme an obvious one at that early time, but its inherent complexity soon became equally evident and it never achieved practical success. Backmann projected two cylindrical cars that traveled in parallel shafts and balanced one another from opposite ends of common cables that passed over a sheave in the upperworks. Around the inside of each shaft extended a spiral

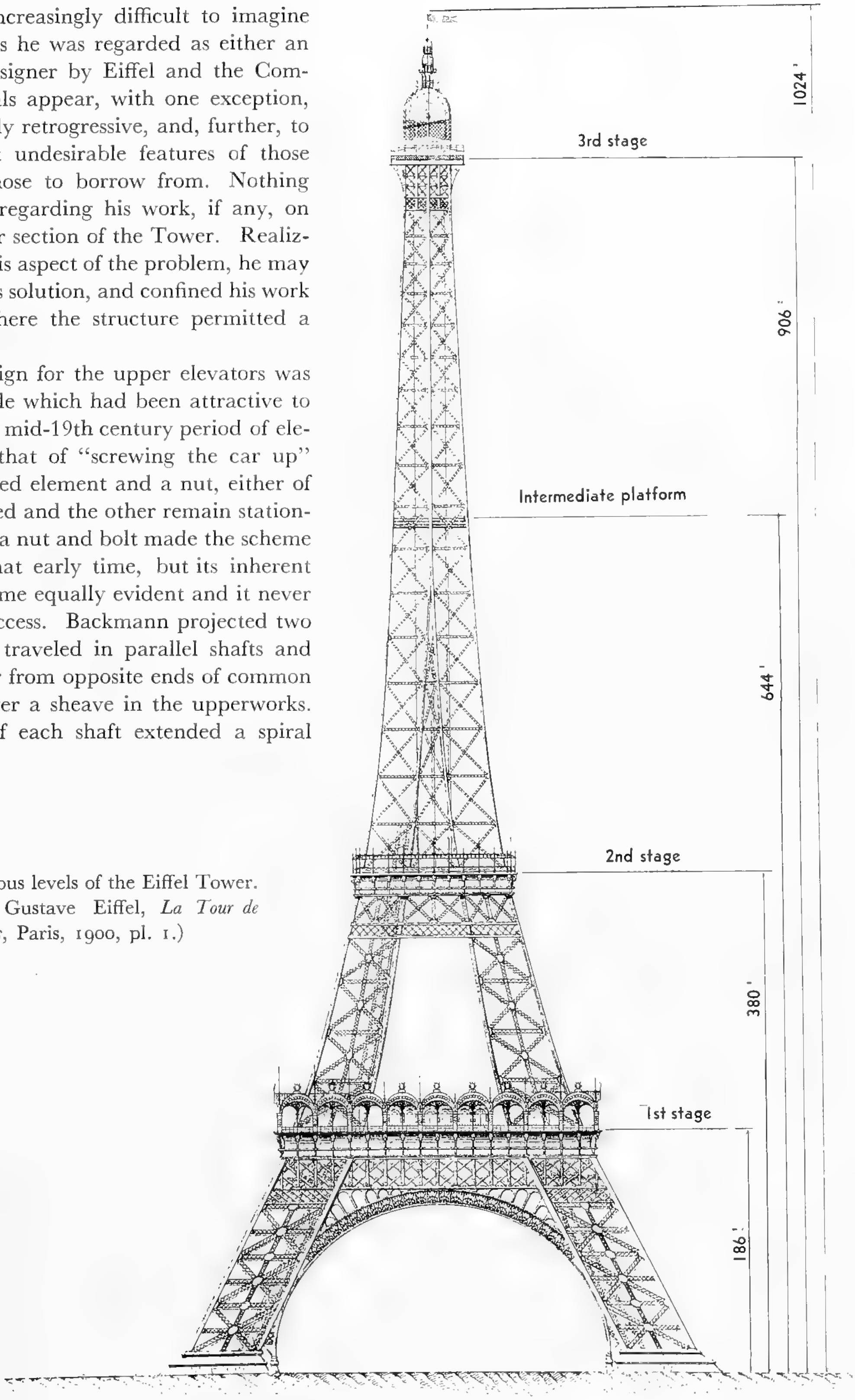

Figure 22.—Various levels of the Eiffel Tower. (Adapted from Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, pl. 1.)

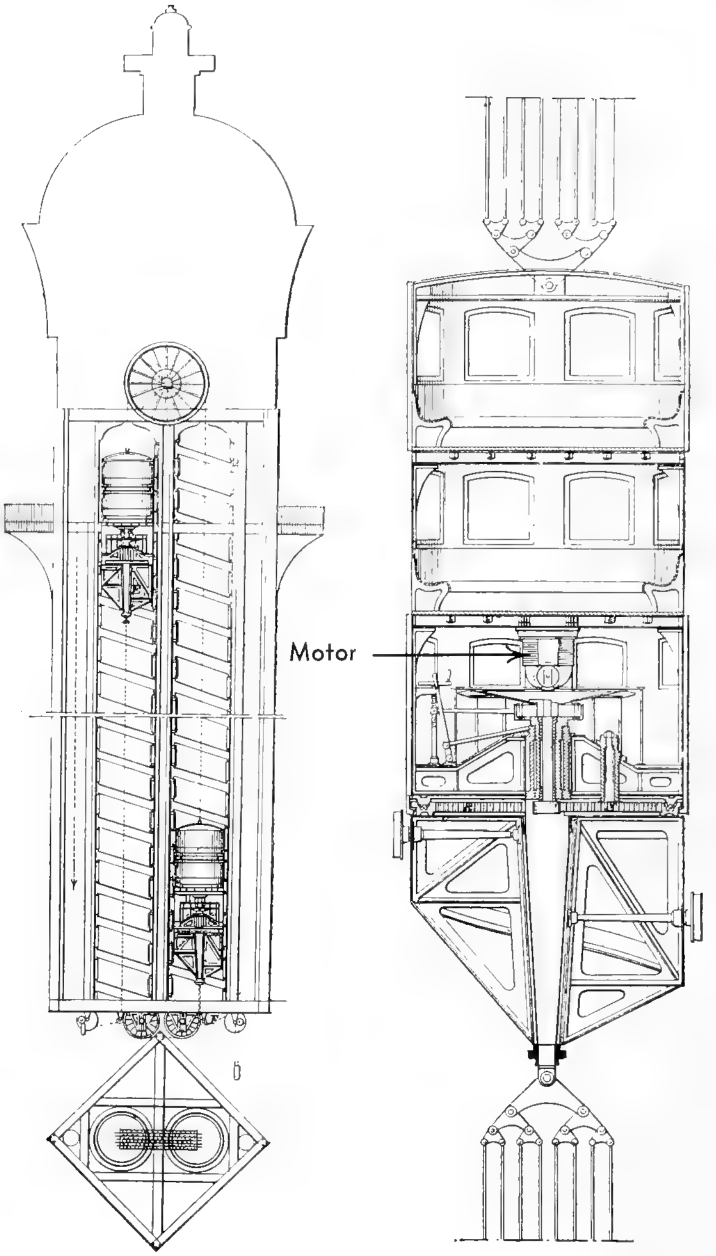

Figure 23.—Backmann's proposed helicoidal elevator for the upper section of the Eiffel Tower. The cars were to be self-powered by electric motors. Note similarity to the Miller system (fig. 20). (Adapted from *The Engineer* (London), Aug. 3, 1888, vol. 66, p. 101.)

track upon which ran rollers attached to revolving frames underneath the cars. When the frames were made to revolve, the rollers, running around the track, would raise or lower one car, the other traveling in the opposite direction (fig. 23).

In the plan as first presented, a ground-based steam engine drove the frames and rollers through an endless fly rope—traveling at high speed presumably to permit it to be of small diameter and still transmit a reasonable amount of power—which engaged pulleys on the cars. The design was remarkably similar to that of the Miller Patent Screw Hoisting Machine, which had had a brief life in the United States around 1865. The Miller system (see p. 19) used a flat belt rather than a rope (fig. 20). This plan was quickly rejected, probably because of anticipated difficulties with the rope transmission.[9]

Backmann's second proposal, actually approved by the Commission, incorporated the only—although highly significant—innovation evident in his designs. For the rope transmission, electric motors were substituted, one in each car to drive the roller frame directly. With this modification, the plan does not seem quite as unreasonable, and would probably have worked. However, it would certainly have lacked the necessary durability and would have been extremely expensive. The Commission discarded the whole scheme about the middle of 1888, giving two reasons for its action: (1) the novelty of the system and the attendant possibility of stoppages which might seriously interrupt the "exploitation of the Tower," and (2) fear that the rollers running around the tracks would cause excessive noise and vibration. Both reasons seem quite incredible when the Backmann system is compared to one of those actually used—the Roux, described below—which obviously must have been subject to identical failings, and on a far greater scale. More likely there existed an unspoken distrust of electric propulsion.

That the Backmann system should have been given serious consideration at all reflects the uncertainty surrounding the entire matter of providing elevator service of such unusual nature. Had the Eiffel Tower been erected only 15 years later, the situation would have been simply one of selection. As it was, Eiffel and the commissioners were governed not by what they wanted but largely by what was available.

THE OTIS SYSTEM

The curvature of the Tower's legs imposed a problem unique in elevator design, and it caused great annoyance to Eiffel, the fair's Commission, and all others concerned. Since a vertical shaftway anywhere within the open area beneath the first platform was esthetically unthinkable, the elevators could be placed only in the inclined legs. The problem of reaching the first platform was not serious. The legs were wide enough and their curvature so slight in this lower portion as to permit them to contain a straight run of track, and the service could have been designed along the lines of an ordinary inclined railway. It was estimated that the great majority of visitors would go only to this level, attracted by the several international restaurants, bars and other features located there. Two elevators to operate only that far were contracted for with no difficulty—one to be placed in the east leg and one in the west.

To transport people to the second platform was an altogether different problem. Since there was to be a single run from the ground, it would have been necessary to form the elevator guides either with a constant curvature, approximating that of the legs, or with a series of straight chords connected by short segmental curves of small radius. Eiffel planned initially to use the first method, but the second was adopted ultimately, probably as being the simpler because only two straight lengths of run were found to be necessary.

Bids were invited for two elevators on this basis—one each for the north and south legs. Here the unprecedented character of the matter became evident—there was not a firm in France willing to undertake the work. The American Elevator Company, the European branch of Otis Brothers & Company, did submit a proposal through its Paris office, Otis Ascenseur Cie., but the Commission was compelled to reject it because a clause in the fair's charter prohibited the use of any foreign material in the construction of the Tower. Furthermore, there was a strong prejudice against foreign contractors, which, because of the general background of disfavor surrounding the project during its early stages, was an element worth serious consideration by the Commission. The bidding time was extended, and many attempts were made to attract a native design but none was forthcoming.

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[9] Mechanical transmission of power by wire rope was a well developed practice at this time, involving in many instances high powers and distances up to a mile. To attempt this system in the Eiffel Tower, crowded with structural work, machinery and people, was another matter.

As time grew short, it became imperative to resolve the matter, and the Commission, in desperation, awarded the contract to Otis in July 1887 for the amount of $22,500.[10] A curious footnote to the affair appeared much later in the form of a published interview[11] with W. Frank Hall, Otis' Paris representative:

> "Yes," said Mr. Hall, "this is the first elevator of its kind. Our people for thirty-eight years have been doing this work, and have constructed thousands of elevators vertically, and many on an incline, but never one to strike a radius of 160 feet for a distance of over 50 feet. It has required a great amount of preparatory study and we have worked on it for three years."
>
> "That was before you got the contract?"
>
> "Quite so, but we knew that, although the French authorities were very reluctant to give away this piece of work, they would be bound to come to us, and so we were preparing for them."

Such supreme confidence must have rapidly evaporated as events progressed. Despite the invaluable advertising to be derived from an installation of such distinction, the Otises would probably have defaulted had they foreseen the difficulties which preceded completion of the work.

The proposed system (fig. 24) was based fundamentally upon Otis' standard hydraulic elevator, but it was recognizable only in basic operating principle (fig. 25). Tracks of regular rail section replaced the guides because of the incline, and the double-decked cabin (fig. 29) ran on small flanged wheels. This much of the

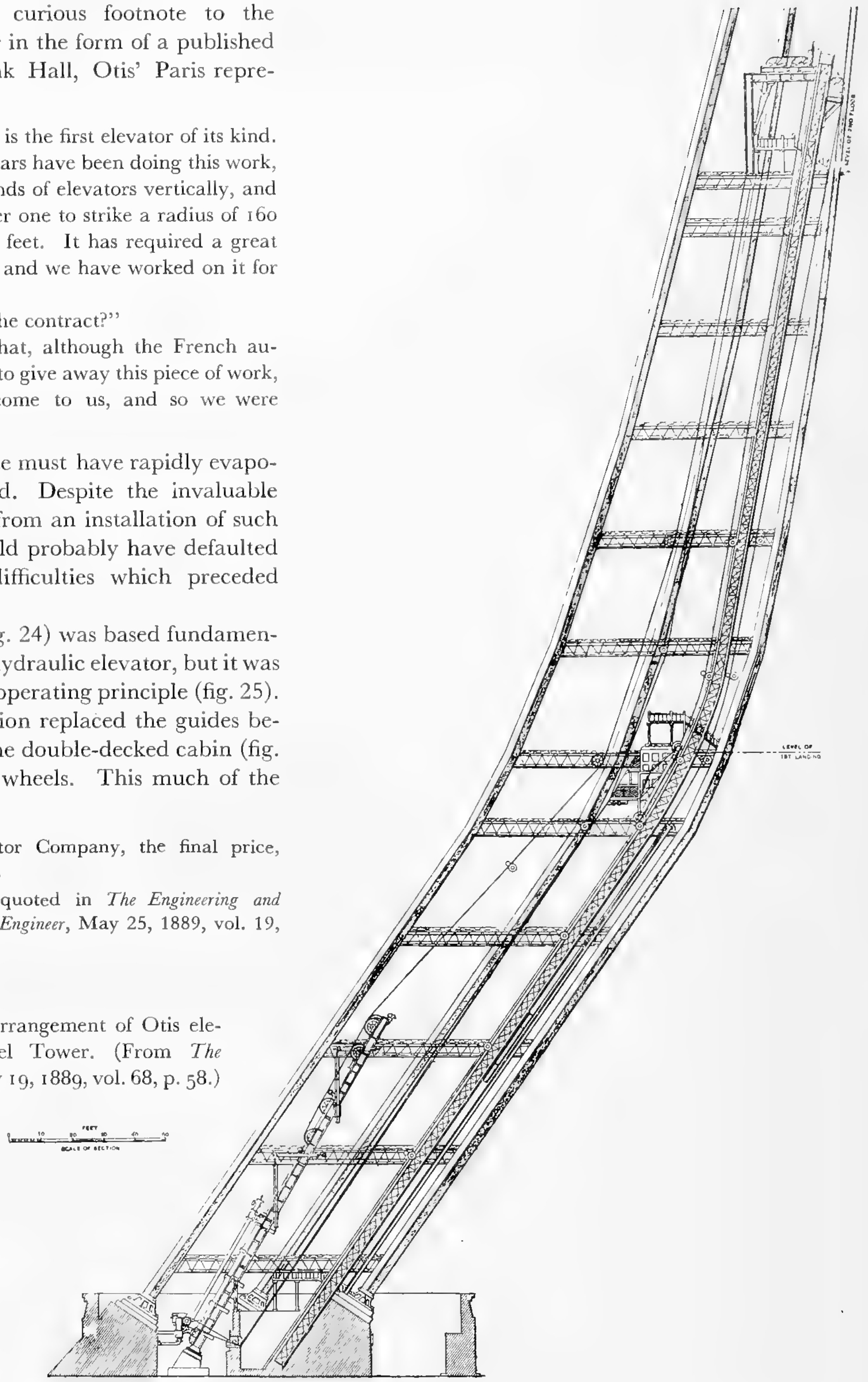

Figure 24.—General arrangement of Otis elevator system in Eiffel Tower. (From *The Engineer* (London), July 19, 1889, vol. 68, p. 58.)

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[10] According to Otis Elevator Company, the final price, because of extras, was $30,000.

[11] In *Pall Mall Gazette*, as quoted in *The Engineering and Building Record and the Sanitary Engineer*, May 25, 1889, vol. 19, p. 345.

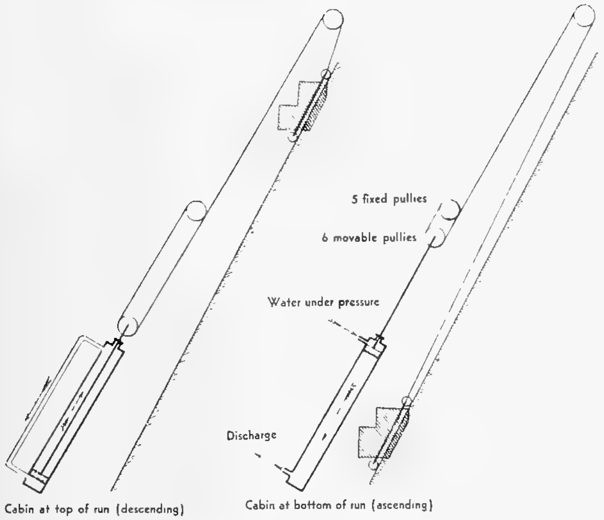
5 fixed pullies
6 movable pullies
Water under pressure
Discharge
Cabin at top of run (descending)
Cabin at bottom of run (ascending)

Figure 25.—Schematic diagram of the rigging of the Otis system. (Adapted from Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, p. 127.)

apparatus was really not unlike that of an ordinary inclined railway. Motive power was provided by the customary hydraulic cylinder (fig. 26), set on an angle roughly equal to the incline of the lower section of run. Balancing the cabin's dead weight was a counterpoise carriage (fig. 27) loaded with pig iron that traveled on a second set of rails beneath the main track. Like the driving system, the counterweight was rope-geared, 3 to 1, so that its travel was about 125 feet to the cabin's 377 feet.

Everything about the system was on a scale far heavier than found in the normal elevator of the type. The cylinder, of 38-inch bore, was 36 feet long. Rather than a simple nest of pulleys, the piston rods pulled a large guided carriage or "chariot" bearing six movable sheaves (fig. 28). Corresponding were five stationary sheaves, the whole reeved to form an immense 12-purchase tackle. The car, attached to the free ends of the cables, was hauled up as the piston drew the two sheave assemblies apart.

In examining the system, it is difficult to determine what single element in its design might have caused such a problem as to have been beyond the engineering ability of a French firm, and to have caused such concern to a large, well-established American organization of Otis' wide elevator and inclined railway experience. Indeed, when the French system—which served the first platform from the east and west legs—is examined, it appears curious that a national technology capable of producing a machine at such a level of complexity should have been unable to deal easily with the entire matter. This can be plausibly explained only on the basis of Europe's previously mentioned lack of experience with rope-geared and other cable-hung elevator systems. The difficulty attending Otis' work, usually true in the case of all innovations, lay unquestionably in the multitudes of details—many of them, of course, invisible when only the successfully working end product is observed.

More than a matter of detail was the Commission's demand for perfect safety, which precipitated a situation typical of many confronting Otis during the entire work. Otis had wished to coordinate the entire design process through Mr. Hall, with technical matters handled by mail. Nevertheless, at Eiffel's insistence, and with some inconvenience, in 1888 the company dispatched the project's engineer, Thomas E. Brown, Jr., to Paris for a direct consultation. Mild conflict over minor details ensued, but a gross difference of opinion arose ultimately between the American and French engineers over the safety of the system. The disagreement threatened to halt the entire project. In common with all elevators in which the car hangs by cables, the prime consideration here was a means of arresting the cabin should the cables fail. As originally presented to Eiffel, the plans indicated an elaborate modification of the standard Otis safety device—itself a direct derivative of E. G. Otis' original.

If any one of the six hoisting cables broke or stretched unduly, or if their tension slackened for any reason, powerful leaf springs were released causing brake shoes to grip the rails. The essential feature of the design was the car's arrest by friction between its grippers and the rails so that the stopping action was gradual, not sudden as in the elevator safety. During proof trials of the safety, made prior to the fair's opening by cutting away a set of temporary hoisting cables, the cabin would fall about 10 feet before being halted.

Although highly efficient and of unquestionable security, this safety device was considered an insufficient safeguard by Eiffel, who, speaking in the name of the Commission, demanded the application of a device known as the rack and pinion safety that was used to some extent on European cog railways. The commissioners not only considered this system more reliable but felt that one of its features was a necessity:

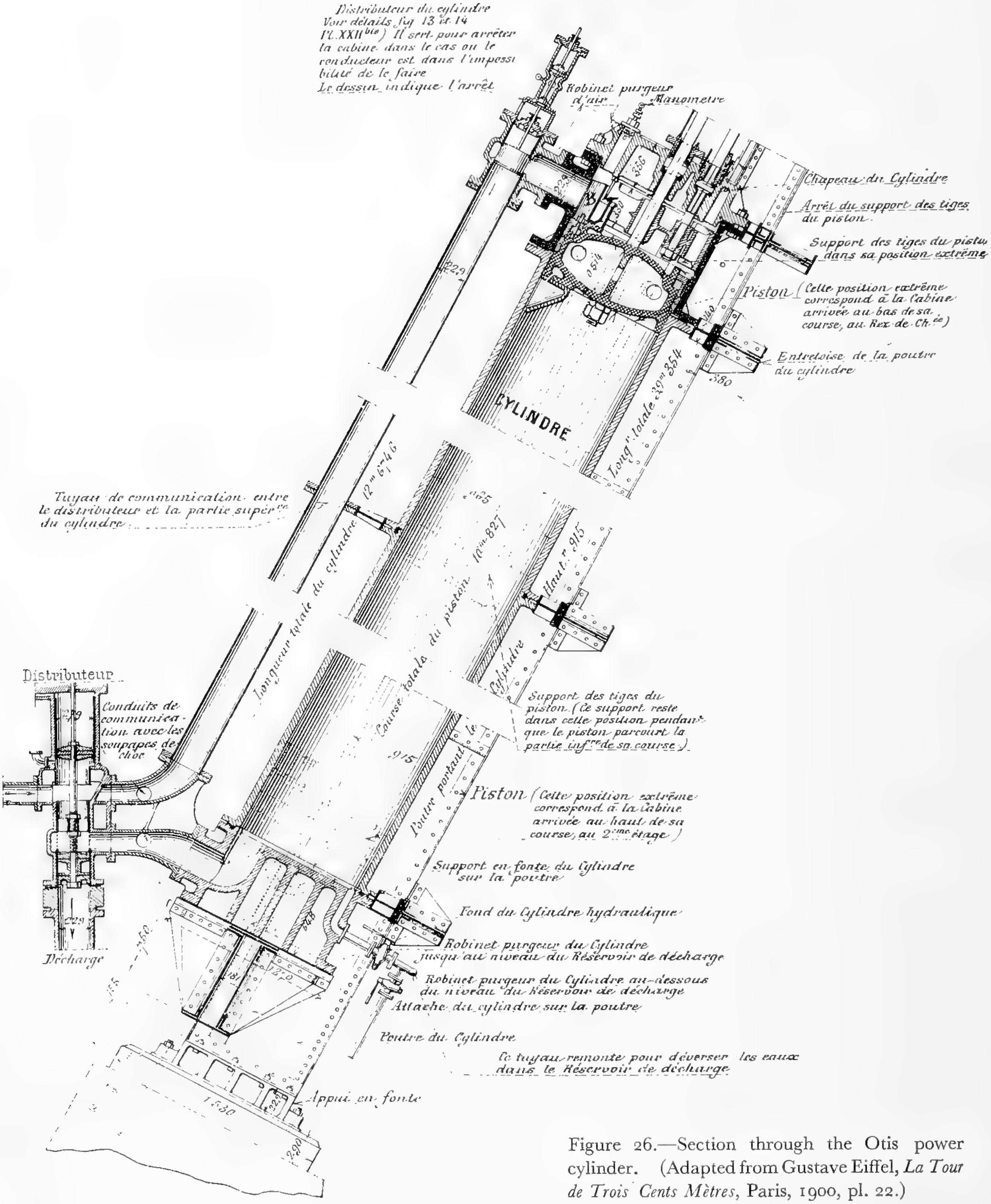
Distributeur du cylindre Voir détails fig 13 et 14 Pl. XXII^bis) Il sert pour arrêter la cabine dans le cas ou le conducteur est dans l'impossibilité de le faire Le dessin indique l'arrêt
Robinet purgeur d'air
Manometre
356
229
350
0514
229
Chapeau du Cylindre
Arrêt du support des tiges du piston.
Support des tiges du pistn dans sa position extrême
Piston (Cette position extrême correspond à la Cabine arrivée au bas de sa course, au Rez de Ch.^ée)
140
Entretoise de la poutre du cylindre
380
CYLINDRE
Long.^r totale 39^m 354
12^m 646
Tuyau de communication entre le distributeur et la partie supér.^re du cylindre
915
10^m 827
Haut.^r 915
Longueur totale du cylindre
Course totale du piston
Cylindre
Support des tiges du piston. (Ce support reste dans cette position pendant que le piston parcourt la partie inf.^re de sa course.)
Distributeur
Conduits de communication avec les soupapes de choc
229
915
Poutre portant le
Piston (Cette position extrême correspond à la Cabine arrivée au haut de sa course, au 2^ème étage)
Support en fonte du Cylindre sur la poutre
Fond du Cylindre hydraulique
648
Robinet purgeur du Cylindre jusqu'au niveau du Réservoir de décharge
Robinet purgeur du Cylindre au-dessous du niveau du Réservoir de décharge
229
Décharge
750
155
181
270
Attache du cylindre sur la poutre
Poutre du Cylindre
Ce tuyau remonte pour déverser les eaux dans le Réservoir de décharge
Appui en fonte
1530
229
290

Figure 26.—Section through the Otis power cylinder. (Adapted from Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, pl. 22.)

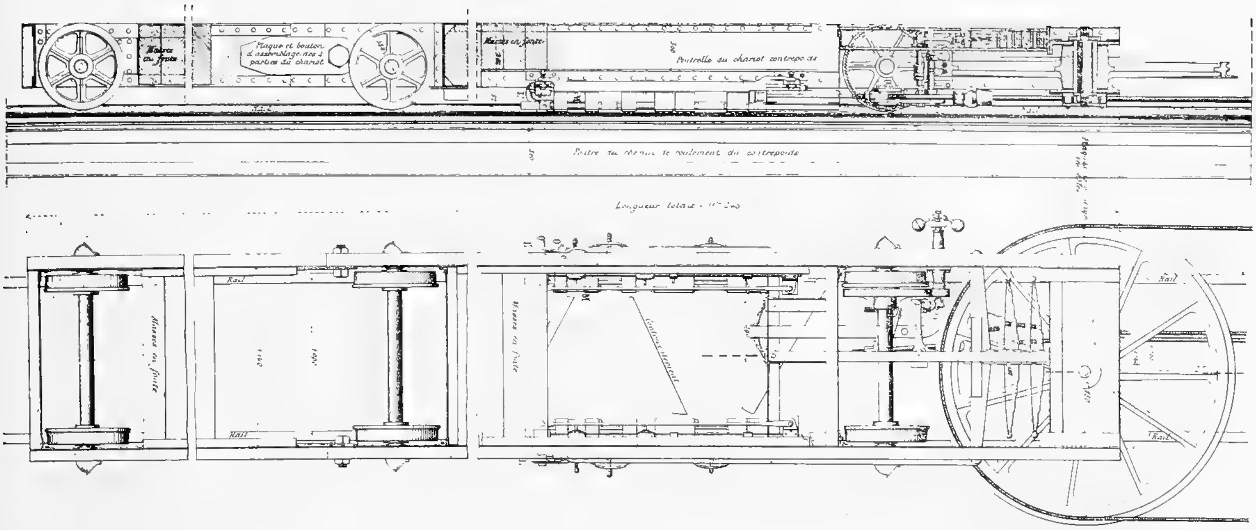
Moises en fonte
Plaque et bouton d'assemblage des 2 parties du chariot
Moises en fonte
Poutrelle du chariot contrepoids
Poutre du chemin de roulement du contrepoids
Longueur totale
Rail
Rail
Moises en fonte
Moises en fonte
Rail
Rail

Figure 27.—Details of the counterweight carriage in the Otis system. (From Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, pl. 22⁴.)

a device that permitted the car to be lowered by hand, even after failure of all the hoisting cables. The serious shortcomings of the rack and pinion were its great noisiness and the limitation it imposed on hoisting speed. Both disadvantages were due to the constant engagement of a pinion on the car with a continuous rack set between the rails. The meeting ended in an impasse, with Brown unwilling to approve the objectionable apparatus and able only to return to New York and lay the matter before his company.

While Eiffel's attitude in the matter may appear highly unreasonable, it must be said that during a subsequent meeting between Brown and Kœchlin, the French engineer implied that a mutual antagonism had arisen between the Tower's creator and the Commission. Thus, since his own judgment must have had little influence with the commissioners at that time, Eiffel was compelled to specify what he well knew were excessive safety provisions.

This decision placed Otis Brothers in a decidedly uncomfortable position, at the mercy of the Commission. W. E. Hale, promoter of the water balance elevator—who by then had a strong voice in Otis' affairs—expressed the seriousness of the matter in a letter to the company's president, Charles R. Otis, following receipt of Brown's report on the Paris conference. Referring to the controversial cogwheel, Hale wrote

> . . . if this must be arranged so that the car is effected [sic] in its operation by constant contact with the rack and pinion . . . so as to communicate the noise and jar, and unpleasant motion which such an arrangement always produces, I should favor giving up the whole matter rather than allying ourselves with any such abortion. . . . we would be the laughing stock of the world, for putting up such a contrivance.

This difficult situation apparently was the product of a somewhat general contract phrased in terms of service to be provided rather than of specific equipment to be used. This is not unusual, but it did leave open to later dispute such ambiguous clauses as "adequate safety devices are to be provided."

Although faced with the loss not only of all previously expended design work but also of an advertisement of international consequence, the company apparently concurred with Hale and so advised Paris. Unfortunately, there are no Otis records to reveal the subsequent transactions, but we may assume that Otis' threat of withdrawal prevailed, coupled as it was with Eiffel's confidence in the American equipment. The system went into operation as originally designed, free of the odious rack and pinion.

That, unfortunately, was not the final disagreement. Before the fair's opening in May 1889, the relationship was strained so drastically that a mutually satisfactory conclusion to the project must indeed have seemed hopeless. The numerous minor structural modifications of the Tower legs found necessary as construction progressed had necessitated certain equivalent alteration to the Otis design insofar as its dependency upon the framework was affected. Consequently, work on the machinery was set back by some months. Eiffel was informed that although everything was guaranteed to be in full operation by opening day on May 1, the contractual deadline of January 1 could not possibly be met. Eiffel, now unquestionably acting on his own volition, responded by cable, refusing all payment. Charles Otis' reply, a classic of indignation, disclosed to Eiffel the jeopardy in which his impetuosity had placed the success of the entire project:

> After all else we have borne and suffered and achieved in your behalf, we regard this as a trifle too much; and we do not hesitate to declare, in the strongest terms possible to the English language, that we will not put up with it . . . and, if there is to be War, under the existing circumstances, propose that at least part of it shall be fought on American ground. If Mr. Eiffel shall, on the contrary, treat us as we believe we are entitled to be treated, under the circumstances, and his confidence in our integrity to serve him well shall be restored in season to admit of the completion of this work at the time wanted, well and good; but it must be done at once . . . otherwise we shall ship no more work from this side, and Mr. Eiffel must charge to himself the consequences of his own acts.

This message apparently had the desired effect and the matter was somehow resolved, as the machinery was in full operation when the Exposition opened. The installation must have had immense promotional value for Otis Brothers, particularly in its contrast to the somewhat anomalous French system. This contrast evidently was visible to the technically unsophisticated as well as to visiting engineers. Several newspapers reported that the Otis elevators were one of the best American exhibits at the fair.

In spite of their large over-all scale and the complication of the basic pattern imposed by the unique situation, the Otis elevators performed well and justified the original judgment and confidence which had prompted Eiffel to fight for their installation. Aside from the obvious advantage of simplicity when compared to the French machines, their operation was relatively quiet, and fast.

The double car, traveling at 400 feet per minute, carried 40 persons, all seated because of the change of inclination. The main valve or distributor that controlled the flow of water to and from the driving cylinder was operated from the car by cables. The hydraulic head necessary to produce pressure within the cylinder was obtained from a large open reservoir on the second platform. After being exhausted from the cylinder, the water was pumped back up by two Girard pumps (fig. 31) in the engine room at the base of the Tower's south leg.

THE SYSTEM OF ROUX, COMBALUZIER AND LEPAPE

There can be little doubt that the French elevators placed in the east and west piers to carry visitors to the first stage of the Tower had the important secondary function of saving face. That an engineer of Eiffel's mechanical perception would have permitted their use, unless compelled to do so by the Exposition Commission, is unthinkable. Whatever the attitudes of the commissioners may have been, it must be said—recalling the Backmann system—that they did not fear innovation. The machinery installed by the firm of Roux, Combaluzier and Lepape was novel in every respect, but it was a product of misguided ingenuity and set no precedent. The system, never duplicated, was conceived, born, lived a brief and not overly creditable life, and died, entirely within the Tower.

Basis of the French system was an endless chain of short, rigid, articulated links (fig. 35), to one point of which the car was attached. As the chain moved, the car was raised or lowered. Recalling the European distrust of suspended elevators, it is interesting to note that the car was pushed up by the links below, not drawn by those above, thus the active links were in compression. To prevent buckling of the column, the chain was enclosed in a conduit (fig. 36). Excessive friction was prevented by a pair of small rollers at each of the knuckle joints between the links. The system was, in fact, a duplicate one, with a chain on either side of the car. At the bottom of the run the chains passed around huge sprocket wheels, 12.80 feet in diameter, with pockets on their peripheries to engage the joints. Smaller wheels at the top guided the chains.

If by some motive force the wheel (fig. 33) were turned counterclockwise, the lower half of the chain would be driven upward, carrying the car with it. Slots on the inside faces of the lower guide trunks permitted passage of the connection between the car and chain. Lead weights on certain links of the chains' upper or return sections counterbalanced most of the car's dead weight.

Two horizontal cylinders rotated the driving sprockets through a mechanism whose effect was similar to the rope-gearing of the standard hydraulic elevator, but which might be described as chain

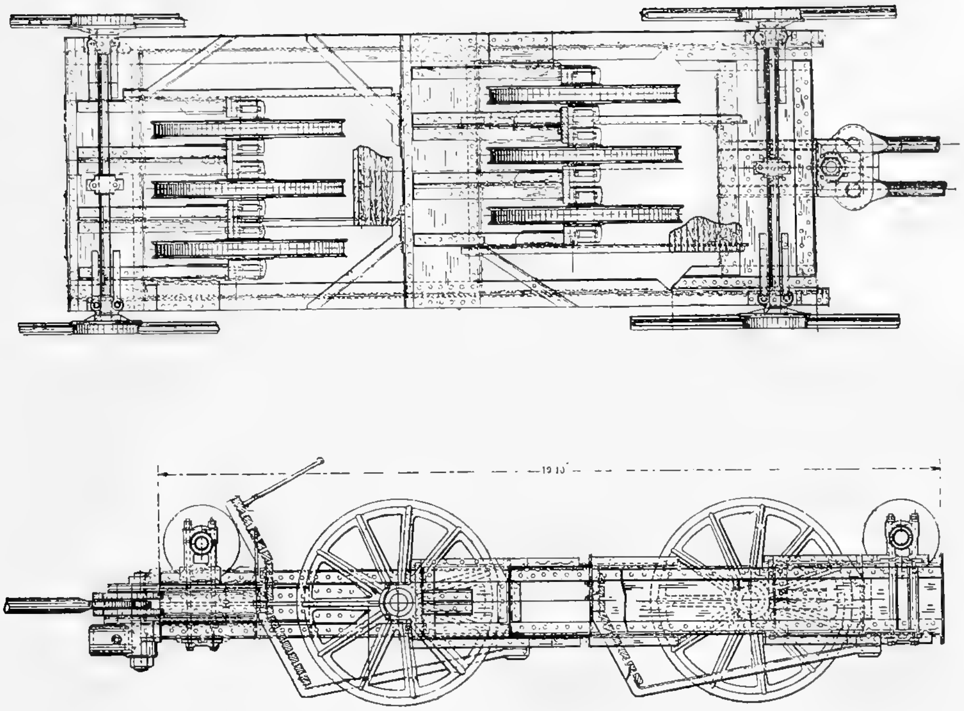

Figure 28.—Plan and section of the Otis system's movable pulley assembly, or chariot. Piston rods are at left. (Adapted from *The Engineer* (London), July 19, 1889, vol. 68, p. 58.)

gearing. The cylinders were of the pushing rather than the pulling type used in the Otis system; that is, the pressure was introduced behind the plungers, driving them out. To the ends of the plungers were fixed smooth-faced sheaves, over which were looped heavy quadruple-link pitch chains, one end of each being solidly attached to the machine base. The free ends ran under the cylinder and made another half-wrap around small sprockets keyed to the main drive shaft. As the plungers were forced outward, the free ends of the chain moved in the opposite direction, at twice the velocity and linear displacement of the plungers. The drive sprockets were thereby revolved, driving up the car. Descent was made simply by permitting the cylinders to exhaust, the car dropping of its own weight. The over-all gear or ratio of the system was the multiplication due to the double purchase of the plunger sheaves times the ratio of the chain and drive sprocket diameters: 2(12.80/1.97) or about 13 : 1. To drive the car 218 feet to the first platform of the Tower the plungers traveled only about 16.5 feet.

To penetrate the inventive rationale behind this strange machine is not difficult. Aware of the fundamental dictum of absolute safety before all else, the Roux engineers turned logically to the safest known elevator type—the direct plunger. This type of elevator, being well suited to low rises, formed the main body of European practice at the time, and in this fact lay the further attraction of a system firmly based on tradition. Since the piers between the ground and first platform could accommodate a straight, although inclined run, the solution might obviously have been to use an inclined, direct plunger. The only difficulty would have been that of drilling a 220-foot, inclined well for the cylinder. While a difficult problem, it would not have been insurmountable. What then was the reason for using a design vastly more complex? The only reasonable answer that presents itself is that the designers, work-

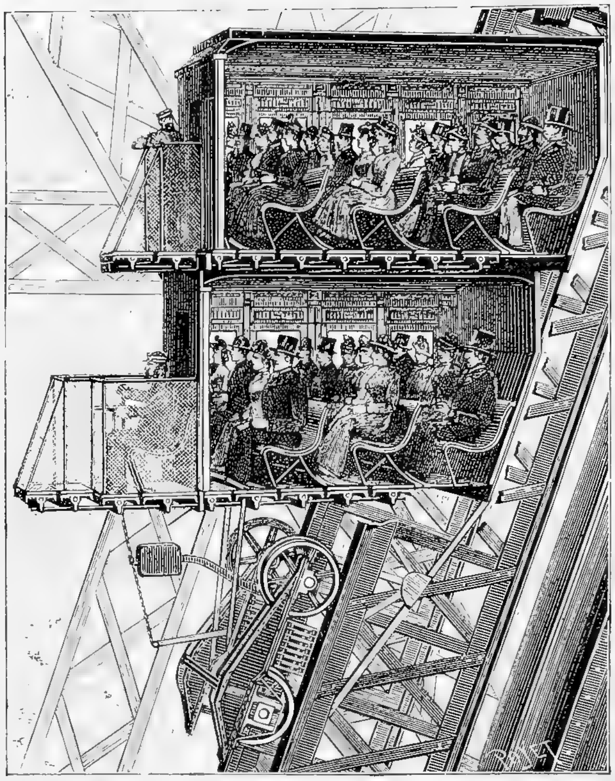

Figure 29.—Section through cabin of the Otis elevator. Note the pivoted floor-sections. As the car traveled, these floor-sections were leveled by the operator to compensate for the change of inclination; however, they were soon removed because they interfered with the loading and unloading of passengers. (From *La Nature,* May 4, 1889, vol. 17, p. 360.)

ing in a period before the Otis bid had been accepted, were attempting to evolve an apparatus capable of the complete service to the second platform. The use of a rigid direct plunger thus precluded, it became necessary to transpose the basic idea in order to adapt it to the curvature of the Tower leg, and at the same time retain its inherent quality of safety. Continuing the conceptual sequence, the idea of a plunger made in some manner flexible apparently suggested itself, becoming the heart of the Roux machines.

Here then was a design exhibiting strange contrast. It was on the one hand completely novel, devised expressly for this trying service; yet on the other hand it was derived from and fundamentally based on a thoroughly traditional system. If nothing else, it was safe beyond question. In Eiffel's own words, the Roux lifts "not only were safe, but appeared safe; a most desirable feature in lifts traveling to such heights and carrying the general public."[12]

The system's shortcomings could hardly be more evident. Friction resulting from the more than 320 joints in the flexible pistons, each carrying two rollers, plus that from the pitch chains must have been immense. The noise created by such multiplicity of parts can only be imagined. Capacity was equivalent to that of the Otis system. About 100 people could be carried in the double-deck cabin, some standing. The speed, however, was only 200 feet per minute, understandably low.

If it had been the initial intention of the designers to operate their cars to the second platform, they must shortly have become aware of the impracticability of this plan, caused by an inherent characteristic of the apparatus. As long as the compressive force acted along the longitudinal axis of the links, there was no lateral resultant and the only load on the small rollers was that due to the dead weight of the link itself. However, if a curve had been introduced in the guide channels to increase the incline of the upper run, as done by Otis, the force on those links traversing the bend would have been eccentric—assuming the car to be in the upper section, above the bend. The difference between the two sections (based upon the Otis system) was 78°9′ minus 54°35′, or 23°34′, the tangent of which equals 0.436. Forty-three percent of the unbalanced weight of the car and load would then have borne upon the, say, 12 sets of rollers on the curve. The immense frictional load thus added to the entire system would certainly have made it dismally inefficient, if not actually unworkable.

In spite of Eiffel's public remarks regarding the safety of the Roux machinery, in private he did not trouble to conceal his doubts. Otis' representative, Hall, discussing this toward the end of Brown's previously mentioned report, probably presented a fairly accurate picture of the situation. His comments were based on conversations with Eiffel and Kœchlin:

> Mr. Gibson, Mr. Hanning [who were other Otis employees] and myself came to the unanimous conclusion that Mr. Eiffel had been forced to order those other machines, from outside parties, against his own judgment: and that he was very much in doubt as to their being a practical success—and was, therefore, all the more anxious to put in our ma-

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[12] From speech at annual summer meeting of Institution of Mechanical Engineers, Paris, 1889. Quoted in *Engineering,* July 5, 1889, vol. 48, p. 18.

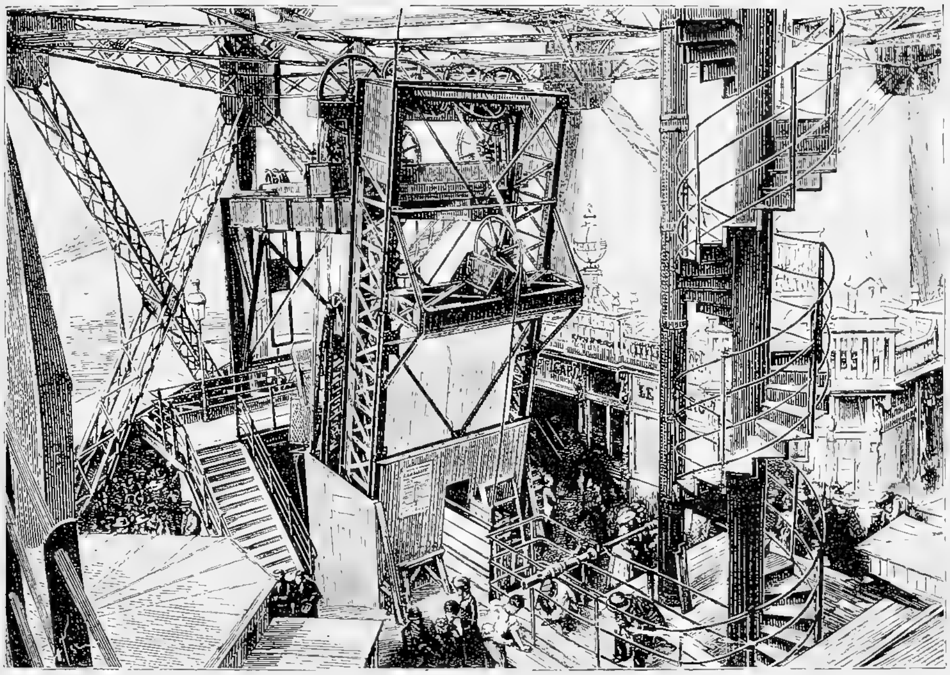

Figure 30.—Upperworks and passenger platforms of the Otis system at second level. (From *La Nature*, Aug. 10, 1889, vol. 17, p. 169.)

chines (which he did have faith in) . . . and if the others ate up coal in proportions greatly in excess of ours, he would have it to say . . . "Gentlemen, these are my choice of elevators, those are yours &c." There was a published interview . . . in which Eiffel stated . . . that he was to meet some American gentlemen the following day, who were to provide him with elevators—grand elevators, I think he said. . . .

The Roux and the Otis systems both drew their water supply from the same tanks; also, each system used similar distributing valves (fig.32) operated from the cars. Although no reports have been found of actual controlled tests comparing the efficiencies of the Otis and Roux systems, a general quantitative comparison may be made from the balance figures given for each (p. 40), where it is seen that 2,665 pounds of excess tractive effort were allowed to overcome the friction of the Otis machinery against 13,856 pounds for the Roux.

THE EDOUX SYSTEM

The section of the Tower presenting the least difficulty to elevator installation was that above the juncture of the four legs—from the second platform to the third, or observation, enclosure. There was no question that French equipment could perform this service. The run being perfectly straight and vertical, the only unusual demand upon contemporary elevator technology was the length of rise—525 feet.

The system ultimately selected (fig. 37) appealed to the Commission largely because of a smiliar one that had been installed in one tower of the famous Trocadero [13] and which had been operating successfully for 10 years. It was the direct plunger system of Leon Edoux, and was, for the time, far more rationally contrived than Backmann's helicoidal system. Edoux, an old schoolmate of Eiffel's, had built thousands of elevators in France and was possibly the country's most successful inventor and manufacturer in the field. It is likely that he did not attempt to obtain the contract for the elevator equipment in the Tower legs, as his experience was based almost entirely on plunger systems, a type, as we have seen, not readily adaptable to that situation. What is puzzling was the failure of the Commission's members to recognize sooner Edoux's obvious ability to provide equipment for the upper run. It may have been due to their inexplicable confidence in Backmann.

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[13] Located near the Tower, built for the Paris fair of 1878.

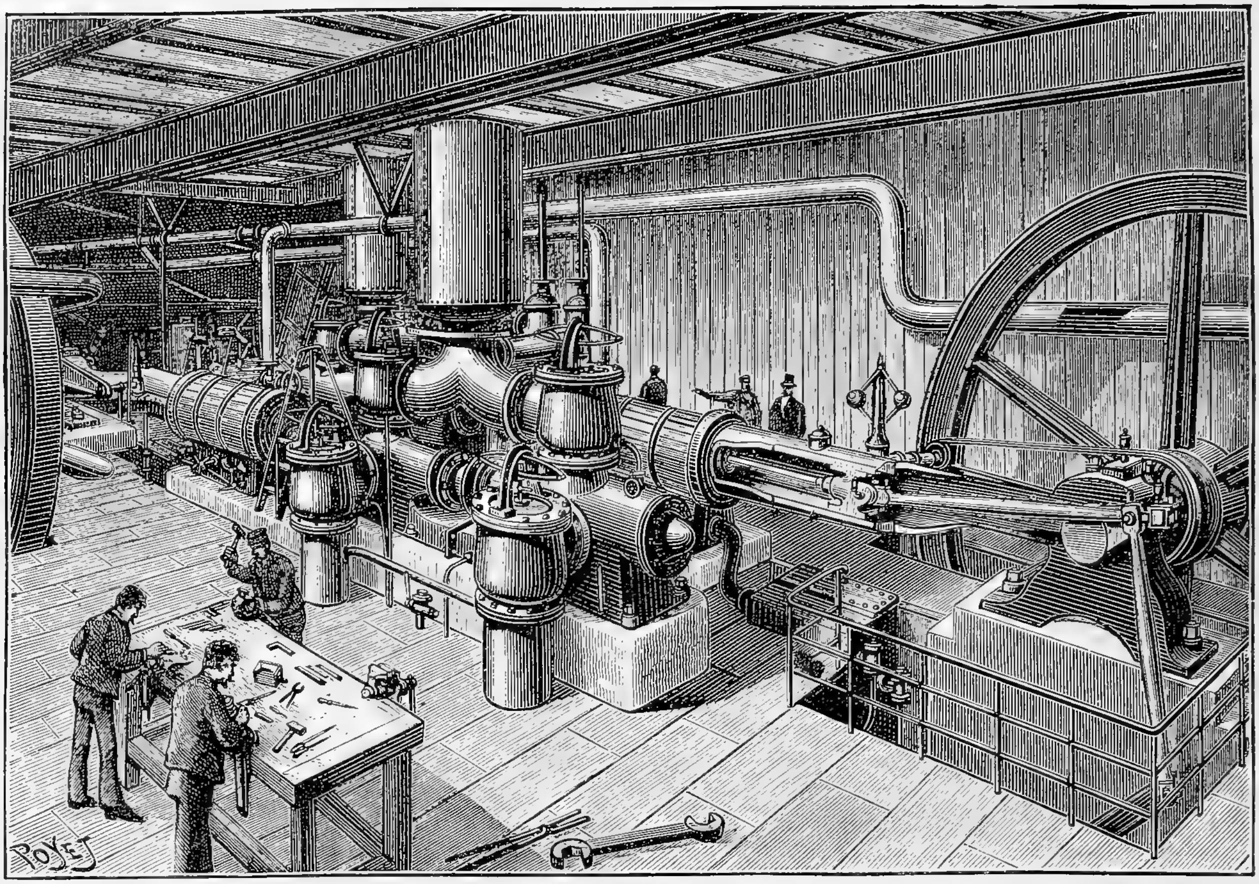

Figure 31.—The French Girard pumps that supplied the Otis and Roux systems. (From *La Nature*, Oct. 5, 1889, vol. 17, p. 292.)

The direct plunger elevator was the only type in which European practice was in advance of American practice at this time. Not until the beginning of the 20th century, when hydraulic systems were forced into competition with electrical systems, was the direct plunger elevator improved in America to the extent of being practically capable of high rises and speeds. Another reason for its early disfavor in the United States was the necessity for drilling an expensive plunger well equal in length to the rise.[14]

As mentioned, the most serious problem confronting Edoux was the extremely high rise of 525 feet. The Trocadero elevator, then the highest plunger machine in the world, traveled only about 230 feet. A secondary difficulty was the esthetic undesirability of permitting a plunger cylinder to project downward a distance equal to such a rise, which would have carried it directly into the center of the open area beneath the first platform (fig. 6). Both problems were met by an ingenious modification of the basic system. The run was divided into two equal sections, each of 262 feet, and two cars were used. One operated from the bottom of the run at the second platform level to an intermediate platform half-way up, while the other operated from this point to the observation platform near the top of the Tower. The two sections were of course parallel, but offset. A central guide, on the Tower's center-line, running the entire 525 feet served both cars, with shorter guides on either side—one for the upper and one for the lower run. Thus, each car traveled only half the total distance. The two cars were connected, as in the Backmann system, by steel cables running over sheaves at the

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[14] Improved oil-well drilling techniques were influential in the intense but short burst of popularity enjoyed by direct plunger systems in the United States between 1899 and 1910. In New York, many such systems of 200-foot rise, and one of 380 feet, were installed.

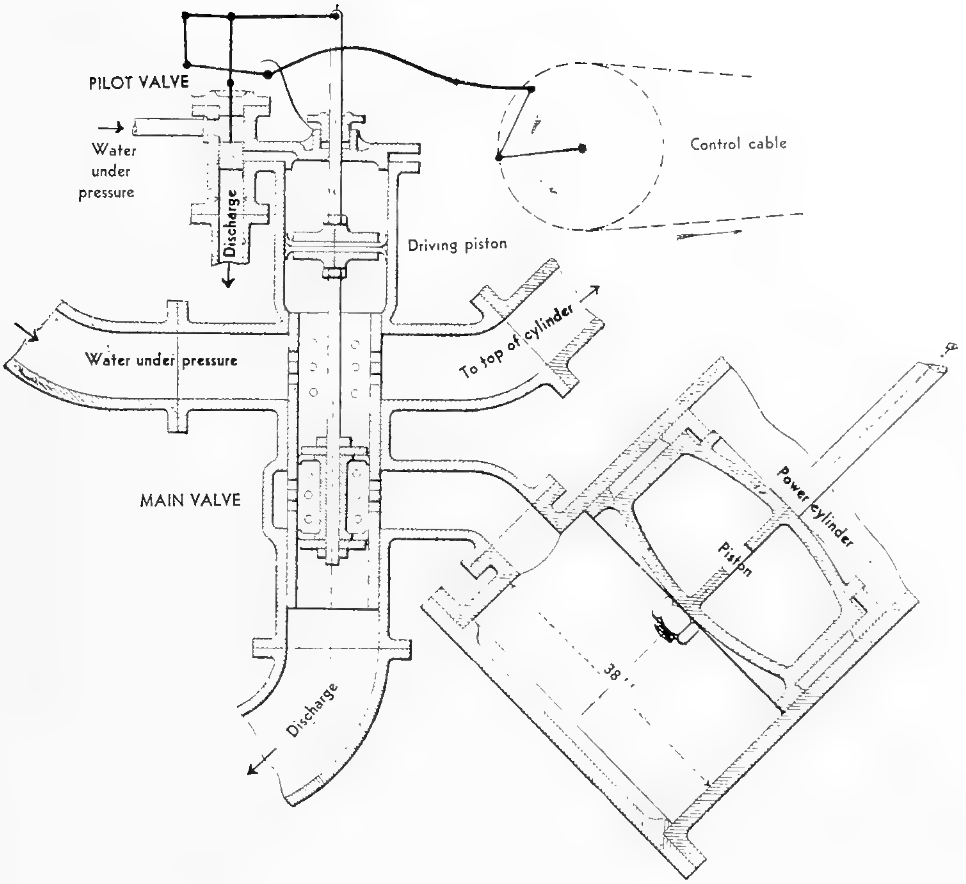

Figure 32.—The Otis distributor, with valves shown in motionless, neutral position. Since the main valve at all times was subjected to the full operating pressure, it was necessary to drive this valve with a servo piston. The control cable operated only the servo piston's valve. (Adapted from Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, p. 130.)

top, balancing each other and eliminating the need for counterweights. Two driving rams were used. By being placed beneath the upper car, their cylinders extended downward only the 262 feet to the second platform and so did not project beyond the confines of the system itself.[15] In making the upward or downward trip, the passengers had to change from one car to the other at the intermediate platform, where the two met and parted (fig. 39). This transfer was the only undesirable feature of what was, on the whole, a thoroughly efficient and well designed work of elevator engineering.

In operation, water was admitted to the two cylinders from a tank on the third platform. The resultant hydraulic head was sufficient to force out the rams and raise the upper car. As the rams and car rose, the rising water level in the cylinders caused a progressive reduction of the available head. This negative effect was further heightened by the fact that, as the rams moved upward, less and less of their

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[15] An obvious question arises here: What prevents a plunger 200 or 300 feet long and no more than 16 inches in diameter from buckling under its compressive loading? The answer is simply that most of this length is not in compression but in tension. The Edoux rams, when fully extended, virtually hung from the upper car, sustained by the weight of 500 feet of cable on the other side of the sheaves. As the upper car descended this effect diminished, but as the rams moved back into the cylinders their unsupported length was correspondingly reduced.

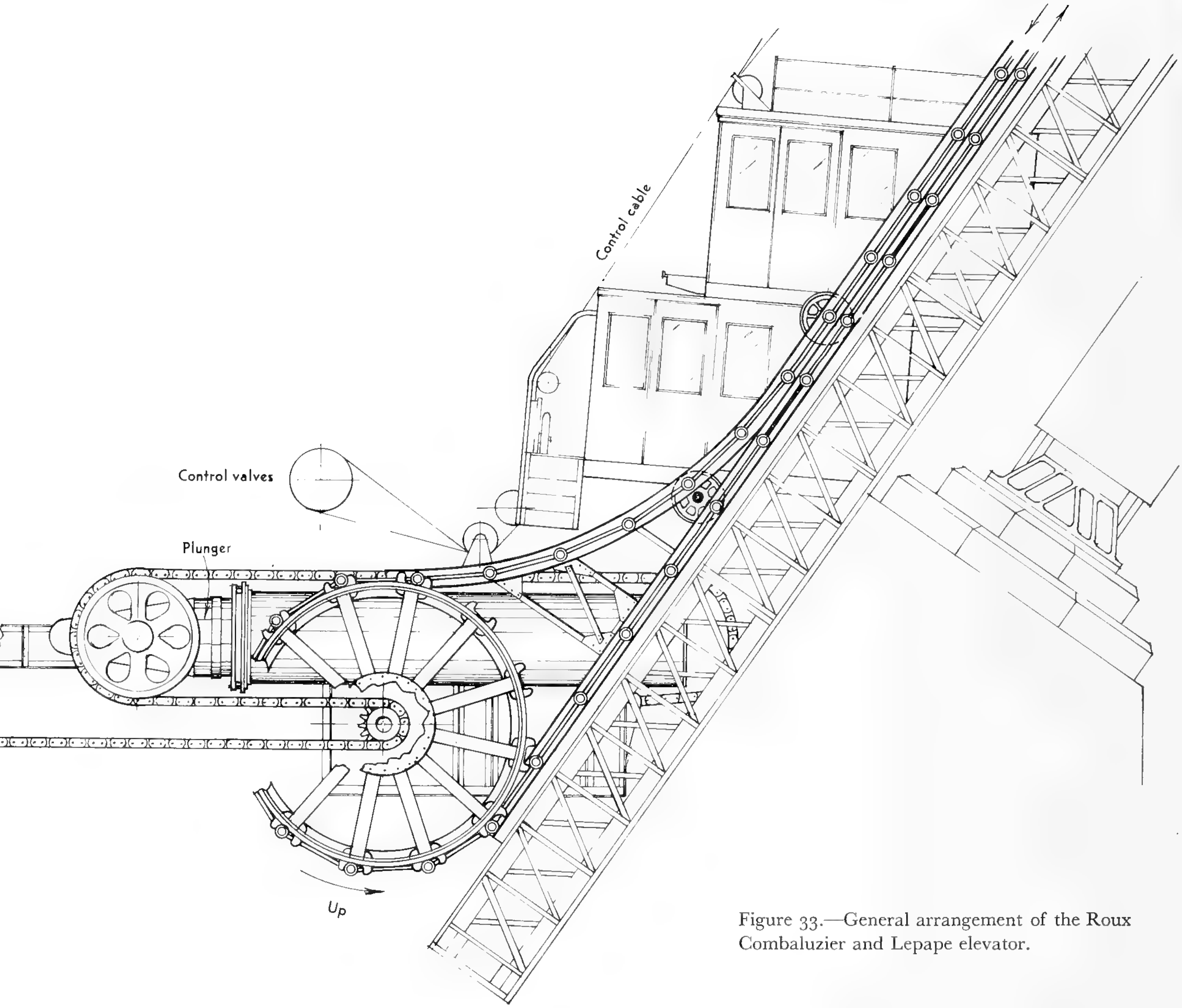
Control cable
Control valves
Plunger
Up

Figure 33.—General arrangement of the Roux Combaluzier and Lepape elevator.

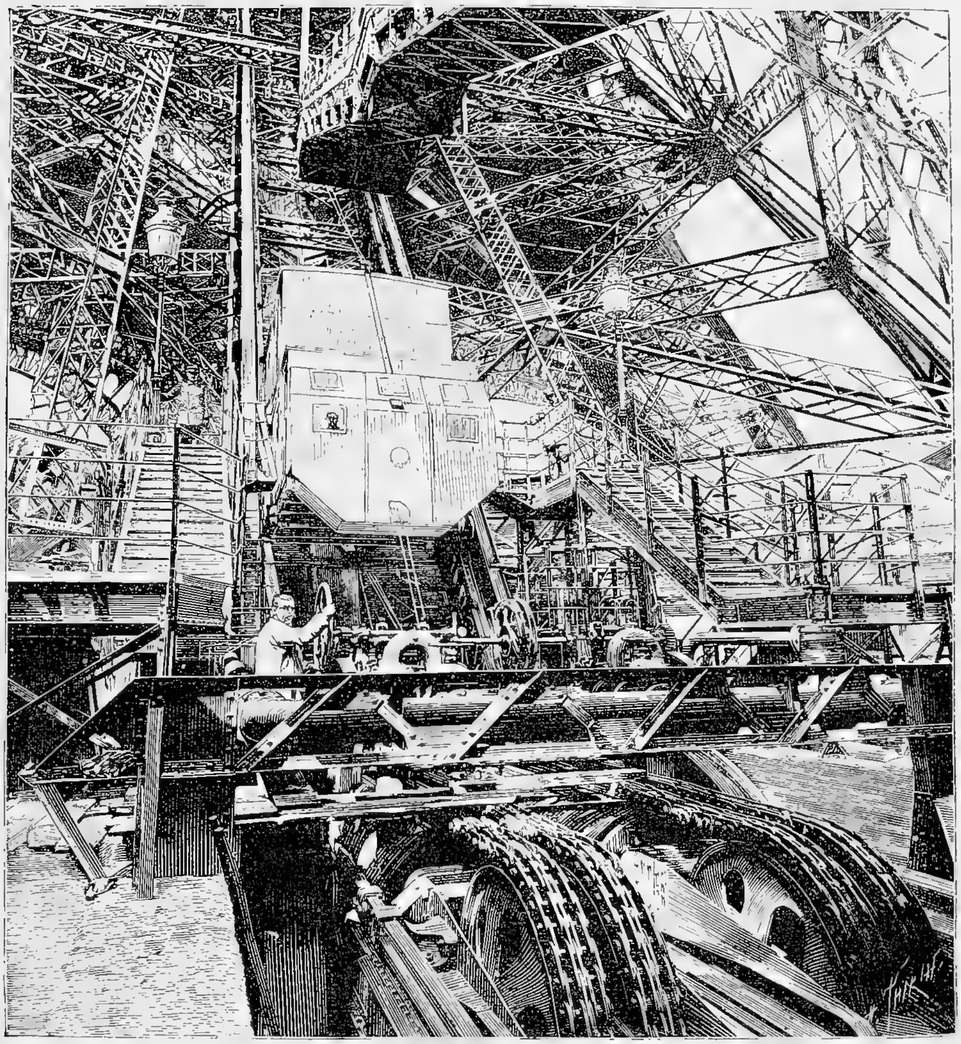

Figure 34.—Roux, Combaluzier and Lepape machinery and cabin at the Tower's base. (From *La Nature*, Aug. 10, 1889, vol. 17, p. 168.)

length was buoyed by the water within the cylinders, increasing their effective weight. These two factors were, however, exactly compensated for by the lengthening of the cables on the other side of the pulleys as the lower car descended. Perfect balance of the system's dead load for any position of the cabins was, therefore, a quality inherent in its design. However, there were two extreme conditions of live loading which required consideration: the lower car full and the upper empty, or vice versa. To permit the upper car to descend under the first condition, the plungers were made sufficiently heavy, by the addition of cast iron at their lower ends, to overbalance the weight of a capacity load in the lower car. The second condition demanded simply that the system be powerful enough to lift the unbalanced weight of the plungers plus the weight of passengers in the upper car.

As in the other systems, safety was a matter of prime importance. In this case, the element of risk lay in the possibility of the suspended car falling. The upper car, resting on the rams, was virtually free of such danger. Here again the influence of Backmann was felt—a brake of his design was applied (fig. 38). It was, true to form, a throwback, similar safety devices having proven unsuccessful much earlier. Attached to the lower car were two helically threaded vertical

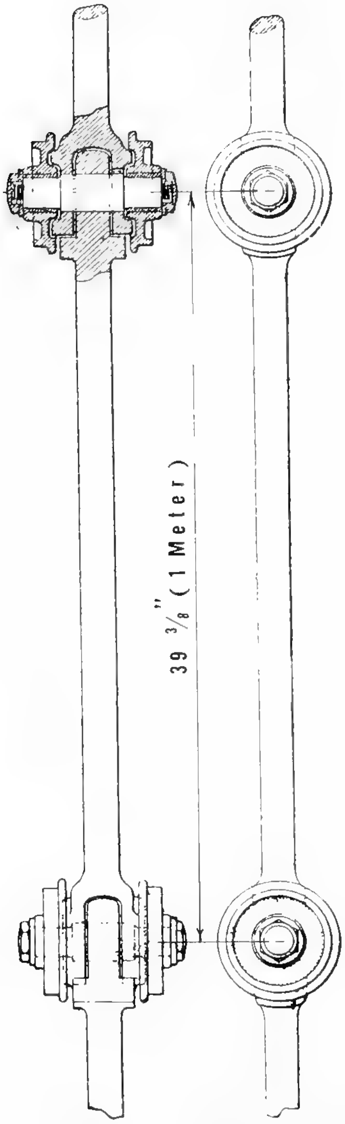

Figure 35.—Detail of links in the Roux system. (From Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, p. 156.)

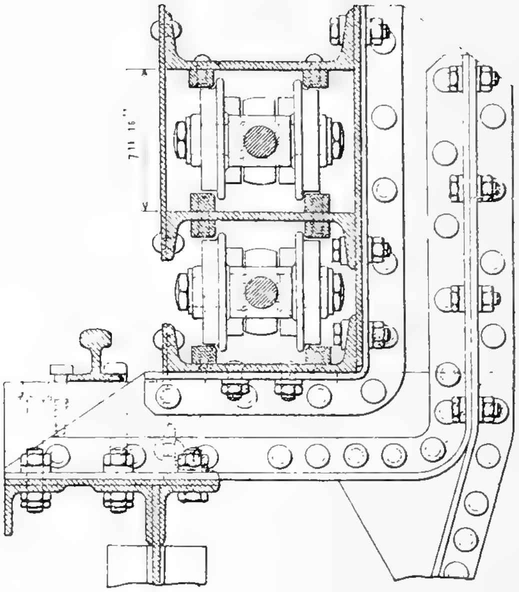

Figure 36.—Section of guide trunks in the Roux system. (From Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, p. 156.)

rollers, working within the hollow guides. Corresponding helical ribs in the guides rotated the rollers as the car moved. If the car speed exceeded a set limit, the increased resistance offered by the apparatus drove the rollers up into friction cups, slowing or stopping the car.

The device was considered ineffectual by Edoux and Eiffel, who were aware that the ultimate safety of the system resulted from the use of supporting cables far heavier than necessary. There were four such cables, with a total sectional area of 15.5 square inches. The total maximum load to which the cables might be subjected was about 47,000 pounds, producing a stress of about 3,000 pounds per square inch compared to a breaking stress of 140,000 pounds per square inch—a safety factor of 46![16]

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[16] M. A. Ansaloni, "The Lifts in the Eiffel Tower," quoted in *Engineering*, July 5, 1889, vol. 48, p. 23. The strength of steel when drawn into wire is increased tremendously. Breaking stresses of 140,000 p.s.i. were not particularly high at the time. Special cables with breaking stresses of up to 370,000 p.s.i. were available.

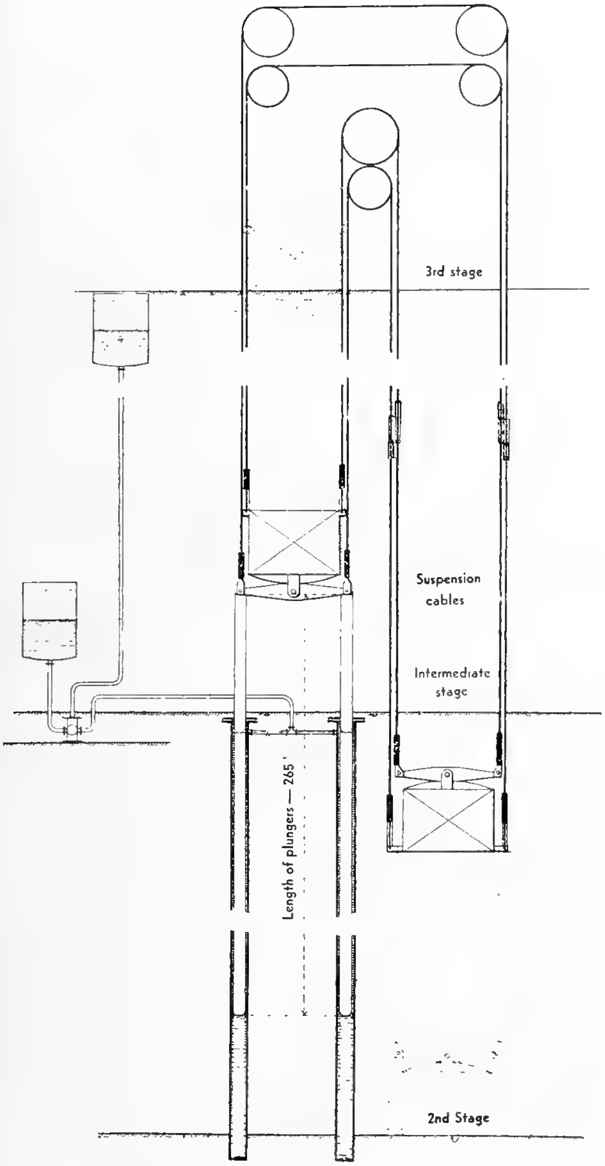
3rd stage
Suspension cables
Intermediate stage
Length of plungers — 265'
2nd Stage

Figure 37.—Schematic diagram of the Edoux system. (Adapted from Gustave Eiffel, *La Tour de Trois Cents Mètres*, Paris, 1900, p. 175.)

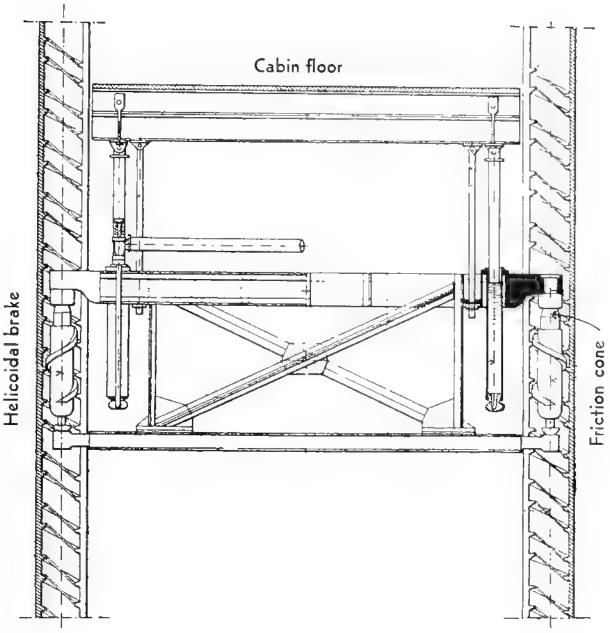
Cabin floor
Helicoidal brake
Friction cone

Figure 38.—Vertical section through lower (suspended) Edoux car, showing Backmann helicoidal safety brake. (Adapted from Gustave Eiffel, *La Tour Eiffel en 1900*, Paris, 1902, p. 12.)

A curiosity in connection with the Edoux system was the use of Worthington (American) pumps (fig. 40) to carry the water exhausted from the cylinders back to the supply tanks. No record has been found that might explain why this particular exception was made to the "foreign materials" stipulation. This exception is even more strange in view of Otis' futile request for the same pumps and the fact that any number of native machines must have been available. It is possible that Edoux's personal influence was sufficient to overcome the authority of the regulation.

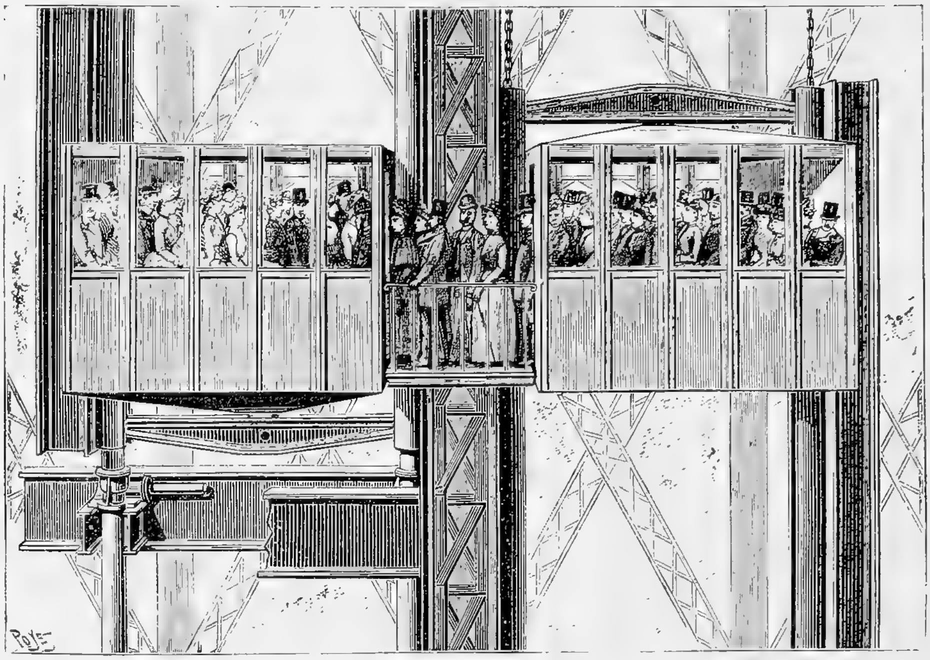

Figure 39.—Passengers changing cars on Edoux elevator at intermediate platform. (From *La Nature*, May 4, 1889, vol. 17, p. 361.)

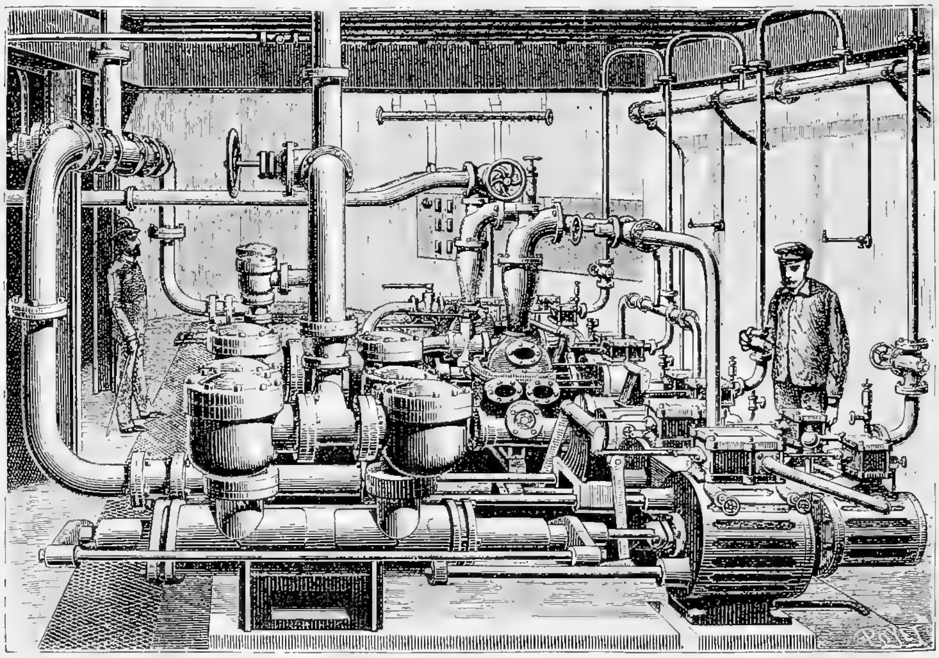

Figure 40.—Worthington tandem compound steam pumps, at base of the Tower's south pier, supplied water for the Edoux system. The tank was at 896 feet, but suction was taken from the top of the cylinders at 643 feet; therefore, the pumps worked against a head of only about 250 feet. (From *La Nature*, Oct. 5, 1889, vol. 17, p. 293.)

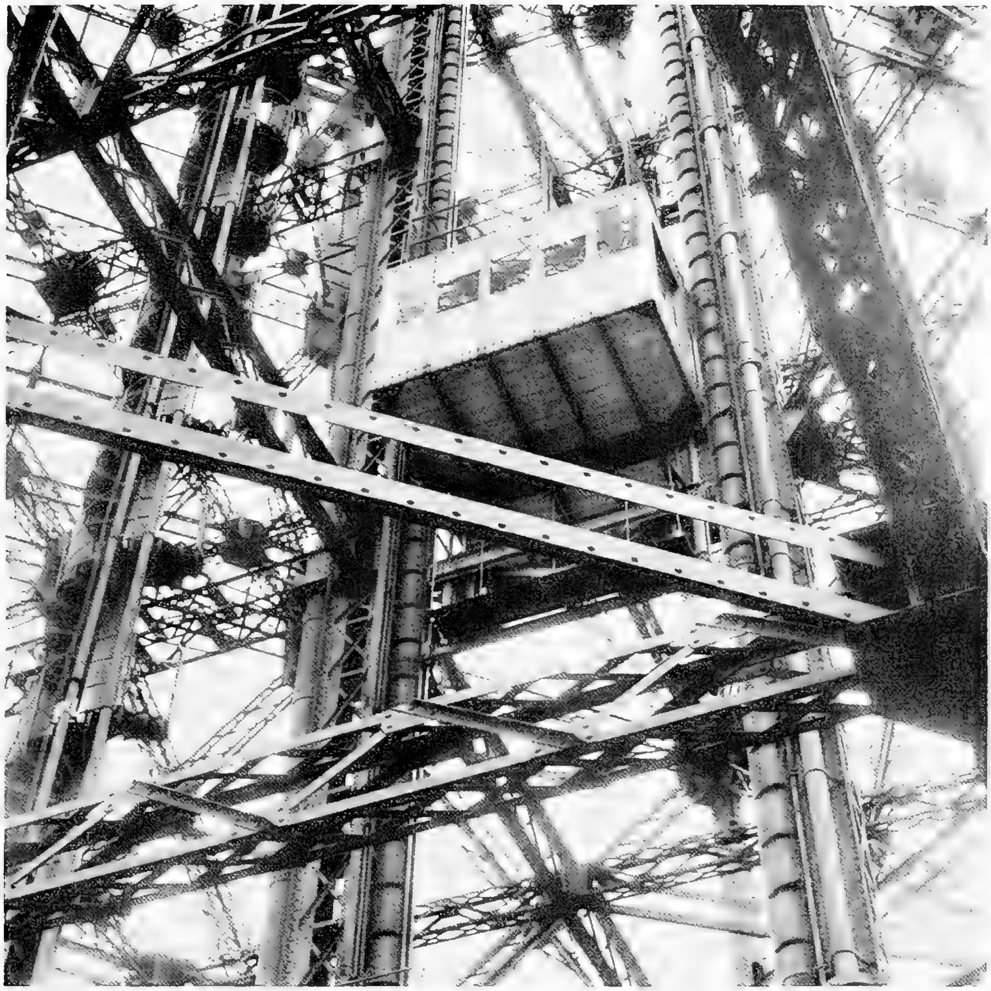

Figure 41.—Recent view of lower car of the Edoux system, showing slotted cylindrical guides that enclose the cables.

Epilogue

In 1900, after the customary 11-year period, Paris again prepared for an international exposition, about 5 years too early to take advantage of the great progress made by the electric elevator. When the Roux machines, the weakest element in the Eiffel Tower system, were replaced at this time, it was by other hydraulics. Built by the well known French engineering organization of Fives-Lilles, the new machines were the ultimate in power, control, and general excellence of operation. As in the Otis system, the cars ran all the way to the second platform.

The Fives-Lilles equipment reflected the advance of European elevator engineering in this short time. The machines were rope-geared and incorporated the elegant feature of self-leveling cabins which compensated for the varying track inclination. For the 1900 fair, the Otis elevator in the south pier was also removed and a wide stairway to the first platform built in its place. In 1912, 25 years after Backmann's startling proposal to use electricity for his system, the remaining Otis elevator was replaced by a small electric one. This innovation was reluctantly introduced solely for the purpose of accommodating visitors in the winter when the hydraulic systems were shut down due to freezing weather. The electric elevator had a short life, being removed in 1922 when the number of winter visitors increased far beyond its capacity. However, the two hydraulic systems were modified to operate in freezing temperatures—presumably by the simple expedient of adding an antifreezing chemical to the water—and operation was placed on a year-round basis.

Today the two Fives-Lilles hydraulic systems remain in full use; and visitors reach the Tower's summit by Edoux's elevator (fig. 41), which is all that remains of the original installation.

BALANCE OF THE THREE ELEVATOR SYSTEMS

The Otis System

Negative effect		
Weight of cabin: 23,900 lb.×sin 78°9′ (incline of upper run)	23, 390 lb.	
Live load: 40 persons @150 lb.=6,000×sin 78°9′	5, 872	
		—29, 262 lb.
Positive effect		
Counterweight: $\frac{55,000\times\sin 54°35' \text{ (incline of lower run)}}{3 \text{ (rope gear ratio)}}$	14, 940 lb.	
Weight of piston and chariot: $\frac{33,060\times\sin 54°35'}{12 \text{ (ratio)}}$	2, 245	
Power: $\frac{156 \text{ p.s.i.}\times 1,134 \text{ sq. in. (piston area)}}{12 \text{ (ratio)}}$	14, 742	31, 927 lb.
Excess to overcome friction		2, 665 lb.

The Roux, Combaluzier and Lepape System

Negative effect		
Weight of cabin: 14,100×sin 54°35′	11, 500 lb.	
Live load: 100 persons @150 lb.=15,000×sin 54°35′	12, 220	
		—23, 720 lb.
Positive effect		
Counterweight: 6,600×sin 54°35′	5, 380	
Power: $\frac{156 \text{ p.s.i.}\times 2 \text{ (pistons)}\times 1,341.5 \text{ sq. in. (piston area)}}{13 \text{ (ratio)}}$	32, 196	37, 576 lb.
Excess to overcome friction		13, 856 lb.

The Edoux System

Negative effect		
Unbalanced weight of plungers (necessary to raise full lower car and weight of cables on lower side)	42, 330 lb.	
Live load: 60 persons @150 lb.	9, 000	
		—51, 330 lb.
Positive effect		
Power: 227.5 p.s.i.×2(plungers)×124 sq. in. (plunger area)		56, 420 lb.
Excess to overcome friction		5, 090 lb.

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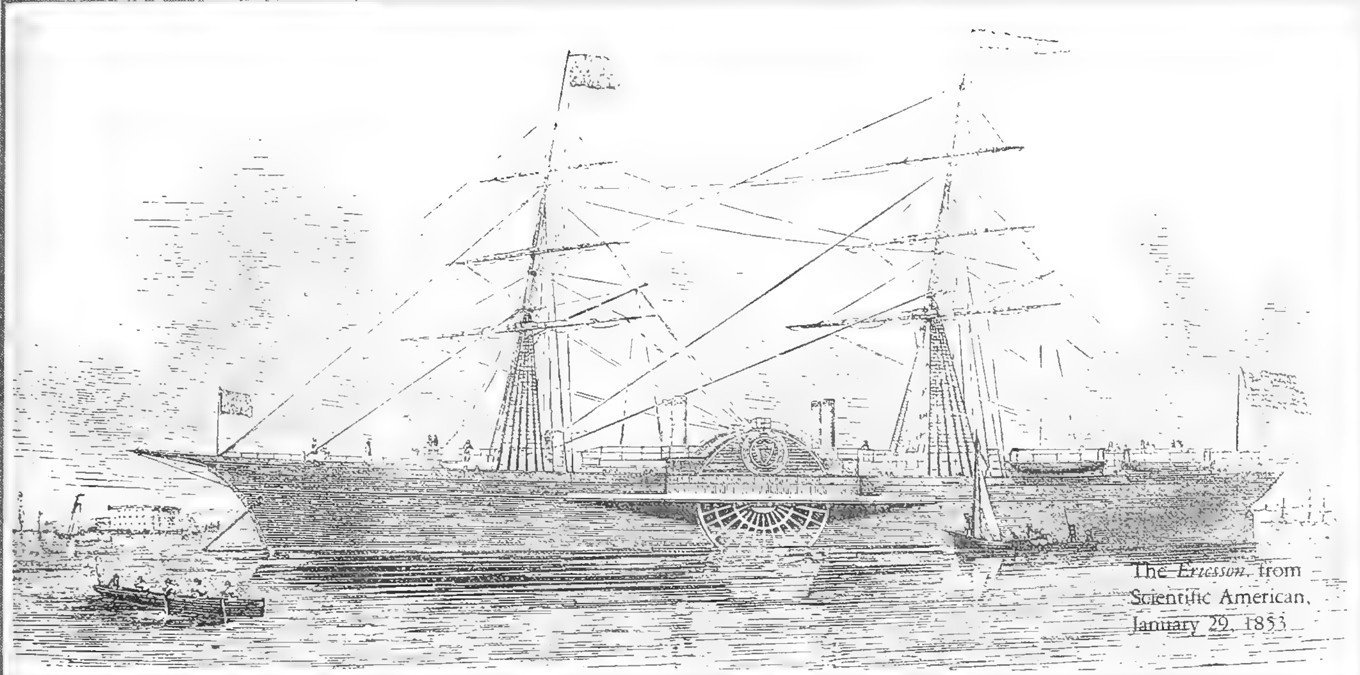
The *Ericsson,* from Scientific American, January 29, 1853

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PAPER 20

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John Ericsson and the Age of Caloric

Eugene S. Ferguson

In the middle of the 19th century John Ericsson built a ship powered by an enormous caloric engine that was expected to demonstrate his "grand principle," that heat—supposed by him and many others to be a material fluid—could be used over and over again as a substitute for fuel.

At a time when the relationship between heat and mechanical work was not entirely clear, the ship's trial run excited a storm of controversy.

A study of the details reveals the difficulties that beset the engineers and scientists who were striving to understand the laws of thermodynamics governing this relationship.

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In 1852 Capt. John Ericsson built the caloric ship *Ericsson*, intended for transatlantic service. The enormous caloric engine of the *Ericsson*, dwarfing even the largest of huge steam engines then in existence on land and sea, was heralded by the popular press as the precursor of a new era in power generation.

The caloric engine was a reciprocating air engine. Its distinctive feature, aside from its size, was a regenerator designed by Captain Ericsson to exploit his "grand principle," which said that caloric (heat) could be used over and over again to produce power. He did not claim to be the author of the principle, but he was its most ardent supporter.

Experience and intuition told many critics that there was a fallacy involved in Captain Ericsson's reasoning, but few of these critics could explain clearly and convincingly just why caloric could not be used more than once.

One might suppose that the caloric theory, in which a subtle elastic fluid called caloric was used to explain the observed phenomena of heat flow, had quietly expired when the mechanical equivalent of heat (one B.t.u.=778 ft.-lb.) had been determined in the 1840's. And no doubt the theory would have expired had not Captain Ericsson announced his support of it in such tangible form. If the *Ericsson* had not been built, it is likely that, as the emerging science of thermodynamics was reported in the journals of learned societies, only an occasional "hear, hear!" would have punctuated the gradual process of correction and clarification; on the other hand, we now should know a great deal less about the intellectual climate into which the new theories were being introduced.

The decade before the Civil War had more than its share of monumental engineering works. The Crystal Palaces in London and in New York, John Roebling's 800-foot Niagara span, the great iron ship *Great Eastern*, the Atlantic Cable, Pennsylvania's Horseshoe Curve, and the Collins Line steamships crossing the North Atlantic on a schedule that defied wind and tide, all were accomplishments that have

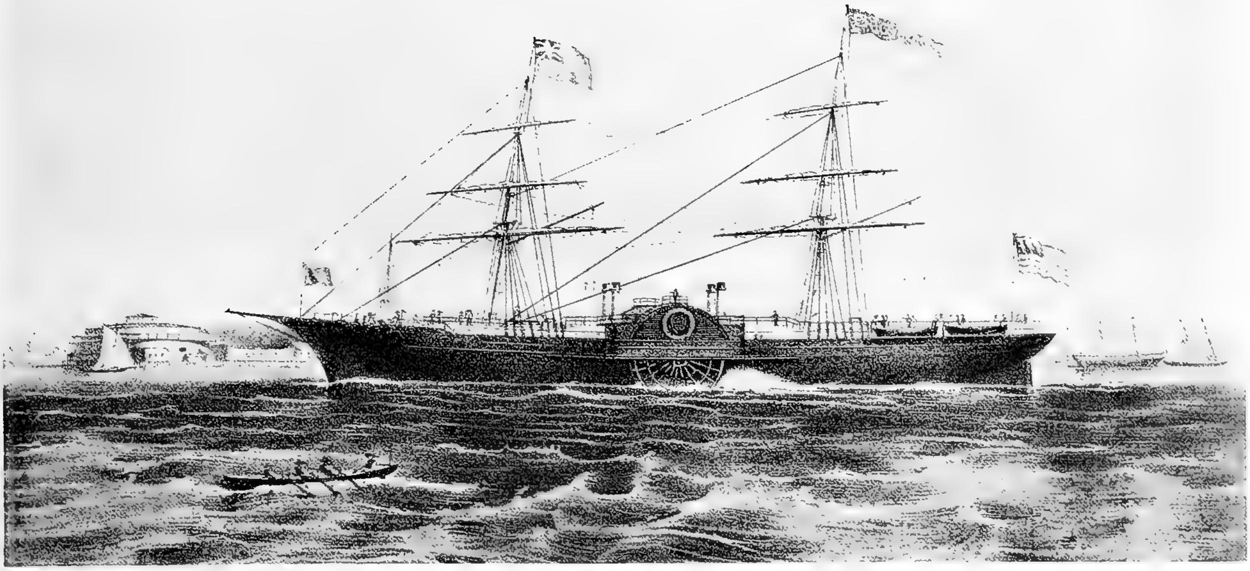

Figure 1.—The *Ericsson* in 1853, from a lithograph published by Sarony & Major, New York. (In United States National Museum.)

such a daring and audacious quality about them that they still move one to admiration. Not the least of such bold achievements was the building of the massive engine of the *Ericsson*. As noted by the *New-York Daily Tribune*, this caloric engine was shown to the world "on a scale unprecedented in the history of inventions." [1]

The *Ericsson* excited a great deal of attention, being the subject of spirited discussions on both sides of the Atlantic. In the course of explaining, debating, attacking, and defending the idea upon which the success of the enterprise depended, engineers and scientists stated, as best they could in the absence of a clear and satisfactory theory of heat, their understanding of the processes involved in the appearance of power at an engine's crankshaft.

It is the object of this article to explore the general state of the art and science of engineering thermodynamics at the middle of the 19th century as reflected by the particularly striking and revealing events and discussions revolving around John Ericsson's controversial ship.

The Builder

Born in Sweden in 1803, John Ericsson came to America in 1839 after an active engineering career of thirteen years in England. Best known for his building of the highly successful *Monitor* during the Civil War, he had earlier successfully promoted the application of the screw propeller to ship propulsion.

His innovations in the design of the railroad locomotive, steam fire engine, and steam engine may not have pointed the direction for the main stream of engineering advance, but his unceasing energy in producing and promoting new ideas unquestionably had a significant effect upon the course travelled by the main stream.

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[1] *New-York Daily Tribune*, January 12, 1853.

The *Ericsson* and Her Engine

The *Ericsson* was a finely modeled wooden ship about 250 feet long, with a beam of 40 feet and depth of hold of 27 feet. Her registered tonnage was 1,903. By way of comparison, the Collins Line ships were about 285 feet long, with a beam of 45 feet and tonnage of 2,750.

The four working cylinders of the engine, vertical and in-line, each 14 feet in diameter and having a stroke of 6 feet, were individually connected to four supply, or compressor, cylinders, each 11½ feet in diameter. A supply cylinder was located above each working cylinder. This ponderous air engine, with a working displacement two and a half times that of the largest steam engines, was connected to a crankshaft on which turned 32-foot paddle wheels at a speed of about 9 revolutions per minute.

No drawings of the *Ericsson's* engine were ever published, and Captain Ericsson's beautifully executed working drawings have not survived; however, the arrangement of each cylinder was similar to that shown in figure 3, which is a copy of the patent specification drawing of 1851.[2] A conjectural sketch of the arrangement of the driving mechanism is given in figure 5. Two sets of working and supply cylinders were forward of the paddleshaft and two sets were abaft of it. A pivoted horizontal working beam transmitted power from the two forward units through a connecting rod to the crank; a second working beam and connecting rod were provided for the after units. The two connecting rods shared a single crankpin.[3]

The device that was designed to make possible the repeated use of caloric was the regenerator. Each regenerator—one was provided for each cylinder—consisted of a chamber 6 feet high, 4 feet wide, and 1 foot thick. This space was filled with 150 sheets of iron wire mesh, which had about 10 wires to the inch in each direction; each wire was about a thirty-second of an inch in diameter.[4]

Atmospheric air was drawn into the upper cylinder as its piston moved downward, and the air was compressed as the piston rose. When a compression pressure of about 8 pounds per square inch was reached, the compressed charge was delivered to the receiver. The air from the receiver was then led through the regenerator, where it was warmed by the screen-wire packing of the regenerator, and into the working cylinder. The furnace beneath the working cylinder further heated the charge of air in the cylinder; the air expanded as it was heated and thus raised the piston of the working cylinder. Finally, the air in the working cylinder, after it had done its work on the piston, was exhausted through the regenerator. The exhaust air warmed the screen-wire packing, which was then ready to impart its energy to the next incoming air charge. Processes of the cycle are outlined in a series of sketches (figure 6), and the cycle is shown on pressure-volume and temperature-entropy coordinates in figure 7.

The remarkable feature of the engine, according to its designer, was the ingenious employment of the regenerator. In it, he said, the spent charge, being exhausted from the cylinder, deposited its caloric as it passed through on its way to the atmosphere. The caloric, lurking among the thousands of tiny spaces

Figure 2.—John Ericsson. (From a photograph by C. D. Fredericks & Co., New York; in division of mechanical and civil engineering, United States National Museum.)

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[2] U.S. Patent 8481, November 4, 1851.

[3] *American Journal of Science and Arts* [*Silliman's Journal of Science*], 1853, ser. 2, vol. 15, pp. 394–395.

[4] The size of the mesh is derived from conflicting evidence: *New-York Daily Times*, January 12, 1853; *Appletons' Mechanics' Magazine and Engineers' Journal*, 1853, vol. 3, pp. 38, 39, 92.

in the screen-wire packing, lay ready to be picked up by the incoming air charge as it passed from the receiver to the working cylinder. Thus, Ericsson maintained, the caloric could be used over and over again. The furnace was needed only to supply the inevitable losses of caloric by radiation and by the "heat lost by the expansion of the acting medium."[5]

How simple the idea appeared, and how attractive! Its implications were not clear to Captain Ericsson, but it will be found that the errors into which he fell were not yet plainly marked or easily explained. On the other hand, a substantial number of engineers and others recognized intuitively that he was, in fact, pursuing a will-o'-the-wisp.

The Trial of the *Ericsson*

The trial voyage, on Tuesday, January 11, 1853, was expected to supply the definitive answer to the questions and speculations that had been accumulating while, over a period of a year or more, the ship and her engine were being built. The information that had been parceled out to the press by Captain Ericsson concerning the caloric engines was accepted for the most part uncritically, and the community at large was prepared to see a revolution in power-plant practice take place in the protected waters of New York Bay.

An assemblage of perhaps 60 people was invited to be present. Editors or reporters of all the New York dailies, Freeman Hunt of the *Merchants' Magazine*, and, according to the *New-York Daily Times*, "a few gentlemen whose scientific abilities render them amply qualified to pronounce judgment upon a project fraught with such momentous results"[6] were taken on board the *Ericsson* at the Battery. One of the scientific gentlemen, Prof. James J. Mapes, consultant on brewing and agricultural chemistry and good friend of the inventor, was present as speaker at the sumptuous banquet that was to crown the festive occasion.

There was, however, one uninvited guest. Orson Munn, the 28-year-old editor of *Scientific American*, slipped on board unnoticed[7] and sounded the only jarring note in an otherwise solid and harmonious chorus of praise. Munn, a patent solicitor who used his paper's columns to promote the inventions of his clients, had not been invited for the reason that Captain Ericsson could hardly expect fair treatment by him, because Ericsson was not Munn's client.

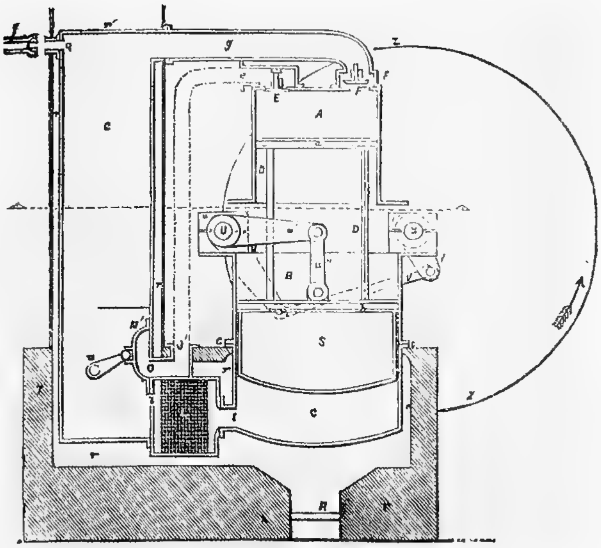

Figure 3.—Patent drawing of Ericsson's caloric engine, 1851. (From *Mechanics' Magazine*, London, July 19, 1851, vol. 55, p. 41.)

The harbor of New York was, as usual, a busy one. There were coastwise and harbor sailing craft, clippers bound out for California, transatlantic packet ships, and, as if to proclaim that the age of steam was here to stay, the Collins liner *Baltic* thrashed her way past the *Ericsson* at her usual 14 knots.[8]

The trial voyage took the *Ericsson* from the Battery to a point off Fort Diamond (now Fort Lafayette) in the Narrows, about 7 miles distant, and return. The ship was under way for about two hours and a half.

A well-planned program—one journal, whose editor was not invited, called it "a sort of 'sell' played off on the reporters"[9]—kept the gentlemen of the press occupied. There was a breakfast for those who had been hurried by the early hour of departure, and wine for those who had not. In the great cabin, Captain Ericsson, using a pasteboard working model, explained "in a very persuasive manner" how the engine worked, and why. When they were not otherwise occupied, the reporters could go down to the engine room, where their host capitalized on the low speed of the great engine by letting his guests embark upon the open tops of the 14-foot pistons. "Our sensation on riding up and down on these huge pistons," wrote one of the editorial riders, "we shall not soon forget."[10] Finally, there was a banquet, followed by speeches, toasts, and long and loud applause. The inevitable resolution, extolling the virtues of the caloric engine and its modest inventor, was drawn up by the committee appointed for the purpose, and its signing by nearly all hands closed the festivities for the day.

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[5] U.S. Patent 8481, November 4, 1851.

[6] *New-York Daily Times*, January 12, 1853.

[7] *Scientific American*, January 22, 1853, vol. 8, p. 149.

[8] *Scientific American*, March 5, 1853, vol. 8, p. 197.

[9] *Appletons' Mechanics' Magazine and Engineers' Journal*, May 1853, p. 117.

As the party scrambled ashore, irreverent editor Munn piped a "Vive la humbug!" Professor Mapes quickly plugged the shocked silence with his exclamation, "Here's a man proposing his own health!"[11]

Next morning, the papers gave their reports to the public. The *New-York Daily Tribune* led off with:[12]

> The demonstration is perfect. The age of Steam is closed; the age of Caloric opens. Fulton and Watt belong to the Past; Ericsson is the great mechanical genius of the Present and the Future.

The *New-York Daily Times* referred to the event as one "which will be held memorable in the ages yet to come."

The *Daily Times* also reported in detail the question and answer session that Captain Ericsson presided over during the trial trip. Some explanation of the uniformly laudatory tone of the press is to be found in the reporters' reactions to the inventor's replies. To anyone who might object to the fact that the ship made only 6½ knots (7½ statute miles per hour) while the Collins liners made 14 knots, it was made abundantly clear that

> . . . it was not intended on this occasion to exhibit the sailing qualities of this vessel; so that this rate of speed should be considered rather as the minimum than the maximum of her capability.

There were mechanical imperfections in the engines that Captain Ericsson was well aware of, he said, and they would be rectified. Besides, the power could be augmented by increasing the size of the cylinders. He had from the first wanted to make the cylinders 16 feet in diameter, but the constructors would not then attempt so large a casting. Now, said Captain Ericsson, Messrs. Hogg and Delamater (the constructors) would be glad to make 20-foot diameter cylinders "at their own risk." This pronouncement was met by "great applause." And when the Captain said that the trial "has exceeded my highest anticipations," the cabin rang with cheers.[13]

The *Scientific American's* treatment of the incident was on the whole reasonable. Editor Munn noted that "the designer and constructors of . . . [the] machinery have shown themselves to have long heads, and skilful hands. We have never seen anything to compare with the castings." He did, however, question the competence of the newspaper writers who were present on this occasion, stating that Captain Ericsson was "far more modest of what he has done than they are." He ventured the thought that "we cannot but think that the good opinion of one eminent practical engineer in favor of the hot air engine would be worth more than all the rest of the daily paper fraternity besides."[14]

In February the *Ericsson* made a round trip to Washington, a voyage of about 500 miles, at a speed variously reported as averaging 4.7 to 6.0 knots,[15] while the public was assured that "she made no attempt to try her speed on her way hither, that forming no part of the object of her voyage." The ship was visited in Washington by President Fillmore, President-Elect Pierce, and delegations from both houses of Congress. Captain Ericsson convinced the Secretary of the Navy that a large caloric frigate could be built that would attain a minimum speed of 10 knots with a maximum fuel consumption of 8 tons of coal in 24 hours. Accordingly, the Secretary asked the Congress to appropriate $500,000 to have Captain Ericsson build such a vessel.[16] Fortunately, the Committee on Naval Affairs quietly laid the request aside.

There was never any question about the fact that the caloric engine propelled the *Ericsson*. However, merely moving a ship was not enough. In order to compete successfully with existing engines the caloric engine had to move a ship at least twice as rapidly as it had done thus far, and this was clearly beyond its capacity.

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[10] *Ericsson's Caloric Engine; Articles . . . Taken from the Daily Journals of the City of New York*, Washington, 1853, p. 6.

[11] *New-York Daily Times*, January 12, 1853.

[12] *New-York Daily Tribune*, January 12, 1853.

[13] *New-York Daily Times*, January 12, 1853.

[14] *Scientific American*, January 22, 1853, vol. 8, p. 149.

[15] *Scientific American*, March 5, 1853, vol. 8, p. 197.

[16] *National Intelligencer*, Washington, February 25 and March 3, 1853.

When the inventor became convinced finally that the maximum rather than the minimum of the *Ericsson's* capability had been demonstrated, his financial backers underwrote for the ship a new caloric engine with smaller cylinders, to be operated at higher pressure. When this new engine was tried in New York Bay, with the ship performing beautifully and with no outside observers on board, "at the very moment of success—of brilliant success,"[17] a violent squall hit the ship. An open cargo door, open for the discharge of rubbish, allowed her to fill rapidly and she sank to the bottom. She was quickly raised; but, in spite of its announced success, the new engine was replaced by a steam engine. No public explanation was given by Captain Ericsson at this time for the abandonment of his caloric engine.

The caloric engine was claimed to be safer and vastly more economical than a steam plant. It was safer—there was no boiler to explode—but it is doubtful whether the caloric engine was more economical in pounds of fuel burned per horsepower hour output. When the additional bulk of the engine is considered, as compared to a steam power plant, it becomes evident why Captain Ericsson finally was forced to return to steam. If an air engine operating at the low pressures then attainable were made powerful enough to compete with a steam engine, its bulk would have exceeded the capacity of the ship's hull. In a later patent, for an "improvement in air-engines," Captain Ericsson referred to the caloric engine of the *Ericsson:* "Experience has demonstrated that the power of such engines will always be found insufficient for practical purposes."[18]

State of the Art

In his 1824 essay on work and heat, Sadi Carnot had observed that "in spite of the efforts of many enterprising souls to improve heat engines, and in spite of the satisfactory state to which engines have been brought, their theory is but little understood, and attempts to improve them are still guided nearly by chance."[19]

The situation was not materially different in 1852, although Carnot and his successors had developed the principles that led eventually to coherent and demonstrable statements of the laws of thermodynamics. The men who actually designed and built engines were not generally conversant with the latest findings of scientists. If occasionally an engineer waded through an English paper or the translation of a French or German work, the implications of the new ideas were seldom clear because the scientists themselves were groping for, but had not yet established, an orderly theory of heat.

Steam was the dominant motive power, and, both in power and in economy, steam engines were quite highly developed. In size, few exceeded the 2,290 horsepower engine of the Collins liner *Arctic* that consisted of two double-acting cylinders, each 8 feet in diameter with a stroke of 10 feet.[20] In economy, none exceeded the stationary Cornish pumping engines, which required about 2¾ pounds of coal per horsepower hour output.

In the 70 years since Watt's highly successful steam engines had been introduced, numerous attempts had been made to build a safer and more economical prime mover that could be used in their place.[21] There were two general lines of approach to the problem. The first involved the employment of a working fluid other than steam. The second aimed to conserve and utilize heat by internal combustion—that is, by burning fuel in the working space of the engine.

Alcohol, ether, and mercury—all of which have a lower heat of vaporization (requiring less heat to vaporize each pound of liquid) than water—were tried in numerous engines. The inventors assumed that the work done by each pound of vapor was the same for all vapors; therefore, vapor that could be generated with the least expenditure of heat would be the most desirable. In 1824 *Mechanics' Magazine* reported that Sir Humphry Davy had "discovered that the application of a certain gas, 15 times heavier than the atmosphere, to the mechanism of the steam engine, will produce a power fully equal to that which now results from the application of steam." [22] This gas (mercury ?) was not to be the successor to steam, however.

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[17] William Church, *Life of John Ericsson*, New York, 1890, vol. 1, p. 195.

[18] U.S. Patent 13348, July 31, 1855. For note on steam engines in the *Ericsson*, see *Mechanics' Magazine*, London, 1855, vol. 63, pp. 5–6. For outline of subsequent history of the ship, which survived until 1892, see Erik Heyl, *Early American Steamers*, 2 vols., Buffalo, 1956, vol. 2, pp. 79–80. For recent work on air-engine development, see *Philips Technical Review*, 1947, vol. 9, pp. 97–104, 125–134.

[19] Sadi Carnot, *Réflexions sur la Puissance Motrice de Feu*, Paris, 1824; reprinted in *Annales de l'École Normale Supérieure*, ser. 2, 1872, vol. 1, p. 396. Also available in English translation by R. H. Thurston as *Reflections on the Motive Power of Heat*, New York, 1890.

[20] John H. Morrison, *History of the American Steam Navy*, New York, 1903, p. 412.

[21] An excellent summary of the history is George H. Babcock's "Substitutes for Steam," *Transactions of the American Society of Mechanical Engineers*, 1885–1886, vol. 7, pp. 680–741.

A water-ether binary vapor cycle, often discussed, was made to do useful work by at least one builder. Steam, exhausted from a conventional steam engine, was condensed in a tubular heat exchanger, containing ether, that served as an ether boiler. The ether was then expanded in a separate working cylinder and condensed in a conventional surface condenser. Such a power plant was actually used about this time in a vessel plying the Mediterranean between Marseilles and Algiers.[23]

Dozens of internal combustion engines, in which the energy of fuel was imparted directly to the working medium, had been designed and tested since the time of Christiaan Huygens, who in 1680 tried to use gunpowder in a vertical engine cylinder. In the 1820's, Samuel Brown built in England a number of atmospheric gas engines in which an intermittent gas flame in the working cylinder heated air for each stroke of the engine. Instead of making use of the expansive force of the heated air, the designer arranged for the air to be cooled, and the vacuum thus produced enabled the atmosphere to do work on the outside face of the piston. Samuel Morey, in America, adapted the idea to a turpentine engine and added a carbureting chamber to evaporate and collect the combustible turpentine vapor. But the internal combustion engine in any form was not in general use by midcentury.

Heated air had been more successfully employed by compressing a charge of air in a compressor cylinder, heating the charge in a furnace, and delivering it under pressure to a working cylinder. James Glazebrook, an English engineer, when designing an air engine in 1797, noted the advantage of using the air exhausted from the working cylinder to assist the furnace in heating the next charge of air.[24] This was the idea of the regenerator, which in Captain Ericsson's caloric engine was to be referred to as the "grand principle." Robert and James Stirling, of Scotland, patented air engines in 1827 and 1840,[25] and for three years one of their engines supplied power for a foundry in Dundee.[26] A regenerator had been considered by the Stirlings as a necessary unit in each of their designs, and the 1840 improvement consisted of a separate "plate box," or regenerator, an imperfect version of the one finally adopted by Captain Ericsson.

Nor was Captain Ericsson a latecomer among air-engine designers. In 1826, in England, he had built an air engine with a separate vessel for heating the air, and a "refrigerator" for cooling it; while this engine would run, it could not be lubricated satisfactorily because of high air temperatures. It had no regenerator.[27] In 1833 Ericsson patented his first "caloric" engine (fig. 8), which had a regenerator in the form of a tubular heat exchanger.[28] In the ensuing discussion of the merits of the caloric idea as advanced by Ericsson, the celebrated Professor Faraday devoted one of his popular lectures to Ericsson's engine. The inventor probably was in the audience when the professor, at the outset of his lecture, declared that it had just occurred to him that the explanation that he had carefully prepared of the engine's principle was in error, and that at the moment he did not know why the engine worked at all.[29]

A host of other ideas for prime movers had been brought forward in the decades before 1850. Like the caloric engine, many of the engines would run and would do useful work; but of all the schemes for supplanting steam engines with superior prime movers, none had yet been able to show an economic advantage over conventional steam systems. It was on this shoal that many a promising device was grounded. The question of "Will it pay?" was one that had to be convincingly answered in the affirmative before an engine could be sold to a critical buyer. Let us look for a moment, then, at the actual performance of the caloric engines of the *Ericsson.*

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[22] *Mechanics' Magazine,* London, 1824, vol. 1, p. 68.

[23] *Practical Mechanics Journal,* London, 1853–1854, vol. 6, p. 217; W. J. M. Rankine, *A Manual of the Steam Engine,* ed. 15, London, 1902, p. 444.

[24] British Patent 2164, August 3, 1797.

[25] British Patents 5456, July 20, 1827, and 8652, October 1, 1840.

[26] *Minutes of Proceedings of Institution of Civil Engineers,* London, 1853, vol. 12, p. 600.

[27] *Ibid.,* p. 351.

[28] British Patent 6409, April 4, 1833.

[29] *Mechanics' Magazine,* London, March 1, 1834, vol. 20, p. 368.

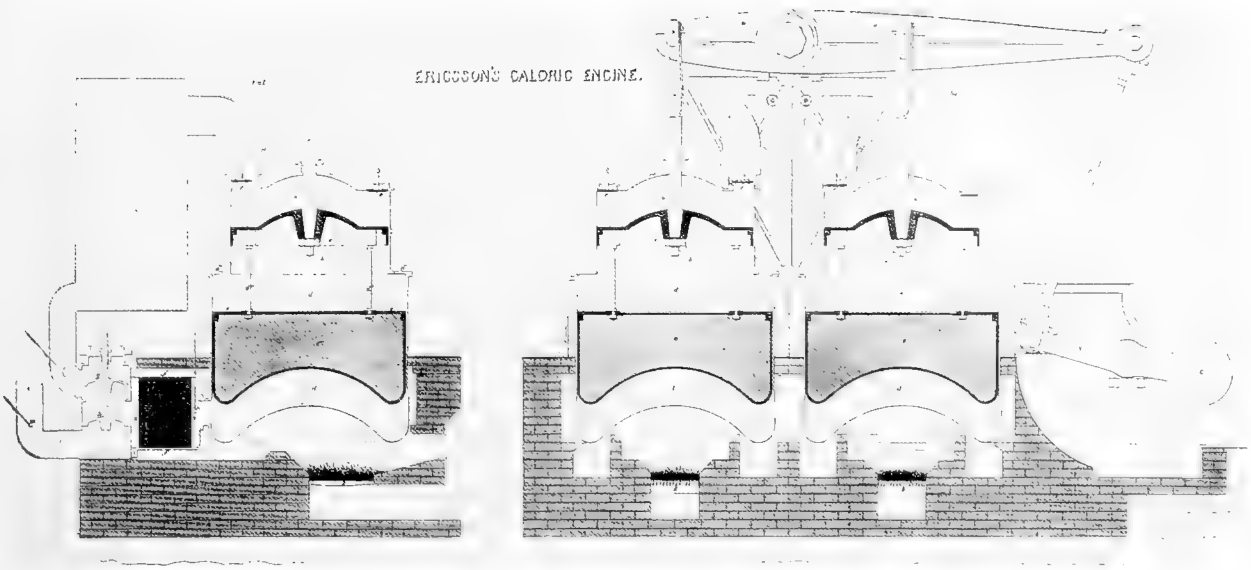

Figure 4.—Two-cylinder stationary test engine built before the engine for the *Ericsson* was started. Each working cylinder was 6 feet in diameter. The length of stroke was 2 feet. (From *Appletons' Mechanics' Magazine and Engineers' Journal*, February 1853, vol. 3, pl. 2.)

Performance Figures

Captain Ericsson never chose to subject his caloric engine to examination by a competent observer and he published no performance figures that exhibited evidence of their having been determined by an actual test of the engine.

When critics began to analyze the performance of the engine, using such data as they could find, and to publish their results, Ericsson was quick to question the motives, experience, ability, and conclusions of each writer, but he was not willing to give actual performance figures. Inadvertently, he gave a few data in his replies to his "detractors," and some indication of his understanding of thermodynamic principles was thus supplied.

Captain Ericsson particularly objected to the mathematical approach of Maj. John G. Barnard, which had been published serially.[30] Barnard—an Army engineer who had graduated from West Point in 1833 at the age of 18, ranking second in a class of 43—made a series of elaborate calculations; but even allowing for faulty data, his results were frequently in error. He became so involved in details that he was unable to sustain a convincing argument. However, he was well aware of the mechanical equivalent of heat, and stated clearly its application to the regenerative feature of the caloric engine. Captain Ericsson characterized Major Barnard's calculations as "symbolical mystification, the horror of all practical men—a mystification which smatterers invariably inflict on them," and proceeded to show, by diagrams and arithmetic, that the "theoretical power of the engine was 1313 horses."[31]

Major Barnard had concluded that the indicated horsepower of the caloric engine was 262.[32] Captain Ericsson, during his press conference in the *Ericsson*, had said it was 600. The *Scientific American* arrived at the preposterously precise figure of 244.572 horsepower. Various other calculations ranged from 116 to 316 horsepower.[33]

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[30] *Appletons' Mechanics' Magazine and Engineers' Journal*, 1853, vol. 3, pp. 82–86, 152–158, 217–221.

[31] *Ibid.*, pp. 121–122.

[32] *Ibid.*, p. 218.

[33] *Scientific American*, 1853, vol. 8, p. 149; *Mechanics' Magazine*, London, 1853, vol. 58, p. 170 [208 hp.]; *American Journal of Science and Arts*, 1853, ser. 2, vol. 15, p. 405 [316 hp.]; *Proceedings of the American Academy of Arts and Sciences*, 1852–1857, vol. 3, p. 29 [116 hp.]; *Minutes of Proceedings of Institution of Civil Engineers*, 1853, vol. 12, pp. 331, 348 [208 and 226 hp.].

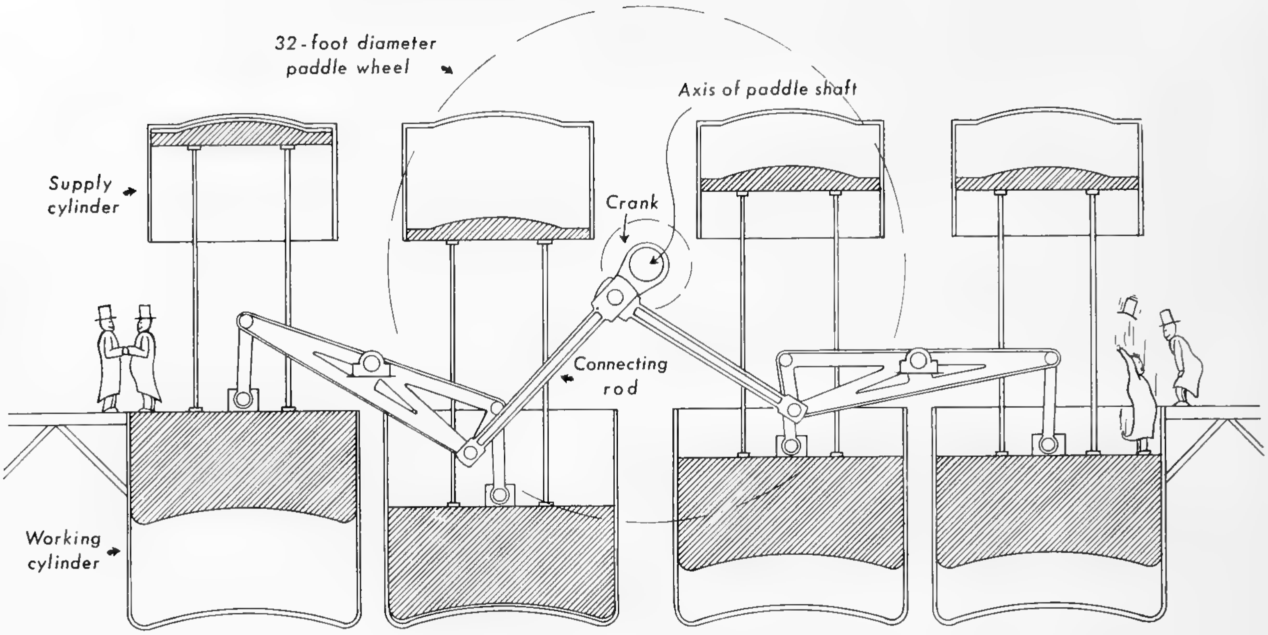

Figure 5.—Conjectural reconstruction of arrangement of driving gear in the *Ericsson*. Reporters at the trial run rode on the pistons.

A remark of Thomas Ewbank, sometime U.S. Patent Commissioner, became more and more pertinent as the acrimonious debate over the success or failure of the caloric engine continued. "Why theorize, argue and quarrel for months about the weight of a piece of metal," said Mr. Ewbank, "when the scales are at your elbows?"[34] A Prony friction brake dynamometer, although difficult to apply to the ship's engine, could have been used on the so-called 60-horsepower test engine that Captain Ericsson built before proceeding with the *Ericsson's* engine.[35]

The scales are no longer at our elbows, and I have found no complete nor entirely consistent set of data; but I have made a calculation based upon data that were published at the time,[36] making such assumptions as now appear reasonable and in every case weighting my assumptions in favor of the engine. The result, at nine revolutions per minute of the paddleshaft, is about 250 horsepower. My calculation is shown on pages 59 and 60.

A comparison, of sorts, can be made with the reasonably corroborated performance figures for marine steam engines.

The resistance of the *Ericsson*, in the speed range considered, probably varied more nearly as the cube of the velocity, as Prof. William Norton of Yale University assumed in his calculations,[37] than as the square of the velocity, as Ericsson believed. Therefore, an increase of speed from 6½ to 13 knots would require on the order of eight times the power output at 6½ knots; that is, nearly 2,000 horsepower. The *Arctic*, a larger vessel, developed 2,290 horsepower;[38] the *Washington*, about the same size as the *Ericsson*, developed 2,000 horsepower.[39]

Professor Norton, basing his calculations upon horsepower figures for several ocean-going steamers at various speeds, and taking into account the cross-sectional area of the vessels' hulls, estimated the horsepower that would be required to propel a vessel

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[34] *Journal of the Franklin Institute*, 1854, vol. 38, p. 33.

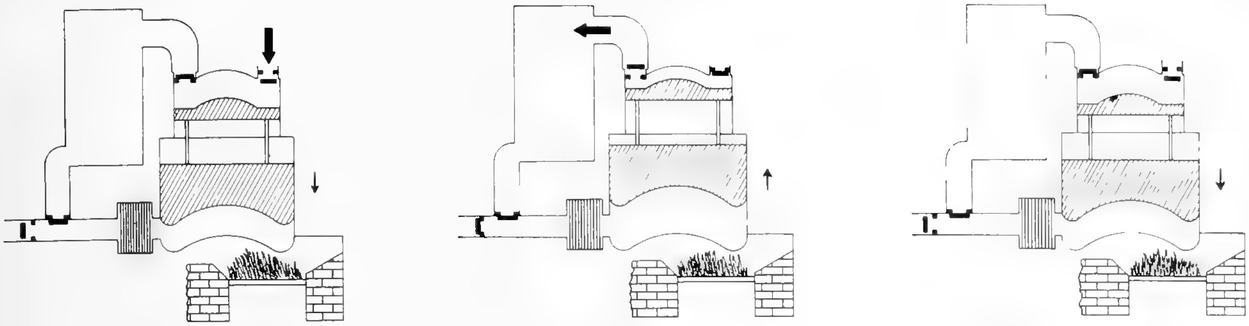
[35] A Prony brake, used to test a rotary steam engine, is described and illustrated in *Appletons' Mechanics' Magazine and Engineers' Journal*, 1852, vol. 2, pp. 26, 91. Such a brake was shown at the Mechanics' Fair in Boston and was reported in *North American Review*, January 1840, vol. 50, p. 227.

[36] The most complete listing is in *Appletons' Mechanics' Magazine and Engineers' Journal*, 1853, vol. 3, pp. 39–40.

[37] *American Journal of Science and Arts*, 1853, ser. 2, vol. 15, pp. 393–413.

[38] *Scientific American*, 1853, vol. 8, p. 189.

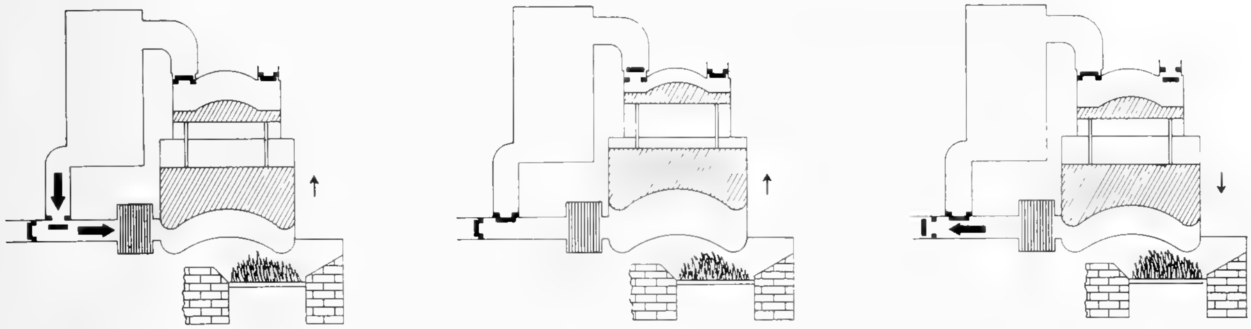
[39] *Scientific American*, 1846–1847, vol. 2, p. 85.



1. Fresh air enters supply cylinder as piston moves downward.

2. Compressed air flows from supply cylinder to receiver when piston nears end of upward stroke.

3. Compressed air remains in receiver during downward stroke of piston.



4. Compressed air flows through regenerator to working cylinder during first part of working stroke.

5. After cutoff, air in working cylinder expands as it receives heat from the furnace.

6. Hot air is exhausted through the regenerator to atmosphere.

Figure 6.—The successive processes of the caloric engine cycle. In each illustration the supply cylinder is above the working cylinder; the receiver is at upper left; and the regenerator is shown as the shaded rectangle below the receiver.

as large as the *Ericsson* at 6½ knots. His results ranged from 247 to 276 horsepower, suggesting again that the actual output of the caloric engine probably was on the order of 250 horsepower.

From the standpoint of fuel consumption, fairly reliable data were available for steamships, but no data were forthcoming for the *Ericsson.* Captain Ericsson said that the actual consumption of coal was 6 tons, and that his furnaces could not possibly burn more than 7 tons in 24 hours. When this statement—made when the ship had been in operation for only a few hours—was challenged, he raised his limit to 8 tons per day.[40] Using his figure for the area of grate surface, it would appear that a normal fire, burning with natural draft, might consume about 12 tons of coal per day.[41] A Collins liner, operating at 6½ knots, would be expected to burn about this latter amount of coal.[42]

The sort of testing to which Captain Ericsson's caloric engines were subjected is indicated by his description of his 60-horsepower engine, after which the *Ericsson's* engine was patterned:

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[40] *Appletons' Mechanics' Magazine and Engineers' Journal*, 1853, vol. 3, pp. 27, 92.

[41] Richard Sennet (*Marine Steam Engine*, ed. 2, London, 1885, pp. 88, 93) gave 21 pounds per hour per square foot as about the minimum consumption for a cramped boiler firebox.

[42] Thomas Tredgold, *Marine Engines and Boilers*, London, n. d., vol. 1, division B, p. 30; George H. Preble, *Chronological History of Steam Navigation*, Philadelphia, 1883, p. 320; *Mechanics' Magazine*, London, 1853, vol. 58, p. 324.

> After putting a moderate quantity of fuel in the furnace, it has been found that the engine works with full power for three hours without fresh feed, and after removing the fires entirely, it has frequently worked for one hour.[43]

The operation of the engine for an hour (under no load) with only the energy stored in the brickwork of the firebox attests merely to the excellence of the engine's construction. However, the phenomenon of an engine operating with no apparent external heat supply bolstered Captain Ericsson's belief in the efficacy of the regenerator. In reply to the objections of one of his critics, he confirmed his belief that "the regenerators are the principal heater," and that "the duty of the furnace will mainly be that of supplying heat lost by radiation, etc., which is no more at high than low speed." [44]

Small air engines, commonly called caloric engines, were built by the thousands in the latter years of the 19th century. These small engines were popular because they would operate without feed water and required little cooling water and little attention. Rated by manpower rather than horsepower ("altogether too high a standard for a Domestic Motor" [45]), the engines were used for pumping water, driving printing presses, and for many other tasks requiring moderate power. A propeller-type cooling fan, for parlor use, was powered by a caloric engine, the "Lake Breeze" fan being advertised as late as 1917.[46] The convenience, not the economy, made such an engine popular. The following statement, which appeared in the promotional literature [47] of the domestic air engine, typified Captain Ericsson's approach to the problem of engine performance:

> In regard to the quantity of fuel required by the new motor it need be only stated that in every trial made it has been found but a fraction of that required by an ordinary high pressure Steam Engine of equal power. Any definite statement on this head would involve the consideration of various kinds of fuel and demand a series of experiments which would be as costly as useless in view of the admitted great economy of the Caloric Engine.

The Grand Principle

"I am sanguine you know," wrote Captain Ericsson—his enthusiasm undampened and his beliefs unaltered more than a year after the caloric engine of the *Ericsson* had been abandoned—"and therefore expect confidently to succeed . . . with the dazzling principle which compels metallic threads to yield more force than mountains of coal." [48] These metallic threads, located in the regenerator, supposedly seized the caloric of the air being exhausted and held it until it could be taken up by the incoming air charge.

This grand principle was simplicity itself, according to Captain Ericsson, who said he could never understand why so many "men of talent repeatedly compromise their reputation by putting forth statements to the public, exhibiting their utter unacquaintance with this all-important property of the principal part of the caloric engine." [49]

Caloric, he said, could be used over and over again. And why not? Professor Cleghorn, at the University of Edinburgh, had said in 1779 that caloric was indestructible and uncreatable.[50] It was, according to the 1819 *Cyclopaedia* of Abraham Rees, "an elastic fluid sui generis, capable of pervading with various degrees of facility, all the solid bodies with which we are acquainted . . . ." The writer in the *Cyclopaedia* explained in detail the meticulous experiments of Count Rumford, which seemed to prove that caloric had no weight, but he dismissed Rumford's work as too gross, writing: "There may be an indefinite series of material substances, each a million times rarer than the preceding . . . ." The fact that it could not be weighed was no proof of its weightlessness.[51]

Appleton's *Dictionary of Machines* (1851) stated that "Caloric is usually treated of as if it were a material substance; but, like light and electricity, its true nature has yet to be determined."

Perhaps the oddest theory was that of a Mr. Wilder, which was published in *Scientific American* in 1847.[52]

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[43] *Appletons' Mechanics' Magazine and Engineers' Journal*, 1853, vol. 3, p. 38.

[44] *Ibid.*, p. 121.

[45] A circular dated November 5, 1857, and signed by John B. Kitching, Ericsson's financial backer for the engine in the *Ericsson* and subsequent caloric engines, *in* collection of Ericsson papers held by American-Swedish Historical Foundation, Philadelphia (hereinafter referred to as *Ericsson Papers*).

[46] Broadside, in data file, division of mechanical and civil engineering, United States National Museum.

[47] Circular. See footnote 45.

[48] Ericsson to Messrs. Stoughton, Tyler, and Bloodgood, January 16, 1855. *Ericsson Papers;* see footnote 45.

[49] *Appletons' Mechanics' Magazine and Engineers' Journal*, 1853, vol. 3, p. 123.

[50] Joseph H. Keenan, "Adventure in Science," *Mechanical Engineering*, May 1958, vol. 80, pp. 79–83.

[51] Abraham Rees, *Cyclopaedia*, London, 1819, "Caloric."

[52] Vol. 3, 1847–1848, p. 449.

"It has been proved," wrote Mr. Wilder, "that explosions in steam engines are the consequence of the escape of elementary caloric . . . ." This caloric, he went on, is an "*imponderable* fluid of incalculable velocity which will shatter to pieces everything that offers resistance to its progress in a certain direction." Editor Munn agreed with Mr. Wilder except in one detail: "We differ from Mr. Wilder in our opinion regarding what *his* caloric is. We believe it to be electricity."

The idea that caloric was an indestructible fluid was supported by a general belief that a given quantity of heat, used to generate steam for a steam engine, passed through the engine without any diminution in quantity. Carnot, in his 1824 treatise, made this assumption, although his notes indicate that he was not satisfied with this aspect of the caloric theory.[53]

Mechanics' Magazine,[54] of London, in 1852 explained why "the production of mechanical force by heat is unaccompanied by any loss of heat." The amount of heat contained in a given quantity of steam could be determined by condensing the steam in a water bath and noting the rise of temperature of the water. If the same quantity of steam were conducted to the water bath through a steam engine cylinder, the engine would produce useful work, and it would be found that the "*same* elevation of temperature will take place as when the steam was not previously employed" in the engine.

Captain Ericsson was not concerned with describing caloric, however. He intended to use it—over and over again.

Although Ericsson fostered the popular idea that the caloric was trapped in the interstices of the wire mesh—numbering some 50,000,000 "minute cells"[55]—and was to be given back to the next charge of air passing through the regenerator, a calculation shows that no such fanciful explanation is needed. The total volume of the iron in the wire mesh was nearly 5⅓ cubic feet.[56] When the regenerator reached equilibrium conditions, there would be a gradient of temperature from the cold end of the regenerator to the hot end. The cold end was probably about 120° F., while the hot end may have been close to the operating temperature of the working cylinder, about 480° F. Taking into account the specific heats of air and iron, it can be shown that any element of the regenerator would be heated and cooled by successive charges of air through a range of not more than fifteen degrees. Thus, the regenerator was of ample size to act as a heat exchanger, but a regenerator, unfortunately, could not, even under the influence of Captain Ericsson's sanguinity, seize caloric after it had done work and return it to the engine to be used over again.

The regenerative principle is widely used today in power plants. In gas turbine power plants, a heat exchanger is employed to heat air on its way from the compressor to the combustion chamber. The exhaust air from the turbine is the heating medium. In steam power plants, steam is bled off from the turbine at as many as eight different stages, to be used for heating feed water in shell-and-tube type heat exchangers. The purpose of the regenerator is to reduce irreversible heating of the working medium; that is, to use a source of heat only slightly above the temperature of the medium being heated. Several engineers in Captain Ericsson's time recognized that the regenerator could utilize heat that would otherwise be wasted, but not heat that already had done work.

Other contemporaries of Ericsson were not troubled by any such niceties. Professor Harvefeldt, of Sweden, who may have been the one who planted the seed of the caloric engine, was quoted as having said in a lecture, attended by the young John Ericsson, that "there is nothing in the theory of heat which proves that a common spirit-lamp may not be sufficient to drive an engine of a hundred horsepower." [57]

John O. Sargent, confidant and solicitor for Captain Ericsson, had said in 1844 at a public lecture in Boston that "Ericsson's theory of heat is altogether in opposition to the received notion, that the mechanical force produced will bear a direct known proportion to the caloric generated . . . ." [58]

In the same vein, the editor of *Appletons' Mechanics' Magazine and Engineers' Journal* wrote: [59]

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[53] Carnot, op. cit. (footnote 19).

[54] Vol. 56, p. 449.

[55] *New-York Daily Times*, January 12, 1853. Also, see footnote 57.

[56] See footnote 4. No calculation of volume was made in 1853.

[57] *Appletons' Mechanics' Magazine and Engineers' Journal*, 1852, vol. 2, p. 261.

[58] *Ibid.*

[59] *Appletons' Mechanics' Magazine and Engineers' Journal*, 1853, vol. 3, p. 117.

> There is a fundamental principle involved in the "regenerator" of Ericsson, Stirling, and others, which, could it be employed without drawbacks or losses, would allow one ounce of coal per day to pump out the Niagara river, and keep it dry.

Professor Pierce, in the American Academy of Arts and Sciences, said that he considered the idea that heat cannot be used over and over again to be a fundamental rule, which has only a single exception, that of steam . . . ." [60] Even the brilliant Lord Kelvin, as late as 1848, said: [61]

> The conversion of heat into mechanical effect is probably impossible, certainly undiscovered. . . . This opinion seems to be nearly universally held. . . . A contrary opinion, however, has been advocated by Mr. Joule of Manchester, some very remarkable discoveries which he has made . . . seeming to indicate an actual conversion of mechanical effort into caloric. No experiment is adduced in which the converse operation is exhibited . . . .

By 1853 Lord Kelvin had resolved his difficulty, but among practicing engineers the 1848 ideas persisted for many years longer.

The reason is quite understandable for the persistence of the belief that no heat was consumed in passing through a steam engine. Because of the low thermal efficiency of steam engines then in use (on the order of 2 to 5 percent) and the difficulty of measuring the quantities of heat involved, any discrepancy between the heat added to and removed from the steam cylinder was charged to a loss by radiation.

The carefully controlled experiments by Regnault in Paris finally established a measurable difference between the heat added to steam in a boiler and the heat rejected to a condenser. Regnault's results complemented those of Joule. Regnault showed that heat could be converted to work; Joule, that work could be converted to heat.

On reading very carefully the several patent specifications of Captain Ericsson, one will always find a clause that tends to prove that the inventor was not trying to get more energy from a fuel than it contained, but that he wanted merely to utilize the energy in its entirety. In his 1851 patent [62] appears the paragraph:

> Accordingly, while in the steam-engine the caloric is constantly wasted by being passed into the condenser or by being carried off into the atmosphere, the caloric is [in the caloric engine] employed over and over again, dispensing with the employment of combustibles, excepting for the purpose of restoring the heat lost by the expansion of the acting medium and that lost by radiation; also for the purpose of making good the small deficiency unavoidable in the transfer and retransfer of the caloric.

The phrase "heat lost by the expansion of the acting medium," if construed as the mechanical equivalent delivered to the working piston, acquits Captain Ericsson of the charge that he was proposing a perpetual motion device. But even this point is obscured by his statement, in another place, that the actual "loss of heat" by this expansion was "two ounces of coal per hour per horse-power." He used a heating value for coal of 11,000 British thermal units per pound.[63] Had he recognized the significance of mechanical equivalent of heat, which had been determined experimentally by Joule several years earlier,[64] he might have avoided the statement that ($\frac{1}{8}\times 11{,}000=$) 1,375 British thermal units of heat would produce one horsepower-hour (or 2,545 Btu) of work. There was so much conflicting evidence being published in the various technical journals at the time, however, that Captain Ericsson can perhaps be excused for not extracting from the welter of confusion the simple fact that was later recognized as the key to the First Law of thermodynamics.

But if Captain Ericsson did not attempt to violate the First Law, which is unlikely, it is certain that his theory of heat was in direct opposition to the Second Law of thermodynamics. If he accepted the conclusion of Regnault as fact, and admitted that 5 percent of the heat had been converted to work, he might immediately say: "Yes, but there is still a waste of 95 percent; I will recover that." There was, in 1853, no clear explanation why that was not possible.

The Second Law, in terms of everyday experience, says that heat will not, of its own accord, flow from a lower to a higher temperature. This leads to the corollary pertinent to the caloric engine: No heat engine, taking heat from a single source, can convert all the heat to work and produce no other effect.

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[60] *Proceedings of the American Academy of Arts and Sciences*, 1852–1857, vol. 3, p. 28.

[61] Quoted in Keenan, op. cit. (footnote 50), p. 82.

[62] U.S. Patent 8481, November 4, 1851.

[63] *Appletons' Mechanics' Magazine and Engineers' Journal*, 1853, vol. 3, p. 38.

[64] The order of development is tabulated in *Minutes of Proceedings of Institution of Civil Engineers*, 1853, vol. 12, p. 574.

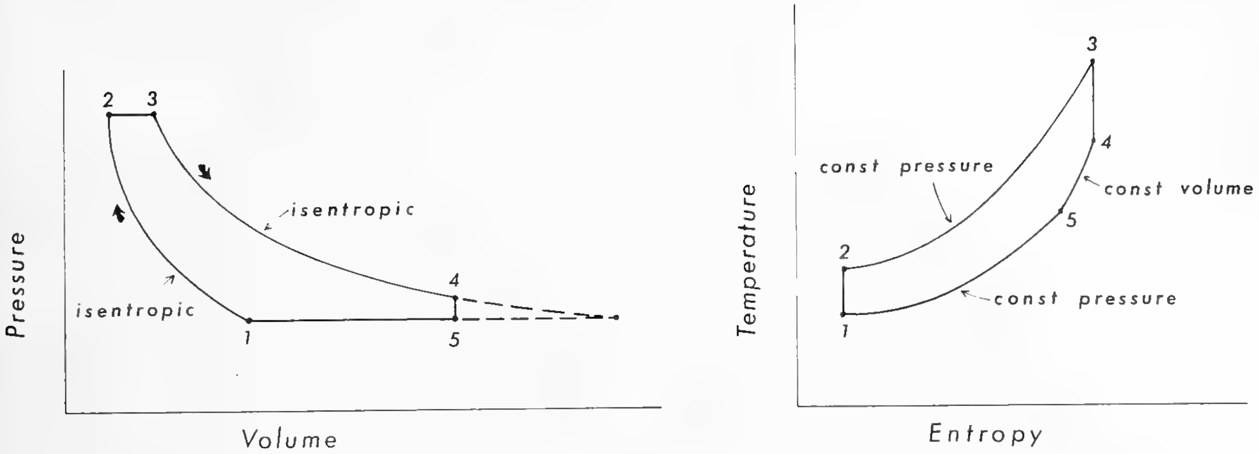

Figure 7.—Idealized caloric engine cycle, thermodynamically similar to the Stirling air engine cycle and to the modern gas turbine cycle. The toe (dotted) of the *p-v* diagram can be approached in the gas turbine cycle, while the constant volume expansion 4–5 is necessary in the reciprocating air engine cycle because of limitations on maximum cylinder volume.

That is, part of the energy supplied to the working cylinder can be converted to work, and only part of it, whether or not a regenerator is used. The portion of energy that can be converted depends upon the temperature at which heat is added to the working medium (source temperature) and the temperature at which heat is rejected to a condenser or the atmosphere by the working medium (receiver temperature). Under the operating conditions of the caloric engine of the *Ericsson*, the maximum convertible portion of heat to work was about one-third, and it is probable that the actual conversion was more like one-sixteenth.

It is not surprising that Ericsson was snared by the Second Law, which had only just been stated in English by Lord Kelvin, who properly credited Carnot and Clausius with the necessary ideas. It was to take another generation of intellectual struggle to get the two laws and their implications arranged in an intelligible form.[65]

The views and beliefs of many of Captain Ericsson's American contemporaries have already been indicated. An accurate appraisal of the ideas of other practicing engineers in the United States cannot be made because there existed in 1853 no association of engineers competent to discuss the caloric engine. However, the British Institution of Civil Engineers devoted at least three of its weekly meetings in 1853 to a "calm and deliberate discussion" of the caloric engine.[66]

Sir George Cayley, an elderly member of the Institution who for half a century, off and on, had been working on an air engine of his own design, was not dismayed by the idea that perpetual motion was involved in the caloric argument. A billiard ball on a smooth surface would, he pointed out, roll on forever if friction did not intervene. The escape of heat in the caloric engine resembled friction. He was confident that, if the practical difficulties such as radiation losses and destructively high metal temperatures could be overcome, the regenerative principle was capable of reducing the consumption of fuel "to an infinitesimal quantity."[67]

At the other extreme, Mr. Hawksley, another member, stated flatly that "the machine involved a mechanical fallacy, as the regenerator produced no mechanical effect whatever." Air passed and repassed the regenerator as a result of the movement of pistons; therefore the regenerator could not be the cause of the pistons' movement. He conceded that the engine would run, but, he said, "no part of these results were, however, produced by the regenerator but, on the contrary, simply by the coal consumed under the cylinder bottom. . . ."[68]

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[65] Keenan, op. cit. (footnote 50).

[66] *Minutes of the Proceedings of Institution of Civil Engineers,* 1853, vol. 12, p. 351.

[67] *Ibid.,* pp. 334–335.

[68] *Ibid.,* pp. 349, 593.

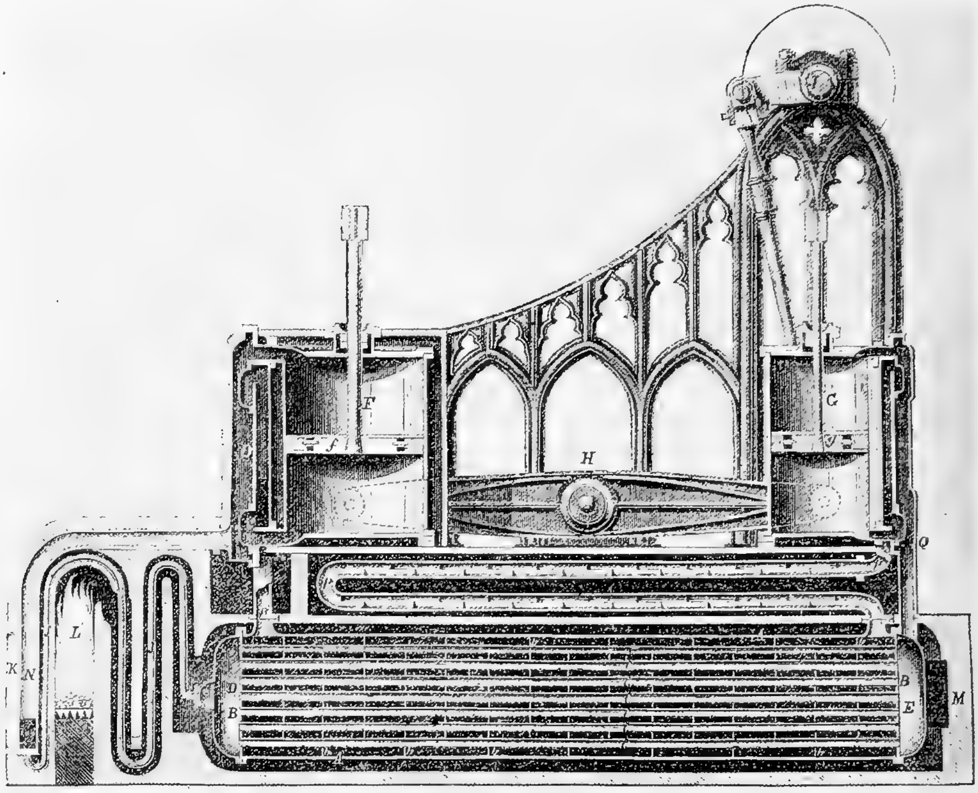
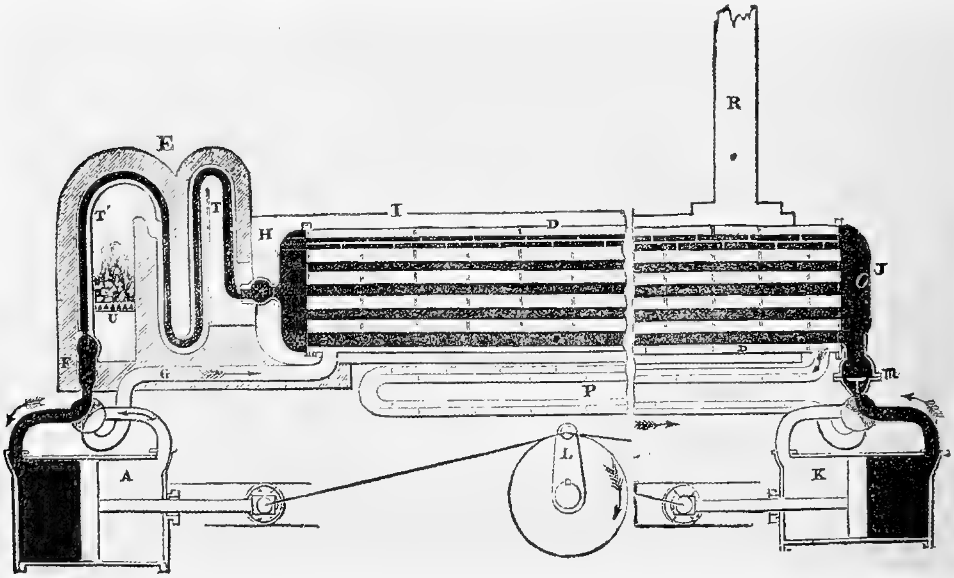


Figure 8.—Two versions of Ericsson's caloric engine, 1833. The same elements as used in the later engines—compressor, heater, regenerator, and working cylinder—are present in this earlier version of the caloric engine, designed while John Ericsson was in England. Aside from unsolved problems of lubrication, this engine, like others built by Ericsson, was promising so long as actual performance tests were not made. (Top, reproduced from wood engraving in *Scientific American*, Jan. 29, 1853, vol. 8, p. 153. Bottom, from *Mechanics' Magazine*, London, Nov. 9, 1833, vol. 20, p. 81.)



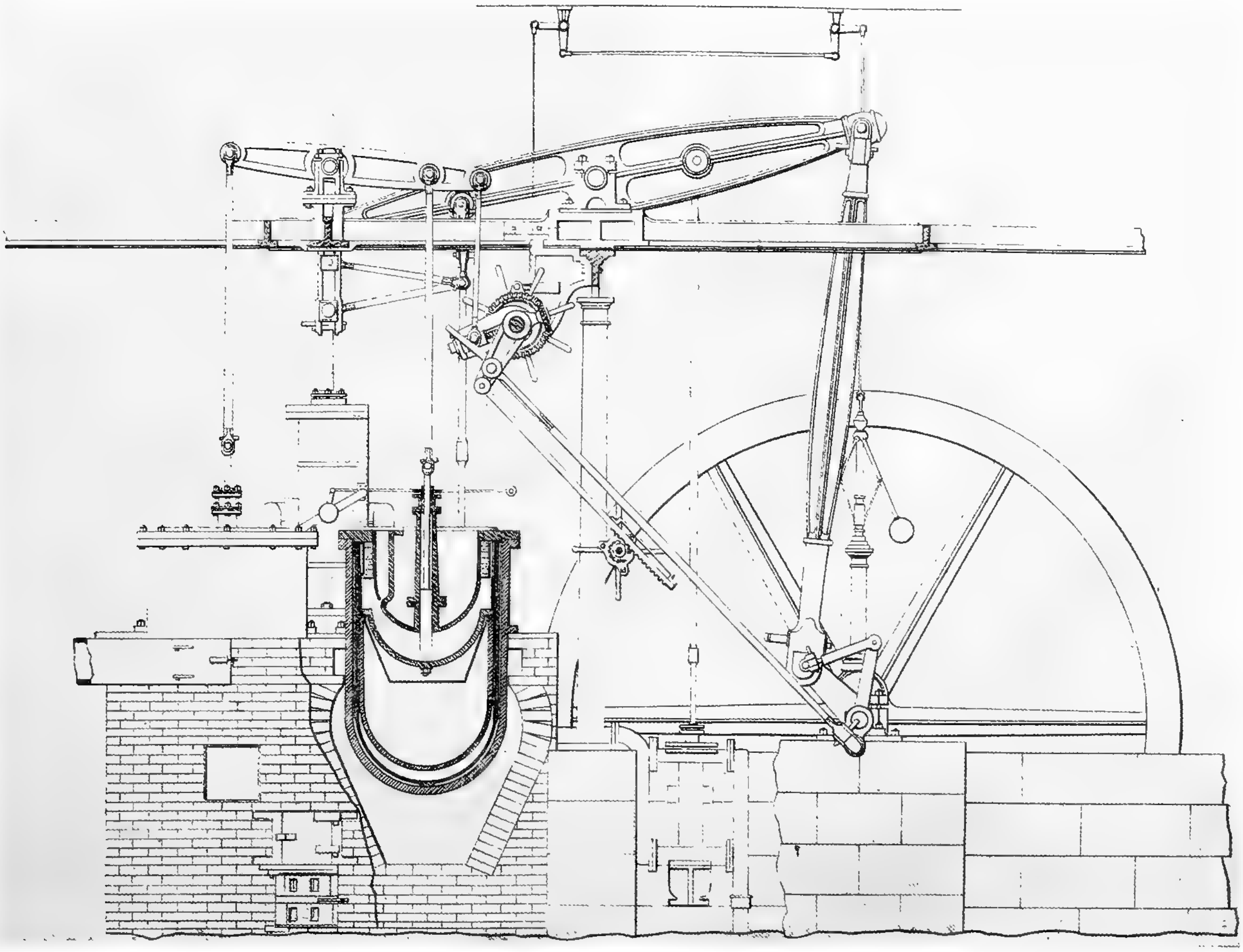


Figure 9.—Stirling air engine, 1845. Although the Stirlings had been experimenting with the regenerative cycle for nearly 30 years, their first practical engine was built around 1844. One of two air vessels is shown cut away. The air that is used as the working fluid is transferred alternately from the space above the displacer piston through the generator to the space below it; meanwhile, air is supplied to and returned from the working cylinder, shown between the two air vessels. (From *Minutes of Proceedings of the Institution of Civil Engineers*, 1845, vol. 4, pl. 24.)

Benjamin Cheverton, not as dogmatic as Mr. Hawksley, thought the principle of the regenerator faulty. He agreed that caloric was not consumed when work was produced, but he pointed out that "the change takes place, not in the quantity, but in the intensity of heat." He was groping in the direction of the concept of availability, and he was the first to admit that his argument was circumspect for "want of an adequate terminology." [69]

Captain Fitzroy, of the Royal Navy, sometime captain of the renowned *Beagle*, said that the chief argument against the imputed fallacy was the fact that the *Ericsson* had "actually been propelled . . . through the water." The relative economy of air and steam was, he said, "entirely another question." [70]

Karl Wilhelm Siemens—later Sir William, whose name is associated with the regenerative furnace for metallurgical purposes that he was soon to introduce—attempted to deal quantitatively with the question of economy. He had concluded that the "theoretical consumption of a perfect caloric engine amounted to only one-fourteenth part of the theoretical consumption of a Boulton and Watt condensing engine." He stated he believed that this economy was not practically attainable in the caloric engine, but that he was hard at work on a steam engine he hoped would approach the ideal.[71]

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[69] *Ibid.*, pp. 316–317.

[70] *Ibid.*, p. 350.

Professor Faraday recalled that he had, 20 years before, believed heated air might be used as a motive power, but even then he had, "with some diffidence, ventured to express his conviction of the almost unconquerable practical difficulties surrounding the case, and of the fallacy of the presumed advantages of the regenerator." He still retained his doubts.[72]

The vice president of the Institution, Isambard Kingdom Brunel, who at this time was completely engrossed with the details of planning his monumental ship *Great Eastern*, "agreed in considering the regenerator to be a mystification, and the difficulty of the matter arose from its plausibility. It was extremely difficult to disprove that which did not exist at all." It looked like perpetual motion to him, and he was "inclined to regard it just as he would any attempt to produce perpetual motion." [73]

Mr. Pole, a steam engineer, exhibiting perhaps more diplomacy than wisdom, made the observation with regard to the "so-called regenerator" that it would be found, "as in many other disputed cases, the truth lay between the extremes." [74]

The measure of the situation on both sides of the Atlantic was taken by F. A. P. Barnard, professor of chemistry and natural history at the University of Alabama. His comments appeared in *Silliman's Journal of Science:* [75]

> The confusion of thought which appears to prevail on the subject, is probably in a great degree owing to the fact, that the theory of heat, in its relation to force, has recently undergone a great and important change; so that men, who argue from its doctrines as taught twenty years ago, are liable to commit the most serious errors.

In 1855, when he was about to patent another version of his air engine, Captain Ericsson declared: "I yet contend that a mass of wire not greater than a common haystack will on this principle, some day, be found to yield more motive power than a mountain of coal." [76]

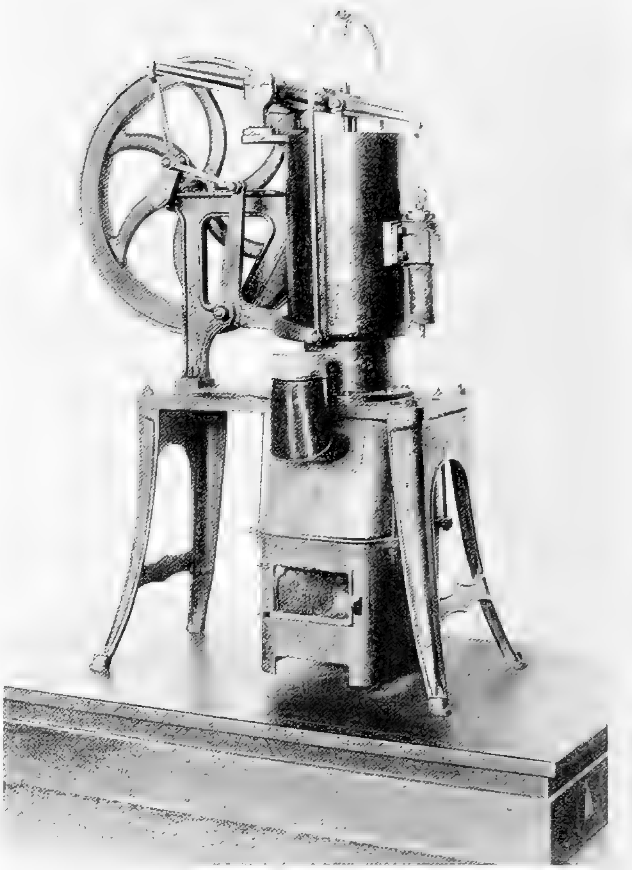

Figure 10.—This hot-air pumping engine, patented by Ericsson in 1880, is an example of the small domestic air engines, without regenerators, that were manufactured in large quantities from about 1860. The engine shown here—built by the Rider-Ericsson Engine Company as serial no. 18,637—measures 66 inches in over-all height. (USNM 309533; Smithsonian photo 39028–A.)

When Mr. Cheverton heard of the new engine, he stated his view of Captain Ericsson's work: [77]

> Mr. Ericsson certainly displays great talent in devising mechanical riddles wherewith to puzzle the engineering

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[71] *Ibid.*, pp. 345–346.

[72] *Ibid.*, pp. 348–349.

[73] *Ibid.*, p. 349.

[74] *Ibid.*, p. 594.

[75] *American Journal of Science and Arts* [*Silliman's Journal of Science*], 1853, ser. 2, vol. 16, p. 218.

[76] Ericsson to P. B. Tyler, January 17, 1855. *Ericsson Papers;* see footnote 45.

[77] *Mechanics' Magazine*, London, 1856, vol. 64, p. 82.

world. His ingenuity is unquestionable; but it is thrown away on inventions which betray, in a very remarkable manner, the absence of true philosophical conceptions of the physical ideas embodied in their operations; and their fallacies are so curiously concealed in his contrivances, that he is not only led astray himself, but many people are induced to follow him in pursuit of the *ignis fatuus* of his vagrant imagination.

Any careful student of Captain Ericsson's engineering activities—as distinguished from his promotional activities—must sympathize with Mr. Cheverton, even though he may not fully subscribe to his sentiment. Certain it is, however, that the epic of the *Ericsson* demonstrated dramatically, as no lesser undertaking could have done, the uncertain state of understanding of the principles of engineering thermodynamics in the 1850's.

ESTIMATE OF POWER DEVELOPED

The following calculations, based on approximate data, have been made to support my estimate of 250 horsepower output of the *Ericsson's* engine (page 50). The net work output at the paddle shaft is determined as the difference between the working cylinders' output and the input to the supply cylinders, reduced by factors to account for departure of the actual from idealized operating conditions.

The maximum design pressure of the engine was 12 pounds per square inch gage. The reports of the trial trip agree on 8 pounds per square inch as the attained pressure. I have found no evidence that a higher pressure was attained while this engine was in the ship.

The data upon which my calculations were based are as follows:

Working cylinders, single acting	
Number of cylinders	4
Diameter of each cylinder	14 ft.
Length of stroke	6 ft.
Supply (compressor) cylinders, single acting	
Number of cylinders	4
Diameter of each cylinder	11 ft. 5 in.
Length of stroke	6 ft.
Clearances (assumed)	0
Inlet air pressure (assumed)	14.5 p.s.i. abs.
Maximum air pressure in cycle, approx. 8.3 p.s.i. gage	23.0 p.s.i. abs.
Point of cutoff in working cylinder	¾ stroke
Working strokes per minute	9

The work output of a single working cylinder during one cycle of operation (one revolution) is represented in figure *a* by the area bounded by the p-v trace 1–2–3–4–5. Cylinder volumes at point of cutoff, v_3, and at end of stroke, v_4, are 680 and 906 cubic feet, respectively. Assuming isentropic expansion of air during process 3–4, p_4 can be shown to be 15.4 pounds per square inch absolute.

Work, W, for the individual processes is calculated as follows:

$$W_{1-2}=0 \qquad (1)$$

$$W_{2-3}=p_2(v_3-v_2)=23.0\times 144(680-0)$$
$$=2,250,000 \text{ ft. lb.} \qquad (2)$$

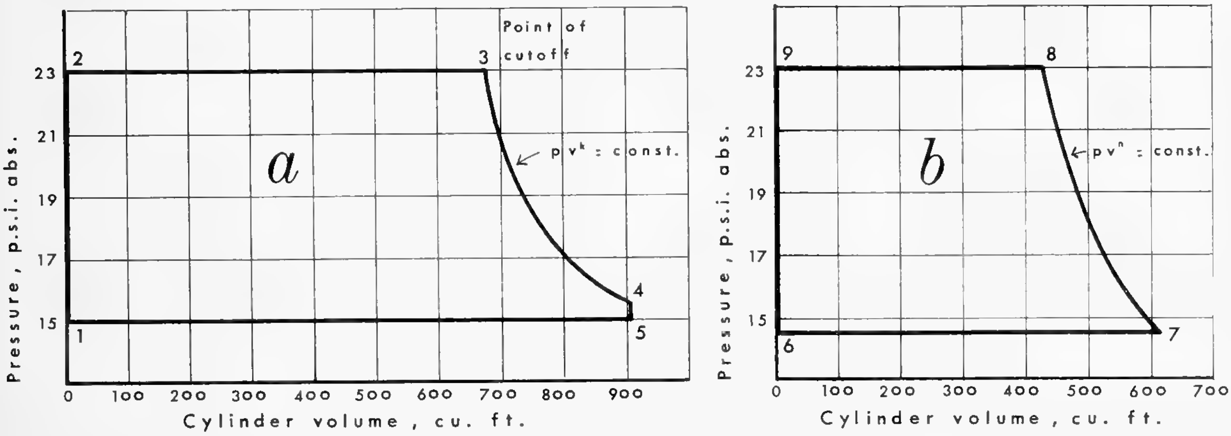

Figure 11.—Pressure-volume diagram: *a*, For working cylinder; *b*, for supply cylinder.

$$W_{3-4}=\int_{3}^{4} pdv \text{ where } p_3v_3^k=p_4v_4^k$$

$$=\frac{p_4v_4-p_3v_3}{1-k}$$

$$=15.4\times144\times906-23.0\times144\times680$$
$$=607{,}000 \text{ ft. lb.} \qquad (3)$$

$$W_{4-5}=0 \qquad (4)$$

$$W_{5-1}=p_5(v_1-v_5)=15.0\times144(0-906)$$
$$=-1{,}960{,}000 \text{ ft. lb.} \qquad (5)$$

The sum of equations (1) through (5) is 897,000 ft. lb., the work output.

Similarly, the work input to a single supply cylinder during one cycle of operation (one revolution) is represented in figure *b* by the area bounded by the p-v trace 6–7–8–9. Cylinder volumes at beginning of compression, v_7, and at end of compression, v_8, are 612 and 430 cubic feet, respectively, if the compression process is assumed to be polytropic with $n=1.30$.

Work, W, for individual processes is calculated as follows:

$$W_{6-7}=p_6(v_6-v_7)=14.5\times144(0-612)$$
$$=-1{,}280{,}000 \text{ ft. lb.} \qquad (6)$$

$$W_{7-8}=\frac{p_7v_7-p_8v_8}{1-n}$$

$$=\frac{14.5\times144\times612-23.0\times144\times430}{-0.30}$$
$$=477{,}000 \text{ ft. lb.} \qquad (7)$$

$$W_{8-9}=p_8(v_8-v_9)=23.0\times144(430-0)$$
$$=1{,}423{,}000 \text{ ft. lb.} \qquad (8)$$

The sum of equations (6) through (8) is 620,000 ft. lb., the work input.

Assuming a "diagram factor" (actual indicated work÷indicated work according to idealized p-v diagrams) of 0.90, and assuming an over-all mechanical efficiency (accounting for friction losses) of 0.90, the net work output per revolution for the four pairs of cylinders may be written

$$0.90\times0.90(897{,}000-620{,}000)\times4=904{,}000 \text{ ft. lb.} \qquad (9)$$

Multiplying net work (equation 9) by 9 revolutions per minute and dividing by 33,000 foot pounds per horsepower-minute gives the net horsepower output at the paddle shaft as 247:

$$\text{Net horsepower output}=\frac{904{,}000\times9}{33{,}000}=247 \text{ hp.}$$

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A Study for a Scale Model

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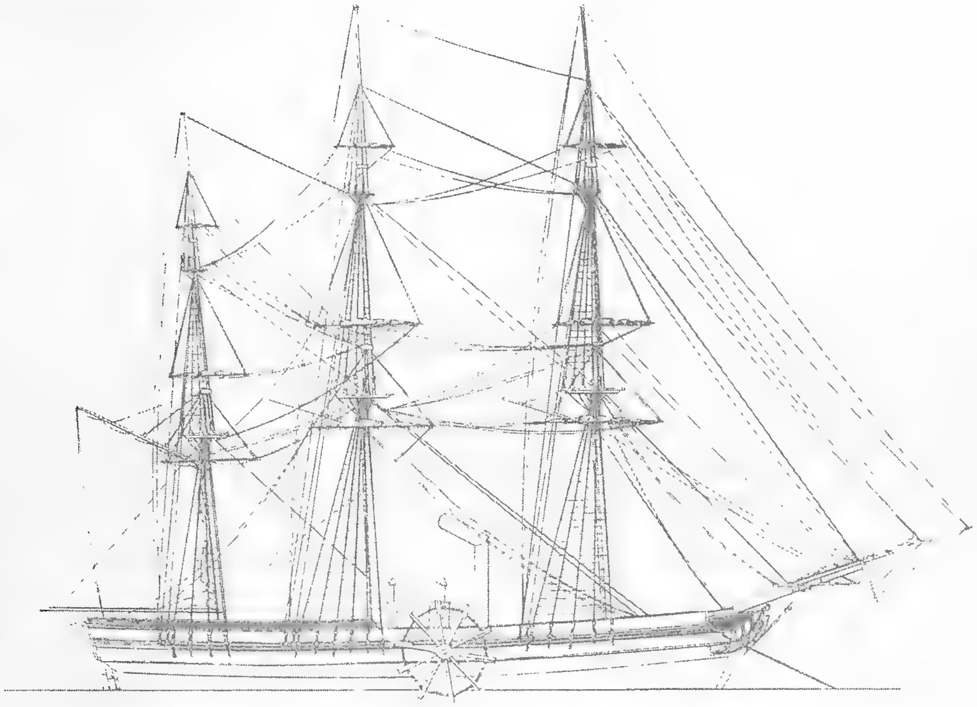

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PAPER 21

THE PIONEER STEAMSHIP SAVANNAH:

A STUDY FOR A SCALE MODEL

Howard I. Chapelle

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The Pioneer Steamship SAVANNAH:

A Study for a Scale Model

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The original plans of the pioneer transatlantic steamer Savannah *no longer exist, and many popular representations of the famous vessel have been based on a 70-year-old model in the United States National Museum. This model, however, differs in several important respects from contemporary illustrations.*

To correct these apparent inaccuracies in a new, authentic model, a reconstruction of the original plans was undertaken, using as sources the ship's logbook and customhouse description, a French report on American steam vessels published in 1823, and Russian newspaper accounts contemporary with the Savannah's *visit to St. Petersburg on her historic voyage of 1819. The development of this research and the resulting information in terms of her measurements and general description are related here.*

THE AUTHOR: *Howard I. Chapelle is curator of transportation in the United States National Museum, Smithsonian Institution.*

THE UNITED STATES NATIONAL MUSEUM has in its watercraft collection a rigged scale model purported to be of the pioneer transatlantic steamer *Savannah*. For many years this model was generally accepted as being a reasonably accurate representation and was the basis for countless illustrations. Curiously enough, the model (USNM 160364) does not agree with the published catalog description [1] as to the side paddle wheels. Neither does it agree with the material in the Marestier report,[2] which is accepted as the only source for a contemporary picture of the *Savannah*.

The recent naming of an atomic-powered ship in honor of the famous steamer greatly increased popular interest in the pioneer ship and its supposed model. Consequently, the National Museum undertook the research necessary to correct or replace the existing model. This research has been carried out by the staff of the Museum's transportation division with the aid of Frank O. Braynard of the American Merchant Marine Institute, Eugene S. Ferguson, curator of mechanical and civil engineering at the Museum, and others.

The *Savannah* crossed from Savannah, Georgia, to Liverpool, England, in the period May 22 to June 20, 1819, and proceeded to the Baltic, where she entered at St. Petersburg (now Leningrad), Stockholm, and a few other ports. On her return she reached Savannah on November 30, and on December 3 she

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[1] Carl W. Mitman, *Catalogue of the Watercraft Collection in the United States National Museum*, U.S. National Museum Bulletin 127, 1923.

[2] Jean Baptiste Marestier, *Mémoire sur les Bateaux à Vapeur de Etats-Unis d'Amérique*, Paris, 1823.

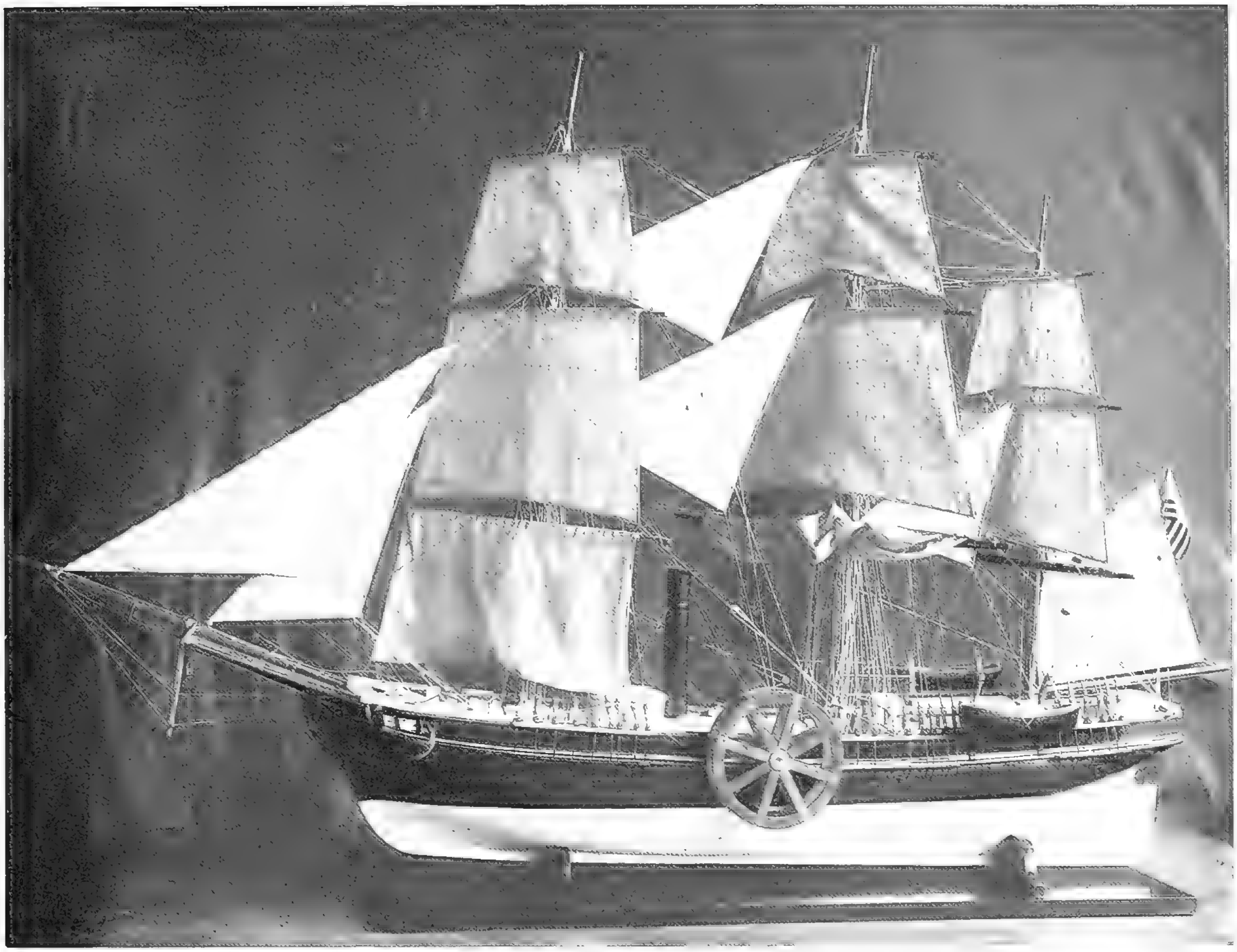

Figure 1.—Old model of the *Savannah,* built under the supervision of Captain Collins. This model has been removed from exhibition in the United States National Museum because of inaccuracies. (*USNM* 160364; *Smithsonian photo* 14355.)

sailed for Washington, D.C., arriving on December 16. Her original logbook now on exhibition in the Museum,[3] covers the period between March 28, 1819, when she first left New York for Savannah, to December 1819 when she was at Washington.

The old model (fig. 1) was built about 1890–1892 by Lawrence Jenson, a master shipwright and model builder of Gloucester and Rockport, Massachusetts, under the supervision of Capt. Joseph Collins of the U.S. Fish Commission. Notes in the records of the Museum's transportation division show that the research for this model was done by Captain Collins through use of an unidentified lithograph, printed after the transatlantic voyage, and what then could be learned about American sailing ships contemporary with the *Savannah.* In these notes the complaint is made that no contemporary representation of the steamship had then been found.

The old, inaccurate model, built to the scale of one-half inch to the foot, represents an auxiliary, side-wheel, ship-rigged steamer. The model scale measurements are about 120 feet in over-all length, 29 feet in beam, and 13 feet 6 inches depth in hold. The

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[3] A memorandum dated April 20, 1899, in the manuscript file on the watercraft collection shows that the Museum had both the rigged model and the original logbook at that time. Also in the collection were a coffee urn and miniature portrait of the *Savannah*'s captain, Moses Rogers, that had been presented to him abroad; later, these items were returned to the donor. A cup and saucer belonging to Captain Rogers also had been given to the Museum, and they are now in its historical collection.

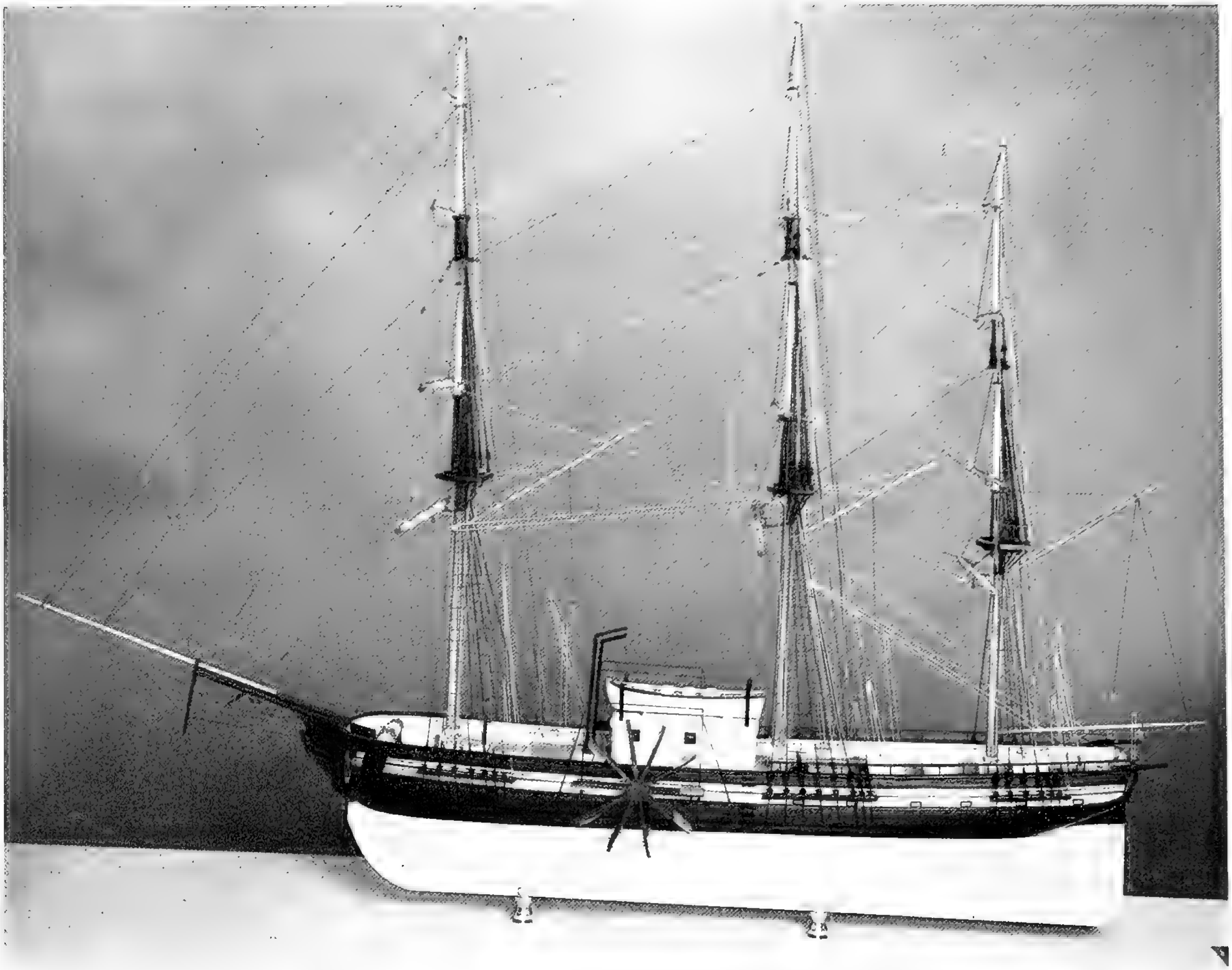

Figure 2.—The United States National Museum's new model of the *Savannah*. This model was built by Arthur Henning, Inc., of New York City, from the ship's plans as reconstructed by staff members of the Museum's division of transportation. (*USNM* 319026.)

tonnage is stated on the exhibit card to have been about 350 tons, old measurement. The model has crude wooden side paddles of the radial type, a tall straight smokestack between fore and main masts, a small deckhouse forward of the stack, a raised quarterdeck, and a round stern.

The first step in the research for creating a more faithful representation of the *Savannah* was to obtain the customhouse description of the ship. It was readily established that she was built as a sailing packet ship by the Fickett and Crockett shipyard [4] at Corlaer's Hook, East River, New York, and that she was launched August 22, 1818. Her register shows that she was 98 feet 6 inches in length between perpendiculars, 25 feet 10 inches in beam, 14 feet 2 inches depth in hold, of 319 70/94 tons burthen, and with square stern, round tuck, no quarter galleries, and a man's bust figurehead.

These dimensions of the *Savannah* required the researchers to investigate the method of taking register dimensions in 1818. It was found that the customhouse rule then in effect measured length between perpendiculars above the upper deck, from "foreside of the main stem" to the "after side of the sternpost." The beam was measured outside of plank at the widest point in the hull, above the main wales. If a vessel were single-decked, the depth was measured alongside the keelson at main hatch from ceiling to underside of deck plank; if double-decked, one-half the measured beam was the register depth.[5] However, inspection of the register of a number of ships of 1815–1840 showed that, in practice, double-decked ships commonly were measured as single-decked ships; this obviously was the case in the *Savannah*. Also, due to the lack of precise measuring devices, the register dimensions were not always accurate, particularly those of the length, which often were in error as much as one foot in a hundred, as was found by investigation of various classes of vessels. Because of inherent difficulties in measuring to the required points, this condition lasted even after steel tapes were introduced late in the 19th century.

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[4] Robert Greenhalgh Albion, *Square Riggers on Schedule*, Princeton, New Jersey, 1938. Between the years 1817 and 1837 the yard of Fickett and Crockett also operated at various times under the name of S. & F. Fickett and the name of Fickett and Thomas. The yard appears to have specialized in the construction of coastal packet ships, because only 4 ocean packets, against 24 coastal packets, were built by the various partnerships in which Fickett was a member.

The Museum's researchers next turned their attention to examination of the Marestier work, a French report on early American steam vessels that had become known to some American marine historians in the 1920's. The author was a French naval constructor who, on orders from his government, had spent two years in the United States between 1819 and 1822 studying American steam vessels, schooners, and naval vessels. The published report contained only material on steam vessels and schooners. The portion dealing with naval vessels was not published, and the manuscript has not been found to the present time (1960). The publication, a rare book, was available in only a few collectors' libraries or public institutions in the United States. In 1930 the writer translated the chapter on schooners,[6] and in 1957 Sidney Withington translated most of the remainder.[7] As a result of these publications and earlier published references, the Marestier material became widely known to persons interested in ships.

Withington's translation states that the *Savannah* measured 30.48 meters (100 feet) in length and 7.92 meters (26 feet) in beam and that she drew 3.66 meters (12 feet) in port and 4.27 meters (14 feet) loaded. Marestier's sketch (see fig. 3) of the outboard of the *Savannah* shows a ship-rigged, flush-decked vessel with a small deckhouse forward of the mainmast and nearly abreast of the side paddle wheels. The stack is a little forward of the deckhouse and has an elbow at its top. Netting quarter-deck rail is shown and a bust figurehead is indicated. The position of the hawse pipe shown at the bow indicates the wheel shaft to have been at or about deck level. For structural reasons, and in compliance with the sketch, the wheel shaft would have been just above the deck.

Marestier's drawings of the engine and paddle wheels[8] are reproduced in figure 4. The nonoscillating engine is inclined toward the paddle-wheel shaft. The connecting rod operates a crosshead to which is pivoted a pitman, or oscillating rod, that operates the paddle-wheel crankshaft. Alongside the steam cylinder is an air pump cylinder, also connected to the crosshead. The steam inlet and outlet pipes enter a valve chest on top of the steam cylinder, which is described as being 1.035 meters (3.4 feet) in diameter, and of 1.5 meters (4.9 feet) in stroke.

The paddle wheels are shown as being of iron, with two fixed arms opposite one another on the hub. The other arms (four above and four below the fixed arms) are pivoted to the hub and held spread by chain stays. These eight blades fold, in pairs, to each of the fixed arms. The wheels are shown in elevation, with the upper pivoted arms folded on top of the fixed arms, and in cross section; the latter shows the shape of the buckets, hub, and outboard bearing of the shaft. The wheels are described as being 4.9 meters (16 feet) in diameter, while the buckets are 1.42 meters (4.65 feet) wide and 0.83 meters (2.72 feet) deep. The two outer corners of each bucket are snyed off at nearly 45°. The wheels are shown folded in the sketch; according to the description, they could be unshipped from the shaft and stowed on deck when desired. The method of removing the wheels from the shaft is not described, but from the drawings it seems probable that they were detached from the shaft by removing a lock bolt outboard and sliding the wheels off the square shaft. The hub seems adequate for this. Marestier states that this removal could be accomplished in 15 to 20 minutes; the logbook shows that it took 20 to 30 minutes to perform this operation at sea.

Marestier states that the ship had spencer masts and trysails on fore and main, and a spencer mast on the mizzen for a spanker; he illustrates these as having

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[5] L. M'Kay, *The Practical Shipbuilder*, New York, 1839.

[6] Howard I. Chapelle, *The Baltimore Clipper*, Salem, Massachusetts, 1930, pp. 112–134.

[7] Sidney Withington, translator, *Memoir on Steamboats of the United States of America by Jean Baptiste Marestier*, Mystic, Connecticut, 1957.

[8] *Ibid.*, pl. 7, figs. 32, 33, 35.

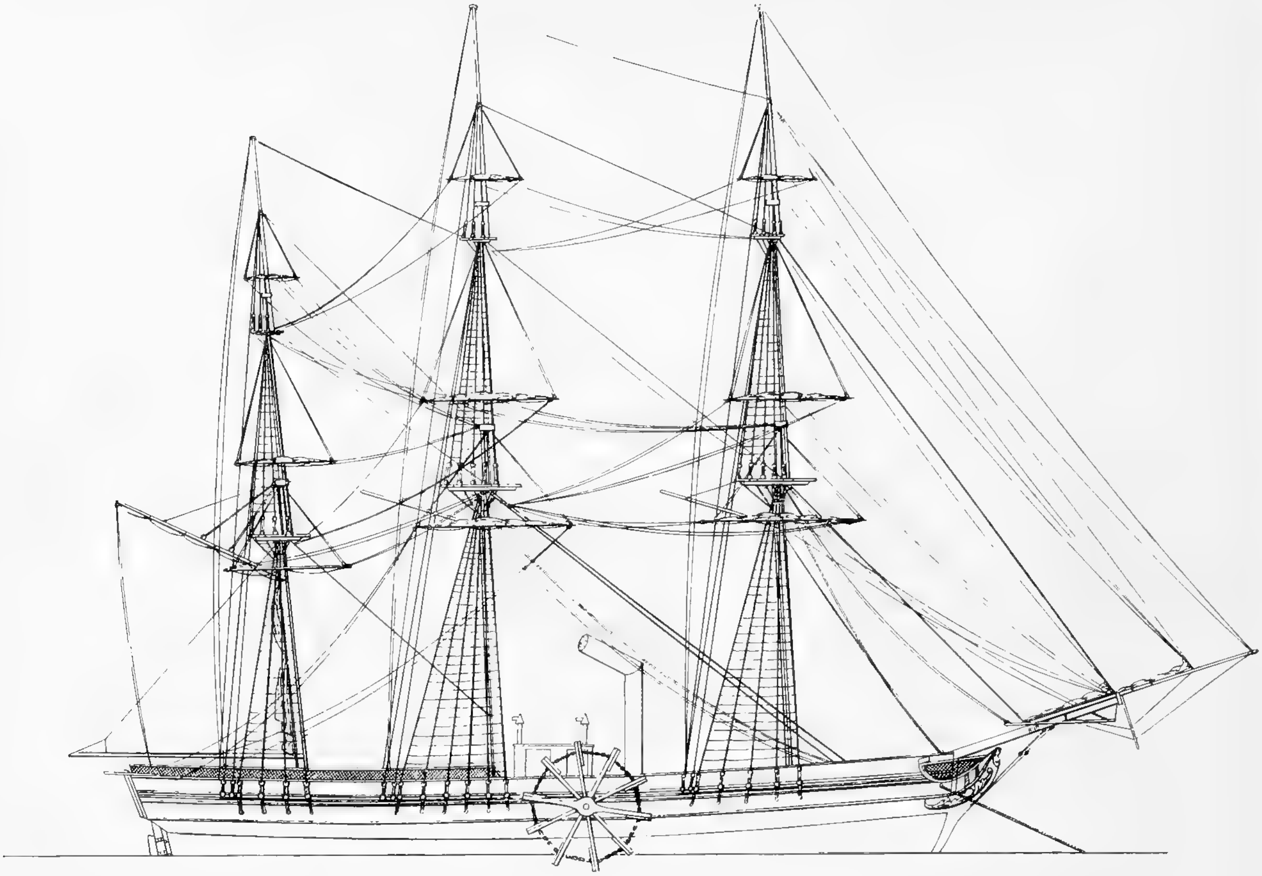

Figure 3.—Marestier's sketch of the *Savannah* (from plate 8 in Withington's translation of the Marestier report). Heights of lower masts are excessive by all known American masting rules; and, according to Marestier's drawing of the engine (see figure 4), the deckhouse is too short.

royal poles, but with no royal yards crossed.[9] The smokestack is described as pivoted. The mainstay is double, setting up at deck, near rail, and forward of the foremost shrouds of the foremast to clear the stack and foremast.

The boilers were in the hold, but Marestier gives no dimensions. However, he comments that, in American steamers, the space for steam in the boilers varied from 6 to 12 times the capacity of the cylinder. He gives the *Savannah*'s boiler pressure as 2 to 5 pounds per square inch and the maximum revolution of the wheels as 16 revolutions per minute. The boilers could burn coal or wood. Judging by Marestier's sketch of the ship, the stack was at the firebox end; the boiler or boilers were underneath the engine.

The log of the *Savannah* gives little useful technical information other than that the ship readily made 9 to 10 knots under sail in fresh winds, showing she could sail well. Under steam alone the log credits the ship with a speed of 6 knots; Marestier estimated her speed at 5¼ knots in smooth water. The log shows that she usually furled her sails when steaming, though on a few occasions she used both steam and sail. In her crossing from Savannah to Liverpool she appears to have been under steam for a little less than 90 hours in a period of about 18 days (out of the total of 29 days and 11 hours required to cross). There is no evidence of any intent to make the whole passage under steam alone, for the vessel was intended to be an auxiliary, with sails the chief propulsion.

Captain Collins states in his notes that the ship was built by Francis Fickett as a Havre packet, that she

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[9] *Ibid.*, pl. 3, fig. 10.

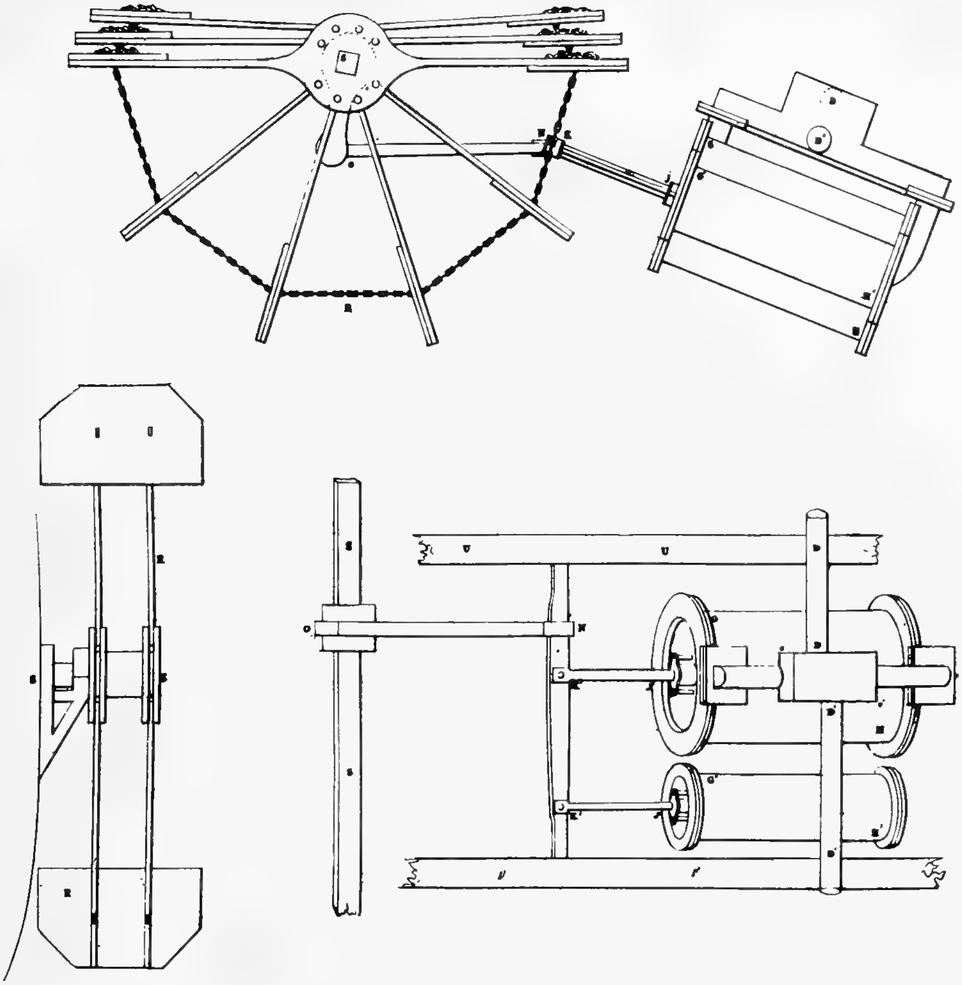

Figure 4.—Marestier's drawings of the *Savannah*'s engine (from plate 7 in Withington's translation of the Marestier report). The graphic dimensions do not precisely correspond to the scale of dimensions in Marestier's text, nor with other recorded measurements.

stowed 75 tons of coal and 25 cords of wood, and cost $50,000. Apparently quoting Preble[10] to a great extent, he also states that the engine developed 90 horsepower and had a 40-inch diameter cylinder with a stroke of 5 feet.

Preble states that the ship was purchased for conversion to a steamer after launching and gives statements by Stevens Rogers, sailing master of the *Savannah*, to the effect that the ship was built as a Havre packet and that the project ruined financially one of the investors, William Scarborough. Rogers, who made these statements in 1856, also said the ship was built by "Crocker and Fickett." Contemporary newspapers, quoted by Preble, state that the ship had 32 berths in staterooms for passengers.

Morrison[11] credits the building of the *Savannah* to Francis Fickett and says she was intended for the Havre packet run. He states that the vessel cost $50,000; that her paddle wheels, each with eight buckets, were 16 feet in diameter; and that she had canvas wheel boxes supported by an iron frame. Morrison also relates the history of the ship after her return from Russia—the removal and the sale of her machinery to James P. Allaire, the operation of the ship as a sailing packet between New York and Savannah under the ownership and command of Captain Holdridge, and her stranding and loss during an east-northeast gale on November 5, 1821, at Great South Beach, off Bellport, on the south shore of Long Island. He also states that the steam cylinder of her engine was exhibited at the Crystal Palace Fair in New York during 1853, and that the ship proved uneconomical due to the large amount of space occupied by the engine, boilers, and fuel, leaving little space for cargo. Morrison apparently used some of the statements made in 1836 and 1856 by Stevens Rogers, who was the sailing master on the famous voyage.

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[10] Geo. Henry Preble, *A Chronological History of the Origin and Development of Steam Navigation, 1543–1882*, Philadelphia, 1883.

[11] John H. Morrison, *A History of American Steam Navigation*, New York, 1930.

Tyler[12] names the stockholders of the Savannah Steamship Company, owner of the *Savannah.* The company was proposed by Capt. Moses Rogers, and its shareholders were William Scarborough, John McKenna, Samuel Howard, Charles Howard, Robert Isaacs, S. C. Dunning, A. B. Fannin, John Haslett, A. S. Bullock, James Bullock, John Bogue, Andrew Low, Col. J. P. Henry, J. Minis, John Sparkman, Robert Mitchell, R. Habersham, J. Habersham, Gideon Pott, W. S. Gillet, and Samuel Yates. Tyler establishes, by the company's charter, that the objective was to institute a New York-Savannah packet service, for which the *Savannah* was to be the first ship. He shows that, due to the economic depression of 1819, the *Savannah* sailed to Liverpool in ballast and without passengers. Her fuel capacity is given as 1,500 bushels (75 tons) of coal and 25 cords of wood. [It should be noted that 1,500 bushels of bituminous coal does not quite equal 75 tons.] Tyler quotes S. C. Gilfillan[13] as to criticisms of the engine and its design.

Partington[14] estimated coal consumption to be nearly 10 tons a day; remarked on the uneconomical arrangement of the ship, with the engine and boiler occupying the greater part of the space amidships, between fore and main masts; and located the axle of the paddle wheel "above the bends," that is, in the topsides above the wale. The description he gives of the unshipping of the wheels is that the pivoted blades were removed and the fixed blades, in horizontal position, were left on the shaft. This agrees with a Russian description referred to later. The logbook repeatedly speaks of "shipping" and "unshipping" the paddle wheels, indicating that the wheels were entirely removed from the shafts and stowed on deck.

Watkins[15] showed, by the account books of Stephen Vail, owner of the Speedwell Ironworks near Morristown, New Jersey, that the engine was built by Vail, but apparently to designs by Daniel Dod. The latter built the *Savannah*'s boiler at Elizabeth, New Jersey, and made some parts of the engine, which he furnished, incomplete in some instances, to Vail. These account books, which were in the possession of John Lidgerwood of New York City in 1890, show the steam cylinder to have had an inside diameter of 40⅜ inches and a 5-foot stroke. Reference in the account books to an error in Dod's draught of a piston proves that Dod designed the engine.

Watkins states that the engine was rated at 90 horsepower. He does not give the diameter of the pump cylinder, but, judging by the scaling of Marestier's drawing and by a rather indefinite entry in the Vail account book, it appears to have been between 17 and 18 inches. Quoting Captain Collins at some length, Watkins writes that the mainmast was placed farther aft than was usual in a sailing ship, and that the vessel had a round stern. Collins apparently based his opinion upon an unidentified "contemporaneous lithograph" and upon "all other illustrations of this famous vessel." Collins' conception of the appearance of the *Savannah* is shown in a drawing by C. B. Hudson that is reproduced as the frontispiece in Watkins' publication. A statement by Stevens Rogers that was published in the *New London Gazette* in 1836 appears to have been the original source for statements regarding the *Savannah's* fuel capacity, her sale, and her loss in 1821 while owned and commanded by Capt. Nathaniel Holdredge, "now master of the Liverpool packet ship *United States.*" Watkins also gives a picture of Stevens Rogers' tombstone, on which there is a small carving purported to be of the *Savannah.* The tombstone was made in 1868.

From a Russian newspaper contemporary with the *Savannah*'s visit to St. Petersburg, Frank Braynard found a statement that the vessel had two boilers, each 27 feet long and 6 feet in diameter.[16] It was also shown she had at least one chain cable. Considerable information on the cabin arrangement and the method of folding the wheels was also obtained from this Russian source.

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[12] David Budlong Tyler, *Steam Conquers the Atlantic*, New York and London, 1939.

[13] S. C. Gilfillan, *Inventing the Ship*, New York, 1935.

[14] Charles Frederich Partington, *An Historical and Descriptive Account of the Steam Engine*, London, 1822.

[15] J. Elfreth Watkins, "The Log of the *Savannah*," in *Report of the U.S. National Museum for the Year Ending June 30, 1890*, 1891, pp. 611–639.

[16] Previously, the author had assumed there was one boiler with two flues.

In spite of a very extensive bibliography on the *Savannah*, the basic sources for reliable technical description are Marestier's report on American steamers, the logbook of the ship, Watkins' extracts from the Speedwell Iron Works account book, the customhouse records, and some of the statements made by Stevens Rogers between 1836 and 1856. Plans of the ship, or a builder's half-model, have not been found. Marestier's sketch of the *Savannah*, which is not a scale drawing, and his drawings of the engine and paddle wheels were the only available illustrations upon which reconstruction could be based.

Through the efforts of Malcolm Bell, Jr., of Savannah, Georgia, and Frank Braynard, a search was made by Russian authorities at Leningrad for contemporary references to the ship. This work resulted in information as to how the side wheels were folded, the dimensions of the boilers, and some description of the cabins and fittings

As to the ship itself, the customhouse registered dimensions are of prime importance; they fix the over-all hull dimensions within reasonable limits. A vessel of 1818 measuring 98 feet 6 inches between perpendiculars would have been 100 to 104 feet long at rail. The type of ship represented by the *Savannah* is well established. All references are in agreement that she was built as a packet ship—a Havre or transatlantic packet in most accounts.

The packet ships listed by Albion [17] show that all the pioneer ships of the transatlantic Black Ball Line—which began operation with the sailing of the 424-ton *James Monroe* on January 5, 1818—measured at least 103 feet 6 inches between perpendiculars. Two of the pioneer ships of the first Havre Line—which did not begin operation until 1822—were under 98 feet between perpendiculars. The second Havre Line began operation in 1823; of its four pioneer packets, two were purchased general traders measuring under 98 feet between perpendiculars. The coastal packets built between 1817 and 1823 were all under 100 feet between perpendiculars. It is apparent, then, that the size of the early packets did not indicate, with any degree of certainty, the trade in which they might be employed.

Belief that the *Savannah* was built as a Havre packet is based upon Stevens Rogers' statements, and her size obviously does not make this impossible; nevertheless, it seems highly improbable that she was built for the Havre service because no Havre line of packets had been organized as early as 1818 out of New York or Savannah so far as can be found. However, the matter is not of very great concern as it is probably true that the models of coastal and transatlantic packet ships were quite similar at the period of the *Savannah*. This statement is supported by the plan of a coastal packet built seven years after the *Savannah*.

The hull-type of these early packets can be established. While no half-models or plans of packets built before 1832 could be found, offset tables of a Philadelphia-New Orleans packet of 1824–1825 were obtained through the courtesy of William Salisbury, an English marine historian who had been studying the British mail packets. These offset tables had been sent from Washington on March 25, 1831, by John Lenthall, U.S. naval constructor, to William Morgan and Augustin Creuze, London editors, for publication.[18] The offset tables were for a packet ship 103 feet between the perpendiculars of the builder (rather than between those of the customhouse) and 27 feet moulded beam. An examination of the files on American packet vessels in the collection of Carl C. Cutler, curator emeritus of the Mystic Marine Museum, showed with certainty that the offsets were for the *Ohio*, built at Philadelphia late in 1825. The drawings of this ship (fig. 5) were made from the offset tables and from other measurements; minor details are from portraits of packet ships, particularly of the first *New York* (1822–1834) of the Black Ball Line.

The *Ohio* was two-decked, with the upper deck flush. She had rather straight sheer, 27-inch bulwarks, a moderately full but easy entrance, a fine, long run, and little drag to the keel. The midsection was formed with moderately short and rising floor, round and easy bilge, and some tumble-home in the topside. The stem raked a good deal for a ship-rigged vessel; the post raked slightly. There was a distance of 6 feet between upper and lower deck planks. The stern was of the square transom, round tuck form, as mentioned in the *Savannah*'s register. Lenthall reported the *Ohio* to have been a good sailer and to have had other desirable qualities. She was registered as being of 351.86 tons burthen, 105.5 feet between perpendiculars, and 27.4 feet in extreme

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[17] *Op. cit.* (footnote 4).

[18] William Morgan and Augustin Creuze, eds., *Papers on Naval Architecture*, London, n. d., no. 12, p. 387.

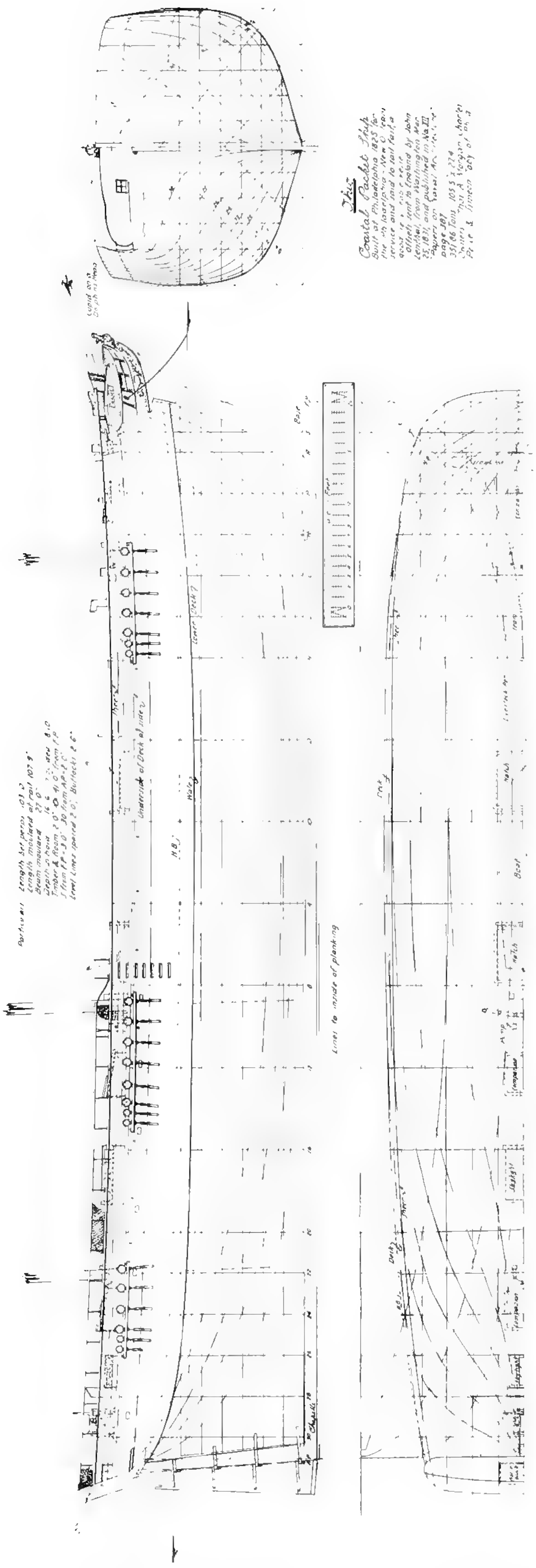
Particulars
Lines to inside of planking
Underside of Deck at side
The Coastal Packet Ship

Figure 5.—Lines of the coastal packet ship *Ohio*, built at Philadelphia in 1825 for the Philadelphia-New Orleans run. The *Ohio* represents the general type of early American packet ships.

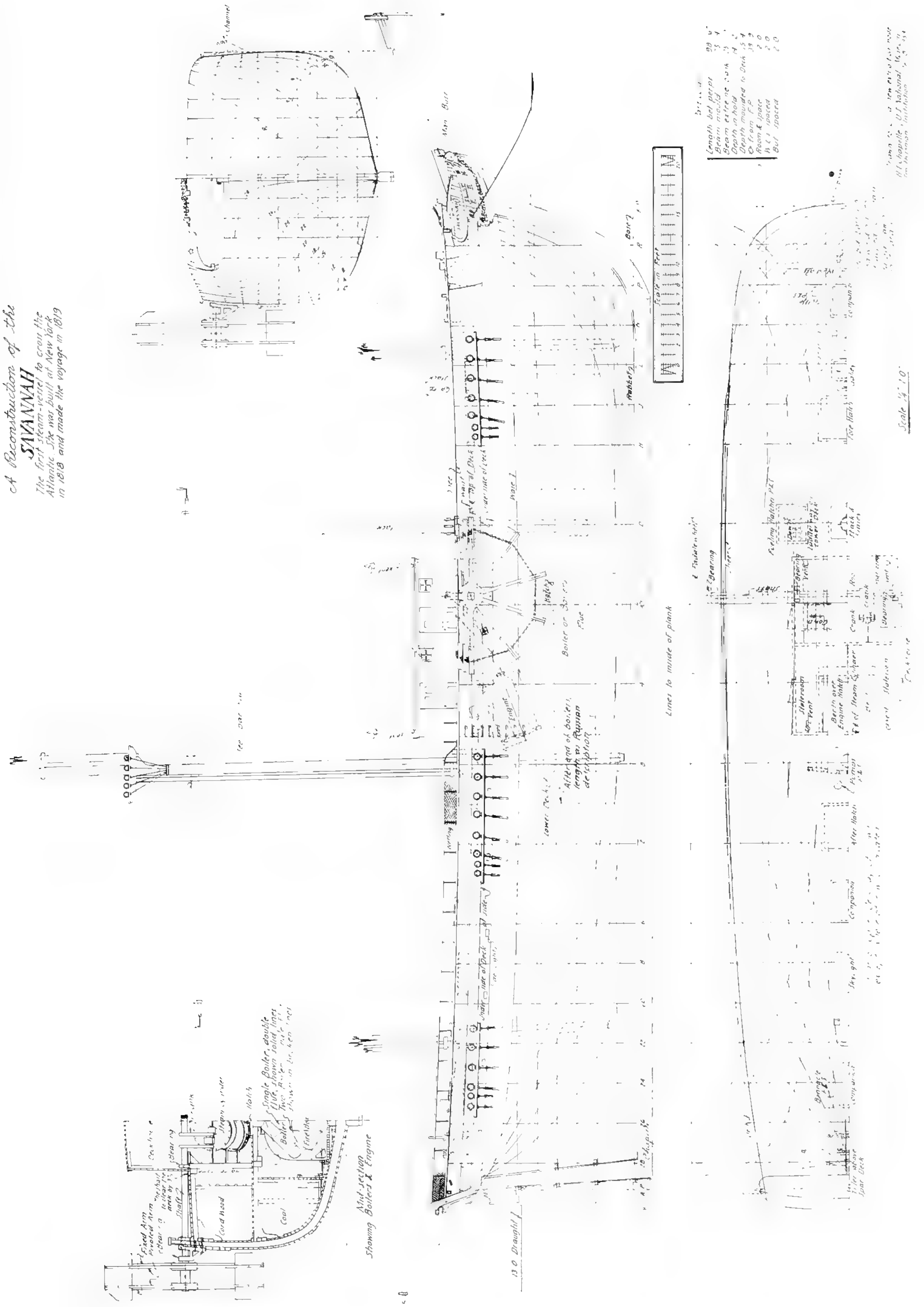
A Reconstruction of the SAVANNAH
The first steam-vessel to cross the Atlantic. She was built at New York in 1818 and made the voyage in 1819
Lines to inside of plank
Scale in Feet
Scale 1/4" = 1'0"
Boiler or Boilers
Lower Decks
Midsection Showing Boilers & Engine
13.0 Draught

Figure 6.—Reconstruction of the hull lines and general arrangement of the *Savannah*.

beam. She was, therefore, about 7 feet longer and about 2 feet 3 inches wider than the *Savannah.* The plan shows she was about 2 feet 4 inches deeper in hold than the *Savannah*, and, according to Cutler, she had "an unexpected degree of sophistication for a coastal packet of that period." [19] By modern standards, the *Ohio* shows a well-advanced design for the period.

Reconstructing the Plans

The first step in the reconstruction of the *Savannah*'s plans was to block out the register dimensions on a scale of one-quarter inch to the foot in a drawing and then to work out the profile, using the *Ohio* plan as a general guide. This produced a hull about 100 feet 9 inches in length at main rail to inside of plank, or "moulded"; 25 feet 6 inches moulded beam, allowing 3 inches for plank (as usual in a ship of this size and date); and about 15 feet 4 inches moulded depth at side, keel rabbet to underside of upper deck. The bulwarks were drawn at 28 inches height. Next, the mast positions were decided by prorating from the plan of the *Ohio* the position of each mast from the fore perpendicular and then modifying these positions slightly by use of masting rules contained in M'Kay's book [20] of 1839.

Since it appears that the *Savannah* may not have been purchased for conversion to a steamer until near the date of her launch and because of the lack of identification of the lithograph referred to by Collins, the statement that the mainmast was placed farther aft than normal was rejected. At launch her mast partners would have been in place and the deck laid. Any alterations in the position of the mainmast then would have made it impractical for the owners to demand them of the builders without heavy additional expense. In addition, the plan, as it was developed, indicated no need for such alteration.

The plan of the engine, drawn to the same scale as the profile plan, was shifted about on the lower deck in the hull profile to determine where the engine and side paddle wheel shaft might be located. A little experimentation and study made it certain that the proper location could be estimated within a foot or so, to scale, as to fore and aft positions. The after end of the cylinder, and its piping, had to clear the mainmast by at least 9 to 10 inches to allow removal of the cylinder head for inspection and repair. The position of the wheels, stack, and masts in Marestier's sketch of the ship make it certain that the engine was on the lower deck, abaft the paddle wheel shaft. Due to differences between the dimensions stated by Marestier and in the Vail account books and what the graphic scale in Marestier's engine drawings produce, the exact dimensions of the engine are uncertain. Nevertheless, they can be approximated with enough accuracy for our purpose. As a result of this treatment, it seems fully apparent that the engine was abaft the paddle wheel shaft, with frame extending abaft the mainmast on the lower deck; there does not appear to be a practical alternative in the light of the available evidence. This matter will be referred to again.

The size of the cylinder and its valve chest and the inclined position of the cylinder indicate conclusively that the valve chest was in the mainhatch, which would normally be just forward of the mainmast. Even then, the after flange of the cylinder would just clear the lower deck, allowing 6 feet between decks, as in the *Ohio*. The cylinder would have been about 6 feet long; the graphic scale indicated 6 feet 3 inches. The diameter of the cylinder plus height of valve chest seems to have been 5 feet 9 inches to 6 feet. Because of the use of the crosshead and a connecting rod, pivoted at crosshead, the oscillating rod (or pitman) and piston together equalled twice the stroke plus allowance for stuffing box, crosshead, and pitman bearings. Therefore, the engine's over-all length, from head of cylinder to the centerline of the side paddle wheel shaft, could not have been much less than 15 feet 9 inches, and probably as much as 16 feet 2 inches, thus making the length at extreme clearance of crank throw as much as 19 feet. These dimensions indicate that the centerline of the side paddle wheel shaft must have been from 38 to 39 feet from the forward perpendicular. It is not clear how the wheel shaft was mounted in the vessel. Taking into consideration her depth and her reported draught, light and loaded, the Marestier sketch, and the hull structure then used, it seems reasonable to place the centerline of the shaft (which seems to have been about 7 to 8 inches square) about 12 inches above the upper (or spar) deck to allow proper dip of the blades. This position would have given proper blade immersion at the mean draught of 13 feet.

In order to get the engine below deck, and to get the boiler or boilers placed, it was necessary to cut a large opening in the two decks. It may be assumed that this opening was big enough to take the cylinder, without valve chest, and also the boilers, which went into the hold. Taking the proportions of other boilers as shown by Marestier, it has been estimated that the *Savannah* might have had a boiler about 18 to 20 feet in length, 7 to 8 feet wide, and 6 to 6½ feet high at firebox. The form might be the same as that of *Fulton the First*, illustrated in the translation of Marestier's report.[21] However, since the Russian descriptions [22] indicate there were two boilers, each measuring 6 feet in diameter and 27 feet in length, the two boilers would have reached past the mainmast if they were located in the same manner and in the same place as the boilers shown in the illustration of *Fulton the First*. Consequently, if the Russian description is accepted, there would have been a need for longer fuel (coal) spaces in the wings.

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[19] Letter from Carl C. Cutler to the author, November 24, 1958.

[20] *Op. cit.* (footnote 5).

The boilers, then, were the largest piece of equipment to be passed through the decks; for this an opening (estimated to have been about 10½ feet wide and 8½ feet long) probably was cut through both decks about 3 feet forward of the main hatch, which was commonly a little forward of the mainmast. The boilers could then have been lowered, after end first, into the hold. The opening in the lower deck could then have been closed, except for a small hatchway perhaps, and the steam cylinder let down to the lower deck and moved aft into position. To allow the crosshead to reach its maximum travel, the opening in the upper deck would have been about 10½ feet wide—the over-all width of the engine frame—and would have been left open, inside the deckhouse.

The width of the boilers might be particularly important because it would determine the deadrise at floor in the hull. The apparently precise dimensions of the boilers given in the Russian description were utilized to arrive at a suitable hull form. Both a single boiler and a double boiler (as described in the Russian accounts) were placed in the hull to assure the correct space estimates.

Since the engine, as shown by Marestier, had an air-pump cylinder alongside the steam cylinder (with the pistons of both attached to the crosshead), it is evident that a condenser was employed. This condenser would not have been much larger than the air-pump cylinder. It may have been placed under the side paddle wheel axle on the lower deck, but its mode of operation is unknown. Possibly it was of the jet type, with pumps operating off the paddle wheel axle and with a return of condensate from a hot well into the feed water line. A number of possibilities could be mentioned, all speculative. However, there was no doubt that this equipment could be properly installed in the reconstructed hull, either on the lower deck or in the hold.

Two questions have been raised as to machinery arrangement—whether the engine, and boilers also, might have been forward of the wheel shaft, and whether the wheel shaft was above or below deck. If the engine were placed forward of the wheel shaft, the wheels might be farther aft than is proposed in the reconstruction. However, the smokestack could not then be forward of the wheel shaft as shown by Marestier because it would have had to pass through the engine frame, thus interfering with the movement of the large crosshead. If the engine were abaft the wheel shaft, the stack could have been only as shown by Marestier. The boilers might then have been forward of the wheel shaft only if the stack were at the end away from the firebox. However, the length of the boilers as indicated by the Russian description would then have required them to pass through the bows!

Models have been built of the *Savannah* in which the engine and boilers are forward of the paddle wheel shaft, and the shaft below the main deck. This was accomplished by placing the engine off center so that the stack came through the decks alongside it. This is an impractical arrangement because it would have created an impossible ballasting problem. The weight of the engine, to port in the models, would have to have been counteracted by ballast to starboard. Due to the coal bunkers, and the possibility of two boilers below the engine in the hold, there would not have been room for sufficient ballast. In addition, were such ballasting possible, the combined weights were too far forward to give proper trim, and a great deal more ballast would have been required far aft, a most impractical proceeding.

The position of the wheel shaft was determined as described earlier. The ship was apparently well-advanced in construction at the time of purchase. Her clamps and shelves supporting her upper deck beams, which then would have been in place, were important strength members. In reconstructing, to place the wheel shaft below these members would not only bring the engine nearly level—it is described and shown inclined by Marestier—but also would immerse the paddle blades too deeply for the draft and depth of the hull. To place the shaft below or through the lowest clamp member would require the shaft centerline to be at least 3 feet below the upper deck, and this would contradict Marestier. These questions indicate the importance of a scaled drawing when deciding arrangement in the reconstruction of a ship under the circumstances existing in the *Savannah.* Some models have been built with the shaft below deck by disregarding the structural and dimensional objections just outlined.

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[21] Withington, *op. cit.* (footnote 7), pl. 9, figs. 55, 56.

[22] Report of Malcolm Bell, Jr., and Frank Braynard.

The question of the number of boilers originally was raised by Braynard. A single boiler with double flues was a common boiler design in American steamboats of 1818–1828, and this form of boiler is shown in a number of Marestier's drawings. In general descriptions, "boiler" and "boilers" are often used interchangeably, and this probably came about through confusion over the number of flues. A "single boiler, double flues," would thus become "boilers," apparently. The Russian description specifically states there were two boilers, and gives specific dimensions; though these probably are not exact. Either a single boiler with double flues, or double boilers, each with a single flue, could have been fitted in the reconstruction. However, fuel space is affected and, with double boilers, the cross-sections of the bunkers are reduced to about 20 square feet each; therefore, the bunkers would have to become much longer. It may be said that the boiler capacities in relation to dimensions of the steam cylinder as indicated in the Russian description far exceed those given by Marestier. As a practical matter of ship design, it seems that the single boiler would have been a more logical fitting than double boilers. The boilers were apparently of copper, and expensive. However, this matter does not affect the hull-form and dimensions established for the reconstruction, as the drawings proved. The Russian description does show that the cargo space was extremely small and practically nonexistent, indicating the effect of the large boiler capacity.

All requirements that have been given can be approximated for space necessary in the hull. It is established that the ship carried about 75 tons of coal and 25 cords of wood. The coal would take up from about 1,700 to 1,850 cubic feet of space, and because of its weight it would have to be bunkered alongside the boilers in the lower hold, where there would be ample room, in the reconstruction, for two bunkers, each in excess of 30 square feet in cross section and about 28 feet in length for a single boiler; one third more bunker space, in length, would be required for double boilers. Such bunkers would together hold about the required tonnage or cubic footage. The cord wood would have required, say, two bunkers each of about 60 square feet in cross section and 20 to 24 feet in length. Because of the light weight, the cord wood could have been stowed in the wings on the lower deck. There is room for the required stowage on the lower deck in the reconstructed hull, leaving ample passages under either side of the engine frame.

Marestier shows the location of the stack as being abreast the buckets on the forward side of the paddle wheels, and it has been so placed in the reconstruction. The deckhouse shown in Marestier's sketch extends from a little forward of the mainmast to a little forward of the paddle wheel axle. Probably this house actually covered the main hatch and the crank-connecting-rod hatchway; therefore, Marestier shows it too short. In the reconstruction, the deckhouse works out as between 17 and 18 feet long. Its width can only be guessed at, but it probably would have been as wide as the opening cut in the upper deck for machinery—say 11 feet. Perhaps this house contained the engineer's stateroom and that of his assistant, as well as a ladderway to the engine room. Doors on the sides of the house gave access to these spaces and to the inboard shaft bearings. Bunker hatches were probably forward of the house and outboard; these are taken as being about 2 feet 6 inches wide and 3 feet 6 inches long—large enough to allow coal baskets to be lowered through them, as well as to allow cord wood to be passed below.

A fidley hatch, in which the stack passed through the upper deck, would have been a square hatch forward of the deckhouse. This hatch, about 2½ to 3 feet square, would have been fitted with an iron or iron-bound fidley grating, with solid cover over. The stack could have been swivelled, to bring the elbow to leeward. The upper portion of the stack probably overlapped the lower portion at least 3 to 4 feet above the fidley coaming, and the upper stack rested on a collar bearing at the bottom of the overlap. Perhaps straps were bolted to the side of the upper stack to take heaving bars athwartships, by which two men could rotate the upper stack to turn the elbow to leeward.

The bearings of the paddle wheel axle were perhaps four in number. Two, one either side of the crank, may have been secured to the engine frame just inside the deckhouse walls. Two were certainly outboard, one on each side, fastened to the topsides, as shown in Marestier's sketch of the wheel construction. The axle, probably square in cross section, turned only at the bearings and wrist pin. It may have been cast in two parts, each with a crank arm, and then joined by the wrist pin, after the latter had been turned.

The wheels, shown in much detail in Marestier's sketches of the engine, had flanged hubs to which the pivoted arms or spokes were bolted. The fixed arms were integral parts of the outer hubs. The inner flanges were cast with the hubs. To fold the blades, the fixed arms were brought parallel to the rail, then the chain span between each pair of the pivoted blades on top of the wheel was disconnected and a pair of the blades, each way, were dropped on top of the fixed arms, or blades, and lashed there. The wheel was then given a half-revolution and the process repeated. The wheel could then have been unshipped from the hub by sliding it off the square shaft end after removing, let us suppose, a bolt or pin in the hub. Some writers, like Collins, refer to a "jointed" or "hinged" axle, but Marestier makes no mention of such an arrangement; indeed, his sketch makes a "broken" axle impractical. The wheels could have been removed from the axle and lifted aboard by use of tackles from the main yard ends, or from a fore spencer gaff if it were made long enough. However, as stated in the Russian description, the pivoted blades were removed and stowed aboard, leaving only the two fixed arms in a horizontal position outboard. This is a far more convenient treatment than unshipping the whole wheel, as might be supposed from logbook mention of "shipping" or "unshipping" the wheels.

There remain some other matters to be explored. The ship was fitted with 32 passenger berths in staterooms. The passenger accommodations for first class passengers in the early (1820–1830) packets were aft, on the lower deck. The berths would have been about 6 feet 2 inches long, and 2½ feet wide. With berths placed athwartships and allowing for cabin bulkheads, there would have remained a space at least 10 to 12 feet wide down the centerline of the ship. This space would have provided space for a mess table and a lounge area. Each stateroom would then have been about 7 feet long fore and aft and could have contained four athwartship berths. The space available abaft the middle of the after cargo hatch would have allowed four staterooms on each side and room at the extreme stern for a small master's cabin, with toilets on each side. The cabin of the mates and stewards, containing two berths each, would then have been about abreast of the fore end of the after cargo hatch.

The galley would have been on the lower deck, just abaft the foremast and forward of the fore cargo hatch. Food would have been carried aft along the lower deck to the cabin, by way of passages on either side of the engine frame. Cabin stores would have been in the hold below the passenger accommodation, and here food, water, and other stores would have been kept. A small cargo space, say of about 1,500 to 2,500 cubic feet, depending on bunkers, would have been possible in the after hold. A fore cargo hold of about 1,000 to 1,500 cubic feet of contents could be expected; forward of this would have been sail locker, spare rigging gear, and a cable tier. On the lower deck, above these spaces, a forecastle might have had berths for 12 to 14 men. The cables and chain would be passed through the forecastle to the cable tier below by chutes leading from cable scuttles in the upper deck abaft the windlass on each side of the centerline of the ship.

The upper deck, abaft the mainmast, was reserved for use of the passengers and officers of a packet. The low, 28-inch bulwarks were insufficient to give proper protection there, so they were increased by employing a 16-inch rail made of a cap supported by iron stanchions above the main rail. This rail was closed in by a tarred netting extending from the main rail upward to the quarter-deck rail cap and running from the mainmast aft to the stern. This is plainly shown in Marestier's sketch of the *Savannah* as well as in some portraits of early packet ships.

Though the passenger accommodations described were far from palatial by modern standards, they were considered adequate in the 1820's and for almost 15 years afterwards. The staterooms had no individual toilets. Usually there were two small toilets, one on each side of the stern cabin, at the extreme stern on the lower deck, in the quarters. Usually the master's stateroom and toilet were to starboard, with a public space and toilet to port. Sometimes toilets for the crew were placed forward, on either bow abaft the catheads on the upper deck. These were small cabinets accommodating one person each, and with the door closed for privacy there was not room to stand. To enter the user backed in, crouching. Such cabinets are not shown by Marestier, so probably the crew used the headrails, as then was usual in merchant vessels.

The hull-form to be chosen had to enclose all spaces that have been described or listed. Since the *Savannah* is known to have sailed quite fast for her length, her lines had to equal those of the *Ohio;* however, her smaller size and other factors indicated a somewhat different hull-form, with harder turn of the bilge and a little less deadrise. Due to the position of the machinery, the effect of its weight and that of the necessary fuel had to be considered. The midsection, or cross section of greatest area, would have to have been only a little abaft the paddle wheel axle to allow proper trim with a minimum of ballast. It was found by this criterion that the midsection of the reconstructed hull was located in proportion to length in a comparable manner to that of the *Ohio.* The run could have been made about as long and easy, in proportion, as that of the *Ohio*; likewise, the entrance could have been equally well designed for sailing. Probably a little ballast—stone, gravel, sand or pig iron—was required under the temporary flooring of the cargo holds, most of it abaft the mainmast. Some ballast would normally have been placed under the cabin stores, in the run. The boilers, engine, and fuel weights were relatively important. To trim the ship, with minimum ballast, the location of the machinery weights would have to have been about as shown in the reconstruction drawings. It may be observed that the engine and fuel weights are relatively great for the recorded hull dimensions and resultant displacement limitation, indicating only a small quantity of ballast would have been employed under any circumstance.

Using the *Ohio* as a guide, the midsection was formed to comply with the dimensions of the boilers and with due regard to the small dimensions of the *Savannah.* The result was a section having very moderate rise of straight floor, carried farther out in proportion to beam than in the *Ohio*, but with rather easy turn of the bilge and moderate tumble-home in the upper topsides. This section has a form found in plans of some American freighting ships of 1815–1830, but with slightly slacker bilge.

The stern used in the reconstruction was the "square stern and round tuck" seen in the *Ohio* and referred to in the *Savannah*'s register. Collins' "round stern," shown in Hudson's drawing, did not come into use in America until about 1824, and then in naval ships only, so far as existing plans of American vessels show.

The reconstructed hull-form (figure 6) shows the man's bust figurehead mentioned in the register, and the supporting head and trail mouldings employed in the packets and other American ships of the period. The figurehead may have had some relation to the original or intended name of the ship prior to her purchase for conversion. No detailed description has been found. A ship built to the drawing would at least sail well and would carry her machinery, fuel, etc., as indicated in the descriptions that exist. Whether or not the hull is precisely like that of the original ship can never be determined until the original plan, or model, is found. The proposed deck arrangement is shown in dotted lines, in plan view.

The rig shown in figure 7 is based upon Marestier's sketch and his incomplete description. Since the ship had long royal poles on her topgallant masts it is highly probable she crossed royal yards, like the later packet ships. The proportions for the length of spars are based upon the masting rules given by M'Kay[23] in 1839. The fore spencer gaff, used as a crane for handling coal and cargo if the fore or main yards were not available, may have been long enough to be used also as a crane to handle the side wheels. The stack and mainstays may have made the fore spencer sail a nuisance, so it may not have been set while the vessel had her engine. In general, aside from the use of the spencers on fore and main, the sail plan shown is of standard proportions and arrangement of 1815–1825. For rigging, Darcy Lever's book[24] was consulted. The drawing of the reconstructed *Savannah*'s sail plan agrees with contemporary sail plans of ships in the author's collection. The log shows she set studding sails and had all the light canvas of a ship of her type.

There remain a number of matters that do not directly concern the reconstruction project but which are of sufficient technical importance to warrant comment. Apparently the engine was mounted on a wooden frame consisting of two large oak timbers on each side, say about 10″×10″, one above the other, that probably supported iron saddles in which the two cylinders rested. Between each pair would have been the iron track, or channel, in which the ends of the crosshead travelled, along the axis of the engine in elevation. These frames measured about 9 feet 2 inches, outside to outside, and reached from the beams of the upper deck on either side of the crank hatchway to abaft the mainmast on the lower deck. It is probable that the fore and after ends of the frame were supported by stanchions stepped on

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[23] M'Kay, *op. cit.* (footnote 5).

[24] Darcy Lever, *Sheet Anchor*, London, 1808–1811. (Reprint, Providence, Rhode Island, 1930.)

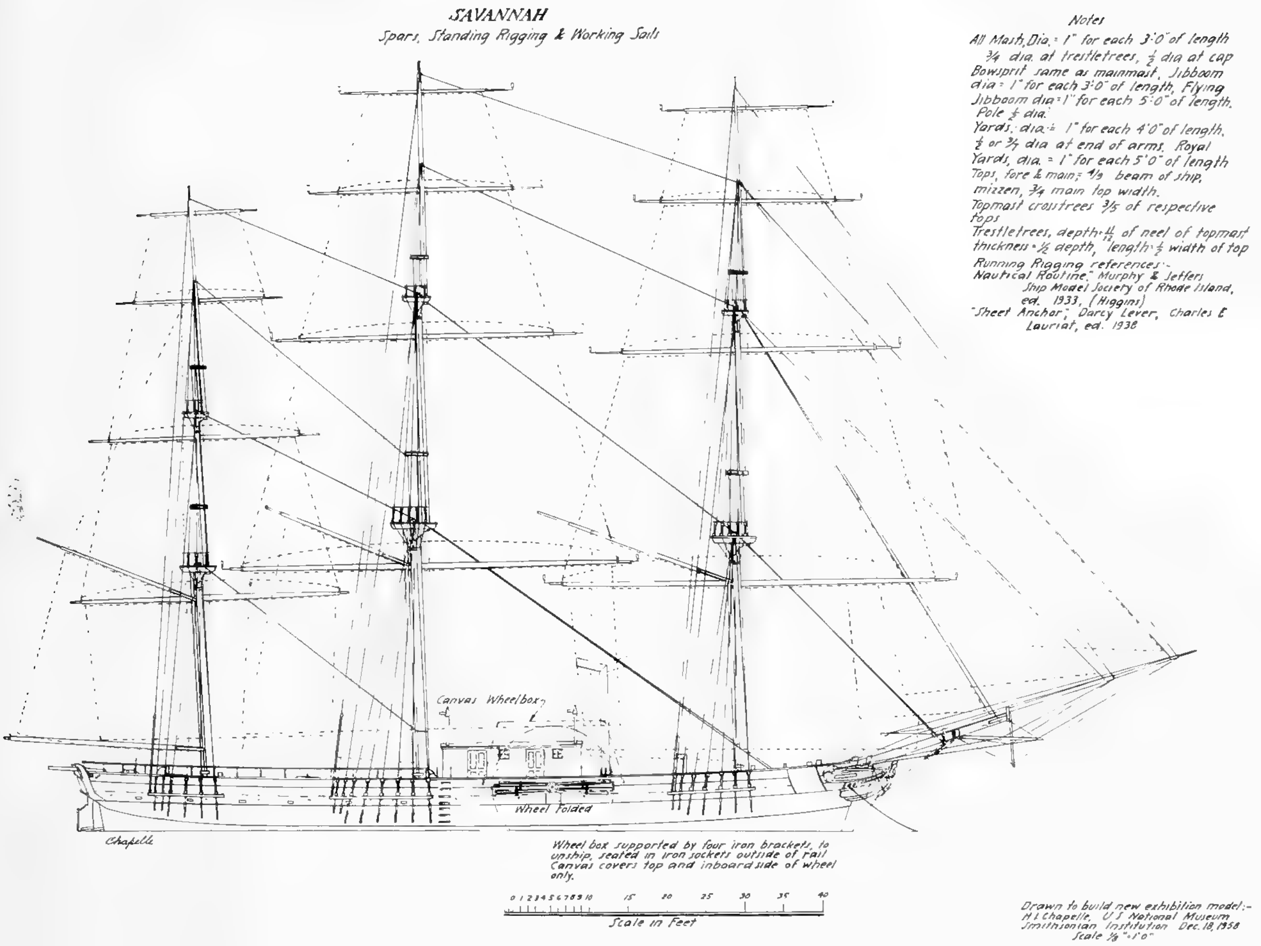
SAVANNAH
Spars, Standing Rigging & Working Sails
Notes
All Masts, Dia. = 1" for each 3'0" of length
3/4 dia. at trestletrees, 1/2 dia at cap
Bowsprit same as mainmast, Jibboom
dia = 1" for each 3'0" of length, Flying
Jibboom dia = 1" for each 5'0" of length.
Pole 1/2 dia.
Yards, dia = 1" for each 4'0" of length.
1/2 or 3/4 dia at end of arms. Royal
Yards, dia. = 1" for each 5'0" of length
Tops, fore & main = 4/9 beam of ship,
mizzen, 3/4 main top width.
Topmast crosstrees 3/5 of respective
tops
Trestletrees, depth = 11/12 of neel of topmast
thickness = 1/2 depth, length = 1/2 width of top
Running Rigging references:-
"Nautical Routine," Murphy & Jeffers
Ship Model Society of Rhode Island,
ed. 1933, (Higgins)
"Sheet Anchor," Darcy Lever, Charles E
Lauriat, ed. 1938
Canvas Wheelbox
Wheel Folded
Chapelle
Wheel box supported by four iron brackets, to
unship, seated in iron sockets outside of rail
Canvas covers top and inboard side of wheel
only.
0 1 2 3 4 5 6 7 8 9 10 15 20 25 30 35 40
Scale in Feet
Drawn to build new exhibition model:-
H I Chapelle, U S National Museum
Smithsonian Institution Dec. 18, 1958
Scale 1/8" = 1'0"

Figure 7.—Reconstructed drawing of spar and outboard profile of the *Savannah*. Dotted lines indicate working sails. Standing rigging only is shown. Royal yards were set flying and were crossed only when the ship was under full sail, never at anchor.

the lower deck at the fore end and in the hold at the after end. The crosshead was of iron and probably had shoes at the ends to work in the tracks or channels in the frame. To help steady the crosshead, these shoes probably were a foot or more long, for the loading of the crosshead is spread out. The pitman to the paddle wheel shaft is to starboard of the centerline of the engine; the steam cylinder piston is slightly off center of the frame and crosshead; and the piston of the air cylinder is close to the port engine frame. The steam lines to the valves of the steam cylinder come in horizontally over the frames. As has been mentioned, the frame may also have supported the paddle wheel axle bearings at the crank.

This engine has been criticized by some writers (see Tyler's[25] résumé of Gilfillan's[26] comments), but the *Savannah* logbook shows it gave no trouble, and should be compared with the logs of *Sirius* and *Great Western* as summarized by Tyler. The relatively slow piston speed and small power put little strain on the moving parts. Tallow was probably used for lubrication, being introduced into the valve chest by pots on top of the casing, where radiated heat would melt the tallow. From the valve chest the melted tallow was carried into the cylinder, and from there probably passed into the jet condenser. No doubt the lubricant became a sludge that had to be removed from the condenser at least once every 48 hours. There is

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[25] David Budlong Tyler, *Steam Conquers the Atlantic*, New York and London, 1939.

[26] S. C. Gilfillan, *Inventing the Ship*, New York, 1935.

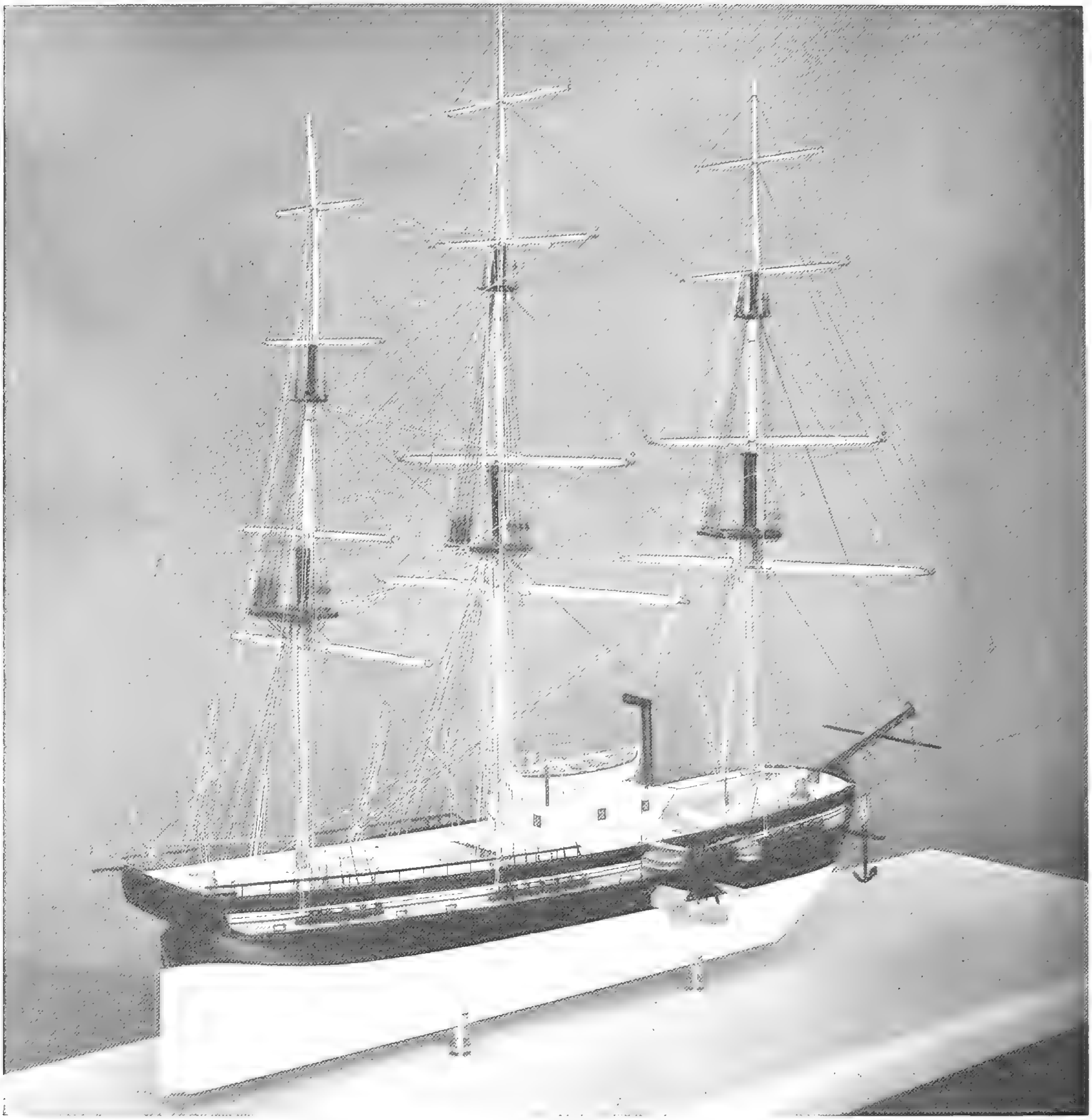

Figure 8.—Stern-quarter view of the new model of the *Savannah*, showing one wheel partially folded and the iron frames for canvas wheel-boxes in place.

no real evidence that the engine and boilers suffered any great strains; the operating pressure of steam must have been low at all times. The boilers were probably of very low efficiency and made steam slowly. Fuel consumption was high, and, according to the logbook, the vessel ran out of coal when she reached the English coast; however, she had enough fuel left to steam up the Mersey to Liverpool, probably using wood. At the time she ran out of coal she had used her engine about 80 to 83 hours. While this indicates a fuel consumption of almost a ton per hour, it must be remembered that the intermittent opera-

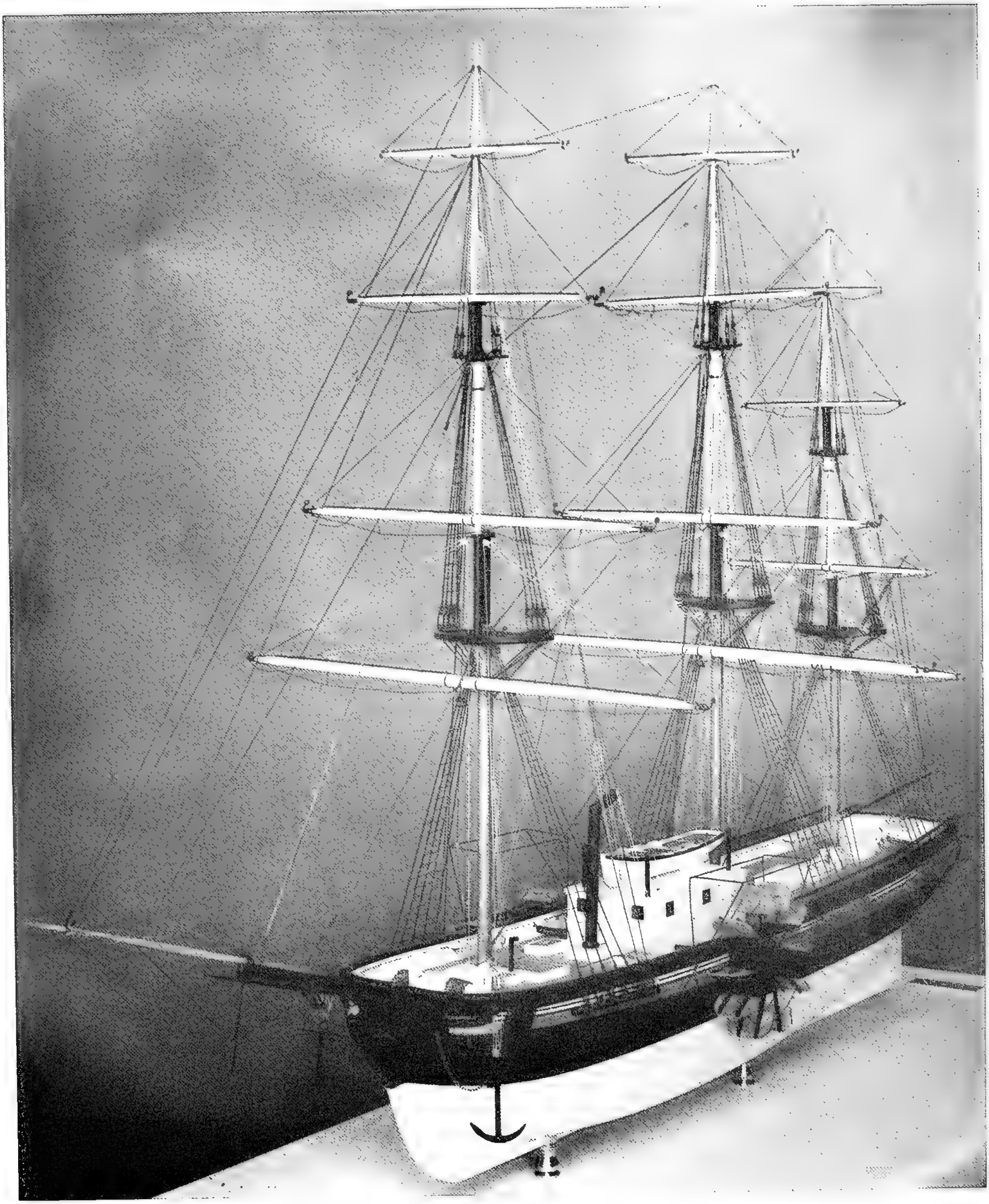

Figure 9.—Bow-quarter view of the new model of the *Savannah*, showing deck arrangement details.

tion of the engine required expenditure of fuel to raise steam in cold boilers over and over again. This was one of the weaknesses in the auxiliary steamship, particularly, as in the case of the *Savannah*, when the engine was used a number of times during a voyage without long periods of continuous operation. Also, there is doubt that the vessel carried as much as 75 tons of coal; she probably had no more than 55 to 60 tons aboard, if the figure of 1,500 bushels is correct. It is impossible to establish exact weight-cubic measurements with the available data.

Though the authorities quoted seem to agree that the *Savannah* could steam only 4½ to 5¼ knots in smooth water, her logbook credits her with 6 knots under steam alone at sea. However, this is probably an approximation affected by current and sea rather than a truly logged speed.

Judging by references in the logbook, the *Savannah* carried one boat on the stern davits. The davits, shown in Marestier's sketch, would handle a boat of about 16 to 18 feet in length. At sea the boat was probably carried on top of the deckhouse. The vessel obtained a new boat during her European trip. It is probable that the lack of passengers is why a second boat, which could have been stowed on the deckhouse roof, was omitted.

There is no record of how the *Savannah* was painted, except that the logbook refers to her "bright" strake. Packets appear to have followed what once was a Philadelphia practice in having a varnished band along the topsides. Marestier's sketch indicates that there may have been four or five bands of color, beginning at or a little above deck and wide enough for the top band to be up about two-fifths the height of the bulwarks. The hull was commonly black. The bands were red, white, and blue and there was a "bright" strake, or alternate black and varnished bands. These bands were about 3 to 5 inches wide. Sometimes the "bright" band, as mentioned in the *Savannah* logbook, was along the topside just above and adjacent to the top of the wale, or belt of thick planking, or might be the uppermost strake of the wale. Perhaps the *Savannah* had a wide bright band above the wale and multicolored bands just above the deck. The headrails were painted black, with mouldings at top and bottom of rails and with knees picked out with very narrow bands of yellow, or "beading." The figurehead was then commonly painted in natural colors, to suit the form of head if a figure or a bust. The bowsprit and davits probably were black. Deck structures were probably white, the neck natural, with waterways and inside of bulwarks white, the stack black, and rail caps varnished.

In this period it was unusual to copper a wooden ship before launch, so it is doubtful that the *Savannah* was copper sheathed. Since her voyage occurred during a period of financial depression, it is probable that her bottom was "white" (tallow and verdigris).

The reconstruction described herein produced a plan for a model that complied to the fullest extent with all the known dimensions and descriptions of the *Savannah* that have yet been found. The result showed that the United States National Museum's old model could not be altered to agree with the known features of the *Savannah* and that a new model was therefore necessary. So that the new model would be comparable to other models of early American steamers, existing or intended, in the Watercraft Collection, it was constructed on the scale of one-quarter inch to the foot. The new model (figs. 2, 8, and 9) is now on exhibition at the Smithsonian Institution.

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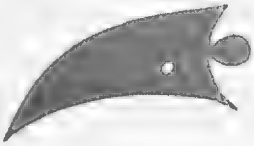

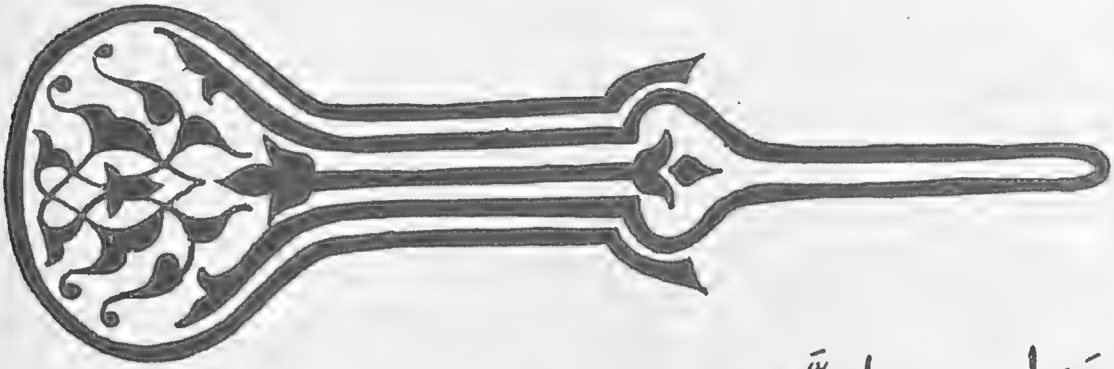

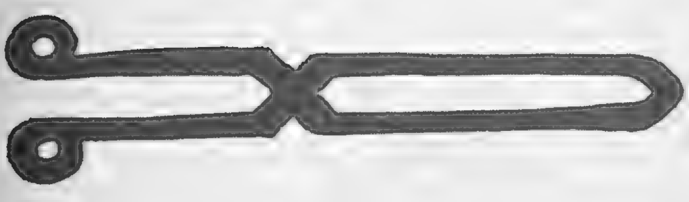

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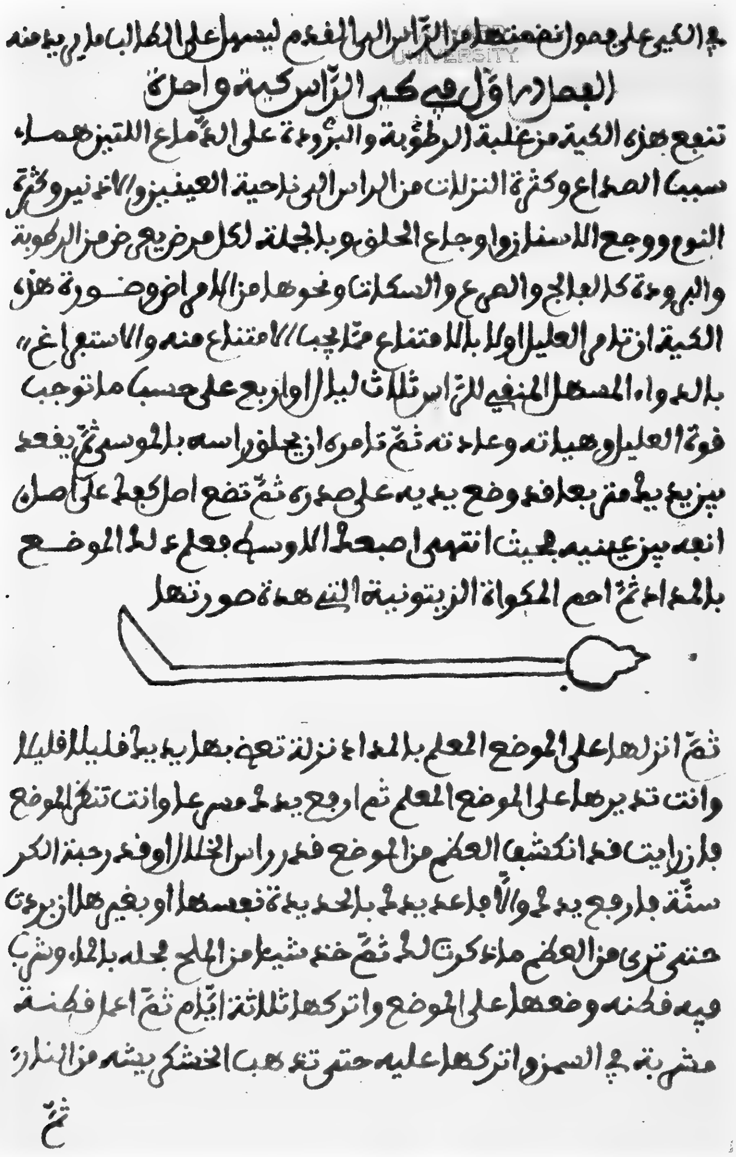

في الكيء على حسب ان نضمنها من الراس الى القدم ليسهل على الطالب ما يريد منه

الفصل الاول في كي الراس كية واحدة

تنفع هذه الكية من غلبة الرطوبة والبرودة على الدماغ اللتين هما
سبب الصداع وكثرة النزلات من الراس الى ناحية العينين والاذنين وكثرة
النوم ووجع الاسنان واوجاع الحلق وبالجملة لكل مرض يكون من الرطوبة
والبرودة كالفالج والصرع والسكات ونحوها من الامراض وصورة هذه
الكية ان تامر العليل اولا بالاستفراغ مما يجب الاستفراغ منه والاستفراغ
بالدواء المسهل المنقي للراس ثلاث ليال او اربع على حسب ما توجب
قوة العليل وسنه وعادته ثم تامره ان يحلق راسه بالموسى ثم يقعد
بين يديك متربعا واضعا يديه على صدره ثم تضع اصل كفك على اصل
انفه بين عينيه فحيث انتهى اصبعك الوسطى فعلم ذلك الموضع
بالمداد ثم احم المكواة الزيتونية التي هذه صورتها

ثم انزلها على الموضع المعلم بالمداد نزلة تقبض بها يدك قليلا قليلا
وانت تديرها على الموضع المعلم ثم ارفع يدك مسرعا وانت تنظر الموضع
فان رايت قد انكشف العظم من الموضع قدر راس الخلال والا فرد يدك الكرة
ثانية فارفع يدك والا فاعد يدك بالحديدة بعينها او بغيرها ان بردت
حتى ترى من العظم ما ذكرت لك ثم خذ شيئا من الملح فحله بالماء وتشرب
فيه قطنة وضعها على الموضع واتركها ثلاثة ايام ثم احمل قطنة
مشربة في السمن واتركها عليه حتى تذهب الخشكريشة من النار

ثم

Figure 1.—Reproduction of a page from original Arabic manuscript indexed as "Cod. N.F. 476A" at Oesterreichische Nationalbibliothek in Vienna. Courtesy Oesterreichische Nationalbibliothek.

Drawings and Pharmacy in al-Zahrāwī's 10th-Century Surgical Treatise

by Sami Hamarneh

Probably the earliest independent work in Arabic Spain to embrace the whole of medical knowledge of the time is the encyclopedic al-Taṣrīf, *written in the late 10th century by Abū al-Qāsim al-Zahrāwī, also known as Abulcasis. Consisting of 30 treatises, it is the only known work of al-Zahrāwī and it brought him high prestige in the western world.*

Here we are concerned only with his last treatise, on surgery. With its many drawings of surgical instruments, intended for the instruction of apprentices, its descriptions of formulas and medicinal preparations, and its lucid observations on surgical procedures, this treatise is perhaps the oldest of its kind.

Scholars today have available a translation of the text and reproductions of the drawings, but many of the latter are greatly modified from the originals.

This study reproduces examples of al-Zahrāwī's original illustrations, compares some with early drawings based on them, and comments on passages in the treatise of interest to students of pharmacy and medical therapy.

THE AUTHOR: *Sami Hamarneh undertook this research into the history of medicine in connection with his duties as associate curator of medical sciences in the United States National Museum, Smithsonian Institution.*

THE INTRODUCTION OF THE WRITINGS of Abū al-Qāsim Khalaf ibn ʿAbbās al-Zahrāwī—better known as Abulcasis (d. ca. 1013)—to Western Europe was through the Latin translation of his surgical treatise (maqālah) by Gerard of Cremona (d. 1187).[1] The response to this treatise, thereafter, was much greater than the attention paid to the surgery of any of the three renowned physicians of the Eastern Caliphate: al-Rāzī (Latin, Rhazes, d. ca. 925), the greatest clinician in Arabic medicine; al-Majūsī (Haly Abbās, d. 994), the author of the encyclopedic medical work, *al-*

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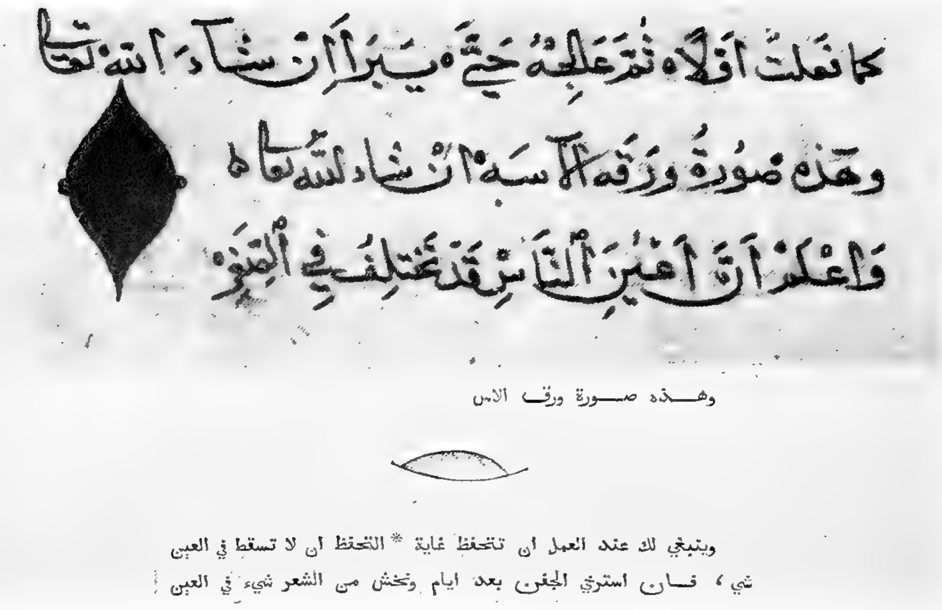
[1] George Sarton, *Introduction to the History of Science*, Baltimore, 1927, vol. 1, p. 681.



كما فعلت أولاً ثم تعالجه حتى يبرأ إن شاء الله تعالى

وهذه صورة ورقة الآسة إن شاء الله تعالى

واعلم أن أعين الناس قد تختلف في الكبر

وهذه صورة ورق الاس

وينبغي لك عند العمل ان تتحفظ غاية * التحفظ ان لا تسقط في العين
شي ، فان استرخي الجفن بعد ايام وتخش من الشعر شيء في العين ؛

Figure 2.—The myrtle-leaf shape recommended for paper on which medicine is to be placed for cauterizing eyelid. *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Bottom*, from Channing, *Albucasis*.

Malakī; [2] and Ibn Sīnā (Avicenna, 980–1037), the author of the famous *al-Qānūn fī al-Ṭibb*, a codification of the whole of medical knowledge. Because of the widespread dissemination of this Latin version in medieval Europe beginning with the latter part of the 12th century, al-Zahrāwī attained more prestige in the West than he did in Arabic Spain, his native country, or in any other part of the Islamic world.[3]

The fame attached to this surgical treatise, the 30th and last in al-Zahrāwī's encyclopedic work *al-Taṣrīf Liman ʿAjiza ʿan al-Taʾlīf*, is founded on certain merits. The text is characterized by lucidity, careful description, and a touch of original observation of the surgical operations to which the treatise as a whole is devoted.[4] Al-Zahrāwī furnishes his own drawings of the surgical and dental instruments he used, devised, or recommended for a more efficient performance. The illustrations were intended to provide instructional material for apprentices—whom al-Zahrāwī calls his children—as well as for the benefit of those who would read the work later on.[5] The treatise is

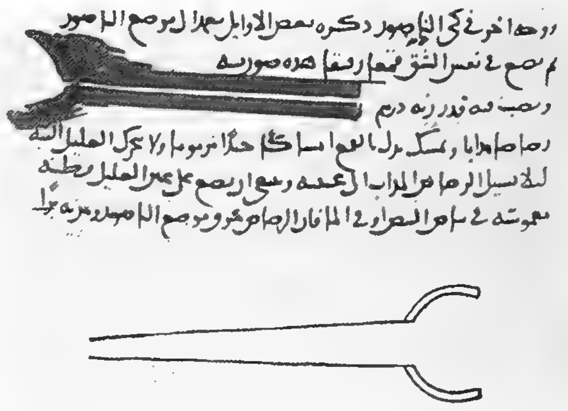


Figure 3.—Small funnel for pouring heated lead into fistula of the eye for cauterization. *Top*, from original Arabic manuscript (Vel. 2491), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom*, from Sudhoff, *Chirurgie*, courtesy National Library of Medicine.

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[2] Mohammad S. Abu Ganima, in *Abul-Kasim ein Forscher der Arabischen Medizin*, Berlin, 1929, suggested that description of operations in al-Majūsī's surgery is clearer than that in al-Zahrāwī's—a statement which does not seem acceptable.

[3] Max Neuburger, *Geschichte der Medizin*, Stuttgart, 1911, vol. 2, pt. 1, pp. 178–179.

[4] Heinrich Haeser, *Lehrbuch der Geschichte der Medizin und der epidemischen Krankheiten*, Jena, 1875, vol. 1, pp. 578–584; and Donald Campbell, *Arabian Medicine and Its Influence on the Middle Ages*, London, 1926, vol. 1, p. 88.

[5] See the prelude to the treatise.

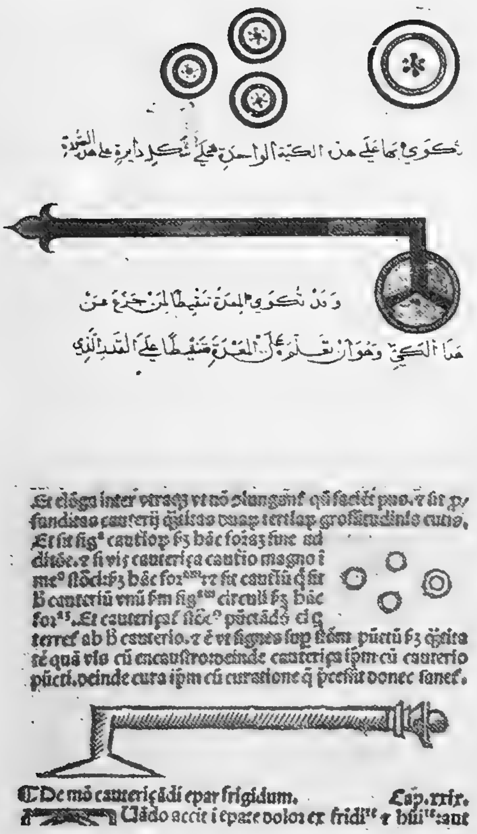

Figure 4.—Circular cauterization in stomach ailments. *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Bottom*, from the 1531 Latin edition of Pietro d'Argellata, *Chirurgia Argellata cum Albucasis*, hereinafter cited as Argellata 1531, courtesy National Library of Medicine.

probably the oldest one known today that contains such instructive surgical illustrations and text.[6]

This surgical treatise has been investigated, translated, and commented upon by eminent historians of medicine and surgery to whose works I shall refer in this article. However, the pharmaceutic and therapeutic details of the treatise have been somewhat overlooked.

As to the various illustrations of the surgical instruments (over 200 figures in all), an almost complete representation of samples has been introduced by Channing,[7] Leclerc,[8] Gurlt,[9] Sudhoff,[10] and others. Nevertheless, a good number of the reproduced drawings are greatly modified, most likely having been influenced by earlier illustrations in several Latin and vernacular versions of the treatise.[11] This becomes clearer on comparison with seven Arabic manuscripts that have not been fully examined by Western scholars before and that—in several instances—show more authentic drawings of al-Zahrāwī's surgical instruments than any heretofore published.[12]

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[6] Fielding H. Garrison (*An Introduction of the History of Medicine*, ed. 4, rev., Philadelphia, 1929, p. 132), states, in reference to "Sudhoff and others," that many drawings earlier than those of al-Zahrāwī have been discovered in medieval manuscripts. However, Garrison overlooked the fact that al-Zahrāwī's surgical illustrations were mainly depicted for instructional purposes—a unique approach. It should be noted also that al-Zahrāwī died almost a century earlier than Garrison thought. See also Martin S. Spink, "Arabian Gynaecological, Obstetrical and Genito-Urinary Practice Illustrated from Albucasis," *Proceedings of the Royal Society of Medicine*, 1937, vol. 30, p. 654.

[7] Johannis Channing, *Albucasis de Chirurgia. Arabice et Latine*, Oxford, 1778, 2 vols. (hereinafter referred to as Channing, *Albucasis*). The text has many errors in spelling and grammar, but Leclerc went too far in criticizing this edition, which has many merits. Moreover, the surgical illustrations (reproduced from the Huntington and Marsh manuscripts of the Bodleian Library) in Channing's edition are of special interest.

[8] Lucien Leclerc, *La Chirurgie d'Abulcasis*, Paris, 1861 (hereinafter referred to as Leclerc, *Abulcasis*). This excellent French version was first published in a series of articles in *Gazette Médicale de l'Algérie*, and seems influenced by Channing's edition more than Leclerc admits. Leclerc consulted several Arabic copies of the treatise as well as Latin and vernacular translations, but only a few of these Arabic manuscripts are considered complete. The Arabic manuscripts studied for the present article are not the same as those used by Leclerc. See also Leclerc's monumental work, *Histoire de la Médecine Arabe*, Paris, 1876, vol. 1, pp. 453–457.

[9] Ernst Gurlt, *Geschichte der Chirurgie und ihrer Ausübung Volkschirurgie-Alterthum-Mittelalter-Renaissance*, Berlin, 1898, vol. 1, pp. 620–649, with more than 100 figures. In the text and illustrations, Gurlt relied upon Leclerc's translation and modified drawings of the surgical instruments; nevertheless, he presents a brief, systematic study—probably the best so far—of the entire treatise.

[10] Karl Sudhoff, *Beiträge zur Geschichte der Chirurgie im Mittelalter*, Leipzig, 1918 (hereinafter referred to as Sudhoff, *Chirurgie*), vol. 2, pp. 16–84, with a few plates. Although Sudhoff consulted the fragmentary Arabic manuscript indexed as "Cod. Arab. 1989" in Gotha, Germany, he relied mainly upon Latin versions of the treatise and the illustrations contained in them.

[11] See Leclerc, *Abulcasis*, in introduction.

[12] The seven Arabic manuscripts are indexed as "Berlin MS. Or. fol. 91," temporarily at Universitätsbibliothek Tübingen, in Germany; "Escorial MS. Arabe No. 876," at Biblioteca del Monasterio de San Lorenzo el Real de El Escorial, in Spain; "Wien MS. Cod. N.F. 476 A.," at Oesterreichische Nationalbibliothek, in Vienna; and "Ali Emiri Arabi No. 2854," "Besir Ağa Nos. 502 and 503," and "Veliyyudin No. 2491," all at

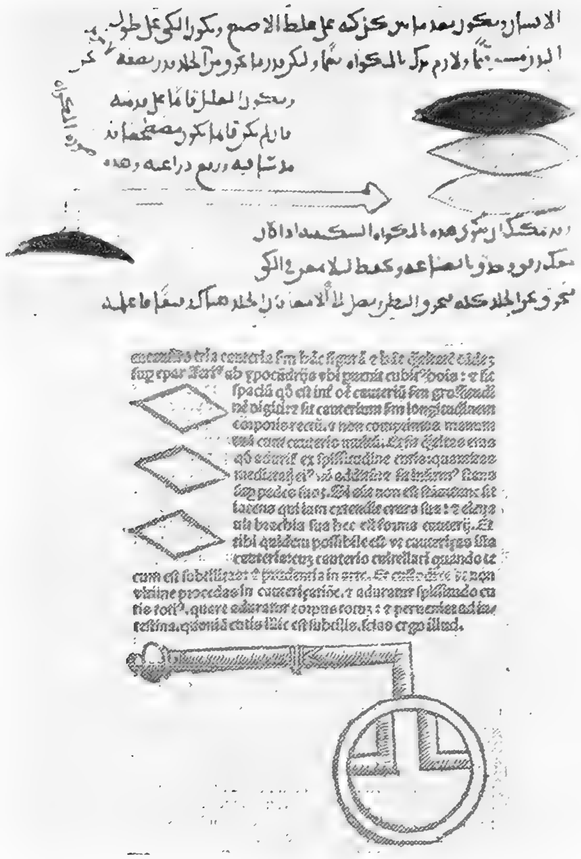


Figure 5.—Ink markings for identifying place of cauterization. *Top,* from original Arabic manuscript (Vel. 2491), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom,* from Argellata 1531, courtesy National Library of Medicine.

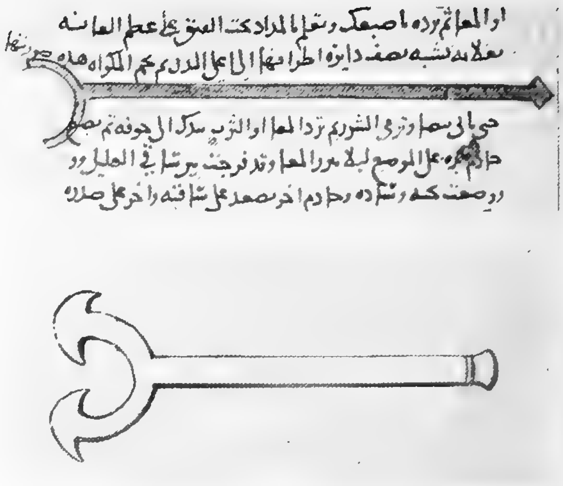


Figure 6.—Cautery in hernia. *Top,* from original Arabic manuscript (Vel. 2491), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom,* from Leclerc, *Albulcasis.*

This article therefore, is an attempt to present a sample of these illustrations with brief comments regarding certain figures and passages of interest to pharmacy and medical therapy.

With much gratitude I express my indebtedness to Prof. G. Folch Jou of Madrid, to Dr. A. Süheyl Ünver and Mr. H. Dener of Istanbul, and to the librarians of the depository institutions for their cooperation in the reproduction of the manuscripts on microfilm.

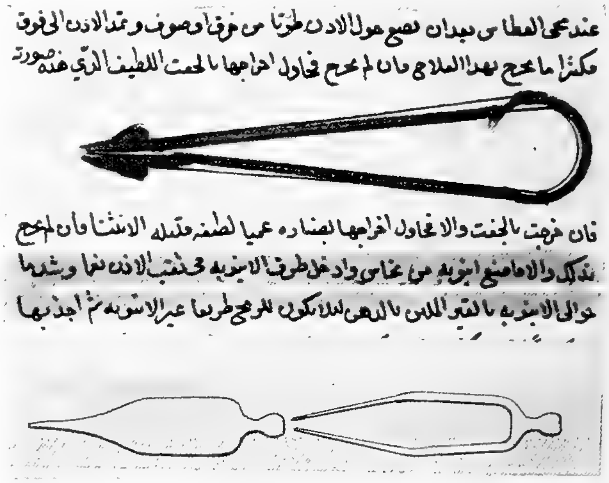
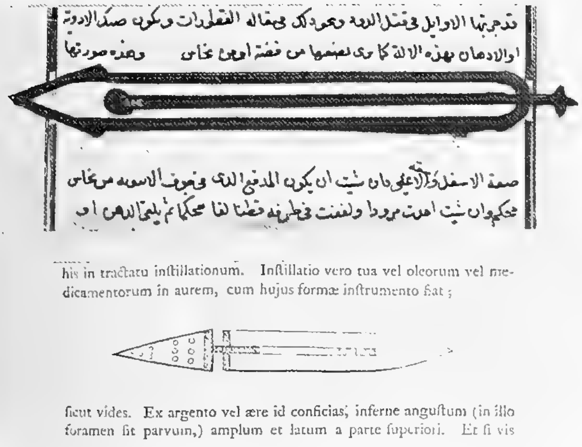


Figure 7.—Fine tweezer for removing foreign bodies from the ear. *Top,* from original Arabic manuscript (Ali 2854), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom,* from Leclerc, *Abulcasis.*

Süleymaniye Umumi Kütüphanesi Müdürlüghü, in Istanbul. Hereinafter these manuscripts are referred to, respectively, as Tüb. MS. 91; Esc. 876; Wien 476 A; Ali 2854; Bes. 502; Bes. 503; and Vel. 2491. The Smithsonian Institution recently obtained a microfilm copy of Bankipore Manuscript No. 17 from the Khuda Bakhsh O. P. Library, Patna (Bihar), India. This manuscript, containing only the 30th treatise of *al-Taṣrīf,* was copied in 1189; therefore, it is the earliest dated Arabic manuscript of the surgical treatise known to exist. The surgical illustrations therein add weight to the belief that the Arabic manuscripts show more originality in the drawings than do the later copied versions, which often were inaccurate and possibly distorted. About ten other illustrations from the Arabic manuscript in Istanbul indexed as "Topkapi MS. No. 1990" (which contains 215 beautifully illustrated figures) were presented by A. S. Ünver and Hüseyin Usman in an extract titled "Meşhur Arab Cerrahi Elbülkasimi Zehravi ve onum Kitabül Cerrâhiyesi," Istanbul, 1935. See also Ünver, *Serefeddin Sabuncouğlu: Kitabül Cerrahiyei Illhaniye,* Istanbul, 1939, pp. [5]–7.



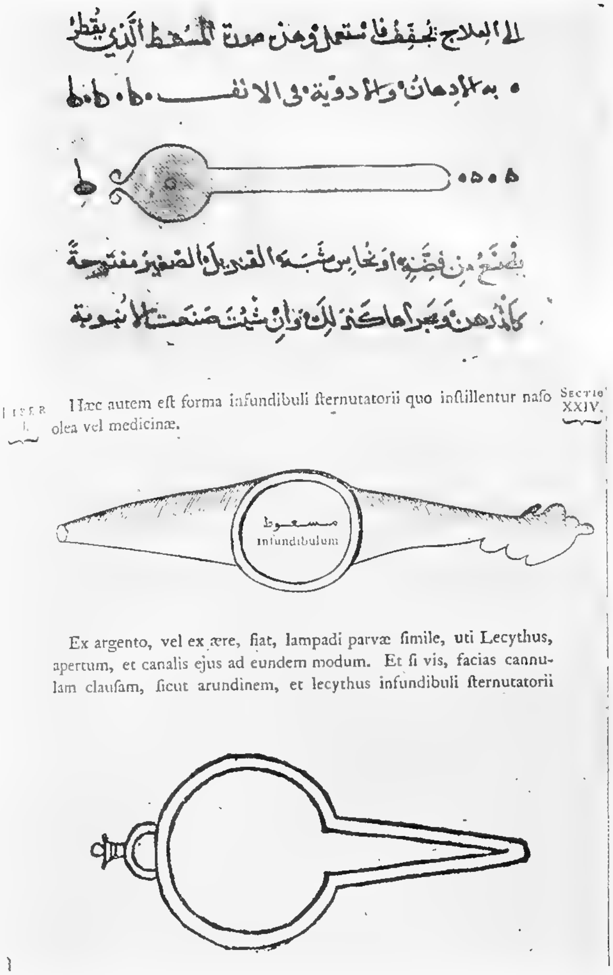
his in tractatu inſtillationum. Inſtillatio vero tua vel oleorum vel medicamentorum in aurem, cum hujus formæ inſtrumento fiat;

ſicut vides. Ex argento vel ære id conficias, inferne anguſtum (in illo foramen ſit parvum,) amplum et latum a parte ſuperiori. Et ſi vis

Figure 8.—Syringe with metal plunger-pump. *Top*, from original Arabic manuscript (Ali 2854), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom*, from Channing, *Albucasis*.

Al-Zahrāwī frequently introduces his treatises with brief instructive and sometimes informative preludes. However, in launching the last treatise of *al-Taṣrīf* he expounded in a most interesting and illuminating manner the status of surgery during his time. He also explains the reasons that forced him to write on this topic and why he wished to include, as he did, precautions, advice, instructional notes, and beautifully illustrated surgical drawings. For example, the prelude to the treatise mentions four incidents that he witnessed, all ending with tragic results because of the ignorance of physicians who attempted to operate on patients without the proper training in anatomy and surgical manipulation. "For if one does not have the knowledge of anatomy," al-Zahrāwī protests, then ". . . he is apt to fall in errors that lead to death as I have seen it happen to many." [13]

Al-Zahrāwī divides his surgical treatise into three sections (abwāb). In the first section (56 chapters)[14] he elaborates upon the uses and disadvantages of cautery in general. And on the ground that "fire touches only the ailing part . . . without causing much damage to surrounding area," as caustic medicine does, he prefers cautery by fire (al-kay bi al-nār) to cautery by medicine (bi al-dawā).[15] This, he adds, "became clear to us through lifelong experience, diligent practice, and thorough investigations of facts." [16]



LIBER I. Hæc autem eſt forma infundibuli ſternutatorii quo inſtillentur naſo olea vel medicinæ. SECTIO XXIV.

Ex argento, vel ex ære, fiat, lampadi parvæ ſimile, uti Lecythus, apertum, et canalis ejus ad eundem modum. Et ſi vis, facias cannulam clauſam, ſicut arundinem, et lecythus infundibuli ſternutatorii

Figure 9.—Metal nose dropper. *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Middle*, from Channing, *Albucasis* (*Smithsonian photo 46891–C*). *Bottom*, from Sudhoff, *Chirurgie*, courtesy National Library of Medicine.

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[13] See introduction to the treatise; for example, Bes. 502, fol. 522v–523v and Vel. 2491, fol. 104r–105v. See also K. P. J. Sprengel, *Versuch einer pragmatischen Geschichte der Arzneikunde*, Halle, 1823, vol. 2, pp. 449–451. George J. Fisher, in "Abul-Casem Chalaf Ibn Abbas al-Zahrāwī, Commonly Called Albucasis," *Annals of Anatomy and Surgery*, July–December, 1883, vol. 8, pp. 24–25, gives a translation of only the first part of the introduction.

[14] There are 56 chapters listed in almost all manuscripts and commentary works I checked except Tüb. MS. 91 and Esc. 876, where only 55 chapters are listed.

[15] Al-Zahrāwī mentions several caustic medicines used in cautery, among which are garlic, mustard, melted lead, slaked or unslaked lime with or without "common" soap, Thapsia (*Ruta graveolens* Linn.), and juice of the Oriental cashew nut (*Senecarpus anacardium* Linn.).

[16] Vel. 2491, fol. 106; Bes. 502, fol. 523r–524v.

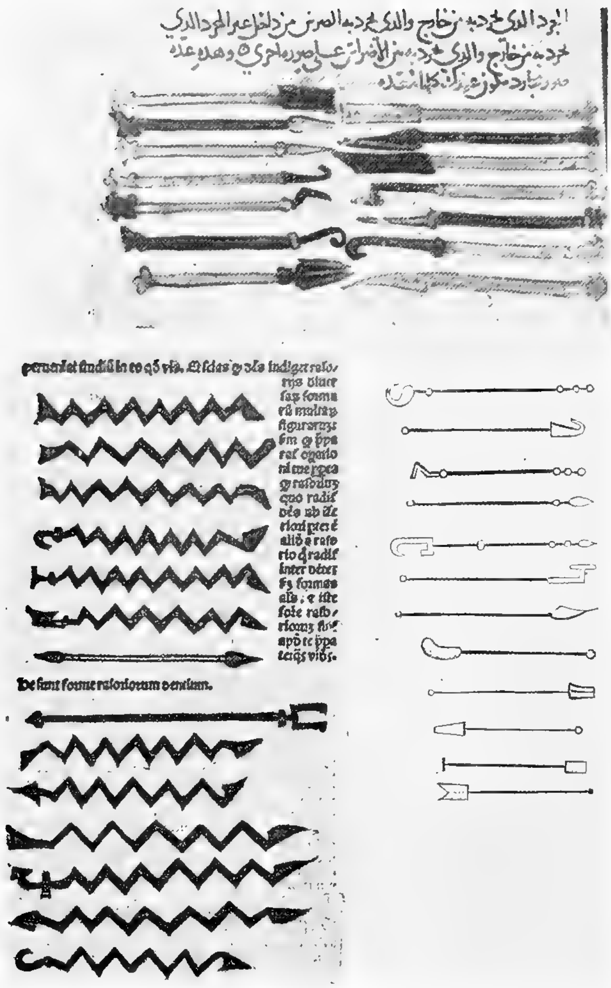

Figure 10.—Dental scrapers. *Top*, from original Arabic manuscript (Vel. 2491), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Left*, from Argellata 1531, courtesy National Library of Medicine. *Right*, from Channing, *Albucasis*.

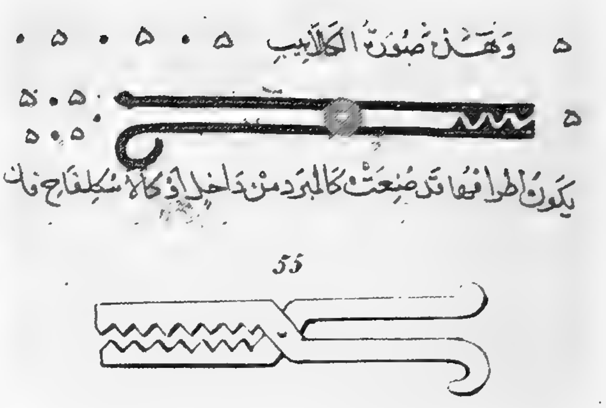

Figure 11.—Dental forceps. *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Bottom*, from Leclerc, *Abulcasis*.

He also proposes that instruments made of iron are more practical in many ways than those made of gold, because often, when gold instruments are put in fire, they either are not heated enough or are overheated, causing the gold to melt.

Al-Zahrāwī gently refutes the superstition that cautery is "good only in springtime," and states that under the right conditions of the body's humors it could be used in all seasons." [17] Although he recommends cautery rather highly, he never minimizes the importance of treatment by drugs. Actually, he encourages the use of drugs, before, with, and after cauterization.[18] For example, in chapter 16 on "the cauterization of eyelid when its hair grows reversedly into the eye," he recommends treatment by cautery and by medicine. In cautery, the area where fire is to be placed is marked with ink in the shape of a myrtle leaf. In drug treatment, the caustic medicine is applied to the eyelid over a paper in the shape of a myrtle leaf (fig. 2).

In chapter 17 the author refers to an ancient method regarding cautery of the fistula in the inner corner of the eye. After incising the fistula, one "dirham" (derived from the Greek "drachma," which is equal to about 2.97 grams) [19] of melted lead is poured into it through a fine funnel used for cauterization (fig. 3).

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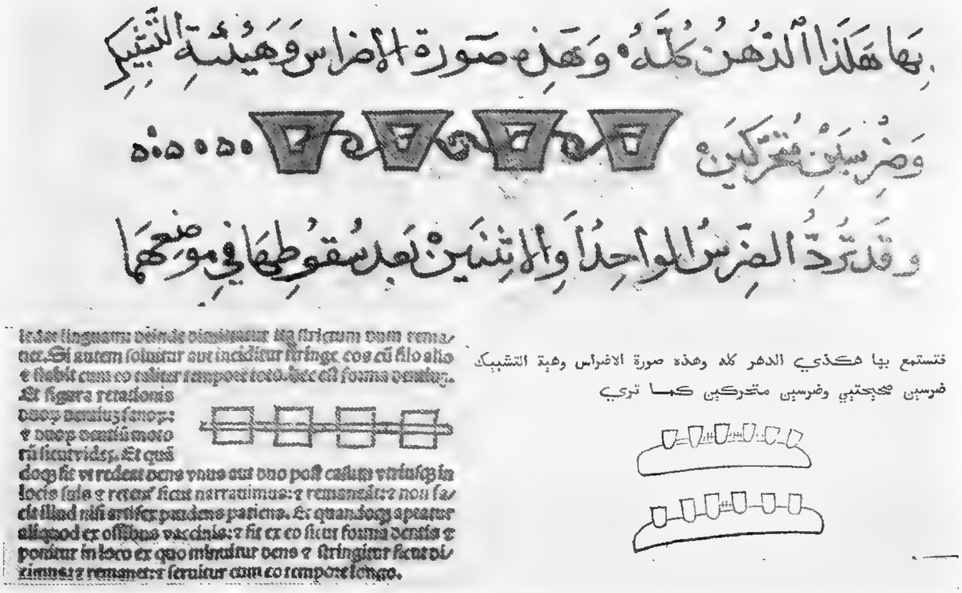
[17] Al-Zahrāwī criticizes those who interpret the saying "cautery is the end of treatment" to mean that cauterization is the best and only conclusive treatment at the physician's disposal. He points out that other treatments, such as drugs, should be resorted to first, and used until they prove of no avail; and he states that only after cautery proves to be the cure should it be considered the completion of medical treatment—"al-kay ākhir al-ṭibb." See Vel. 2491, fol. 106; and Bes. 502, fol. 524r–525v.

[18] For healing, soothing, or emollient purposes, al-Zahwārī suggested medications, such as egg white, salt water (normal saline), sap of psyllium, several ointments, "duhn" of rose, and other "adhān" (plural of "duhn," the fatty or oily essences extracted from various substances through pharmaceutical processes).

[19] For a more accurate estimate of the equivalence of "dirham" according to the area in which the measurement was taken, the reader may consult Walter Hinz, *Islamische Masse und Gewichte umgerechnet ins metrische System*, Leiden, 1955, pt. 1, pp. 2–8; and George C. Miles, *Early Arabic Glass Weights and Stamps*, New York, 1948, p. 6.



بها هكذا الدهر كله وهذه صورة الاضراس وهيئة التشبيك
وضرسين متحركين
وقد ترد الضرس الواحد والاثنين بعد سقوطها في موضعها

فتستمع بها هكذي الدهر كله وهذه صورة الاضراس وهية التشبيك
ضرسين صحيحتين وضرسين متحركين كما تري

Figure 12.—Golden bridge to stabilize shaky teeth. *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Left*, from Argellata 1531, courtesy National Library of Medicine. *Right*, from Channing, *Albucasis.*

In like manner, al-Zahrāwī discusses cautery of the stomach and the "cold liver" in chapters 26 and 27, respectively. The drawings therein represent shapes of the burns on the skin (fig. 4) and marks of ink to be drawn beneath the cartilage of the ribs (fig. 5) for the purpose of spotting the area of operation. Here also he describes carefully and clearly the methods of applying cautery and the types, position, and number of tools employed in each case. He likewise depicts (in chapter 45) instruments used in the treatment of hernia (fig. 6).

The second section (bāb), with about 99 chapters,[20] deals with incision, puncturing, venesection, cupping, surgery on abscesses, and the withdrawal of arrows from the body. Al-Zahrāwī warns that ignorance in such operations may lead to damage of an artery or vein, causing loss of blood "by which life is sustained."[21] Moreover, needle and thread (more than one kind is mentioned) for the stitching of wounds are repeatedly recommended.

According to al-Zahrāwī, foreign bodies that lodge in the ear (chapter 6) are of four origins: (1) "mineral stones" or substances resembling mineral stones such as iron and glass; (2) plant seeds (chick-peas and beans); (3) liquids, such as water and vinegar; and (4) animals, such as fleas. Several instruments are recommended for the removal of such foreign bodies—fine tweezers shaped like a dropper (fig. 7), a syringe with plunger-pump, and a tube made of silver or copper (fig. 8). Also of interest to pharmacy and therapy is the advice in regard to the use of lubricants to be applied before administering these fine instruments into the body's cavities.

Chapter 24 is concerned with the treatment of the polypus that grows in the nose. The various kinds (including cancer growth), shapes, and colors of this type tumor and its treatment by surgery or medicine are described. A hollowed nose-dropper made of metal in the shape of a small kerosene lamp[22] is suggested (fig. 9). The dropper is held by its handle while its contents are heated before use. Applying heat to nose drops was probably proposed because it serves two purposes: it allows easier flow of the "duhn," or the fatty substance used, and it raises the temperature of the drops to that of the body.

In his discussion on dental hygiene,[23] al-Zahrāwī describes scrapers and dental forceps for teeth cleaning and extraction (figs. 10, 11) and brings in a few points of historical interest.[24] He warns of the common error of extracting the adjacent healthy tooth instead of the ailing one due to the patient's sense deception. For a gargle he prescribes salt water, vinegar, and wine (sharāb). To stop hemorrhage he used blue vitriol (al-zāj)—copper sulfate in our modern terminology.

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[20] The contents of several manuscripts (such as Ali 2854. Wien 476 A, Bes. 503, and Tüb. MS. 91) give different numbers,

[21] See, for example, Tüb. MS. 91, fol. 45v; and Bes. 502, fol. 530v.

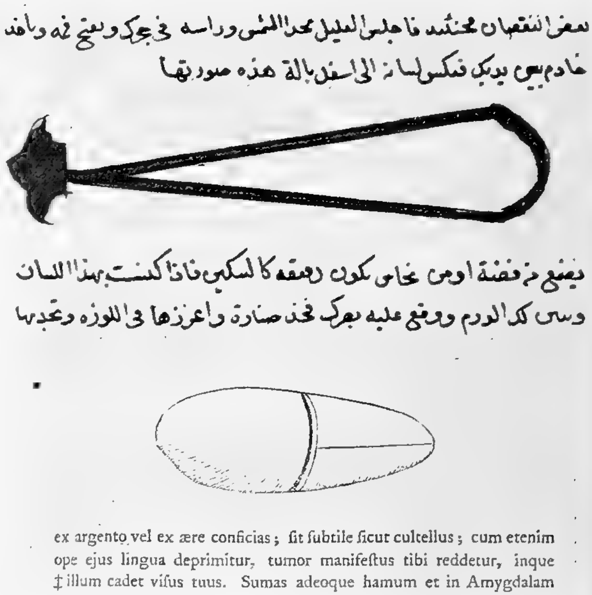
[22] Sudhoff, *op. cit.* (footnote 10), p. 29, fig. 6.

[23] For a more detailed and interesting discussion with beautiful illustrations included, the reader may consult Ch. Niel, "La Chirurgie Dentaire D'Abulcasis Comparée a celle des Maures du Trarza," *Revue de Stematologie,* April 1911, vol. 18, pp. [169]–180 and 222–229.

In chapter 33 al-Zahrāwī discusses bridge-making for the consolidation of shaky teeth (fig. 12). He prefers the use of stable gold over silver which, he says, putrifies and rots in a short time. In a rational approach, he also suggests that the fallen tooth itself, or a similar one shaped out of a cow's bone, be installed and connected with adjacent, stable teeth by a bridge.

Now, turning to chapter 36, we find al-Zahrāwī describing a knife-thin tongue depressor (fig. 13) that he used to facilitate the examination of inflamed tonsils and other swellings of the throat; it was made of silver or copper. And in chapter 37 (chapter 34 in Bes. 503), he describes the excision of an inflamed uvula by surgery. In the same chapter, he also mentions the use of instruments made of steel. Of pharmaceutical interest is the following free translation of the formula he prescribes "as a milder treatment by fumigation . . . to be resorted to only when the swelling is subsiding":[25]

> Take pennyroyal [*Mentha pulegium* Linn.], absinthe [*Artemisia maritima* Linn.], thyme, rue, hyssop, camomile, abrotanum [*Artemisia abrotanum* Linn.], and other similar herbs. Put all in a casserole and cover them with vinegar. Then close tightly with clay [*lutum-sapientiae*]—except for a small hole in the middle of the cover—and boil. Connect one end of a hollowed instrument, a crude form of an inhaler [fig. 14], with the hole in the cover and insert the other end, which contains the nozzle, into the patient's mouth, allowing the vapor to rise up to the uvula. And if you are not able to secure this instrument, take a straw and attach its end to an egg-shell. The egg-shell will prevent burns in the patient's mouth that might be caused by the heated vapor.



ex argento vel ex ære conficias; ſit ſubtile ſicut cultellus; cum etenim ope ejus lingua deprimitur, tumor manifeſtus tibi reddetur, inque ‡ illum cadet viſus tuus. Sumas adeoque hamum et in Amygdalam

Figure 13.—Metal tongue depressor. *Top*, from original Arabic manuscript (Ali 2854), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom*, from Channing, *Albucasis.*

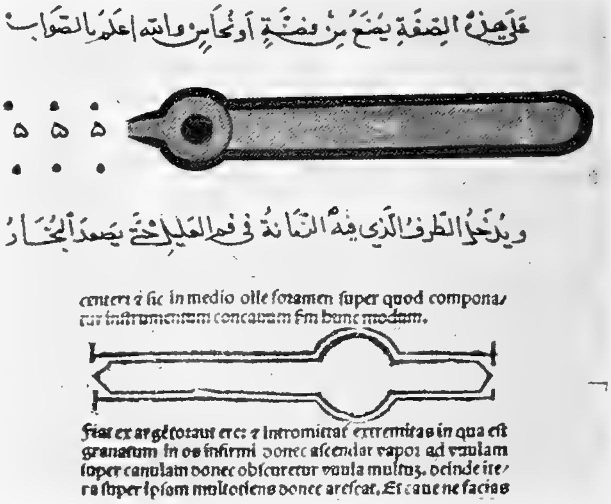


Figure 14.—Crude form of an inhaler. *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Bottom*, from Argellata 1531, courtesy National Library of Medicine.

Al-Zahrāwī repeats in chapter 53, on cancer, what Greek physicians had said earlier, that cancer could be removed by surgery only at its first stage and when found in a removable part of the body, such as the

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[24] It is regrettable that Franz Rosenthal in his fine article "Bibliographical Notes on Medieval Muslim Dentistry" (*Bulletin of the History of Medicine*, 1960, vol. 34, pp. 52–60) failed to refer to this or any other section of al-Zahrāwī's work.

[25] Bes. 502, fol. 538. See also Channing, *Albucasis*, pp. 206–208. For the identification of the drugs and their botanical origins the author of the present paper consulted H. P. J. Renaud and Georges S. Colin, *Tuhfat al-Ahbāb, Glossaire de la Matière Médicale Marocaine*, Paris, 1934, pp. 133, 143, 193–194, and Max Meyerhof, *Un Glossaire de Matière Médicale Composé par Maimonide*, Cairo, 1940, pp. 168–169.

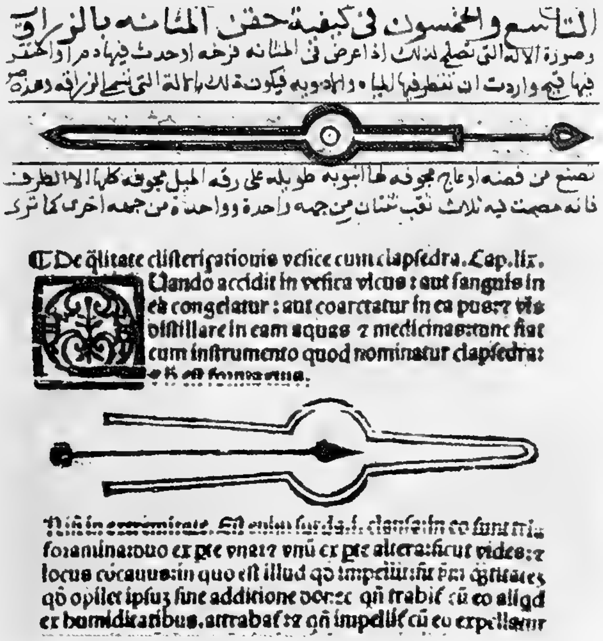

Figure 15.—Metallic syringe for injecting solutions into the bladder. *Top*, from original Arabic manuscript (Bes. 503), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom*, from Argellata 1531, courtesy National Library of Medicine.

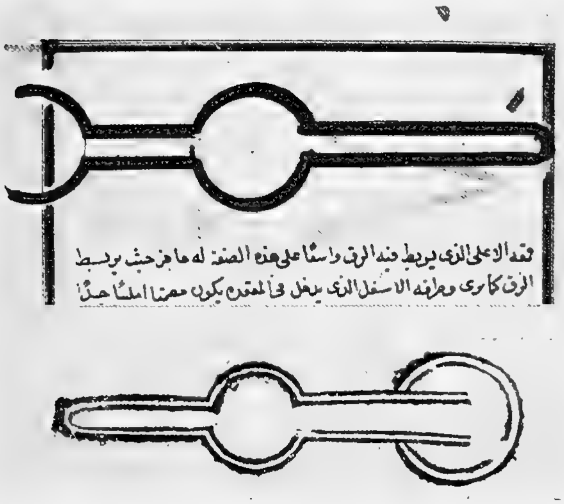

Figure 16.—Metallic or porcelain syringes for injection of enemas. *Top*, from original Arabic manuscript (Ali 2854), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom*, from Argellata 1531, courtesy National Library of Medicine.

breast. Therefore, he confesses that neither he nor any one else he knew of ever applied surgery with success on advanced cancer.[26]

Of special interest in chapter 59 is the metallic "syringe" (fig. 15) used to inject medicinal solutions into the bladder: "The hollow passage [of the syringe] should be exactly equal to the plunger it contains and no more, so that when such fluids from an excess of humors are aspirated they will be drawn out, and likewise when the solutions are injected they will be pushed in easily." Such description of the use of a "bladder syringe" in the late 10th century clearly points to the practical and interesting approach to surgery in *al-Taṣrīf*. Moreover, his description of the removal of a stone from the bladder—an operation we now call lithotomy—is considered a contribution to bladder surgery.

One of the earliest recorded operations for the extractions of two dead fetuses from the womb is clearly described in chapter 76. The account of this case shows not only al-Zāhrawī's intelligent approach as a shrewd observer but also his clinical and surgical ability.

Drawings of bulb-syringe instruments used for administering enemas in ailments of the rectum and for the treatment of diarrhea and colic are depicted in chapter 83. The text describes several kinds of syringes made of silver, porcelain, and copper in various sizes (fig. 16). Of particular interest is an illustration of a syringe, especially recommended for children, to which a piece of leather (jildah) is attached (fig. 17). This instrument is a precursor of our modern bulb syringe.

In chapter 84 al-Zahrāwī turns to the treatmnet of various wounds. He prescribes the following powder formula for use: "Take olibanum [frankincense] and dragon's blood,[27] two parts of each, and three parts of slaked or unslaked lime. Pound them well, pass through a sieve and apply the powder to the wound." In cases of damaged blood vessels, he tied the arteries by ligature, a practice of which he was a pioneer. In another chapter he describes four methods for suturing the intestines.

Al-Zahrāwī, being associated with war casualties and writing his treatise about the end of the 10th

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[26] Tüb. MS. 91, fol. 99v.

[27] Dragon's blood is a resin obtained from the scales covering the surface of the ripe fruits of "*Daemonorops draco* Blume" (Heber W. Youngken, *Textbook of Pharmacognosy*, ed. 6, Philadelphia, 1948, p. 175). See also Renaud and Colin, *op. cit.* (footnote 25), pp. 54–55.

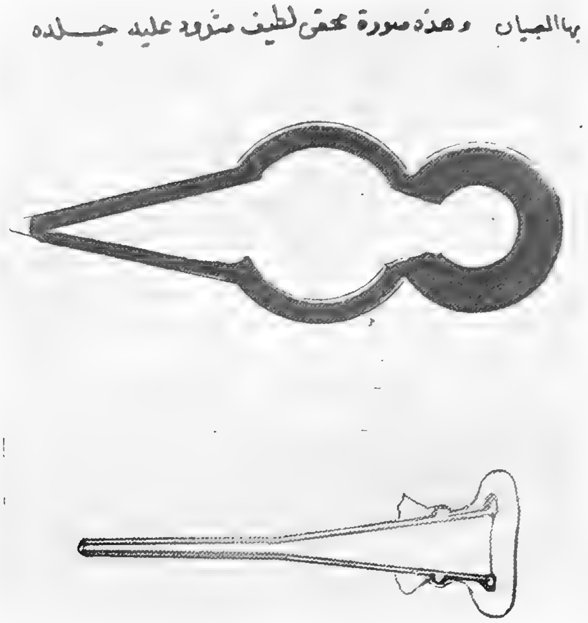
بالصبيان وهذه صورة محقن لطيف مزود عليه جلده

Figure 17.—A crude form of bulb syringe recommended for use with children. *Top*, from original Arabic manuscript (Ali 2854), courtesy Süleymaniye Umumi Kütüphanesi Müdürlügü. *Bottom*, from Leclerc, *Abulcasis*.

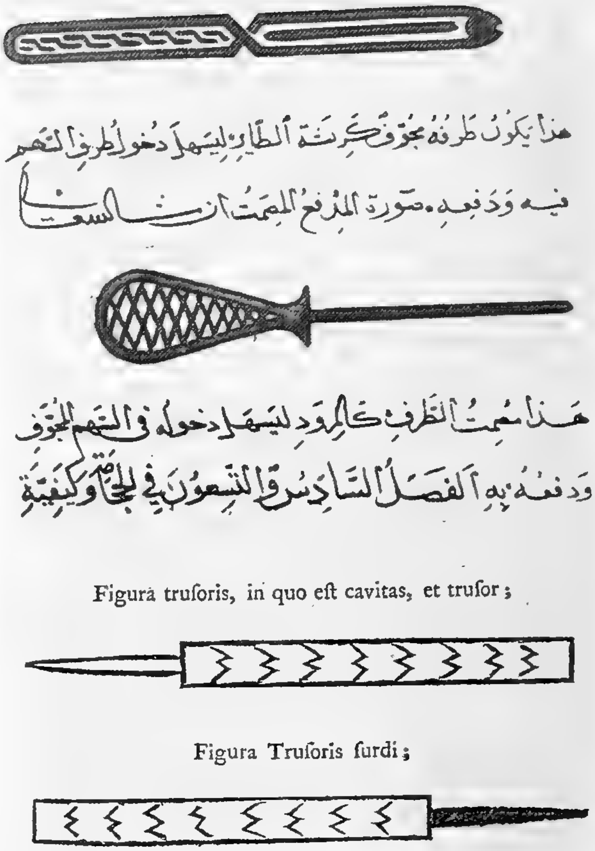
هذا يكون طرفه مجوفا كريشة الطائر ليسهل دخول طرف السهم
فيه ودفعه. صورة المدفع المصمت ان شاء الله تعالى
هذا مصمت الطرف كالمرود ليسهل دخوله في السهم المجوف
ودفعه به. الفصل السادس والتسعون في الحجامة وكيفيتها
Figura truſoris, in quo eſt cavitas, et truſor ;
Figura Truſoris ſurdi ;

Figure 18.—Hooks and forceps used for the extraction of arrows. *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Bottom*, from Channing, *Albucasis*.

century, no doubt had the experience of dealing with cases involving injuries caused by arrows. The text in chapter 94 discloses his observations in elaborate investigations regarding the extraction of various kinds of arrows from the body.[28] Accordingly, several kinds of hooks and forceps for removing arrows are described and depicted in the treatise (see fig. 18). Al-Zahrāwī's mention of Turkish bows and arrows led Freind to believe, erroneously, that the author of the treatise must have lived in the 12th century,[29] notwithstanding the fact that Turkish bows and arrows were in common use in the latter part of the 10th century.

The next chapter, on cupping, mentions the use of cups made of horns, wood, copper, or glass, according to circumstances and the availability of material. The methods of treatment are divided into two kinds: dry cupping, with or without fire, and wet cupping (see fig. 19). He prescribes ointments and aromatic and medicated waters to be applied before and after cupping to facilitate healing. Only when cupping is not possible, as on the nose, fingers, and similar parts of the human body, does he propose the use of leeches for treatment.[30] Evidently this is an indication that he did not, as generally supposed, encourage the widespread use of leeches.

The third and final section, of 35 chapters, deals with the reduction, luxation, and treatment of injured bones, including fracture of the pelvis. The advices and warnings in the prelude of this section appear to repeat some of al-Zahrāwī's sayings that had been covered in his previous introductions. The text, however, presents many facets of interest to the health

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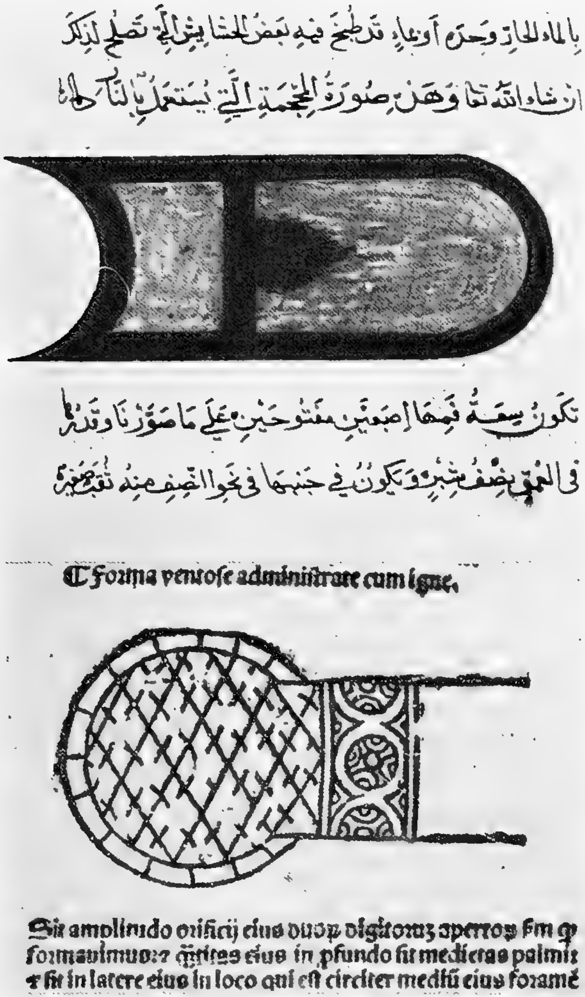
[28] Heinrich Frölich, "Abul-Kasem als Kriegschirurg," *Archiv für klinische Chirurgie*, 1884, vol. 30, pp. 365–376. This well-presented study was reviewed by Paul Schede in *Centralblatt für Chirurgie*, 1884, no. 38, pp. 626–627.

[29] Johannis Freind, *The History of Physick*, London, 1726, vol. 2, p. 129.

[30] In several manuscripts, the chapter on the use of leeches is the last one in the second section of the treatise.



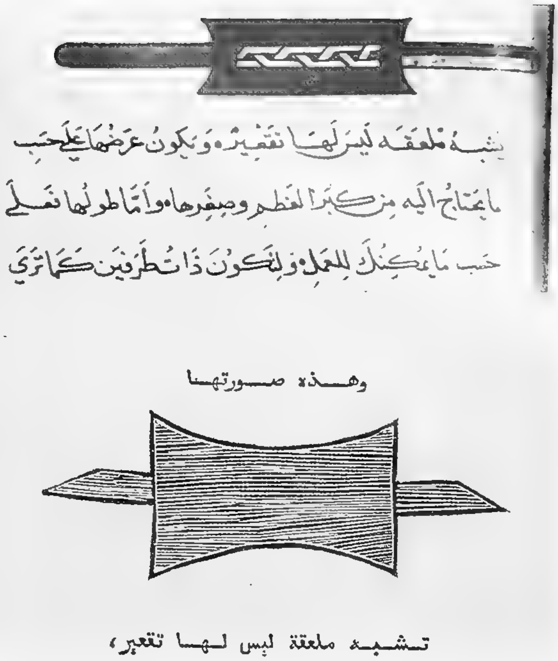
بالماء الحار وحده أو بماء قد طبخ فيه بعض الحشائش التي تصلح لذلك
إن شاء الله تعا وهذه صورة المحجمة التي يستعمل بالنار

تكون سعة فمها إصبعين مفتوحتين على ما صورنا وقدرها
في العمق نصف شبر وتكون في جنبها في نحو النصف منه ثقب صغير

Forma ventoſe adminiſtrate cum igne.

Sit amplitudo orificij eius duoꝝ digitoꝝ apertoꝝ ſm q formauimus: ⁊ q̃ntitas eius in pfundo ſit medietas palmi: ⁊ ſit in latere eius in loco qui eſt circiter mediū eius foramē

Figure 19.—Cupping. *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Bottom*, from Argellata 1531, courtesy National Library of Medicine.



تشبه ملعقة ليس لها تقعير ويكون عرضها على حسب
ما يحتاج إليه من كبر العظم وصغرها وأما طولها فعلى
حسب ما يمكنك للعمل ولتكن ذات طرفين كما ترى

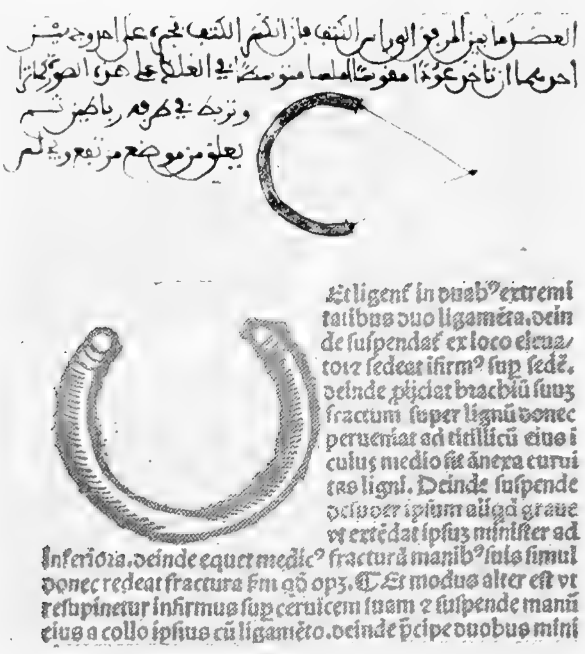
وهذه صورتها

تشبه ملعقة ليس لها تقعير،

Figure 20.—Splint "in the shape of a spoon without a bowl." *Top*, from original Arabic manuscript (Tüb. MS. 91), courtesy Universitätsbibliothek Tübingen. *Bottom*, from Channing, *Albucasis*.

professions. It elaborates upon the application of various forms of bandages and plasters in a variety of operations. Al-Zahrāwī's detailed description relating to fractures of bones is a fine anatomical document of historical interest. He illustrates and describes special methods for tying injured or broken bones, and he suggests that bandages made of soft linen be less and less tight as distance increases from the injured place (chapter 1). For the protection of areas adjacent to the injured part against contact with edges of splints he advocates padding with soft gauze and carded wool. In some cases, to guard against swelling, he preferred a delay of one or more days in applying bandages over splints. Al-Zahrāwī also devised and depicted many kinds and shapes of splints for use in simple and compound fractures of the head, shoulders, arms, fingers, etc. (see fig. 20). For example, in discussing the reduction of the humerus, he recommends a splint consisting of a smooth, thin stick bent in the shape of a bow with two strings, each attached to one end of the stick (fig. 21). The injured bone is then placed in the middle of the bent splint for reduction while the patient is seated on a chair. Tying is applied only when there is no "hot" swelling (chapter 11). One of the remarkable observations made in this section is the description of the paralysis caused by fracture of the spine.

Of interest to historians of medical therapy and pharmacy are the recipes for poultices that al-Zahrāwī recommends for use over fractured bones. For example, he gives the following recipe for one such poultice: "Take the so-called 'mill's dust' [ghubār al-raḥā], which is the part of the wheat flour that clings to the walls of the mill during grinding [lubāb al-daqīq], and, without sifting away the bran, knead



Et ligent in duabꝰ extremi
tatibus duo ligamēta. dein
de ſuſpendat ex loco eleua/
tori ſedeat infirmꝰ ſup ſedē.
deinde pijciat brachiū ſuū
fractum ſuper lignū donec
perueniat ad titillicū eius i
cuius medio ſit ānexa curui
tas ligni. Deinde ſuſpende
[illegible] ipſum aliqd graue
vt extēdat ipſuz miniſter ad
Inferiora. deinde equet medicꝰ fracturā manibꝰ ſuis ſimul
donec redeat fractura ſm qd opz. ¶ Et modus alter eſt vt
reſupinetur infirmus ſup ceruicem ſuam ꝛ ſuſpende manū
eius a collo ipſius cū ligamēto. deinde pcipe duobus mini

Figure 21.—A splint to support the arm. *Top*, from original Arabic manuscript (Cod. N.F. 476A), courtesy Oesterreichische Nationalbibliothek. *Bottom*, from Argellata 1531, courtesy National Library of Medicine.

with white-of-egg to a medium consistency, and apply." Another, more elaborate, recipe calls for 10 dirhams each of the roots of wild pomegranate [*Glossostemon brugieri* D.C.], chickling vetch [the grass pea, *Lathymus sativus*], and white marshmallow; 5 dirhams each of myrrh and aloes; 6 dirhams of white gum Arabic [*Acacia*]; and 20 dirhams of bole [friable earthy clay consisting largely of hydrous silicates of aluminum and magnesium, usually colored red because of impurities of iron oxide]. Procedure was to pound all ingredients gently, pass them through a sieve, and knead with water or white-of-egg (chapter 1).

The question arises as to whether al-Zahrāwī did any human dissection. The answer is uncertain because our knowledge of his life is fragmentary. However, he gives no clue to the dissection of humans in any of the 30 treatises of *al-Taṣrīf*—his only known writings—and there is no evidence that he practiced it in secret. His upright attitude as a Muslim who repeatedly emphasized his adherence to his faith suggests that he relied completely on animal dissection and the writings of his Greek-Roman and Islamic predecessors. Physicians in both the Islamic domain and in Christendom for many centuries were hostile to the idea of human dissection for any purpose because of their traditional socio-religious convictions, considering it an unethical and undignified practice. Perhaps it has been al-Zahrāwī's original contributions to surgery, his enthusiasm in emphasizing the value of anatomical knowledge, and his recognition of the necessity that only well-educated, well-trained doctors should perform surgery that have led some medical historians to wonder whether he did human dissection at some time in his long years of experience.

In Summary

The few examples of illustrations of surgical instruments given here indicate that the Arabic manuscripts, in general, have preserved the original, oriental, artistic features of the drawings in a way that has been overlooked in Latin and vernacular versions of *al-Taṣrīf*.

In presenting his personal observations and original ideas on surgery late in life, al-Zahrāwī, for the most part, was inspired by a thorough acquaintance with Greek and Arabic medical literature supplemented by lifelong intelligent observation and experience.

Through its descriptions and illustrations, the surgical treatise of al-Zahrāwī very likely played a significant role in the designing of improved surgical instruments in the Middle Ages. Also, the treatise no doubt promoted the development of improved surgical techniques in Islam and, through its translations, promoted these techniques to an even greater extent in the West, a fact that justifies the fame of this treatise as the highest expression of the development of surgery in Arabic Spain—a treatise whose influence continued to the Renaissance. It contributed in no small measure to the idea of equipping learned and well-trained surgeons with the best surgical tools and techniques of the time; moreover, it encouraged the invention of new instruments to meet differing circumstances and special conditions. These tools no doubt greatly facilitated the work of the surgeon.

Throughout the text of *al-Tasrīf* al-Zahrāwī gave careful attention to the importance of pharmaceutical preparations in the healing art, including cases requiring surgery.

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The Introduction of SELF-REGISTERING METEOROLOGICAL INSTRUMENTS

Robert P. Multhauf

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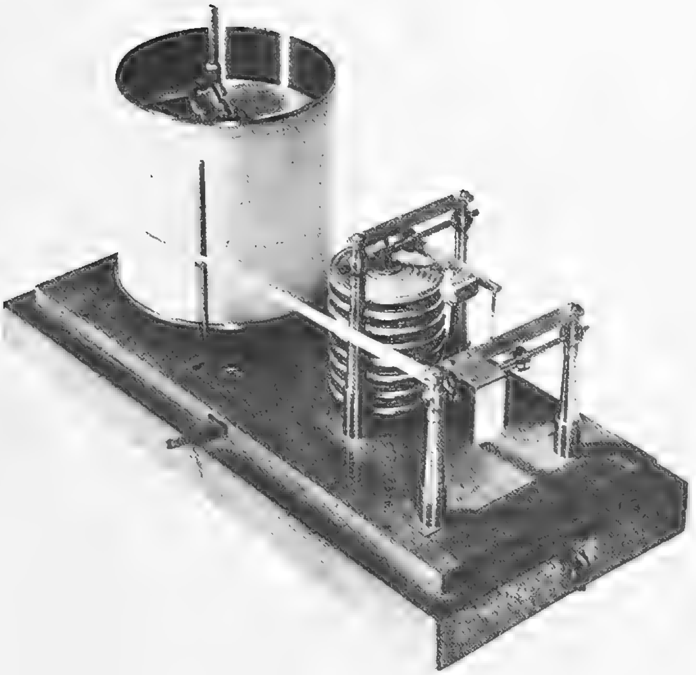

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PAPER 23

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Robert P Multhauf

THE FIRST SELF-REGISTERING INSTRUMENTS 99
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The Introduction of SELF-REGISTERING METEOROLOGICAL INSTRUMENTS

Robert P. Multhauf

The development of self-registering meteorological instruments began very shortly after that of scientific meteorological observation itself. Yet it was not until the 1860's, two centuries after the beginning of scientific observation, that the self-registering instrument became a factor in meteorology.

This time delay is attributable less to deficiencies in the techniques of instrument-making than to deficiencies in the organization of meteorology itself. The critical factor was the establishment in the 1860's of well-financed and competently directed meteorological observatories, most of which were created as adjuncts to astronomical observatories.

THE AUTHOR: *Robert P. Multhauf is head curator of the department of science and technology in the United States National Museum, Smithsonian Institution.*

THE FLOWERING OF SCIENCE in the 17th century was accompanied by an efflorescence of instrument invention as luxurious as that of science itself. Although there were foreshadowing events, this flowering seems to have owed much to Galileo, whose interest in the measurement of natural phenomena is well known, and who is himself credited with the invention of the thermometer and the hydrostatic balance, both of which he devised in connection with experimentation on specific scientific problems. Many, if not most, of the other Italian instrument inventors of the early 17th century were his disciples. Benedetto Castelli, being interested in the effect of rainfall on the level of a lake, constructed a rain gauge about 1628. Santorio, well known as a pioneer in the quantification of animal physiology, is credited with observations, about 1626, that led to the development of the hygrometer.

Both of these contemporaries were interested in Galileo's most famous invention, the thermoscope—forerunner of the thermometer—which he developed about 1597 as a method of obtaining comparisons of temperature. The utility of the instrument was immediately recognized by physicists (not by chemists, oddly enough), and much ingenuity was expended on its perfection over a 50-year period, in northern Europe as well as in Italy. The conversion of this open, air-expansion thermoscope into the modern thermometer was accomplished by the Florentine Accademia del Cimento about 1660.

Galileo also inspired the barometer, through his speculations on the vacuum, which, in 1643, led his disciple Torricelli to experiments proving the limitation to nature's horror of a vacuum. Torricelli's apparatus, unlike Galileo's thermoscope, represented the barometer in essentially its classical form. In his earliest experiments, Torricelli observed that the air tended to become "thicker and thinner"; as a consequence, we find the barometer in use (with the thermometer) for meteorological observation as early as 1649.[1]

The meetings of the Accademia terminated in 1667, but the 5-year-old Royal Society of London had already become as fruitful a source of new instruments, largely through the abilities of its demonstrator, Robert Hooke, whose task it was to entertain and instruct the members with experiments. In the course of devising these experiments Hooke became perhaps the most prolific instrument inventor of all time. He seems to have invented the first wind pressure gauge, as an aid to seamen, and he improved the bathometer, hygrometer, hydrometer, and barometer, as well as instruments not directly involved in measurement such as the vacuum pump and sea-water sampling devices. As in Florence, these instruments were immediately brought to bear on the observation of nature.

It does not appear, however, that we would be justified in concluding that the rise of scientific meteorology was inspired by the invention of instruments, for meteorology had begun to free itself of the traditional weather-lore and demonology early in the 17th

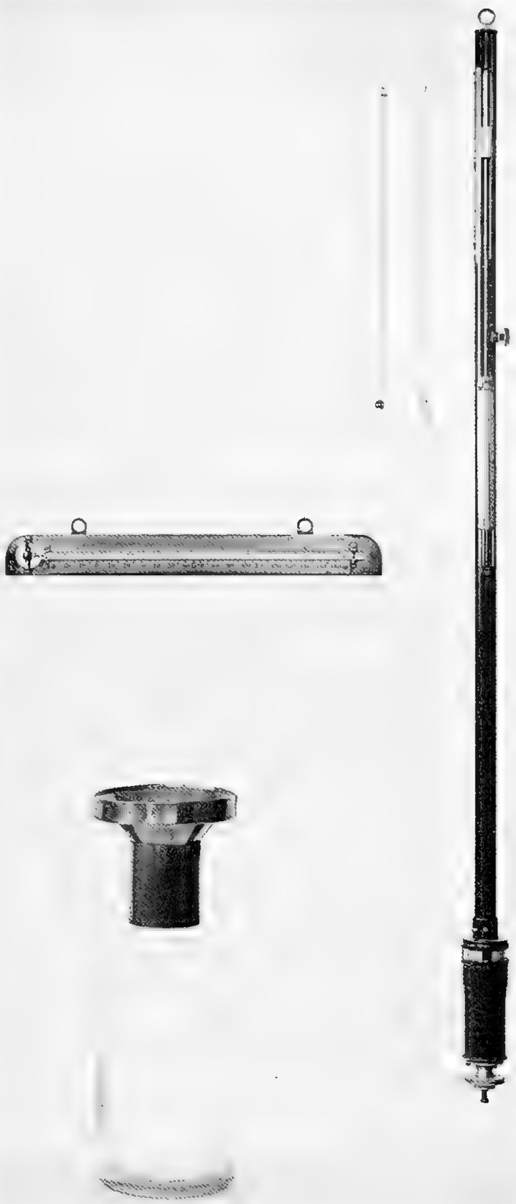

Figure 1.—A set of typical Smithsonian meteorological instruments as recommended in instructions to observers issued by the Institution in the 1850's. *Top* (from left): maximum-minimum thermometer of Professor Phillips, dry-bulb and wet-bulb thermometers, and mercurial barometer by Green of New York. *Lower left:* rain gauge. The wet-bulb thermometer, although typical, is actually a later instrument. The rain gauge is a replica. (*Smithsonian photo 46740.*)

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[1] On early meteorological instruments see A. Wolf, *A History of Science, Technology and Philosophy in the Sixteenth and Seventeenth Centuries*, New York, 1935, and E. Gerland and F. Traumüller, *Geschichte der physikalischen Experimentierkunst*, Leipzig, 1899. On the recognition of the meteorological significance of the barometer by Torricelli and its meteorological use in 1649 see K. Schneider-Carius, *Wetterkunde Wetterforschung*, Freiburg and Munich, 1955, pp. 62, 71.

century. The Landgraf of Hesse described some simultaneous weather observations, made without instruments, in 1637. Francis Bacon's "Natural History of the Wind," considered the first special work of this kind to attain general circulation, appeared in 1622.[2] It seems likely that the rise of scientific meteorology was an aspect of the general rationalization of nature study which occurred at this time, and that the initial impetus for such progress was gained not from the invention of instruments but from the need of navigators for wind data at a time when long voyages out of sight of land were becoming commonplace.

It should be noted in this connection that the two most important instruments, the thermometer and barometer, were in no way inspired by an interest in meteorology. But the observation made early in the history of the barometer that the atmospheric pressure varied in some relationship to visible changes in the weather soon brought that instrument into use as a "weather glass." In particular, winds were attributed to disturbances of barometric equilibrium, and wind-barometric studies were made by Evangelista Torricelli, Edmé Mariotte, and Edmund Halley, the latter publishing the first meteorological chart. In 1678–1679 Gottfried Leibniz endeavored to encourage observations to test the capacity of the barometer for foretelling the weather.[3]

Other questions of a quasi-meteorological nature interested the scientists of this period, and brought other instruments into use. Observations of rainfall and evaporation were made in pursuit of the ancient question of the sources of terrestrial water, the maintenance of the levels of seas, etc. Physicians brought instruments to bear on the question of the relationship between weather and the incidence of disease. The interrelationship between these various meteorological enterprises was not long in becoming apparent. Soon after its founding in 1657 the Florentine academy undertook, through the distribution of thermometers, barometers, hygrometers, and rain gauges, the establishment of an international network of meteorological observation stations, a network which did not survive the demise of the Accademia itself ten years later.

Not for over a century was the first thoroughgoing attempt made at systematic observation. There was a meteorological section in the Academy of Sciences at Mannheim from 1763, and subsequently a separate society for meteorology. In 1783, the Academy published observations from 39 stations, those from the central station comprising data from the hygrometer, wind vane (but not anemometer), rain gauge, evaporimeter, and apparatus for geomagnetism and atmospheric electricity, as well as data from the thermometer and barometer. The Mannheim system was also short-lived, being terminated by the Napoleonic invasion, but systems of comparable scope were attempted throughout Europe and America during the next generation.

In the United States the office of the Surgeon General, U.S. Army, began the first systematic observation in 1819, using only the thermometer and wind vane, to which were added the barometer and hygrometer in 1840–1841 and the wind force anemometer, rain gauge, and wet bulb thermometer in 1843. State weather observation systems meanwhile had been inaugurated in New York (1825), Pennsylvania (1836), and Ohio (1842).[4]

Nearly 200 years of observation had not, however, noticeably improved the weather, and the naive faith in the power of instruments to reveal its mysteries, which had possessed many an early meteorologist, no longer charmed the scientist of the early 19th century. In the first published report of the British Association for the Advancement of Science in 1833, J. D. Forbes called for a reorganization of procedures:

> In the science of Astronomy, for example, as in that of Optics, the great general truths which emerge in the progress of discovery, though depending for their establishment upon a multitude of independent facts and observations, possess sufficient unity to connect in the mind the bearing of the

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[2] Bacon's book emphasizes "direct" and "indirect" experiments, and calls for the systematization of observation, but it does not mention instruments. It is reprinted in Basil Montagu's *The Works of Francis Bacon, Lord Chancellor of England*, London, 1825, vols. 10 and 14.

[3] Wolf, *op. cit.* (footnote 1), pp. 312, 316–320. The interest of the Royal Society in the barometer seems to have been initiated by Descartes' theory that the instrument's variation was caused by the pressure of the moon.

[4] On early meteorology in the United States see the report of Joseph Henry in *Report of the Commissioner of Patents, Agriculture, for the Year 1855*, 1856, p. 357ff.; also, *Army Meteorological Register for Twelve Years, 1843–1854*, 1855, introduction.

> whole; and the more perfectly understood connexion of parts invites to further generalization.
>
> Very different is the position of an infant science like Meteorology. The unity of the whole . . . is not always kept in view, even as far as our present very limited general conceptions will admit of: and as few persons have devoted their whole attention to this science alone . . . no wonder that we find strewed over its irregular and far-spread surface, patches of cultivation upon spots chosen without discrimination and treated on no common principle, which defy the improver to inclose, and the surveyor to estimate and connect them. Meteorological instruments have been for the most part treated like toys, and much time and labor have been lost in making and recording observations utterly useless for any scientific purpose. Even the numerous registers of a rather superior class . . . hardly contain one jot of information ready for incorporation in a Report on the progress of Meteorology . . . .
>
> The most general mistake probably consists in the idea that Meteorology, as a science, has no other object but an experimental acquaintance with the condition of those variable elements which from day to day constitute the general and vague result of the state of the *weather* at any given spot; not considering that . . . when grouped together with others of the same character, [they] may afford the most valuable aid to scientific generalization.[5]

Forbes goes on to call for a greater emphasis on theory, and the replacement of the many small-scale observatories with "a few great Registers" to be adequately maintained by "great Societies" or by the government. He suggests that the time for pursuit of theory might be gained from "the vague mechanical task to which at present they generally devote their time, namely the search for great numerical accuracy, to a superfluity of decimal places exceeding the compass of the instrument to verify."

From its founding the British Association sponsored systematic observation at various places. In 1842 it initiated observations at the Kew Observatory, which has continued until today to be the premier meteorological observatory in the British Empire. The American scientist Joseph Henry observed the functioning of an observatory maintained by the British Association at Plymouth in 1837, and when he became Secretary of the new Smithsonian Institution a few years later he made the furtherance of meteorology one of its first objectives.

The Kew Observatory set a pattern for systematic observation in England as, from 1855, did the Smithsonian Institution in the United States. The instruments used differed little from those in use at Mannheim over half a century earlier[6] (fig. 1). They were undoubtedly more accurate, but this should not be overstressed. Forbes had noted in his report of 1832 that some scientists were then calling for a return to Torricelli, for the construction of a temporary barometer on the site in preference to reliance on the then existing manufactured instruments.

The First Self-Registering Instruments

From the middle of the 17th century meteorological observations were recorded in manuscript books known as "registers," many of which were published in the early scientific journals. The most effective utilization of these observations was in the compilation of the history of particular storms, but where a larger synthesis was concerned they tended, as Forbes has shown, to show themselves unsystematic and noncomparable. The principal problems of meteorological observation have been from the outset the construction of precisely comparable instruments and their use to produce comparable records. The former problem has been frequently discussed, and perhaps, as Forbes suggests, overemphasized. It is the latter problem with which we are here concerned.

The idea of mechanizing the process of observation, not yet accomplished in Forbes' time, had been put forward within a little over a decade of the first use of the thermometer and barometer in meteorology. On December 9, 1663, Christopher Wren presented the Royal Society with a design for a "weather clock," of which a drawing is extant.[7] This drawing (fig. 2)

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[5] J. D. Forbes, "Report upon the Recent Progress and Present State of Meteorology," *Report of the First and Second Meetings of the British Association for the Advancement of Science, 1831 and 1832*, 1833, pp. 196–197.

[6] On the instruments used at Mannheim see Gerland and Traumüller, *op. cit.* footnote 1, p. 349ff. The Princeton physicist Arnold Guyot prepared a set of instructions for observers that was published in *Tenth Annual Report . . . of the Smithsonian Institution*, 1856, p. 215ff. It appears from the *Annual Report of the British Association for the Advance of Science* in the 1830's that the instruments used in England were nearly the same as those later adopted by the Smithsonian, although British observatories were beginning to experiment with the self-registering anemometer at that time. A typical set of the Smithsonian instruments is shown in figure 1.

[7] H. Alan Lloyd, "Horology and Meteorology," *Journal Suisse d'Horlogerie*, November–December, 1953, nos. 11, 12, p. 372, fig. 1.

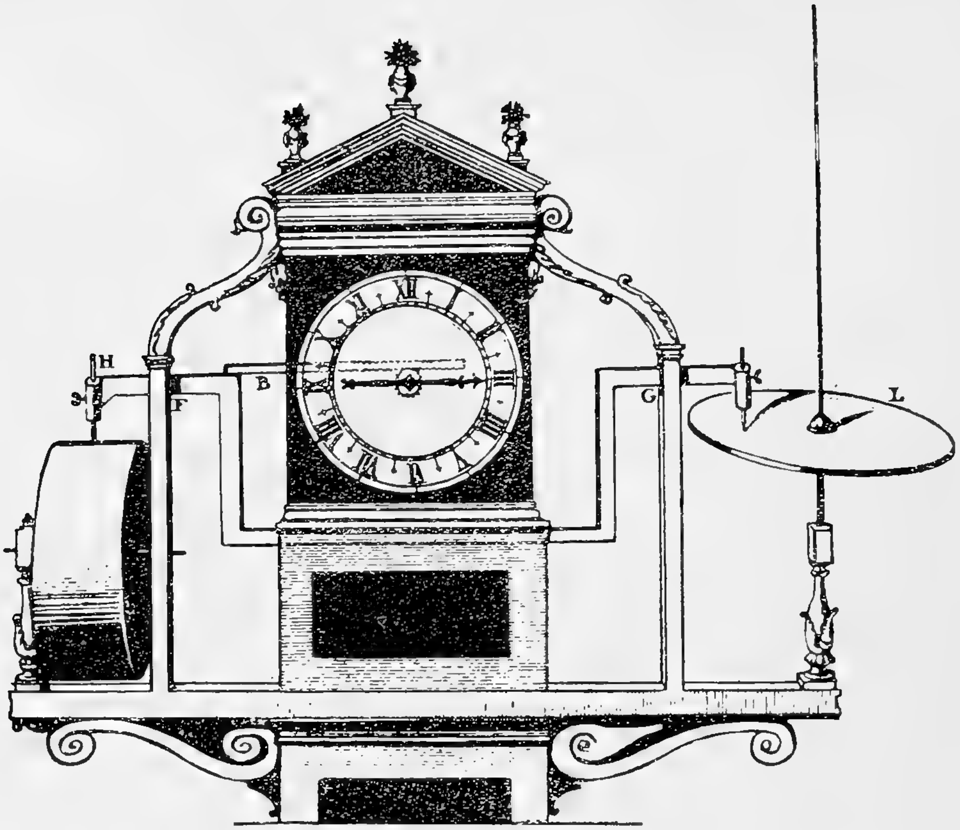

Figure 2.—A contemporary drawing of Wren's "weather clock." (Photo courtesy Royal Society of London.)

shows an ordinary clock to which is attached a pencil-carrying rack, geared to the hour pinion. A discussion of the clock's "reduction to practice" began the involvement of Robert Hooke, who was "instructed" in September 1664 to make "a pendulum clock applicable to the observing of the changes in the weather." [8] This tribute to Hooke's reputation—and to the versatility of the mechanic arts at this time—was slightly overoptimistic, as 15 years ensued before the clock made its appearance.

References to this clock are frequent in the records of the Royal Society—being mainly periodic injunctions to Hooke to get on with the work—until its completion in May 1679. The description which Hooke was asked to supply was subsequently found among his papers and printed by William Derham as follows: [9]

> The weather-clock consists of two parts; *first,* that which measures the time, which is a strong and large pendulum-clock, which moves a week, with once winding up, and is sufficient to turn a cylinder (upon which the paper is rolled) twice round in a day, and also to lift a hammer for striking the punches, once every quarter of an hour.
>
> *Secondly,* of several instruments for measuring the degrees

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[8] R. T. Gunther, *Early Science in Oxford,* vol. 6, *The Life and Work of Robert Hooke,* pt. 1, Oxford, 1930, p. 196. In 1670, Hooke's proposed clock was referred to as "such a one, as Dr. Wren had formerly contrived" (Gunther, p. 365).

[9] William Derham, *Philosophical Experiments amd Observations of . . . Dr. Robert Hooke,* London, 1726, pp. 41–42 (reprinted in Gunther, *op. cit.* footnote 8, vol. 7, pp. 519–520). This description, dated December 5, 1678, predates the Royal Society's request for a description (Gunther, *op. cit.* footnote 8, p. 656) by four months, but the Society no longer has any description of the clock. As to the actual completion of the clock, the president of the Society visited "Mr. Hooke's turret" to see it in January of 1678/79 but it was not reported "ready to be shown" until the following May (Gunther, pp. 506, 518).

> of alteration, in the several things, to be observed. The first is, the barometer, which moves the first punch, an inch and half, serving to shew the difference between the greatest and the least pressure of the air. The second is, the thermometer, which moves the punch that shews the differences between the greatest heat in summer, and the least in winter. The third is, the hygroscope, moving the punch, which shews the difference between the moistest and driest airs. The fourth is, the rain-bucket, serving to shew the quantity of rain that falls; this hath two parts or punches; the first, to shew what part of the bucket is fill'd, when there falls not enough to make it empty itself; the second, to shew how many full buckets have been emptied. The fifth is the wind vane; this hath also two parts; the first to shew the strength of the wind, which is observed by the number of revolutions in the vane-mill, and marked by three punches; the first marks every 10,000 revolutions, the second every 1,000, and the third every 100: The second, to shew the quarters of the wind, this hath four punches; the first with one point, marking the North quarters, viz. N.: N. by E.: N. by W.: NNE.: NNW.: NE. by N. and N.W. by N.: NE. and N.W. The second hath two points, marking the East and its quarters. The third hath three points, marking the South and its quarters. The fourth hath four points, marking the West and its quarters. Some of these punches give one mark, every 100 revolutions of the vane-mill.
>
> The stations or places of the first four punches are marked on a scrowl of paper, by the clock-hammer, falling every quarter of an hour. The punches, belonging to the fifth, are marked on the said scrowl, by the revolutions of the vane, which are accounted by a small numerator, standing at the top of the clock-case, which is moved by the vane-mill.

What, exactly, were the instruments applied by Hooke to his weather clock? It is not always easy even to guess, because it appears that Wren was actually the first to contrive such a device and seems to have developed nearly as many instruments as Hooke. It might be supposed that Hooke would have adapted to the weather clock his wheel-barometer, introduced in 1667, but it also appears that Wren had described (and perhaps built) a balance barometer before 1667.[10] As to the thermometer, we have no evidence of original work by Hooke, but we do have a description of Wren's self-registering thermometer, a circular, mercury-filled tube in which changes in temperature move "the whole instrument, like a wheel on its axis." [11]

The hygroscope (hygrometer) probably existed in more versions than any other instrument, although we know nothing of any versions by Wren. Hooke may have used his own "oat-beard" instrument.[12] Derham follows his description of the clock—which has been quoted above—with a detailed description of a tipping-bucket rain gauge invented by Hooke and used with the clock. He also notes that in 1670 Hooke had described two other types of rain gauge in which a bucket was counterbalanced in one case by a string of bullets and in another by an immersed weight. But here again, Sprat records the invention of a tipping-bucket gauge by Wren before 1667.

Hooke has been generally regarded as the first inventor of an anemometer, in 1662.[13] But this invention was a pressure-plate gauge—that is, a metal plate held with its face against the wind—whereas the gauge used with the weather clock is clearly a windmill type, of which type this may be the first. Wren also had an anemometer, but we have no description of it. Hooke's account does not refer to other instruments which the weather clock is supposed to have had, according to a description quoted by Gunther, which concludes the enumeration of the elements recorded with "sunshine, etc." [14]

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[10] Wren's clock and its wind vane and anemometer, thermometer, barometer, and rain gauge are described by T. Sprat, *The History of the Royal Society . . .* , London, 1667, pp. 312–313. On the balance-barometer, see also footnote 28, below, and figure 4.

[11] Since the above was written, additional information on this clock has been published by H. E. Hoff and L. A. Geddes, "Graphic Recording before Carl Ludwig: An Historical Summary," *Archives Internationales d'Histoire des Sciences*, 1959, vol. 12, pp. 1–25. Hoff and Geddes call attention to a report on the clock by Monconys, who saw the instrument in 1663 and published a brief description and crude sketch (Balthasar Monconys, *Les Voyages de Balthasar de Monconys; Documents pour l'Histoire de la Science, avec une Introduction par M. Charles Henry*, Paris, 1887). Monconys says that the thermometer "causes a tablet to rise and fall while a pencil bears against it." The instrument shown in his sketch resembles a Galilean thermoscope.

[12] Hooke's "oat-beard hygrometer" was described in 1667, but Torricelli seems to have invented the same thing in 1646, according to E. Gerland, "Historical Sketch of Instrumental Meteorology," in "Report of the International Meteorological Congress Held at Chicago, Ill., August 21–24, 1893," O. L. Fassig, ed., *U.S. Weather Bureau Bulletin No. 11*, pt. 3, 1896, pp. 687–699.

[13] But a Dutch patent was awarded to one William Douglas in 1627 for the determination of wind pressure (G. Doorman, *Patents for Inventions in the Netherlands during the 16th, 17th and 18th Centuries*, The Hague, 1942, p. 127), and Leonardo da Vinci left a sketch of both a wind pressure meter and a hygrometer (*Codex Atlanticus*, 249 va and 8 vb).

[14] Gunther, *op. cit.* (footnote 8), pp. 433, 502.

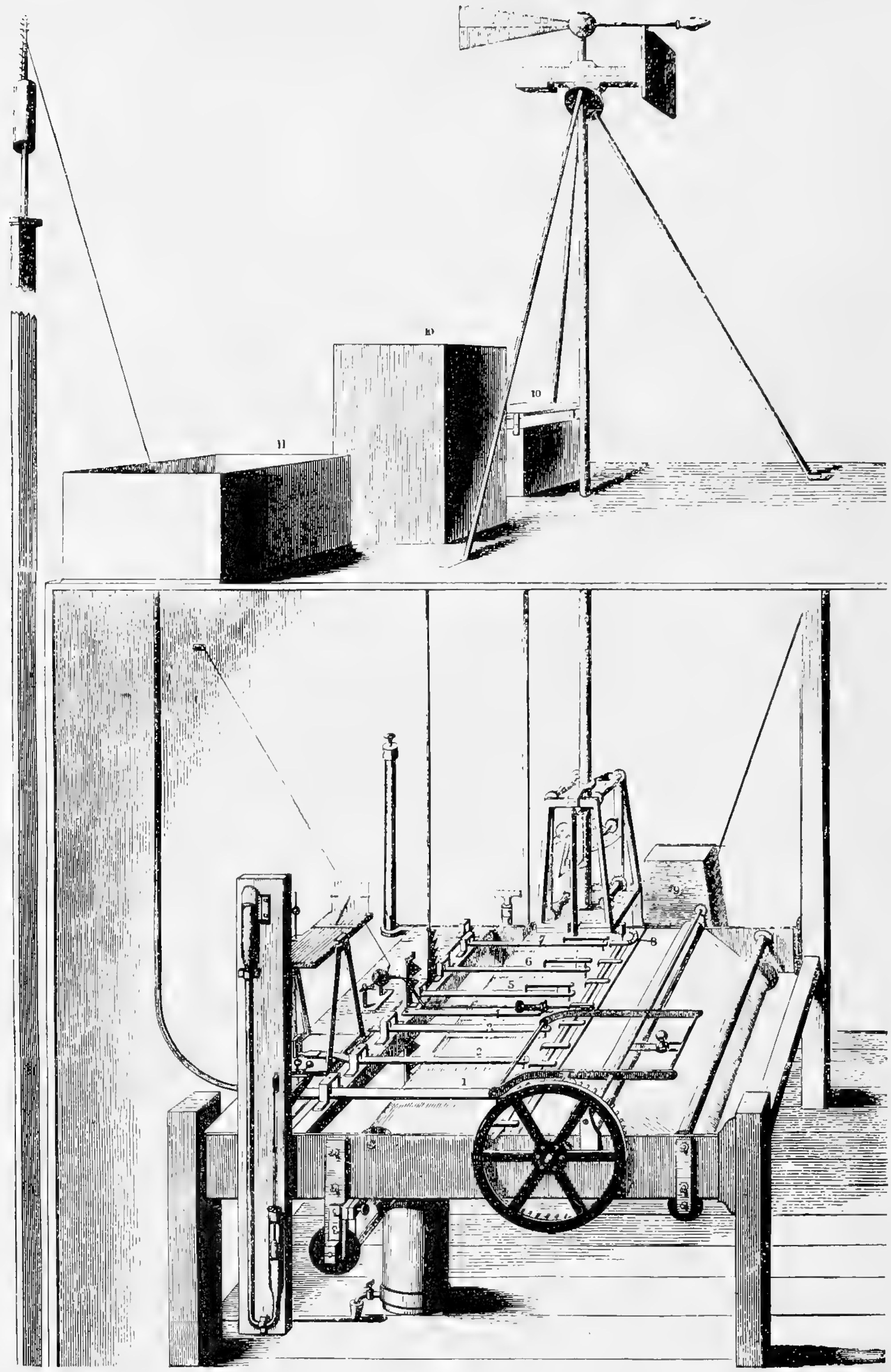

Figure 3.—Dolland's "atmospheric recorder": 1, siphon and float barometer; 2, balance (?) thermometer; 3, hygrometer; 4, electrometer; 5, float rain gauge; 6, float evaporimeter; 7, suspended-weight wind force indicator; 8, wind direction indicator; 9, clock; 10, receivers for rain gauge and evaporimeter. (From *Official . . . Catalogue of the Great Exhibition, 1851*, London, 1851, pt. 2).

One can only wish for further information on the mechanism by which the punches—or in Wren's clock, the pencils—were moved. But it is apparent that Hooke's clock was actually used for some time.

The 17th century was not entirely unprepared for the idea of such a self-registering instrument. Water clocks and other devices in which natural forces governed a pointer were known in antiquity, as were counters of the type of the odometer. A water clock described in Italy in 1524 was essentially an inversion of one of Hooke's rain gauges, that in which a bucket was balanced against a string of bullets.[15] The mechanical clock also had a considerable history in the 17th century, and had long since been applied to the operations of figures through cams, as was almost certainly the case with the punches in Hooke's clock. Still, the combination of an instrument-actuated pointer with a clock-actuated time-scale and a means of obtaining a permanent record represent a group of innovations which certainly ranks among the greatest in the history of instrumentation. It appears that we owe these innovations to Wren and Hooke.

Hooke's clock contributed nothing to the systematization of meteorological observation, and the last record of it appears to have been a note on its "refitting" in 1690. Its complexity is sufficient reason for its ephemeral history, but complexity in machine design was the fashion of the time and Hooke may have intended no more than a mechanistic *tour de force*. On the other hand, he may have recognized the desideratum to which later meteorologists frequently returned—the need for simultaneous observations of several instruments on the same register. In any case, no instrument so comprehensive seems to have been attempted again until the middle of the 19th century, when George Dolland exhibited one at the Great Exhibition in London (see fig. 3). The weather elements recorded by Dolland's instrument were the same as those recorded by Hooke's, except that atmospheric electricity (unknown in Hooke's time) was recorded and sunshine was not recorded. Striking hammers were used by Dolland for some of the instruments and "ever pointed pencils" for the others. Dolland's barometer was a wheel instrument controlling a hammer. His thermometric element consisted of 12 balanced mercury thermometers. Its mode of operation is not clear, but it probably was similar to that of the thermometer developed by Karl Kreil in Prague about the same time (fig. 4). Dolland's wind force indicator consisted of a pressure plate counterbalanced by a string of suspended weights. Altogether, it is not clear that Dolland's instrument was superior to Hooke's, or that its career was longer.[16]

The 171 years between these two instruments were not lacking in inventiveness in this field, but even though inventors set the more modest aim of a self-recording instrument for a single piece of meteorological data, their brain children were uniformly still-born. Then, during the period 1840–1850, we see the appearance of a series of self-registering instruments which were actually used, which were widely adopted by observatories, and which were superseded by superior instruments rather than abandoned. This development was undoubtedly a consequence of the establishment at that time of permanent observatories under competent scientific direction.

Long experience had demonstrated to the meteorologists of the 1840's that the principal obstacle to the success of self-registering instruments was friction. Forbes had indicated that the most urgent need was for automatic registration of wind data, as the erratic fluctuation of the wind demanded more frequent observation than any manual system could accomplish. Two of the British Association's observers produced separate recording instruments for wind direction and force in the late 1830's, a prompt response which suggests that it was not the idea which was lacking. One of these instruments—designed by William Whewell—contained gearing, the friction of which vitiated its utility as it had that of a number of predecessors. The other, designed by A. Follet Osler, was free of gearing; it separately recorded wind pressure and direction on a sheet of paper moved laterally by clockwork. The pressure element was a spring-loaded pressure plate carried

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[15] Battista della Valle, *Vallo Libro Continente Appertiniente ad Capitanii, Retenere and Fortificare una Citta* . . . , Venetia, 1523 (reported under the date 1524 in G. H. Baillie, *Clocks and Watches, an Historical Bibliography*, London, 1951).

[16] Dolland's instrument, called an "atmospheric recorder," is described in the *Official, Descriptive and Illustrated Catalogue to the Great Exhibition, 1851*, London, 1851, pt. 2, pp. 414–415. As the George Dolland who joined the famous Dolland firm in 1804 would have been about 80 years of age in 1850, the George Dolland who exhibited this instrument may have been a younger relative.

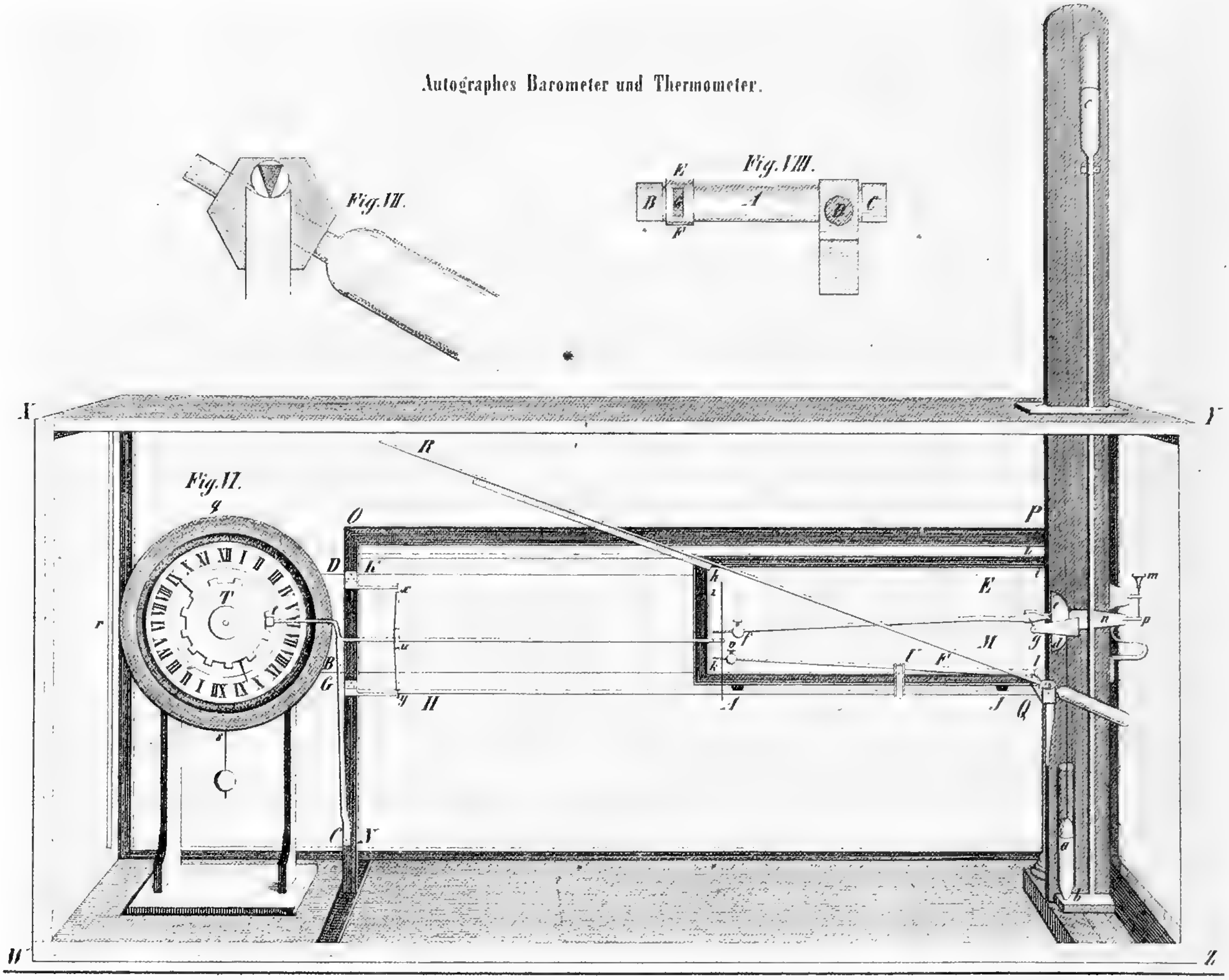

Figure 4.—Kreil's balance thermometer, 1843. (From Karl Kreil, *Magnetische und meteorologische Beobachtungen zu Prag*, Prague, 1843, vol. 3, fig. 1.)

around by the vane to face the wind. Both this plate and the vane itself were made to move pencils through linkages of chains and pulleys.[17] Osler's anemometer (fig. 5) deserves to be called the first successful self-registering meteorological instrument; it was standard equipment in British observatories until the latter part of the 19th century when it was replaced by the cup-anemometer of Robinson.

Self-recording barometers and thermometers were more vulnerable to the influence of friction than were wind instruments, but fortunately pressure and temperature were also less subject to sudden fluctuation, and so self-registration was less necessary. Nevertheless, two events occurred in the 1840's which led to the development of self-registering instruments. One event was the development of the geomagnetic observatory, which used the magnetometer, an instrument as delicate as the barometer

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[17] The Osler anemometer and most of the other self-registering instruments mentioned in this paper are described and illustrated in C. Abbe, "Treatise on Meteorological Apparatus and Methods," *Annual Report of the Chief Signal Officer for 1887*, Washington, 1888. The use of the Osler instrument at the British Association's observatory at Plymouth is mentioned in the Association's annual reports from 1838. There were a number of earlier self-registering anemometers, but no evidence of their extended use. See J. K. Laughton, "Historical Sketch of Anemometry and Anemometers," *Quarterly Journal of the Royal Meteorological Society*, 1882, vol. 8, pp. 161–188.

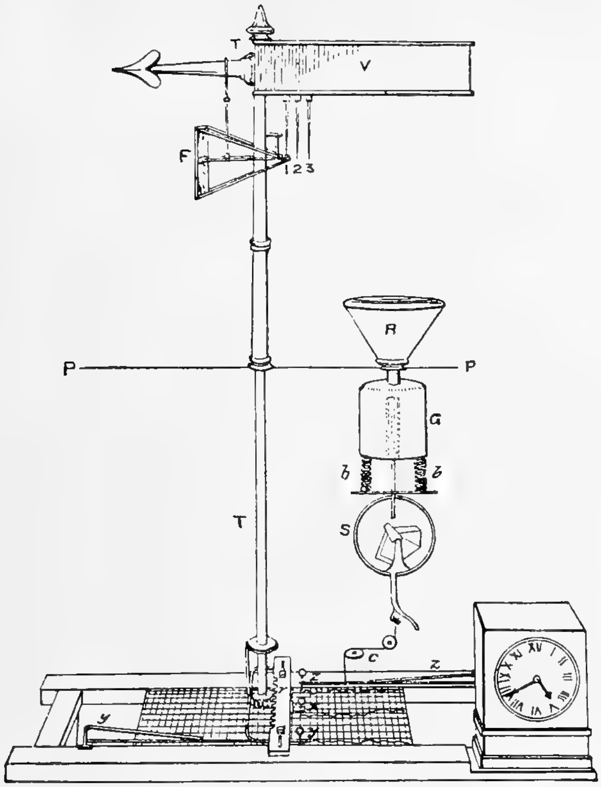

Figure 5.—Osler's self-registering pressure plate anemometer, 1837. The instrument is shown with a tipping-bucket rain gauge. (From Abbe, *op. cit.* footnote 17.)

and thermometer, and (as it then seemed), as subject to fluctuation as the wind vane. The other event was the development of photography, making possible a recording method free of friction. In 1845 Francis Ronalds at Kew Observatory and Charles Brooke at Greenwich undertook to develop apparatus to register the magnetometer, electrometer, thermometer, and barometer by photography.[18] This was six years after Daguerre's discovery of the photographic process. The magnetometers of both investigators were put into use in 1847, and the barometers and thermometers shortly after. They were based on the deflection—by a mirror in the case of the magnetometer and electrometer and by the mercury in the barometer and thermometer—of a beam of light directed against a photographic plate. Brooke exhibited his instruments at the Great Exhibition of 1850, and they subsequently became items of commerce and standard appurtenances of the major observatory until nearly the end of the century (fig. 6). Their advantages in accuracy were finally insufficient to offset the inconvenience to which a photographic instrument was subject.

Before 1850 the British observatories at Kew and Greenwich (the latter an astronomical observatory with auxiliary meteorological activity) had self-registering apparatus in use for most of the elements observed.

Self-Registering Systems

In 1870 the Signal Corps, U. S. Army, took on the burden of official meteorology in the United States as the result of a joint resolution of the Congress and in accordance with Joseph Henry's dictum that the Smithsonian Institution should not become the permanent agency for such scientific work once its permanency had been decided upon. Smithsonian meteorology had not involved self-recording instruments, and neither did that of the Signal Corps at the outset "because of the expense of the apparatus, and because nothing of that kind was at that time manufactured in this country." [19]

But almost immediately after 1870 the Signal Corps undertook an evidently well-financed program for the introduction of self-registration. "Complete outfits" were purchased, representing Wild's system, the Kew system as made by Beckley, Hipp's system (fig. 8), Secci's meteorograph (figs. 9, 10), Draper's system, and Hough's printing barograph and thermograph. Of these only the Kew system, the photographic system already mentioned, could have been obtained before 1867.

Like Kew, Daniel Draper's observatory in Central Park, New York City, was established primarily for meteorological observation.[20] Draper was one of the sons of the prominent scientist J. W. Draper. Hipp was an instrument-maker of Neuchâtel who specialized in precision clocks.[21] The others after whom

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[18] On Ronalds' work see reports of the British Association for the Advancement of Science, from 1846 to 1850. On Brooke's work see *Philosophical Transactions of the Royal Society of London*, 1847, vol. 137, pp. 59–68.

[19] C. Abbe, "The Meteorological Work of the U.S. Signal Service, 1870 to 1871," in Fassig, *op. cit.* (footnote 12), pt. 2, 1895, p. 263.

[20] *Annual Report of the Director of the Meteorological Observatory*, Central Park, New York, 1871, p. 1ff.

[21] *Oesterreichische Gesellschaft für Meteorologie, Zeitschrift*, 1871, vol. 6, pp. 104, 117.

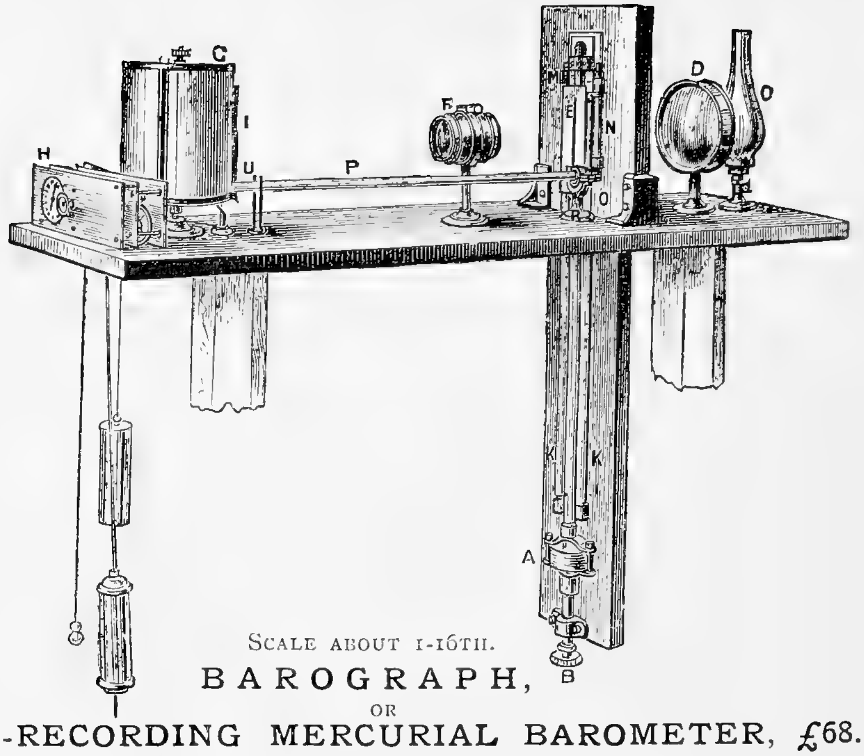

Figure 6.—Photographic registering mercurial barometer, typical commercial version. (From J. J. Hicks, *Catalogue of . . . Meteorological Instruments*, London, n.d., about 1870.)

these "systems" were named were directors of astronomical observatories, which were, at this time, the most active centers of meteorological observation. Wild was at the Bern Observatory,[22] Secci at the Papal Observatory, Rome,[23] and George Hough at the Dudley Observatory, Albany, New York.[24] While the Signal Corps seems to have acquired all of the principal "systems," some interesting instruments were developed at still other observatories, notably by Kreil at the astronomical observatory in Prague.[25] The principal impetus for this full-scale mechanization of observation undoubtedly came from the directors of astronomical observatories.

Thus within little more than the decade of the 1860's were developed five new systems of meteorological self-registry that were sufficiently well thought of to be adopted or copied by observatories outside their places of origin. Wild and Draper tell us that it was decided when their respective observatories were established—in 1860 and 1868—that all instruments should be self-registering. Each was obliged to design his own, being dissatisfied with the photographic registers commercially available. The development of these systems would therefore appear to have been due, in part, to the general spread of a conviction that satisfactory instruments were attainable.

This confidence was warranted, for the decade of the 1850's had seen the appearance of major innovations in the basic instruments—thermometer, barometer, and wind velocity indicator—that made available instruments more adaptable to self-registration. It also saw the development of a new method of electrical registration derived from the telegraph. Sir Charles Wheatstone initiated this small revolution in 1843 when he reported to the British Association that he had constructed an electromagnetic meteorological register which "records the indications of the

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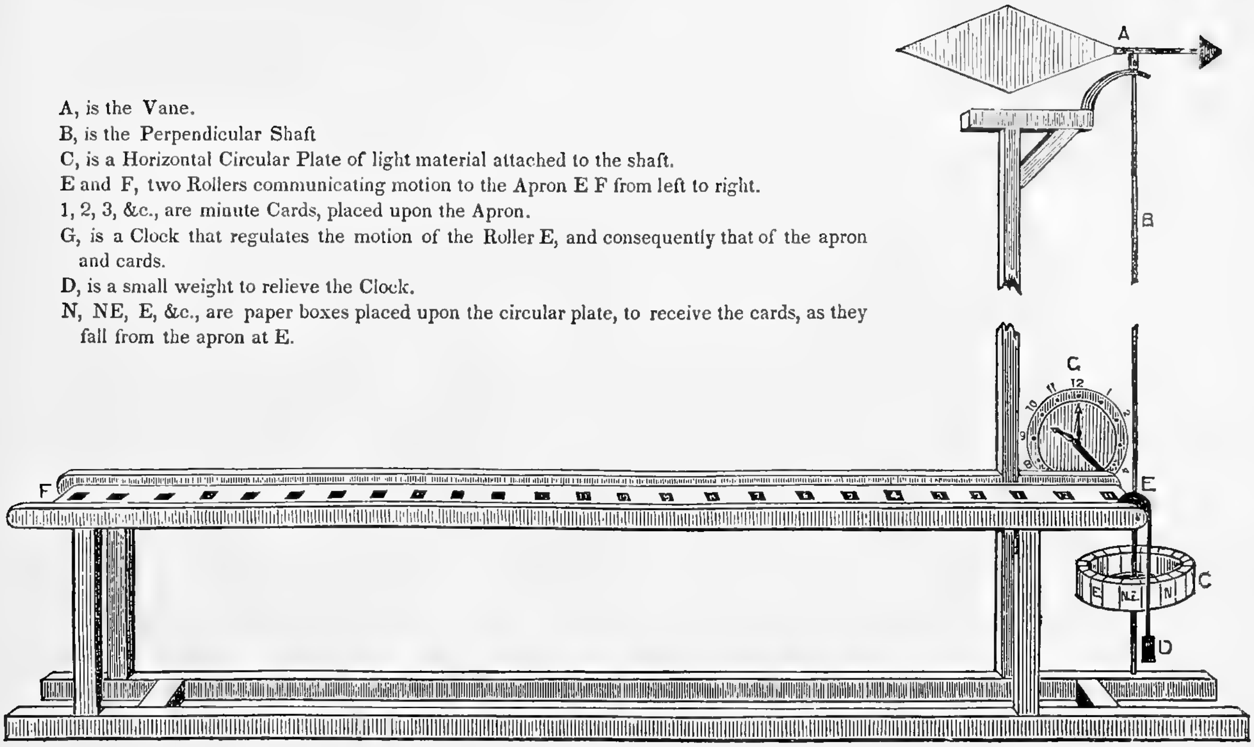
[22] P. H. Carl, *Repertorium für physikalische Technik*, Munich, 1867, p. 162ff.

[23] E. Lacroix, *Etudes sur l'Exposition de 1867*, Paris, 1867, vol. 2, p. 313ff. See also, *Reports of the U.S. Commissioners to the Paris Universal Exposition, 1867*, vol. 3, Washington, 1870, p. 570ff.

[24] *Annals of the Dudley Observatory*, 1871, vol. 2, p. vii ff.

[25] Karl Kreil, *Entwurf eines meteorologischen Beobachtungs-Systems für die österreichische Monarchie*, Vienna, 1850.



A, is the Vane.
B, is the Perpendicular Shaft
C, is a Horizontal Circular Plate of light material attached to the shaft.
E and F, two Rollers communicating motion to the Apron E F from left to right.
1, 2, 3, &c., are minute Cards, placed upon the Apron.
G, is a Clock that regulates the motion of the Roller E, and consequently that of the apron and cards.
D, is a small weight to relieve the Clock.
N, NE, E, &c., are paper boxes placed upon the circular plate, to receive the cards, as they fall from the apron at E.

Figure 7.—In 1838 the pioneer American meteorologist James H. Coffin (1806–1873) devised a self-registering wind direction indicator; in 1849 he improved it as shown here. The band, moved by clockwork, carries cards marked with the day and hour. In Coffin's earlier instrument, a part of which is now in the Smithsonian Institution, the vane carried a funnel for sand, which ran into a circular row of bottles. (From *Proceedings of the American Association for the Advancement of Science*, 1849, vol. 2, p. 388.)

barometer, thermometer and the psychrometer [meaning wet-bulb thermometer] every half hour . . . and prints the results on a sheet of paper in figures," running a week unattended. The working of this register involved the insertion of a conductor in the tubes to make a circuit, the thermometers having open tops.[26] This was ten years after the development of the electromagnetic relay and six years after Wheatsone's introduction of his own telegraph.

Wheatstone's instrument left a very ephemeral record in the meteorological literature, and appears to have been defective or out of fashion with its time, which was concerned with the introduction of photographic instruments. Wheatstone's work was rediscovered, along with that of several other much earlier inventors, by the determined observatory directors of the 1860's.

Of the five systems developed at that time, four used electromagnetic registration, only Draper adhering to a mechanical system (see fig. 11). For temperature measurement Secci and Hough used Wheatstone's electrical system with a mercurial thermometer

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[26] *Report of the 13th Meeting of the British Association for the Advancement of Science, 1843*, 1844, p. xi ff. I have found no other reference to this instrument. Considerable attention was given to the thermometer, however, for Wheatstone proposed to send it aloft in a balloon for the measurement of temperatures at high altitudes. A small clock caused a vertical rack to ascend and descend once in six minutes. The rack carried a platinum wire which moved within the thermometer over 28 degrees. From a galvanic battery and a galvanometer on the ground two insulated copper wires were to extend to the balloon, one connected to the mercury and the other to the clock frame. The deflection of the galvanometer was to be timed with a second clock on the ground. (Professor Wheatstone, "Report on the Electro-Magnetic Meteorological Register," *Mechanics' Magazine*, London, 1843, vol. 39, p. 204).

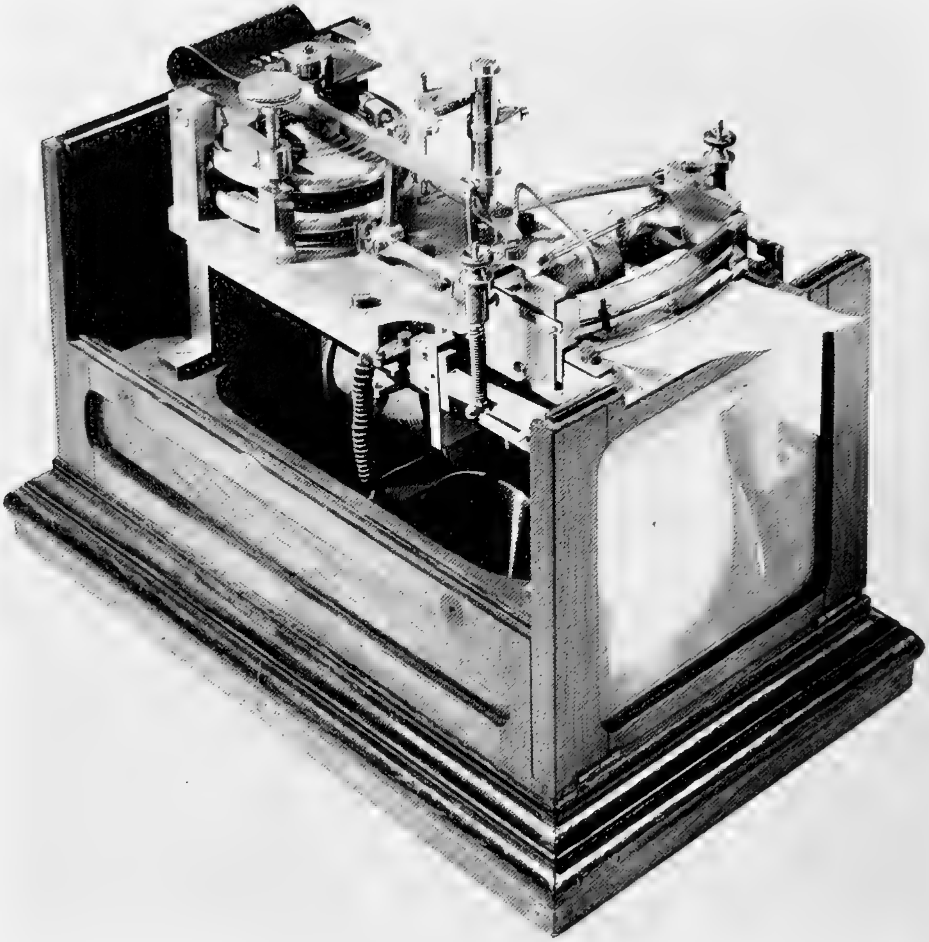

Figure 8.—Hipp's registering aneroid barometer, with a telegraphic printer. (*USNM 314544; Smithsonian photo 46740–D.*)

(fig. 12), but the other four utilized a physical principle which had been proposed periodically for at least a century—the unequal thermal expansion of a bimetallic strip. This principle had been utilized by watchmakers for a quite different purpose—the temperature compensation of the watch pendulum—but its possibilities as a thermometer had been known long before the mid-19th century.[27]

For the measurement of pressure, Secci, Wild, and Draper adopted, or rediscovered, the balance barometer devised by Wren in the 17th century. In this type of instrument (see figs. 13, 15) either the tube or the reservoir of the barometer is attached to one arm of a balance, the equilibrium of which is disturbed by the movement of the mercury in the instrument.[28]

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[27] In 1662 Hooke had proposed the use of a bimetallic pendulum for the temperature compensation of clocks. Thermometers on this principle were described to the Royal Society in 1748 and in 1760 (*Philosophical Transactions of the Royal Society of London*, 1748, vol. 45, p. 128; 1760, vol. 51, p. 823). Some systems used a bimetallic thermometer in the sun and a mercurial instrument in the shade.

[28] This instrument has been persistently associated with Sir Samuel Morland (1625–1695). For example, A. Sprung of the Deutsche Seewarte described his own balance-barometer as a "Wagebarograph nach Samuel Morland" (in L. Loewenherz, *Bericht über die wissenschaftlichen Instrumente auf der Berliner Gewerbeaustellung im Jahre 1879*, Berlin, 1880, p. 230 ff). Sprat (*op. cit.* footnote 10, p. 313) reported that Wren had proposed "balances to shew the weight of the air by their spontaneous inclination." This must, therefore, be Wren's invention, unless he got it from Morland, who does not seem to have published anything about the barometer but only to have described some

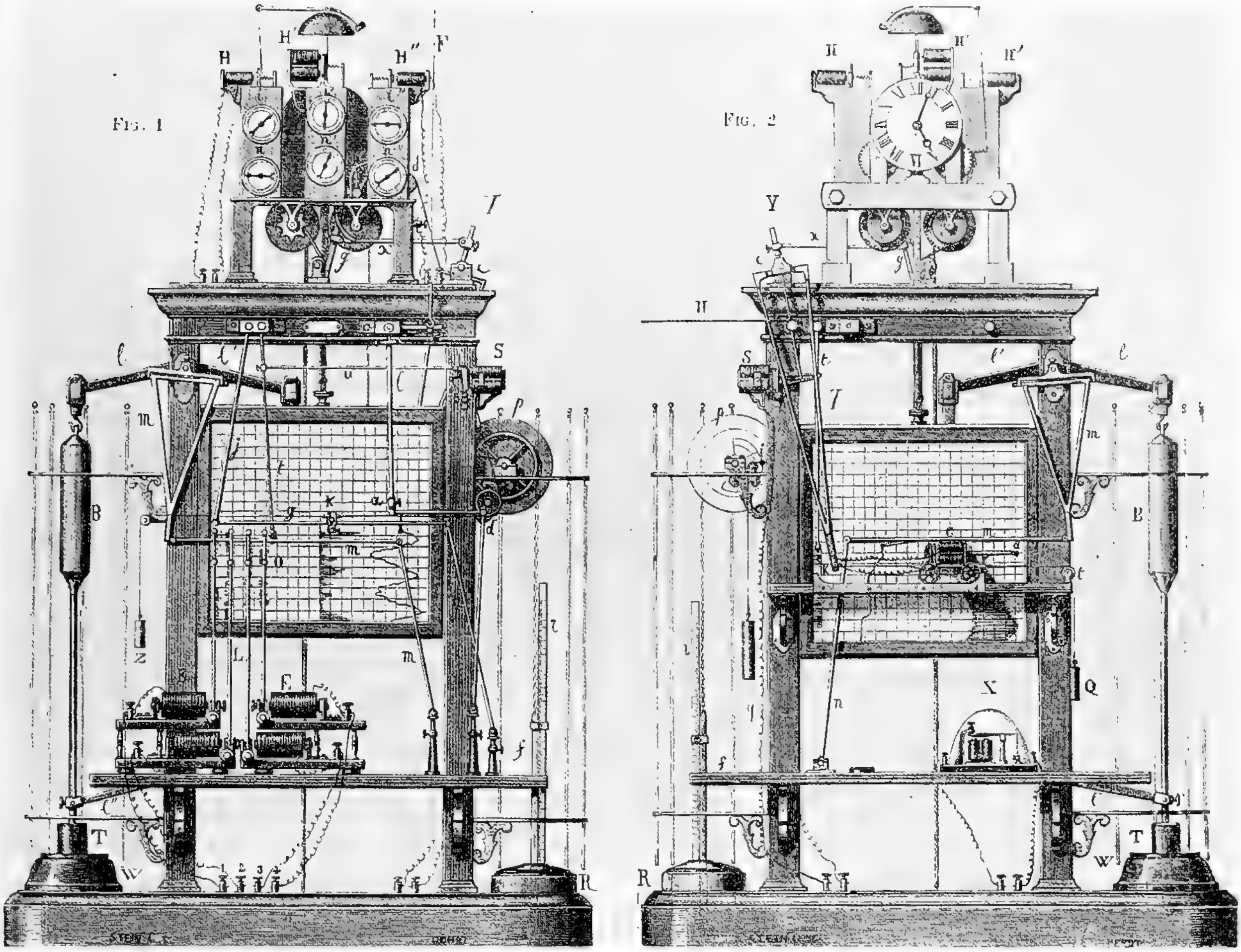

Figure 9.—Front and rear views of Secci's meteorograph, 1867. (From Lacroix, *op. cit.* footnote 22.)

Hough's barometer was an adaptation of the electrical contact thermometer. The movement of the mercury over a certain minute distance within the tube served as a switch to energize an electrical recording system. Hipp, who was perhaps the latest of this group, first applied the aneroid barometer (fig. 8) to self-registration. The idea of the aneroid—an air-tight bellows against which the atmospheric pressure would act—had been advanced by Leibniz in the 17th century and had been the subject of a few abortive experiments in the 18th century. Not until 1848 was an instrument produced that was acceptable to users of the barometer.[29]

As a wind velocity instrument all six systems used the cup-anemometer developed by Robinson in 1846, an instrument whose chief virtue was the care which its inventor had taken to work out the relationship between its movement and the actual velocity of the

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ideas to a friend. But Morland's was probably the *inclined* and not the *balance* barometer. (See under "barometer" in Charles Hutton, *Mathematical and Philosophical Dictionary*, London, 1796, vol. 1; also J. K. Fischer, *Physikalisches Worterbuch*, Göttingen, 1798).

[29] Leibniz, in several letters—beginning with one to Denys Papin on June 21, 1697—proposed the making of a barometer on the model of a bellows. Of subsequent versions of such a barometer, that of Vidi (described by Poggendorff, *Annalen der Physik und Chemie*, 1848, Band 73, p. 620) is generally regarded as the first practical aneroid (see also Gerland and Traümuller, *op. cit.* footnote 1, pp. 239, 323).

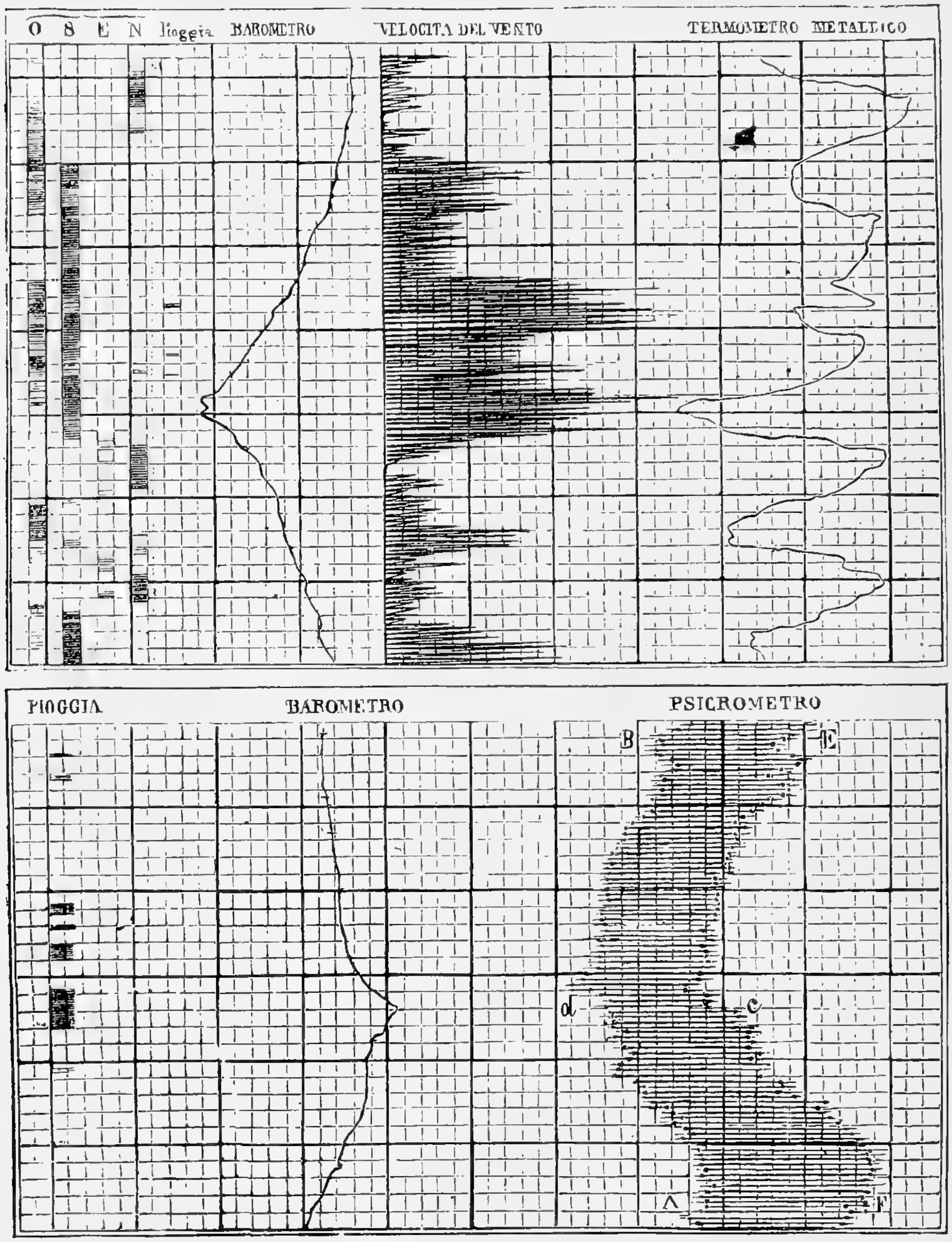

Figure 10.—Chart from Secci's meteorograph. (From Lacroix, *op. cit.* footnote 22.)

wind.[30] Beckley and Draper caused it to move a pencil through gearing; the others used with it electromagnetic counters actuated by rotating contacts.

As has been indicated, the Signal Corps used all six systems, a panopoly of gadgetry which must have been wondrous to behold. Its Secci meteorograph, which had attracted much attention at Paris, was estimated to have cost 15,000 francs. Abbe reported in 1894 that the instruments were long kept in the apparatus room "as a fascinating show to visitors and a

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[30] T. R. Robinson, "Modification of Dr. Whewell's Anemometer for Measuring the Velocity of the Wind," *Report of the 16th Meeting of the British Association for the Advancement of Science, 1846*, 1847, pt. 2, p. 111.

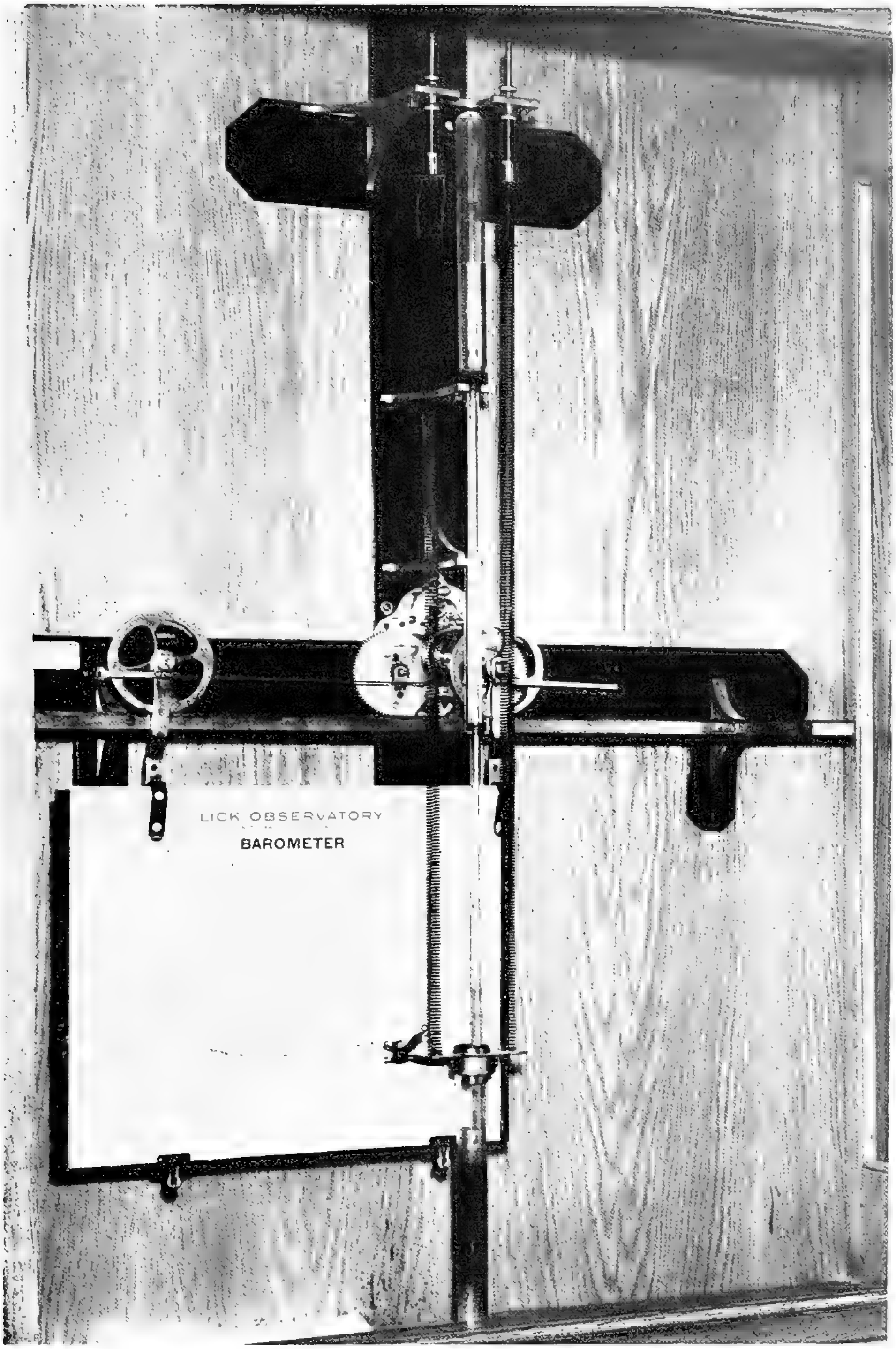
LICK OBSERVATORY
BAROMETER

Figure 11.—Draper's mechanical registering barometer, as used in the Lick Observatory. (Photo courtesy Lick Observatory.)

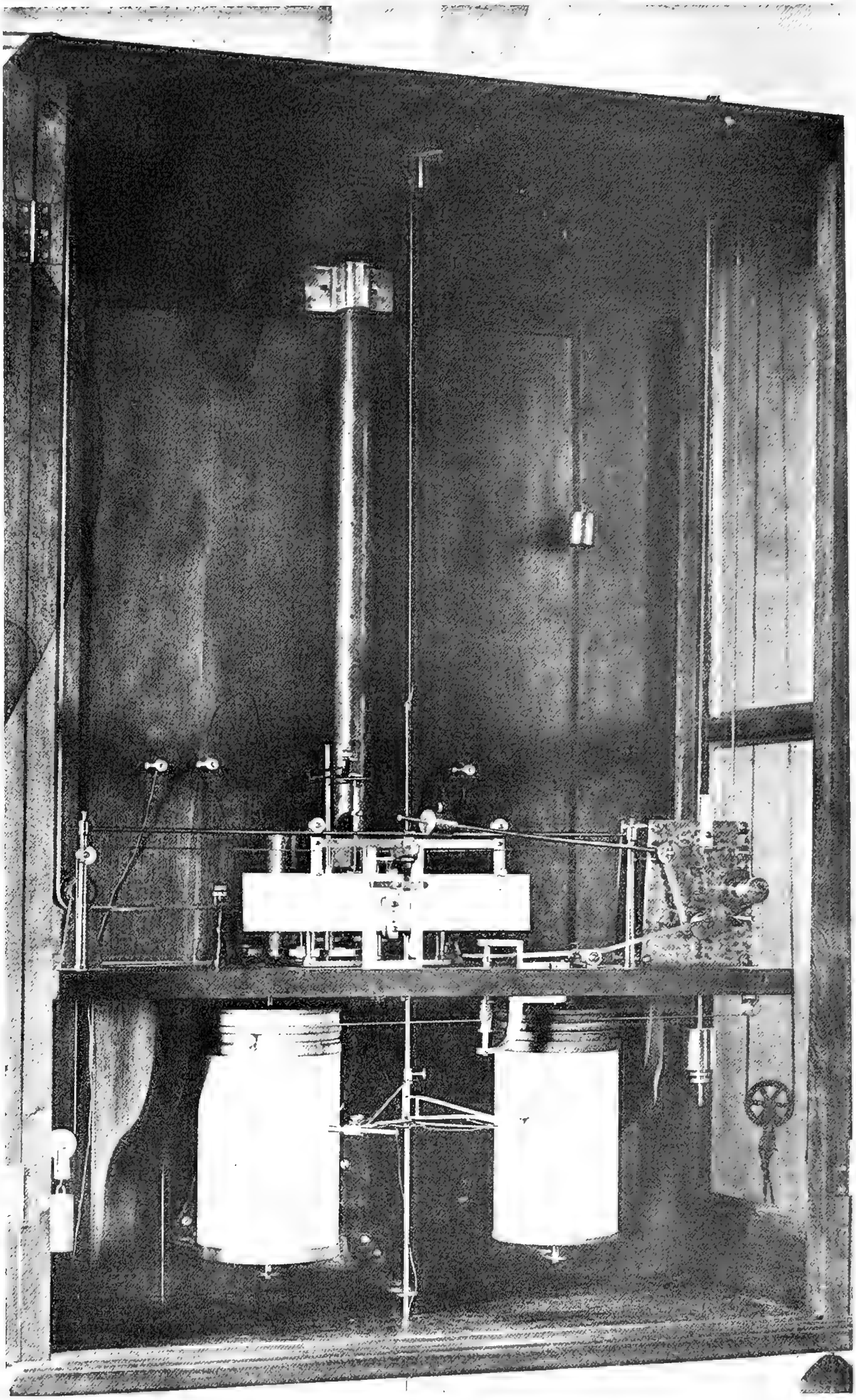

Figure 12.—Hough's electromechanical registering barometer, about 1871.

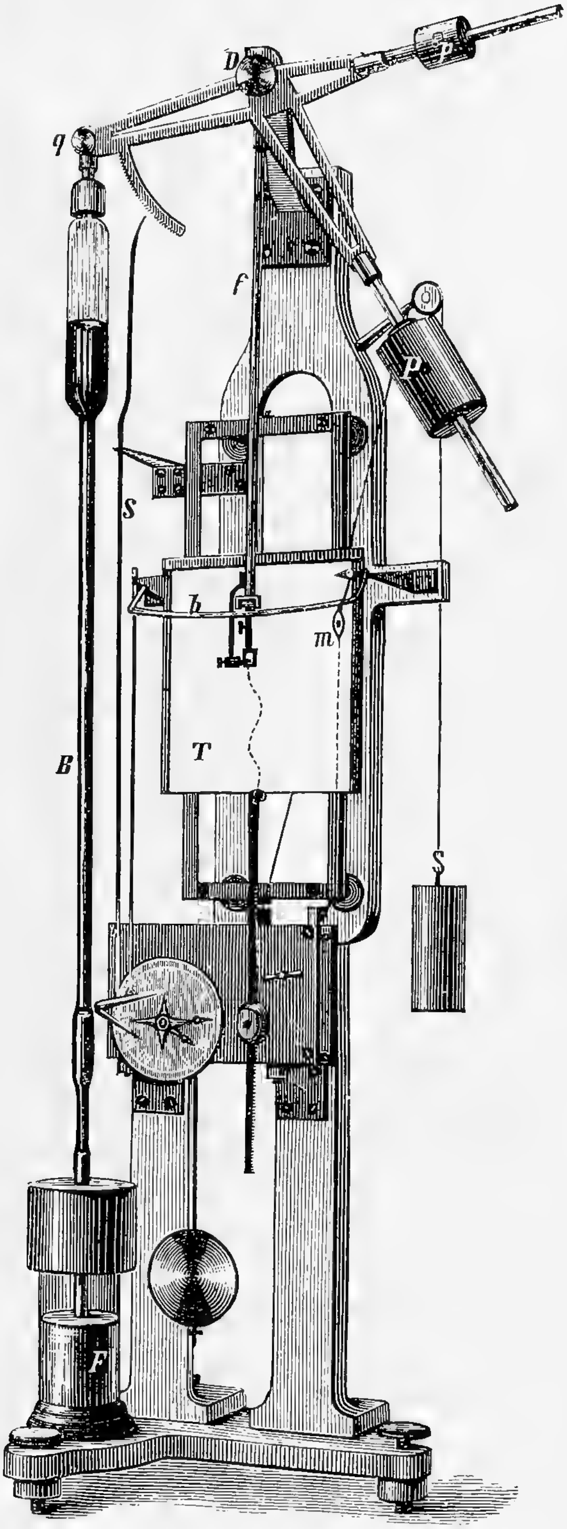

Figure 13.—Feuss' "balance barometer after Samuel Morland," 1880. Wren probably was the originator of this type of instrument. (From Loewenherz, *op. cit.* footnote 28.)

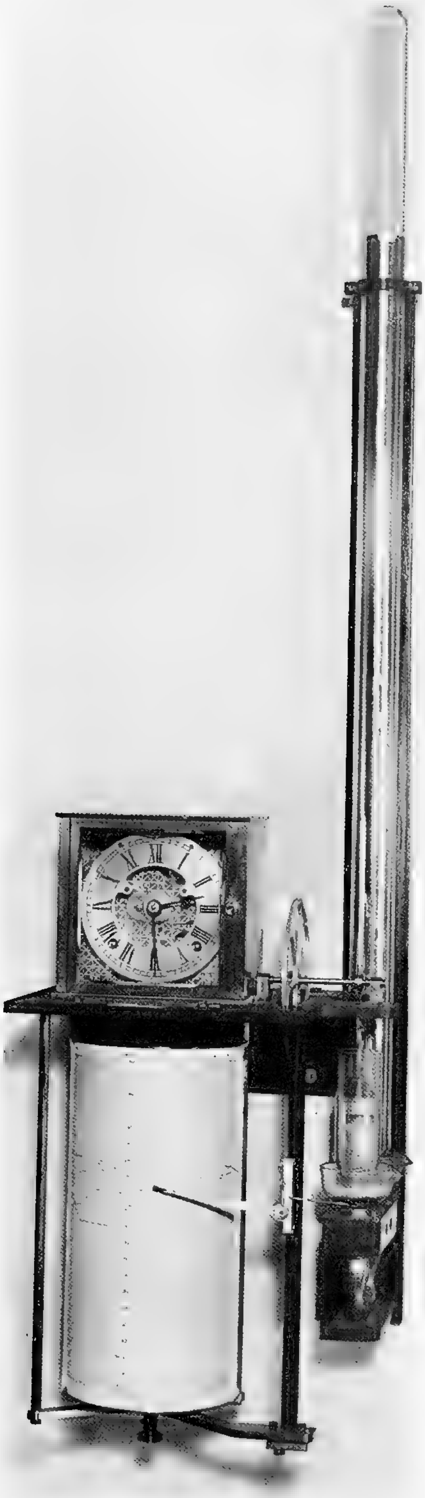

Figure 14.—Marvin's mechanical registering barometer, 1905. This instrument was formerly in the U.S. Weather Bureau. (*USNM 316500; Smithsonian photo 46740–E.*)

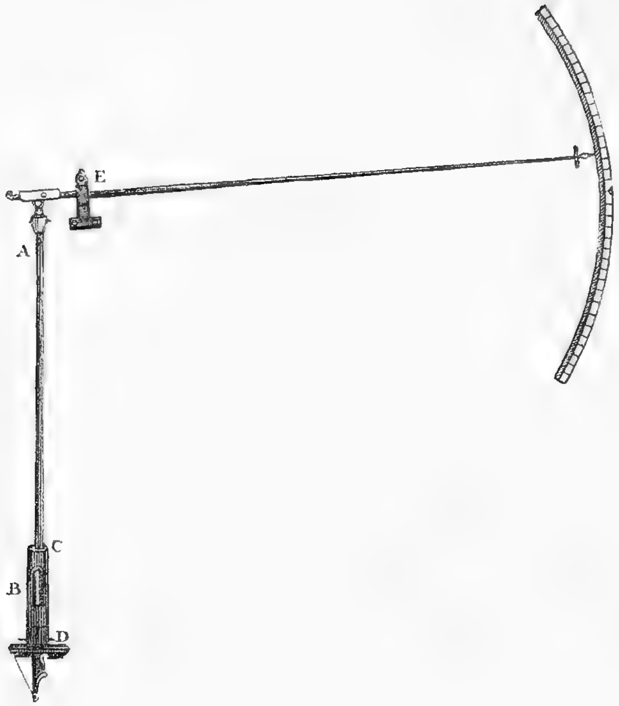

Figure 15.—"Steelyard barometer" as shown in Charles Hutton's *Mathematical and Philosophical Dictionary* (London, 1796, vol. 1, p. 188). Hutton makes no reference to the originator of this instrument; he attributes the "Diagonal" (or inclined) barometer to Samuel Morland.

stimulation to the staff in the invention of other instruments." [31]

From 1875 the question was no longer one of the introduction of self-registering instruments to major observatories but their complete mechanization and the extension of registration to substations. Having accepted self-registration, meteorologists turned their attention to the simplification of instruments. In 1904 Charles Marvin, of what is now the U.S. Weather Bureau, brought the self-registering barometer into something of a full circle by producing an instrument (fig. 14) that was nothing more than Hooke's wheel barometer directly adapted to recording.[32] But this process of simplification had been accomplished at a stroke, about 1880, with the introduction by the Parisian instrument-maker Jules Richard of a self-registering barometer and a thermometer combining the simplest form of instrument with the simplest form of registration (see fig. 16). This innovation, which fixed the form of the conventional registering instrument until the advent of the radiosonde, seems to have stemmed from a source quite outside meteorology—the technology of the steam gauge. Richard's thermometric element was the curved metal tube of elliptical cross-section that Bourdon had developed several decades earlier as a steam gauge. Pressure within such a tube causes it to straighten, and thus to move a pointer attached to one end. Bourdon had opened it to the steam source. Richard filled it with alcohol, closed it, and found that the expansion of the alcohol on heating caused a similar straightening. His barometric element was a type of aneroid, which Hipp had already used but which Richard may have also adopted from a type of steam gauge. For a recording mechanism, Richard was able to use a simple direct lever connection, as the forces involved in his instruments, being concentrated, were not greatly hampered by friction.[33] By 1900 these simple and inexpensive instruments had relegated to the scrap pile, unfortunately literally, the elegant products of the mass attack of observatory directors in the 1860's on the problem of the self-registering thermometer and barometer.[34]

Conclusions

In view of the rarity of special studies on the history of meteorological instruments, it is impossible to claim that this brief review has neglected no important instruments, and conclusions as to the lineage of the

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[31] Abbe, *op. cit.* (footnote 19), pp. 263–264.

[32] Because of its superior accuracy to the aneroid barograph, Marvin's barometer was in use through the 1940's. See R. N. Covert, "Meteorological Instruments and Apparatus Employed by the United States Weather Bureau," *Journal of the Optical Society of America*, 1925, vol. 10, p. 322.

[33] Both of Richard's instruments (described in *Bulletin Mensuel de la Société d'Encouragement pour l'Industrie Nationale*, November 1882, ser. 3, vol. 9, pp. 531–543) were in use at Kew by 1885 and at the U.S. Weather Bureau by 1888. The firm of Richard Freres claimed in 1889 to have made 7,000 registering instruments, of which the majority were probably thermographs and barographs. At that time, certainly no other maker had made more than a small fraction of this number of self-registering instruments. The origin of Richard's thermograph seems to have been the "elastic manometer" described by E. Bourdon in 1851 (*Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1851, no. 562, p. 197). While attempting to restore a flattened still-pipe, Bourdon had discovered the property of tubes to change shape under fluid pressure. The instrument he developed in consequence became the standard steam pressure gauge.

[34] A few of these instruments, such as the Marvin barograph, survived for some time because of their superior accuracy. Even as museum pieces, only a few exist today.

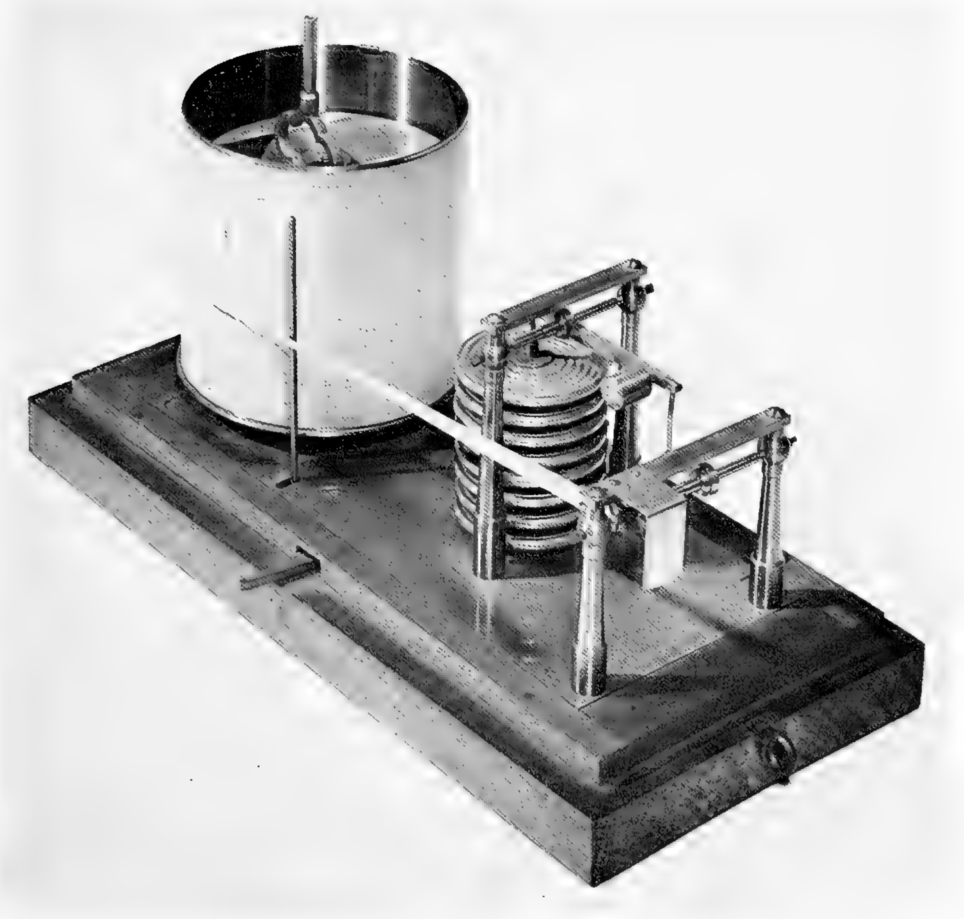

Figure 16.—Richard's registering aneroid barometer, an instrument used at the U.S. Weather Bureau about 1888. The Richard registering thermometer is similar, the aneroid being replaced by an alcohol-filled Bourdon tube. (*USNM 252981; Smithsonian photo 46740–C.*)

late 19th century instruments can only be tentatively drawn. The conclusion is inescapable, however, that the majority of the instruments upon which the self-registering systems of the late 19th century were based had been proposed and, in most cases, actually constructed in the 17th century. It is also evident that in the 17th century at least one attempt was made at a system as comprehensive as any accomplished in the 19th century.

To attribute the success of self-registering instruments in the late 19th century to the unquestionable improvements in the techniques of the instrument-maker is to beg the question, for it is by no means clear that the techniques of the 17th-century instrument-maker were unequal to the task. It should also be noted that the photographic and electromagnetic systems of the 19th century seem to have been something of an interlude, for some of the latest and most durable (all of Draper's and Richard's instruments and Marvin's barograph) were purely mechanical instruments, as had been those of Hooke and Wren. If we conclude that the 19th-century instruments were more accurate, we should also recall Forbes' comments upon the question of instrumental accuracy.

What, then, was the essential difference between the 17th and 19th centuries that made possible the development of the self-registering observatory? It would appear to have been a difference of degree—the maturation in the 19th century of certain features of the 17th. The most important of these features were the spread throughout the western world of the spirit that had animated the scientific societies of Florence and London, the continued popularity of the astronomical observatory as an object of the philanthropy of an affluent society, and the continued existence of the nonspecialized scientist. Under these circumstances such nonmeteorologists as Wheatstone, Henry, Hough, Wild, and Secci had the temerity to range over the whole of the not yet compartmented branches of science and technology, fully confident that they were capable of finding thereby a solution to any problem important enough to warrant their attention.

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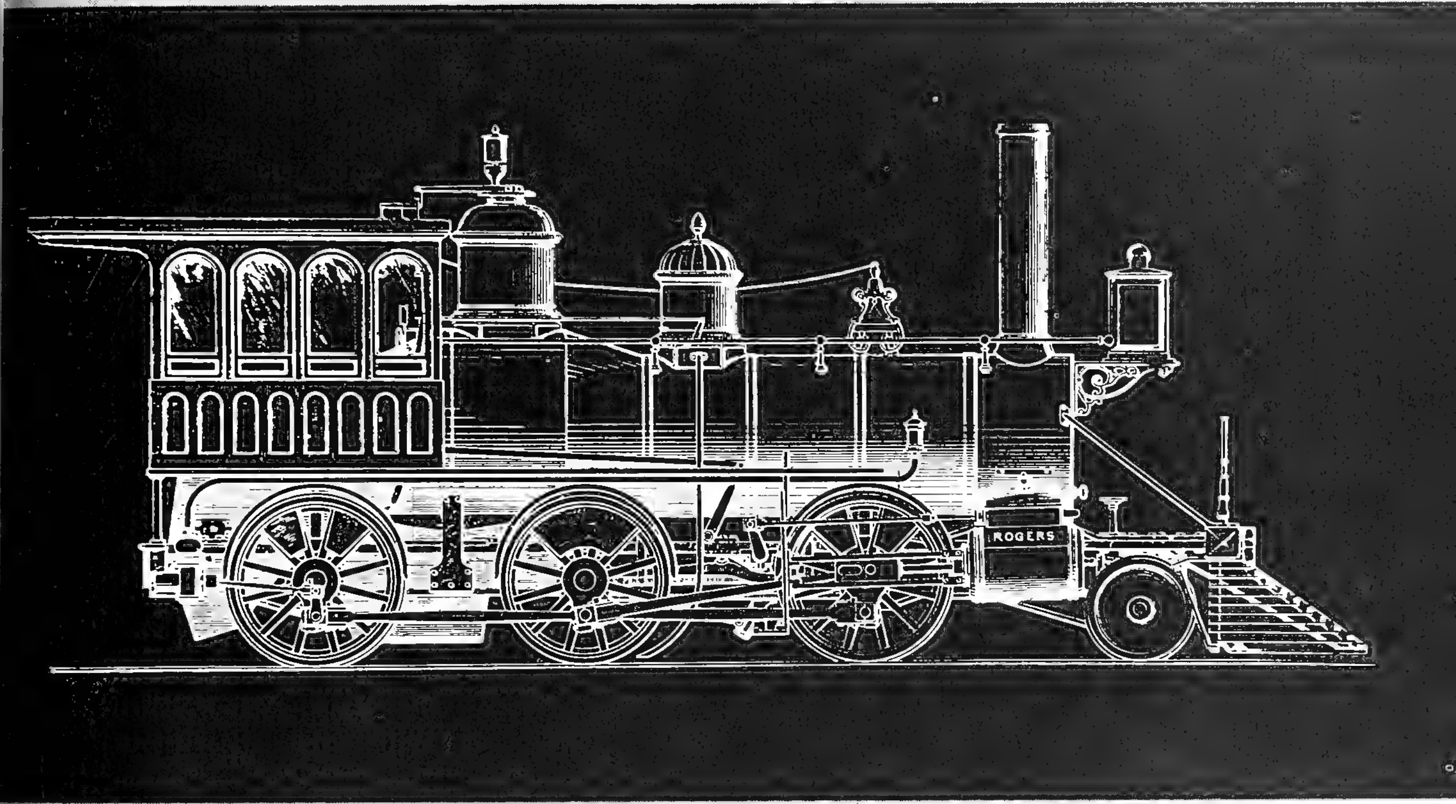

by John H. White

Paper 24 pages 117–131, from

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PAPER 24

INTRODUCTION OF
THE LOCOMOTIVE SAFETY TRUCK

John H. White

INTRODUCTION OF THE LOCOMOTIVE SAFETY TRUCK

John H. White

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Pioneer railroading was dangerous. With increased speed and density of traffic came an increase in catastrophic wrecks that forced operators to take heed for the safety of their passengers and freight. This safety was painfully achieved through the slow process of improving equipment part by part.

Antedating such spectacular post-Civil War advances as the steel rail, automatic coupler, and airbrake, was the invention of the safety truck for locomotives. Intended to lead the bobbing, weaving locomotive around curves on the rough track of the early roads, it did much to reduce the all too numerous derailments that were a major cause of accidents.

THE AUTHOR: *John H. White, is associate curator, in charge of land transportation, in the Smithsonian Institution's Museum of History and Technology, United States National Museum.*

AMERICAN RAILROADS of the early 19th century were cheaply and hastily built. They were characterized by inferior roadbeds, steep grades, sharp curves, and rough track. In spring, poor drainage and lack of ballast might cause the track to sink into the soggy roadbed and produced an unstable path. In winter this same roadbed could freeze into a hard and unyielding pavement on which the rolling stock was pounded to pieces.

In those pioneering times the demand for new roads left little capital to improve or expand existing lines; therefore equipment was needed that could accommodate itself to the existing operating conditions.

The first locomotives used in this country had been imported from England. Designed for well-ballasted track with large-radius curves and gentle gradients, they all too frequently left the rails, and the unsuitability of the essentially rigid British design soon became apparent.

The challenge posed by the American roadbed was met by American mechanics. By the mid-1830's a distinctive American locomotive had evolved that might best be described by the word "flexible." The basic features of its running gear were a bar frame and equalizing levers to provide vertical relief and a leading truck to provide lateral relief. Of these devices the truck was probably the most important, and more readily than any one component distinguished the American running gear from that used by the British before 1860.

It was John B. Jervis who is generally credited with first applying the truck to the locomotive. His design, shown in figure 1, was developed in 1831–32. Its merits quickly became apparent, and by 1835 it

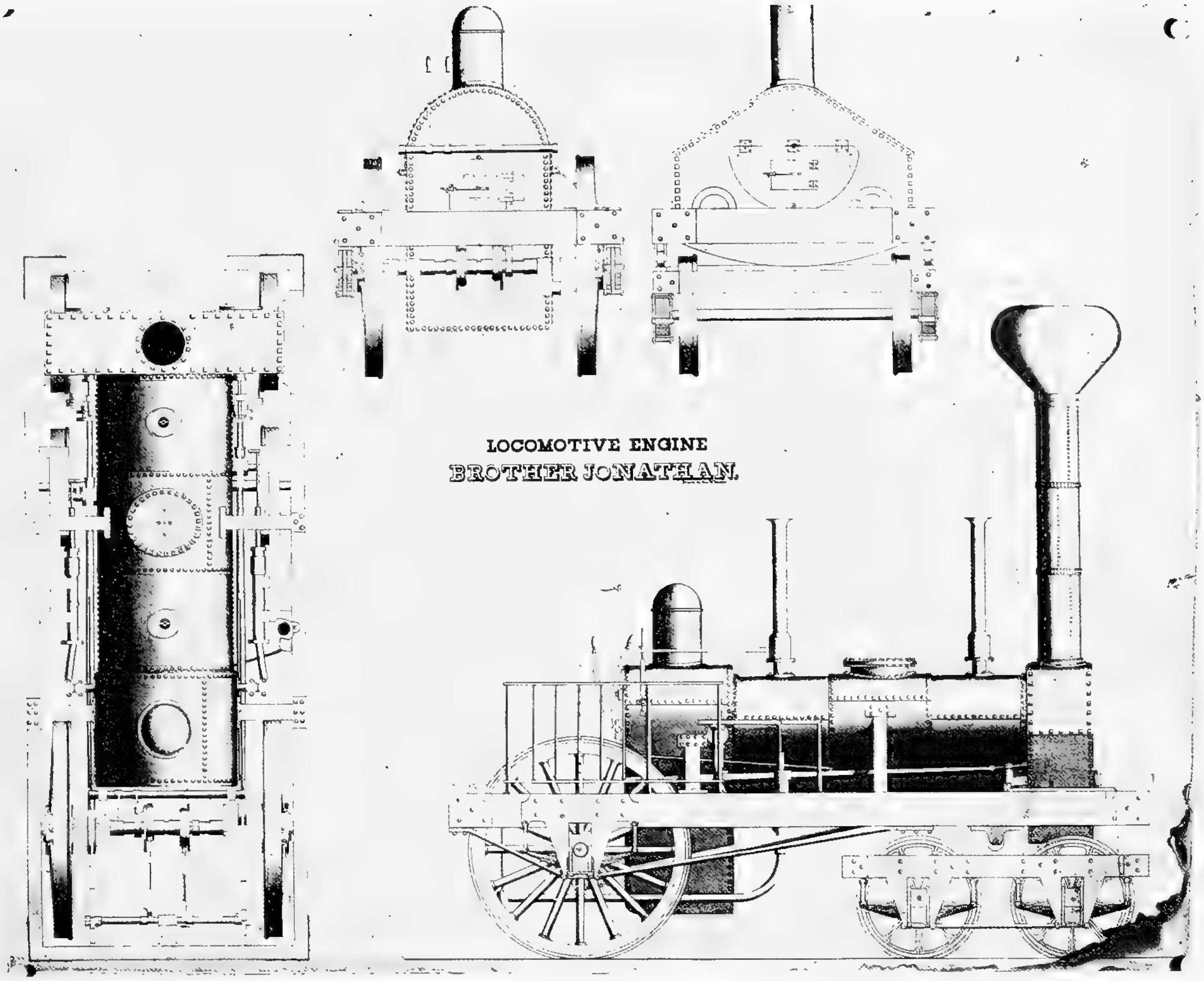

FIGURE 1.—Design drawing showing the 4-wheel leading truck, developed in 1831 by John B. Jervis, applied to the *Brother Jonathan*. This locomotive, one of the earliest to use a leading truck, was built in June 1832 by the West Point Foundry Association for the Mohawk and Hudson Rail Road. The truck is attached to the locomotive frame by a center pin, but the forward weight of the locomotive is carried by a roller which bears on the frame of the truck. (*Smithsonian photo 36716–a*)

had been universally recognized in this country. The truck successfully led the locomotive around sharp curves, the resultant 3-point suspension enabled the machine to traverse even the roughest of tracks, and, altogether, the design did far less damage to the lightly built U.S. lines than did the rigid, imported engines.[1]

The truck frame, fabricated from iron straps and castings, was attached to the locomotive by a pin around which it might rotate. At first the weight was received by rollers or chafing pads mounted on the side beams of the truck. However, the friction of these bearing surfaces and their location at a considerable distance from the center pin combined to restrict the free movement of the truck. By the early 1850's the point of bearing was transferred to the center plate, producing a truck that turned more freely.[2]

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[1] Three-point suspension in a 4–2–0 was easily gained—the center plate of the truck and the two bearings of the driving wheel axle. On a 4–4–0 the center plate served as one point, while the fulcrum of each equalizing lever served as the other two points, thus providing the desirable and highly stable 3-point suspension.

[2] *American Railroad Journal*, 1853, vol. 9, p. 427.

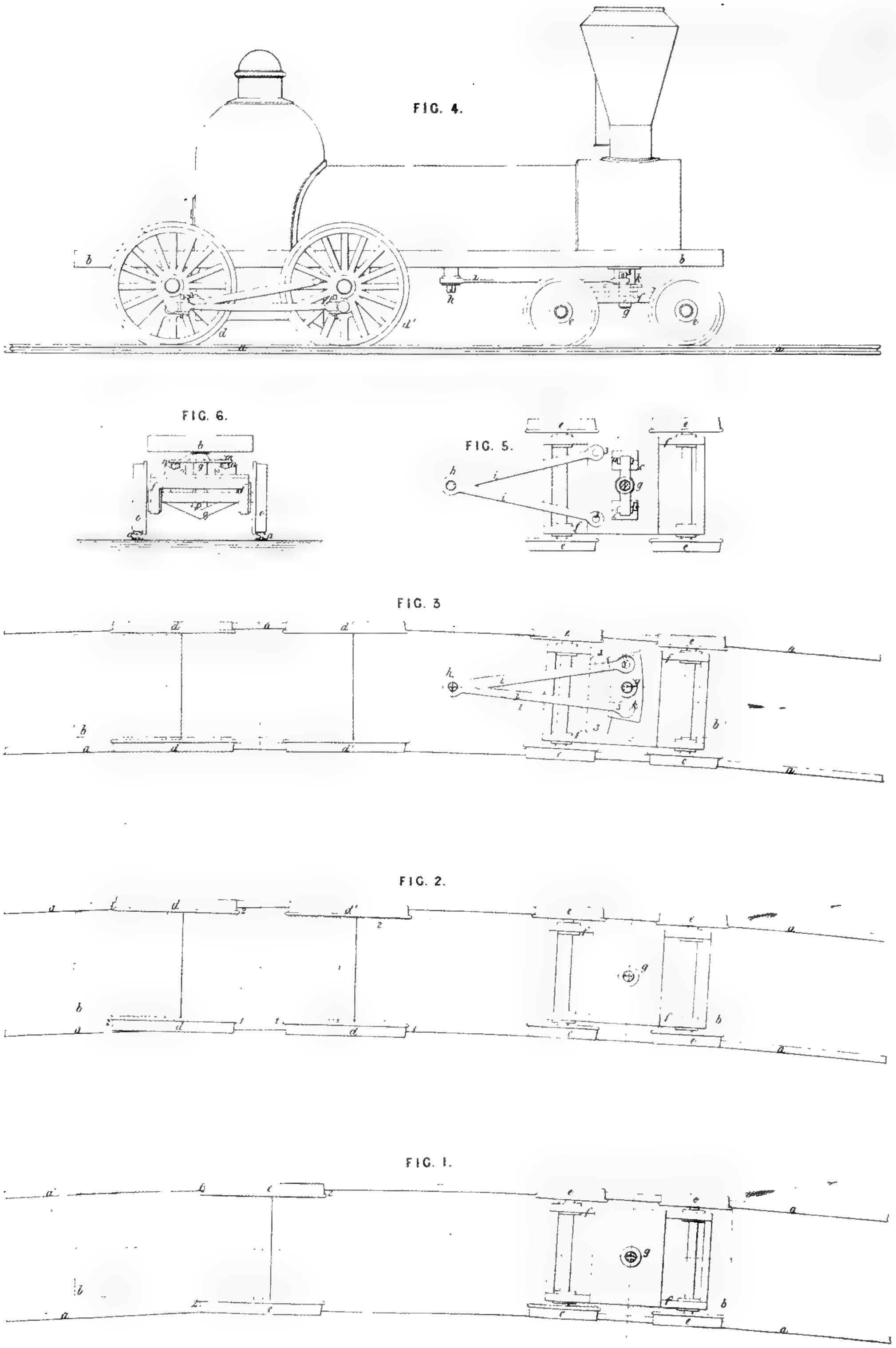
FIG. 4.
FIG. 6.
FIG. 5.
FIG. 3
FIG. 2.
FIG. 1.
a
b
d
d'
e
f
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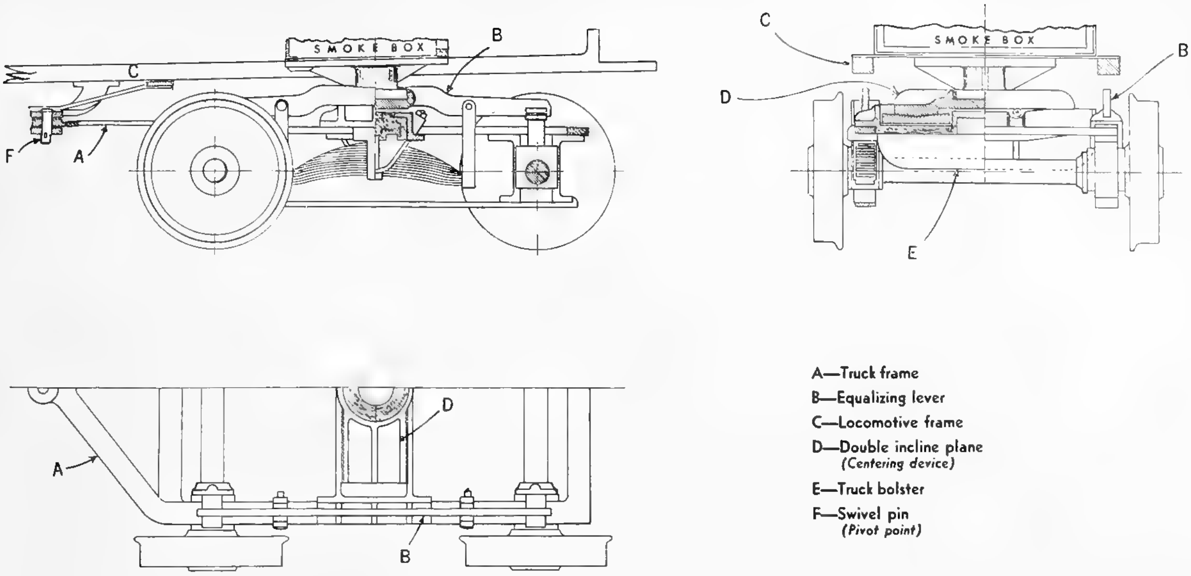
h
i

Figure 2.—The 4-wheel Bissell truck as shown in the drawing for British patent 1273, issued May 5, 1857.



Drawn by J. H. White, June, 1960

FIGURE 3.—Typical 4-wheel Bissell Safety truck of 1860. This drawing is based on plate 69 of Alexander L. Holley's, *American and European Railway Practice in the Economical Generation of Steam*, New York, 1861. (*Smithsonian photo 46946*)

For single axle engines this simple form of truck was entirely satisfactory, but it proved less satisfactory for 4- and 6-coupled machines. Also, as train speeds increased, so did the number of derailments. Many of these could be traced to the inability of the engine to negotiate curves at speed. Levi Bissell, a New York inventor who investigated this problem in the 1850's, correctly analyzed the difficulty. He observed that when the engine was proceeding on straight tracks the leading truck tended to oscillate and chatter about the center pin, and he noted that it was this action that imparted a fearful pitching motion to the locomotive at speed. The derailments were traced to the action of the truck as the engine entered a curve.

This action can be more easily understood from reference to Bissell's patent drawing in figure 2. For example, let us say that an 8-wheel engine, fitted with a center-swing truck, enters a right-hand curve. The left truck wheels bear hard against the left rail. The drivers jam obliquely across the track, with the right front and left rear wheels grinding into the rails. As a result, the locomotive tends to leave the track in the direction of the arrow shown on the figure (bottom drawing). It will be noted that the truck center pintle is in fact the fulcrum for this leverage. Under such strain the truck wheels are particularly likely to leave the rails when they encounter an obstruction. Once derailed, the truck would then spin around on the deadly center pin, throwing the locomotive over.

In effect, then, the center pin of the conventional truck extended the rigid wheel-base of the engine, and caused the truck to act much as would a single set of leading wheels fitted rigidly to the engine frame far ahead of the front driving wheels. Bissell proposed to correct the faults of the conventional truck by fitting the locomotives with his invention, the first practical safety truck to be patented. Since the primary requirements were to keep the leading wheel axles at right angles to the rails whether on a straight or curved track, and to allow the driving axles to remain parallel, or nearly so, to the radial line of the curve, he moved the center pin to a point behind the truck and just in front of the forward driving axle. This shortened the wheelbase of the engine and removed the danger of the pintle serving as a fulcrum between the truck and the driving wheels, thus allowing them to assume a comfortable position on a curve.

Since the truck could assume the correct angle when entering curves, it was claimed in the patent specification that, unless all four wheels were simulta-

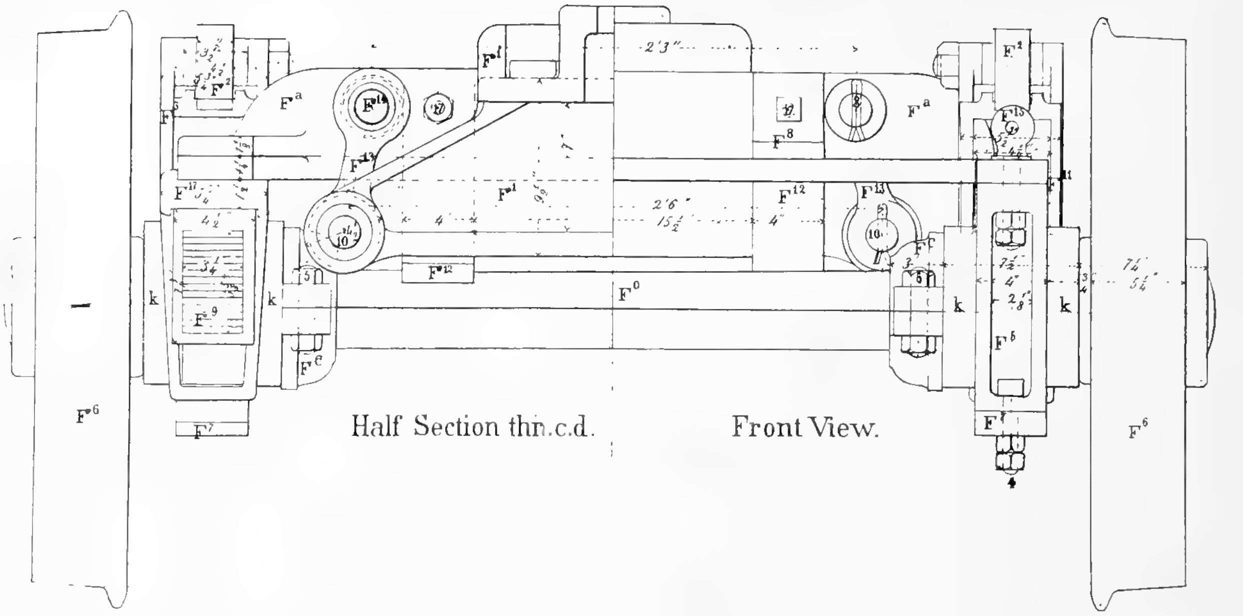


FIGURE 4.—A 4-wheel safety truck fitted with A. F. Smith's swing-bolter centering device. Built by the Hinkley Locomotive Works. From Gustavus Weissenborn, *American Locomotive Engineering and Railway Mechanism*, New York, 1871, pl. 88.

neously lifted off the track, the truck could pass over "quite a considerable obstruction." [3] Bissell further claimed:

> In running on either a straight or curved track one of the truck wheels often breaks off, and the truck swivels around on its center pin in consequence, and throws the engine off the track, but with my device one wheel, or even the two wheels on the opposite sides diagonally of the truck might break off and still the truck would not run off, because its position is set and it has no axis of motion around which it could swing. . . .

The other problem Bissell wished to correct was the oscillation and chatter of the leading truck. This was accomplished by a simple centering device in the form of a pair of V-shaped double incline planes (D on fig. 3) situated at the center of the truck frame (A). The lower planes of the pair were fastened to the truck frame and the upper, cast in the form of a bridge, were attached to the locomotive frame (C) by a center plate. But while the portion of the locomotive's weight assigned to the leading wheels was borne at the center of the truck, as in the conventional design, the center plate was no longer the point of rotation. On a straight track the V's would be at their bottom position and thus prevent the truck from vibrating.[4] When the locomotive entered a curve the planes allowed its forward weight to bear continuously on all four wheels, and at the same time controlled any exaggerated swing caused by centrifugal force.

The centering device is thus explained in the patent specification (figure numbers are omitted):

> I therefore obviate this difficulty [the oscillation of the truck] by providing two inclined planes . . . formed double as shown and of an angle proportioned to the weight of the forward part of the locomotive and the velocity of the same, . . . The position of the inclines is such that the blocks [V's] rest in the lowest part of the double inclines when the engine is on a straight track, and on coming onto a curve the inertia of the engine . . . is expended in going up the inclines, as the truck moves laterally toward the inner part of the curve; and on coming onto a straight line

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[3] Connecting both truck axles with an equalizing lever so that they acted in sympathy with each other also did much to prevent derailments on rough trackage.

[4] Bissell states in the patent specification that inclined planes had been previously applied to railroad car trucks. His claim rested on the application of this device to locomotive trucks.

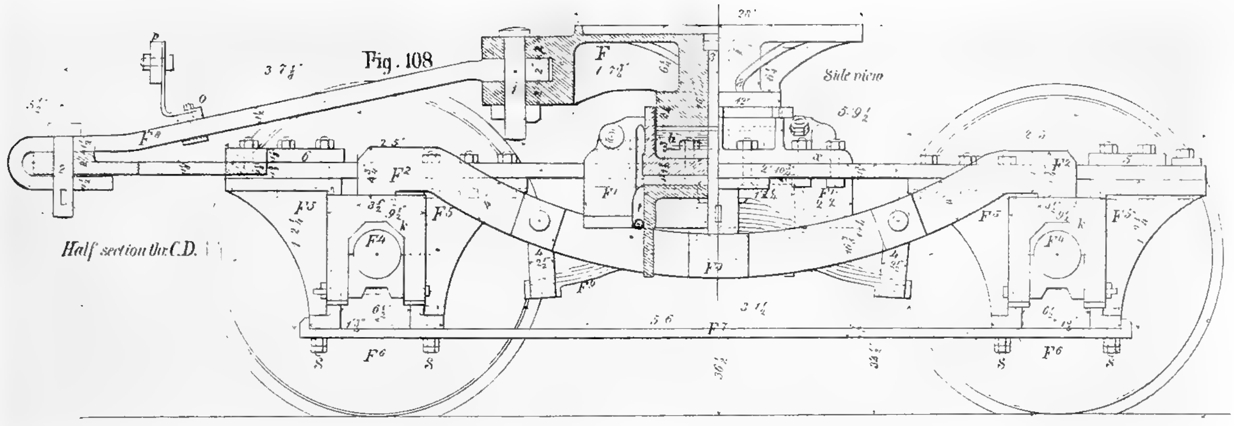

Figure 5.—Detail drawing of the radius-bar truck, patented by William S. Hudson in 1864, as applied to the New Jersey Railroad and Transportation Company *No. 44*. From Gustavus Weissenborn, *American Locomotive Engineering and Railway Mechanism*, New York, 1871, pl. 8.

the blocks, descend to the bottom of the inclines and the engine is prevented from acquiring a sidewise or oscillating motion.

Bissell applied for a U.S. patent on April 23, 1857. His petition was initially denied. A weary debate of several months duration followed between the patent examiner and Bissell's attorneys.

During this time Bissell was busy promoting the application of his truck even though he had no patent for protection. In May of 1857 he showed a working model of his improvement to Gilbert M. Milligan, secretary of the Central Railroad Company of New Jersey.[5] Samuel L. Moore, master mechanic of that railroad, also inspected the model. Both were so impressed that it was decided to fit the device to the locomotive *Lebanon*, which at the time was undergoing repairs at the road's Elizabeth Port, New Jersey, shops.[6] Although the engine was less than 18 months old, her tires were badly worn and she oscillated at high speed.

Early in June of that year a series of tests were held with the *Lebanon*. Moore said of these trials: [7]

> After the said invention of Bissell had been applied the engine was run out onto a curve which she turned apparently with nearly as much facility as she would travel on a straight line, and the forward part of the engine rose on the inclines as the truck entered the curve and remained fixed while running around said curve and then resumed its former position on entering a straight track, and the trial was pronounced by all who saw it as most satisfactory, even by those who before pronounced that it would be a failure.
>
> At a subsequent trial under a full pressure of steam and a velocity of about thirty miles per hour the entering and leaving the curve was equally satisfactory, the same being accurately observed by a man located on the cow catcher. . . . The engine was run at its greatest possible velocity at least forty miles per hour on a straight track and the previous "shaking of the head" [oscillation] was found to be entirely overcome, and the engine run as steadily as a car would have done . . .
>
> At one of the trials a bar of iron ¾ x 4 inches was spiked down across one of the *rails diagonally of the track*, . . . and the employees of the company took the precaution to fill in around the track to facilitate getting the engine back again, supposing she must jump off; however on passing over slowly she still kept the track and the speed was increased until she passed over said bar . . . while under a considerable speed.

Messers. Moore and Milligan heartily endorsed the truck as a complete success. Milligan predicted that [8] "the time is not far distant when locomotives will be considered incomplete and comparatively unsafe without this improvement particularly on roads which have many curves."

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[5] From a sworn statement of G. M. Milligan dated July 2, 1857. This along with letters, petitions, receipts, and other such material quoted in this discussion are from the Patent Office papers housed in the National Archives, Washington, D.C. (hereafter referred to as Patent Office papers).

[6] The *Lebanon* was a 4–4–0, used in freight service, that had been built by the New Jersey Locomotive and Machine Company in December 1855.

[7] Letter dated July 2, 1857, from S. L. Moore (Patent Office papers).

[8] Statement cited in footnote 5.

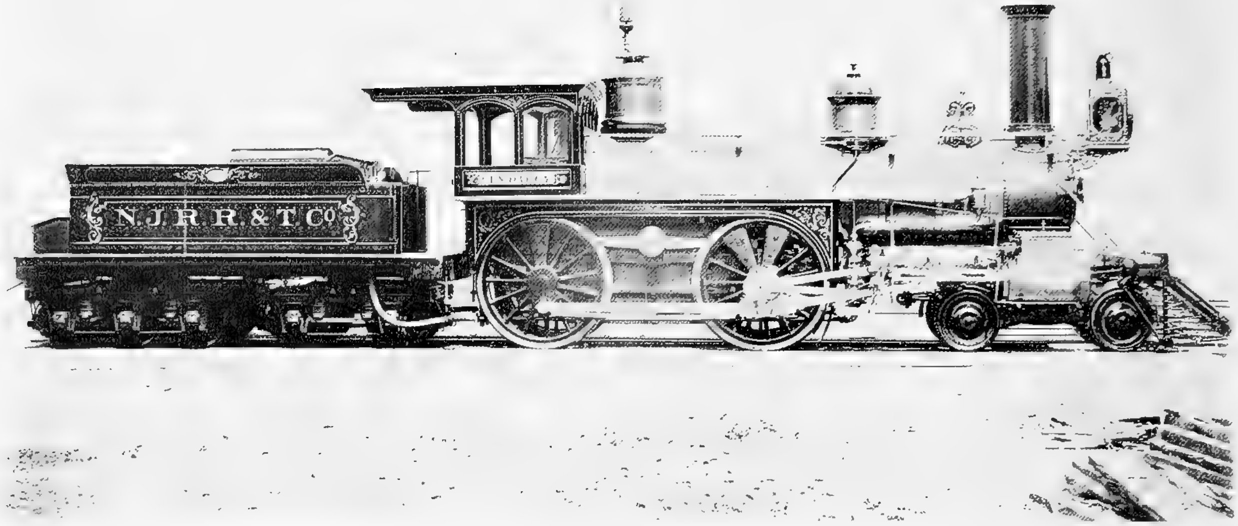

Figure 6.—The New Jersey Railroad and Transportation Company *No. 12*, built in 1868, was equipped with the radius bar truck, a modification by William S. Hudson of the original Bissell truck. The *General Darcy* and several other engines built at the Jersey City shops of the road, under the direction of John Headden, were fitted with the Hudson truck. Note that the radius bar is connected to the truck frame just behind the rear leading wheels. (*Smithsonian photo 46806-l*)

U.S. Patent Commissioner Charles Mason was so impressed by the evidence of the New Jersey trials, reinforced by the arguments of Bissell's attorneys, that he agreed to grant a United States patent.[9] It was issued as no. 17913 on August 4, 1857, and reissued October 18, 1864 as no. 1794. British patent 1273 had been issued earlier (May 5, 1857), and patents were also secured in France, Belgium, Austria, and Russia.

The Rogers Locomotive Works in 1858 was one of the earliest builders to apply the improved truck. By 1860 they had fitted many of their engines with it and were endorsing the device to prospective customers.

In the same year the *American Railway Review* noted that the truck was in extensive use, stating: [10]

> . . . the advantages of the arrangement are so obvious and its results so well established by practice in this country and Europe that a treatise on its principles will hardly be needed.
>
> It is no longer an experiment; and the earlier it is applied to all engines, the better the running and repair accounts will look.

The success of Bissell's invention prompted others to perfect safety trucks for locomotives. Alba F. Smith came forward in 1862 with the simple substitution of swing links (fig. 4) for the incline planes.[11] A swing-bolster truck had been developed 20 years earlier for use on railroad cars,[12] and while Smith recognized this in his patent, he based his claim on the specific application of the idea to locomotive trucks. That the swing links succeeded the incline planes as a centering device was mainly because they

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[9] Letter dated July 11, 1857, Charles Mason to Levi Bissell (Patent Office papers).

[10] *American Railway Review*, February 9, 1860, vol. 2, p. 71.

[11] U.S. patent 34377, February 11, 1862.

[12] Davenport & Bridges, car builders of Cambridge, Massachusetts, in 1841, obtained a U.S. patent for a swing-beam truck.

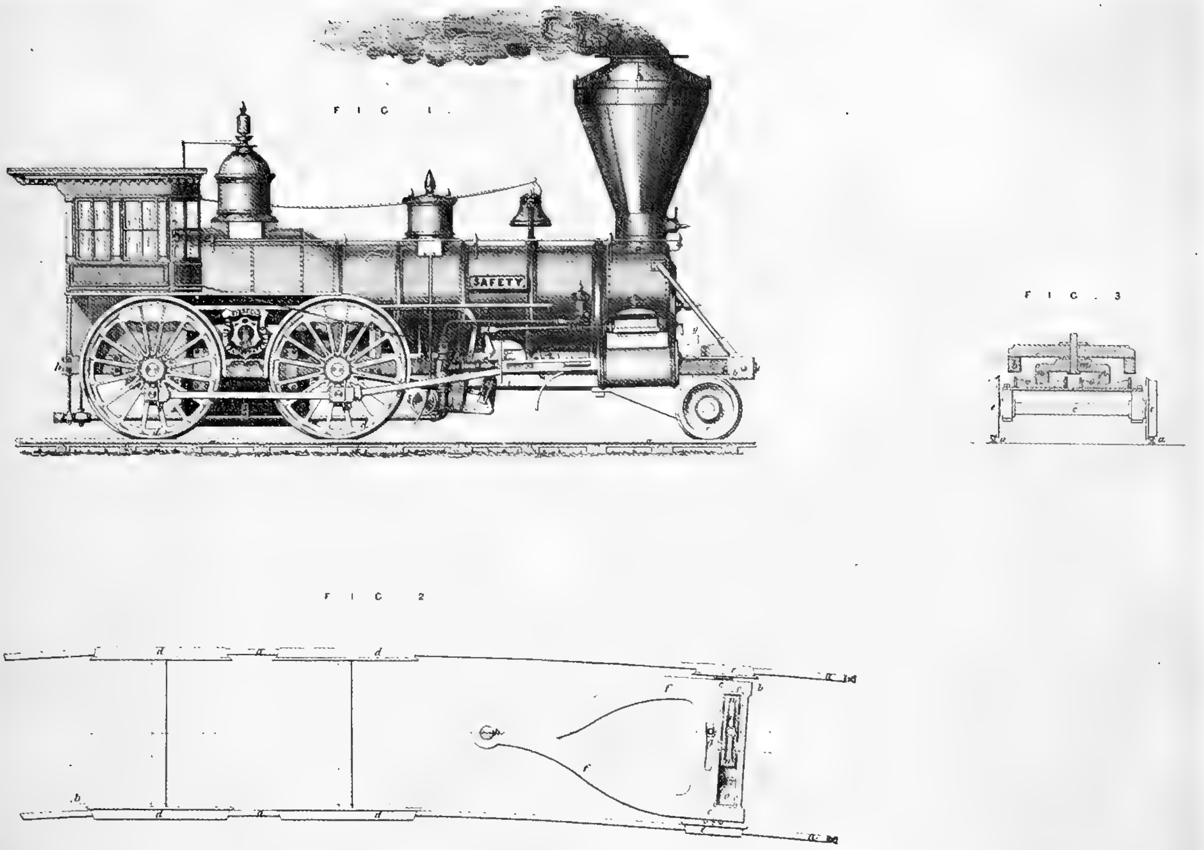

FIGURE 7.—Bissell's 2-wheel truck of 1858 as shown by the drawing for British patent 2751, issued December 1, 1858.

were cheaper and simpler to construct, and not, as has been claimed, that the V's wore out quickly.[13]

Smith's swing-bolster truck, with the heart pendant link, a later refinement, became the dominating form of centering devices and was used well into this century. It was to be superseded in more recent years by the constant resistance and gear roller centering devices which, like Bissell's invention, depended on the double incline plane principle.

The British-born engineer William S. Hudson, superintendent of the Rogers Works and an early proponent of the Bissell truck, in 1864 obtained a patent[14] for improving Bissell's safety truck. Hudson contended that since the Bissell arrangement had a fixed pivot point it could traverse only one given radius accurately. He proposed to replace the fixed pivot with a radius bar (see fig. 5) one end of which was attached to the locomotive under the smoke-box and the other to rear of the truck frame, at the same point of attachment as in the Bissell plan. Thus, according to Hudson, the pivot point could move laterally so that the truck might more easily accommodate itself to a curve of any radius. He further claimed that a better distribution of weight was effected and that the use of the radius bar relieved the center bearing casting of much of the strain of propelling the truck.

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[13] Gustavus Weissenborn in his authoritative *American Locomotive Engineering and Railway Mechanism* (New York, 1871, p. 131), stated that when in use the V's soon acquired a polished surface which seemed to defy wear.

[14] U.S. patent 42662, May 10, 1864.

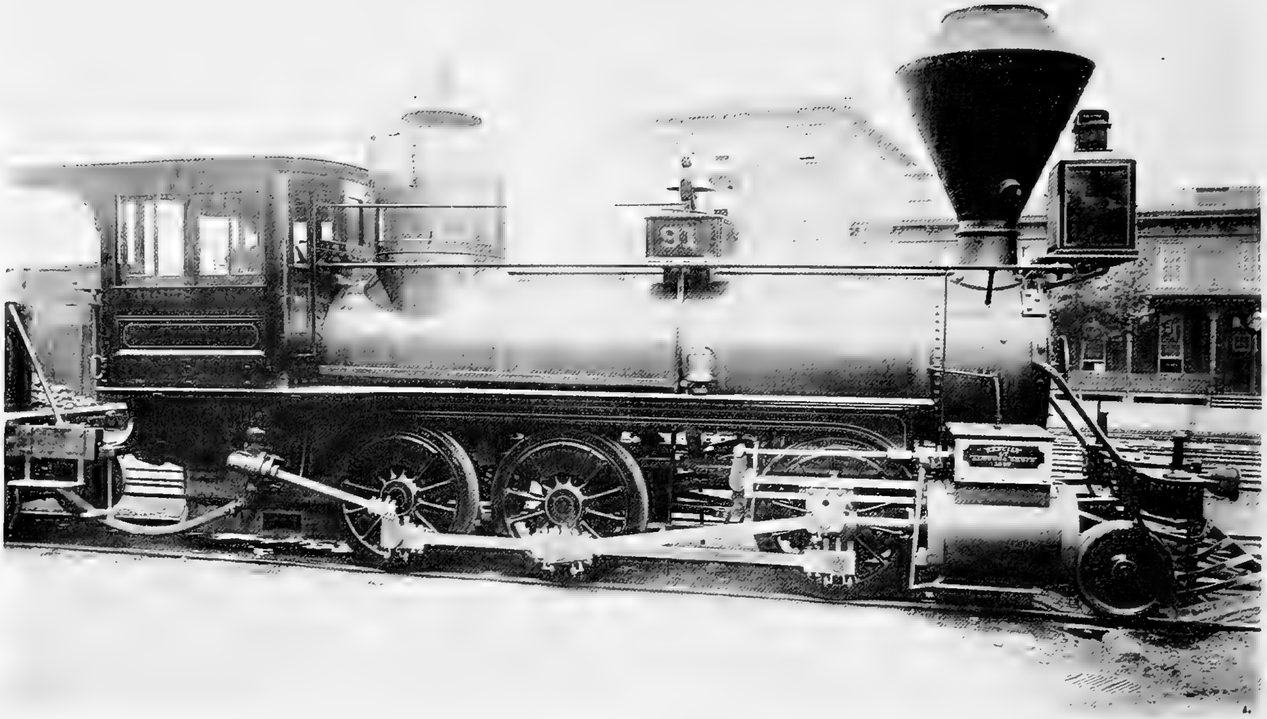

FIGURE 8.—A 2-wheel Bissell truck installed on the Pennsylvania Railroad's *No. 91*. This engine originally an 0–8–0 Winans Camel built in February 1854, was rebuilt by John P. Laird in 1867, at which time the Bissell truck was added. Note that Hudson equalizing lever was not used. (*Smithsonian photo 46806–k*)

The British journal *Engineering*, in an article otherwise friendly to the inventor, expressed some skepticism as to the real merit of Hudson's invention.[15]

> If Mr. Hudson's truck, . . . be examined, it will be seen that the radius link serves no other purpose than that of carrying the truck along with the engine, and this could obviously be equally done by the pivot or central pin of the truck itself.

It is probable that few builders other than Rogers made use of the Hudson radial link.[16] One of these was John Headden, whose *General Darcy*, shown in figure 6, was fitted with the Hudson truck.

Thus, by 1860 there had been perfected and adopted a successful 4-wheel safety truck for 4–4–0's and 4–6–0's used in general mixed and passenger service. But as the decade advanced, the need grew for heavy freight engines that could be safely run at speed. Without a pilot truck, the leading driving axle of the freight engine was generally overloaded. While the application of a 4-wheel truck reduced this front-end overload and permitted faster running it materially reduced the traction of the drivers by bearing too great a portion of the total weight. This loss of traction was of course highly undesirable and generally disqualified the use of 4-wheel trucks for freight engines. What was needed was a truck which would guide the 0–6–0's and 0–8–0's around curves and yet leave the greater portion of the weight on the drivers. The 2-wheel, or pony, truck met these requirements.[17]

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[15] *Engineering*, July 12, 1867, vol. 4, p. 29.

[16] John Headden, master mechanic of the New Jersey Railroad and Transportation Company, built at the road's Jersey City shops several locomotives equipped with Hudson's variety of the Bissell truck. Headden, upon the death of Hudson, succeeded him in 1881 as superintendent of the Roger Works.

[17] It is believed that Harrison, Winans and Eastwick made one of the first uses of a 2-wheel radial truck on a 2–6–0 built at the Alexandrovsky Arsenal, St. Petersburg, in 1844–46. The success or exact particulars of these machines is unknown. See John Jahn, *Die Dampflokomotive in Entwicklungsgeschichtlicher Darstellung Ihres Gesamtaufbaues*, Berlin, 1924, p. 239; Richard E.

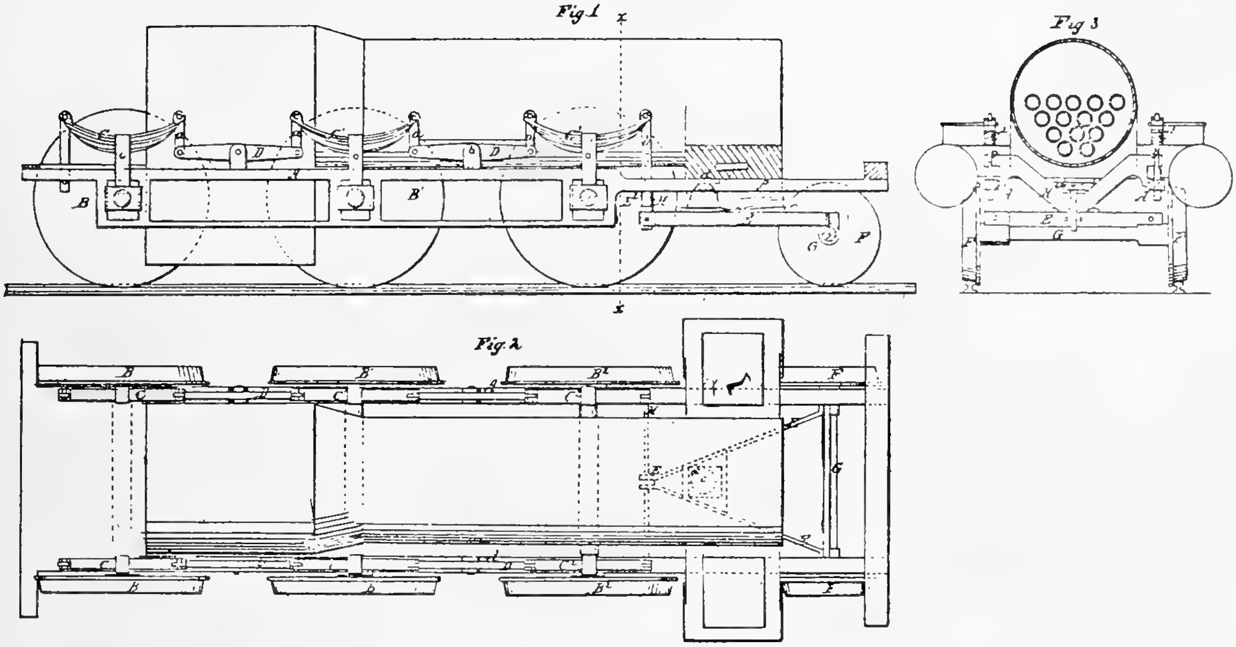

Figure 9.—Running gear and truck designed by John L. Whetstone, as shown in the drawing for U.S. patent 27850, issued April 10, 1860.

Levi Bissell produced the basic patent for such a truck in 1857. Zerah Colburn in September of that year had suggested to Bissell that he develop a 2-wheel truck. Such a device, he believed, would be well received in Britain.[18] He was quite correct, as will shortly be seen.

In nearly every respect Bissell's 2-wheel truck (see fig. 7) followed the idea of the original patent for the 4-wheel truck, which he claimed as the basis for the present invention. The pintle was located behind the truck axle, near the front driving-wheel axle, and the weight was carried by incline planes that also served as the centering device.

A study of the patent drawing in figure 7 reveals several interesting points. Note that the V's, and thus the point of bearing, are slightly in front of the center line of the truck axle. It was suggested in the patent specification that the V's might be placed to the front, rear, or directly over the axle, but in most actual applications they were placed directly over the axle. Note also that the locomotive shown on the figure is obviously a standard high-wheel American type which has suffered the rather awkward substitution of a pony truck for its regular 4-wheel arrangement. It is probable that few if any American types were so rebuilt.

Bissell was granted U.S. patent 21936 on November 2, 1858. British patent 2751 was issued for the same device on December 1, 1858. A few months later, in the summer of 1859, service tests of Bissell's new truck began in England.

First known use of the truck was on the British Eastern Counties Railway *No. 248*, a rigid-frame 2–4–0 built by Kitson in 1855. The leading wheels of the engine, as originally constructed, were attached to the frame in the same manner as the drivers and thus had

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Peunoyer, "Messrs. Harrison, Winans & Eastwick, St. Petersburg, Russia," *Railway and Locomotive Historical Society Bulletin* no. 47, September 1938, p. 46; and Joseph Harrison, Jr., *The Locomotive Engine, and Philadelphia's Share in its Early Improvements*, Philadelphia, 1872, p. 52.

[18] Zerah Colburn, *Locomotive Engineering and the Mechanism of Railways*, . . . , London, 1871, p. 99. Zerah Colburn (1832–1870) was one of the best informed and most vocal authorities on 19th-century American locomotive construction. He not only designed advanced machines while working at the New Jersey Locomotive Works but also advocated many reforms in locomotive design. He published the *Railroad Advocate* in New York City for several years. In 1858 he became editor of *The Engineer* and in 1866 founded the technical journal *Engineering*.

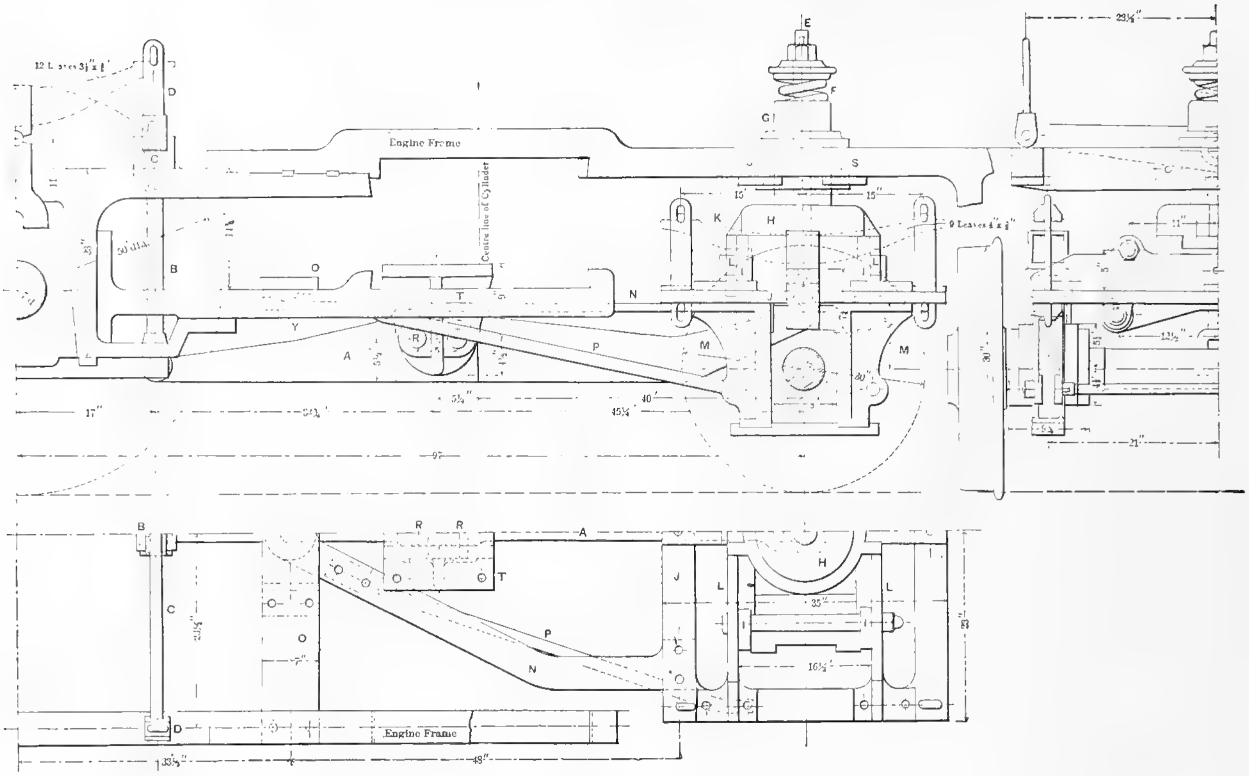

Figure 10.—The Hudson-Bissell truck permitted the introduction of Mogul and Consolidation type freight locomotives. This drawing shows a typical installation for a Consolidation of the 1880's. Item A is the equalizing lever which connects the truck to the springs of the front driving wheels. From figures 891–3 in J. G. A. Meyer, *Modern Locomotive Construction*, New York, John Wiley, 1904, p. 543.

no lateral freedom. For the test the front pedestals, which held the journal boxes of the leading wheels, were cut off and a Bissell pony truck was substituted. About a year later Alexander L. Holley reported on the success of the test.[19] The 248 had operated 17,500 miles, at speeds up to 50 m.p.h., safely and satisfactorily. The engine not only rode more steadily but showed a remarkable reduction in flange wear. The road was so pleased that by 1866 they had equipped 21 locomotives with Bissell trucks.[20] Several other British lines followed the example of the Eastern Counties Railway.

At first Bissell's 2-wheel truck received wider application in Europe than in this country, because most American roads, despite the interest in developing heavier freight locomotives, continued to depend upon the 4–4–0 as a dual-purpose machine. It was not until after 1870, when Mogul and Consolidation types appeared in greater numbers, that the 2-wheel truck became common in the United States.

The first use, known to the writer, of the Bissell pony in this country occurred in November or December of 1859 on the Memphis and Charleston Railroad. D. H. Feger, master mechanic of the railroad reported, eight months later, that since the locomotive had been fitted with the Bissell truck "she has never left the rail and previous to her having this truck she was off the rail almost daily." [21] In

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[19] *American Railway Review*, June 8, 1860, vol. 2, p. 392. Holley was a well known authority on locomotive engineering and the author of several books on the subject.

[20] *Engineering* May 11, 1866, vol. 1, p. 313. By this time (1866), the Eastern Counties Railway had become part of the Great Eastern system.

[21] *American Railway Review* July 26, 1860, vol. 2, p. 38.

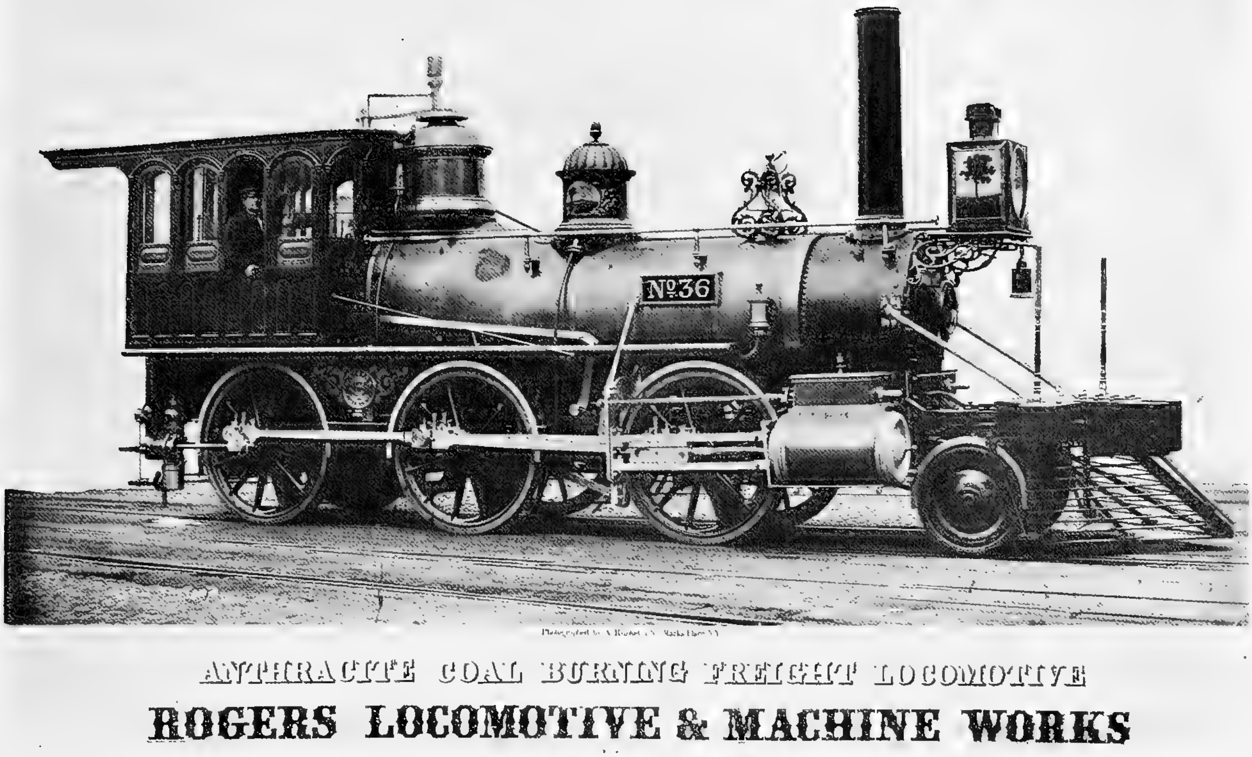

ANTHRACITE COAL BURNING FREIGHT LOCOMOTIVE
ROGERS LOCOMOTIVE & MACHINE WORKS
Nº36

FIGURE 11.—The New Jersey Railroad and Transportation Company *No. 36*, built by the Rogers Locomotive and Machine Works in 1863, was one of the first locomotives to be equipped by this firm with a 2-wheel Bissell truck. (*Smithsonian photo 46806–m*)

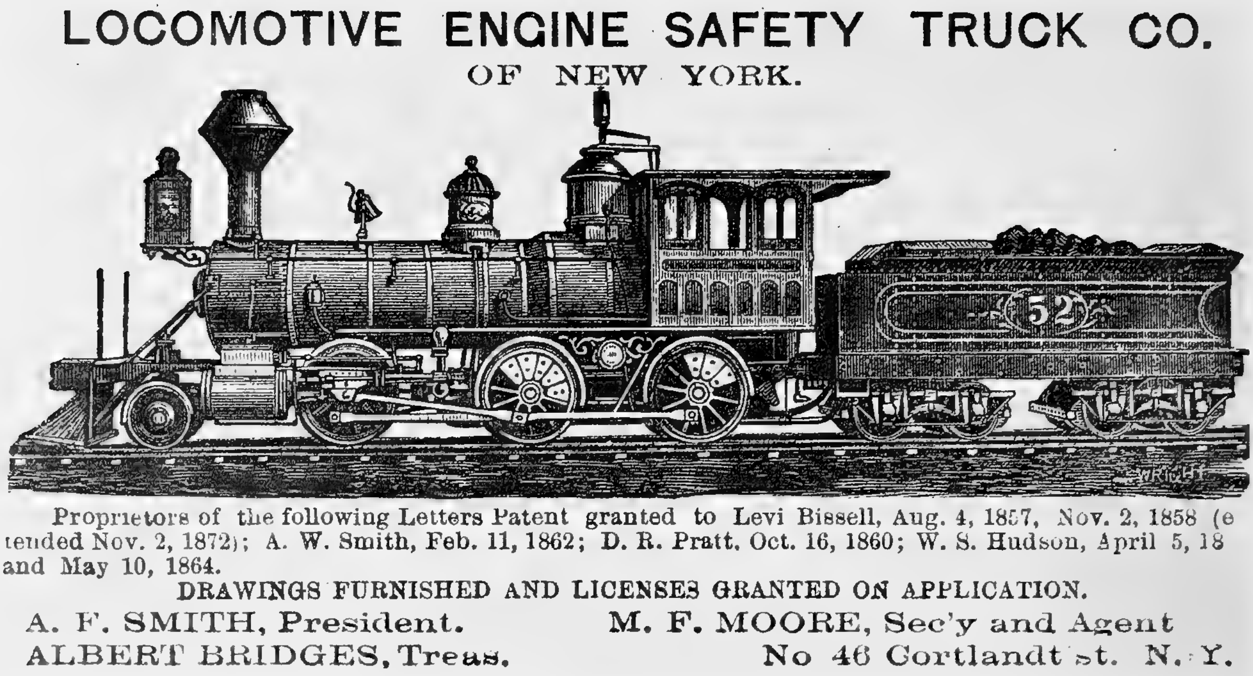
the same report Feger stated that he planned to reequip another locomotive in the same manner.

The Baldwin Locomotive Works in December 1860 built a group of rather awkward looking 2–6–0's for the Louisville and Nashville Railroad. Equipped with Bissell trucks, these were undoubtedly among the very first new locomotives to be so built. The first consolidation type was built by Baldwin in 1866; it was equipped with a 2-wheel Bissell safety truck.

The Rogers Locomotive and Machine Works and the New Jersey Locomotive and Machine Works, both of Paterson, New Jersey, in the early 1860's began building Moguls; these are known to have had Bissell trucks. Other builders followed their example, so that by the 1870's 2-wheel trucks had become relatively common.

It should be noted that the 2-wheel truck was not an absolute success until it was equalized with the front driving axle. This arrangement was perfected in 1864 by William S. Hudson, but before describing his invention it will be helpful to discuss several earlier attempts to equalize pony trucks with the drivers.

In 1857 John P. Laird, then master mechanic of the Marietta and Cincinnati Railroad, rebuilt an old Niles 8-wheeler into a curious 2–6–0 on which only the two rear driving wheels were coupled. The front driver was driven by a chain and sprocket, and the pilot wheels were equalized with the front driving axle. The success or failure of the arrangement has not been definitely determined, but whatever the outcome, Laird continued his experiments when he became superintendent of motive power for the Pennsylvania Railroad in 1862. He abandoned the chain drive for a more conventional arrangement of side rods, but the truck and his plan of equalization were much the same as that tried earlier. Laird used two equalizing levers, attached at one end to the front spring hangers and at the other to the truck,



LOCOMOTIVE ENGINE SAFETY TRUCK CO.
OF NEW YORK.

Proprietors of the following Letters Patent granted to Levi Bissell, Aug. 4, 1857, Nov. 2, 1858 (e tended Nov. 2, 1872); A. W. Smith, Feb. 11, 1862; D. R. Pratt, Oct. 16, 1860; W. S. Hudson, April 5, 18 and May 10, 1864.

DRAWINGS FURNISHED AND LICENSES GRANTED ON APPLICATION.

A. F. SMITH, President.
ALBERT BRIDGES, Treas.

M. F. MOORE, Sec'y and Agent
No 46 Cortlandt St. N. Y.

Figure 12.—Notice of the Locomotive Safety Truck Company listing the patents held by it. From *Railroad Gazette*, March 3, 1876.

but in a way to allow the truck to swing horizontally. The fulcrum for each lever was mounted on the underside of the front frame rail. A number of old 8-wheel Baldwin flexible-beam engines and several Winan's Camels were rebuilt in this way. One of these is shown in figure 8. Laird, however, eventually became dissatisfied with his arrangement and re-equipped the engines with Bissell trucks.

John L. Whetstone on April 10, 1860, obtained U.S. patent 27850, which strikingly anticipated the plan Hudson was to develop four years later.[22] Whetstone did not use a Bissell truck and was in fact more concerned in relieving the excess weight, often a 50% overload, from the front axle of 0–6–0 locomotives and in distributing a portion of that weight to a pony truck. His arrangement may be readily understood from the patent drawing in figure 9. Probably the best features of the design was the transverse H-beam that connected the spring hangers to the truck frame, which in this case also served as the equalizing lever (note that the ball "C" acts as the fulcrum).

Hudson made use of this same device but in a more practical manner. He found that while the Bissell pony truck could satisfactorily adjust itself laterally and could lead the locomotive around curves, it could not handle the varying loads imposed upon it by the rough trackage typical of American railroads. At one moment an undue amount of weight would fall upon the truck because the drivers were over a depression in the roadbed. This condition overloaded the truck's springs and also resulted in a momentary loss of adhesion, causing the drivers to slip. Conversely, when the truck hit a depression too much weight was thrust upon the driving wheels, and broken springs or other damage might result.

Hudson's ingenious remedy to this problem was simple and straightforward (see fig. 10). A heavy equalizing lever that connected the truck to the springs of the front driving wheels was placed on the longitudinal centerline of the locomotive, with the fulcrum under the cylinder saddle. Thus the truck and front driver reacted together to all the inequalities and shocks offered by the roadbed.

---

[22] Whetstone was chief designer for Niles & Co., a Cincinnati locomotive builder. His invention apparently did not receive a test, since the company closed shortly before the patent was granted. No other builder seemed interested.

In October of 1863, under Hudson's direction, two 2–6–0's equipped with Bissell trucks were built at the Rogers Works for the New Jersey Railroad and Transportation Company. Probably some fault was found with the suspension of these machines, numbered 35 and 36, for the next 2–6–0, numbered 39, built for the New Jersey road was equipped with Hudson's equalizer. This engine, completed in January 1865, is believed to be the first Mogul so equipped.[23]

The Locomotive Engine Safety Truck Company (see fig. 11) was formed in the 1870's, with A. F. Smith as president, to exploit the patents of Bissell, Smith, and Hudson. For several years notices appeared in the columns of the *Railroad Gazette* reporting suits by the Company against various railroads and locomotive builders for unauthorized use of their patents. The *Gazette* of May 29, 1875, carries a protest of the Company against the Manchester Locomotive Works for unlicensed use of Smith's patent of 1862. In the issue of August 28, 1875, is reported the Company's success in establishing the validity of Smith's patent:

> Some important settlements for the use of the patent have lately been made with the company, one of them being with the Western Railroad Association, whose headquarters are at Chicago, which includes the principal western roads. Through this the company receives its royalty on several hundred locomotives.

IN SUMMARY

It can be stated that Hudson's modification of the Bissell truck is of unquestioned importance, for without the introduction of the equalizer it is doubtful if the 2-wheel pony truck would have been a complete success on American railroads. Bissell's 4-wheel truck was extensively employed, but it did not enjoy the universal popularity of the 2-wheel truck, and in the 1880's was eclipsed by other forms of 4-wheel safety trucks. The Hudson-Bissell pony truck, however, survived in its basic form to recent times, when, in the late 1940's and early 1950's, the last steam locomotives were constructed in this country.

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[23] Paul T. Warner, "Mogul Type Locomotives," *Railway and Locomotive Historical Society Bulletin* no. 100, April 1959.

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THE MIGRATIONS OF AN AMERICAN BOAT TYPE

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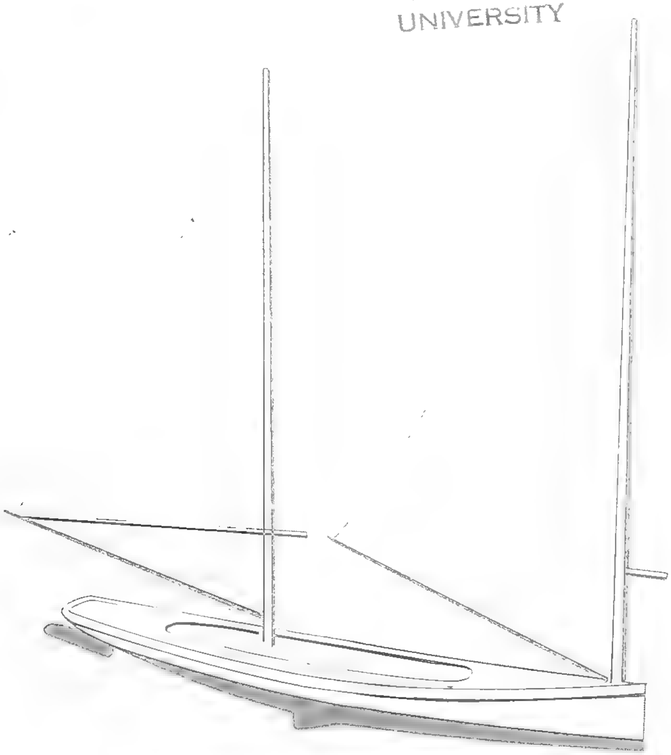

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THE MIGRATIONS OF AN AMERICAN BOAT TYPE

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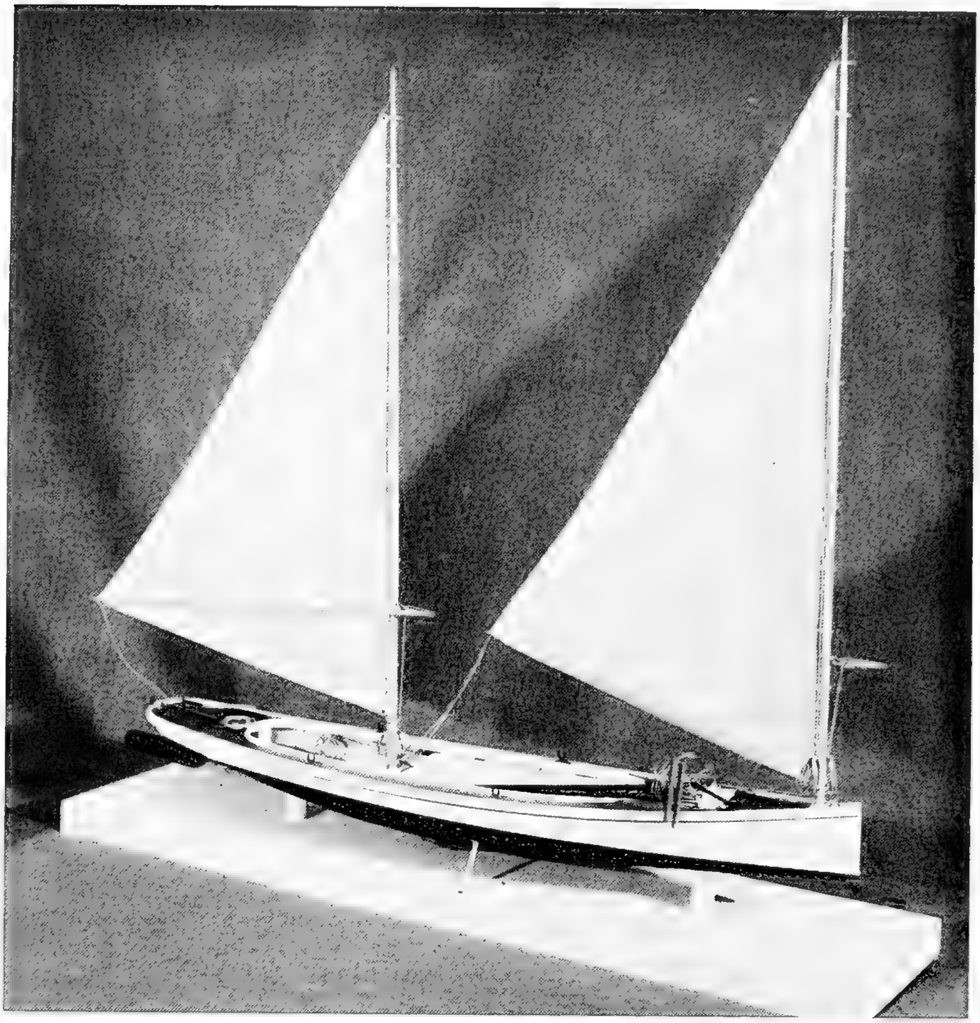

FIGURE 1.—Scale model of a New Haven sharpie of 1885, complete with tongs.
(*USNM 318023; Smithsonian photo 47033–C.*)

The New Haven sharpie, a flat-bottomed sailing skiff, was originally developed for oyster fishing, about the middle of the last century.

Very economical to build, easy to handle, maneuverable, fast and seaworthy, the type was soon adapted for fishing along the eastern and southeastern coasts of the United States and in other areas. Later, because of its speed, the sharpie became popular for racing and yachting.

This study of the sharpie type—its origin, development and spread—and the plans and descriptions of various regional types here presented, grew out of research to provide models for the hall of marine transportation in the Smithsonian's new Museum of History and Technology.

THE AUTHOR: *Howard I. Chapelle is curator of transportation in the U.S. National Museum, Smithsonian Institution.*

FOR A COMMERCIAL BOAT TO GAIN widespread popularity and use, it must be suited to a variety of weather and water conditions and must have some very marked economic advantages over any other boats that might be used in the same occupation. Although there were more than 200 distinct types of small sailing craft employed in North American fisheries and in along-shore occupations during the last 60 years of the 19th century, only rarely was one of these boat types found to be so well suited to a particular occupation that its use spread to areas at any great distance from the original locale.

Those craft that were "production-built," generally rowing boats, were sold along the coast or inland for a variety of uses, of course. The New England dory, the seine boat, the Connecticut drag boat, and the yawl were such production-built boats.

In general, flat-bottomed rowing and sailing craft were the most widely used of the North American boat types. The flat-bottomed hull appeared in two basic forms: the scow, or punt, and the "flatiron," or sharp-bowed skiff. Most scows were box-shaped with raking or curved ends in profile; punts had their sides curved fore and aft in plan and usually had curved ends in profile. The rigs on scows varied with the size of the boat. A small scow might have a one-mast or two-mast spritsail rig, or might be gaff rigged; a large scow might be sloop rigged or schooner rigged. Flatiron skiffs were sharp-bowed, usually with square, raked transom stern, and their rigs varied according to their size and to suit the occupation in which they were employed. Many were sloop rigged with gaff mainsails; others were two-mast, two-sail boats, usually with leg-of-mutton sails, although occasionally some other kind of sail was used. If a skiff had a two-mast rig, it was commonly called a "sharpie"; a sloop-rigged skiff often was known as a "flattie." Both scows and flat-bottomed skiffs existed in Colonial times, and both probably originated in Europe. Their simple design permitted construction with relatively little waste of materials and labor.

Owing to the extreme simplicity of the majority of scow types, it is usually impossible to determine whether scows used in different areas were directly related in design and construction. Occasionally, however, a definite relationship between scow types may be assumed because of certain marked similarities in fitting and construction details. The same occasion for doubt exists with regard to the relationships of sharp-bowed skiffs of different areas, with one exception—the large, flat-bottomed sailing skiff known as the "sharpie.'

The New Haven Sharpie

The sharpie was so distinctive in form, proportion, and appearance that her movements from area to area can be traced with confidence. This boat type was particularly well suited to oyster fishing, and during the last four decades of the 19th century its use spread along the Atlantic coast of North America as new oyster fisheries and markets opened. The refinements that distinguished the sharpie from other flat-bottomed skiffs first appeared in some boats that were built at New Haven, Connecticut, in the late 1840's. These craft were built to be used in the then-important New Haven oyster fishery that was carried on, for the most part, by tonging in shallow water.

The claims for the "invention" of a boat type are usually without the support of contemporary testimony. In the case of the New Haven sharpie two claims were made, both of which appeared in the sporting magazine *Forest and Stream*. The first of these claims, undated, attributed the invention of the New Haven sharpie to a boat carpenter named Taylor, a native of Vermont.[1] In the January 30, 1879, issue of *Forest and Stream* there appeared a letter from Mr. M. Goodsell stating that the boat built by Taylor, which was named *Trotter*, was not the first sharpie.[2] Mr. Goodsell claimed that he and his brother had built the first New Haven sharpie in 1848 and that, because of her speed, she had been named *Telegraph*. The Goodsell claim was never contested in *Forest and Stream*, and it is reasonable to suppose, in the circumstances, that had there been any question concerning the authenticity of this claim it would have been challenged.

No contemporary description of these early New Haven sharpies seems to be available. However, judging by records made in the 1870's, we may assume that the first boats of this type were long, rather narrow, open, flat-bottomed skiffs with a square stern and a centerboard; they were rigged with two masts and two leg-of-mutton sails. Until the appearance of the early sharpies, dugout canoes built of a single white pine log had been used at New Haven for tonging. The pine logs used for these canoes came mostly from inland Connecticut, but they were obtainable also in northern New England and New York. The canoes ranged from 28 to 35 feet in length, 15 to 20 inches in depth, and 3 feet to 3 feet 6 inches in beam. They were built to float on about 3 or 4 inches of water. The bottoms of these canoes were about 3 inches thick, giving a low center of gravity and the power to carry sail in a breeze. The canoes were rigged with one or two pole masts with leg-of-mutton sails stepped in thwarts. A single leeboard was fitted and secured to the hull with a short piece of line made fast to the centerline of the boat. With this arrangement the leeboard could be raised and lowered and also shifted to the lee side on each tack. This took the strain off the sides of the canoe that would have been created by the usual leeboard fitting.[3] Construction of such canoes ceased in the 1870's, but some remained in use into the present century.

The first New Haven sharpies were 28 to 30 feet long—about the same length as most of the log canoes. Although the early sharpie probably resembled the flatiron skiff in her hull shape, she was primarily a sailing boat rather than a rowing or combination rowing-sailing craft. The New Haven sharpie's development[4] was rapid, and by 1880 her ultimate form had been taken as to shape of hull, rig, construction fittings, and size. Some changes were made afterwards, but they were in minor details, such as finish and small fittings.

The New Haven sharpie was built in two sizes for the oyster fishery. One carried 75 to 100 bushels of oysters and was 26 to 28 feet in length; the other carried 150 to 175 bushels and was 35 to 36 feet in length. The smaller sharpie was usually rigged with a single mast and sail, though some small boats were fitted for two sails. The larger boat was always fitted to carry two masts, but by shifting the foremast to a second step more nearly amidships she could be worked with one mast and sail. The New Haven sharpie retained its original proportions. It was long, narrow, and low in freeboard and was fitted with a centerboard. In its development it became half-decked. There was enough fore-and-aft camber in the flat bottom so that, if the boat was not carrying

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[1] *Forest and Stream*, January 23, 1879, vol. 11, no. 25, p. 504.

[2] *Forest and Stream*, January 30, 1879, vol. 11, no. 26, p. 500.

[3] Henry Hall, Special Agent, 10th U.S. Census, *Report on the Shipbuilding Industry of the United States*, Washington, 1880–1885, pp. 29–32.

[4] Howard I. Chapelle, *American Small Sailing Craft*, New York, 1951, pp. 100–133, figs. 38–48.

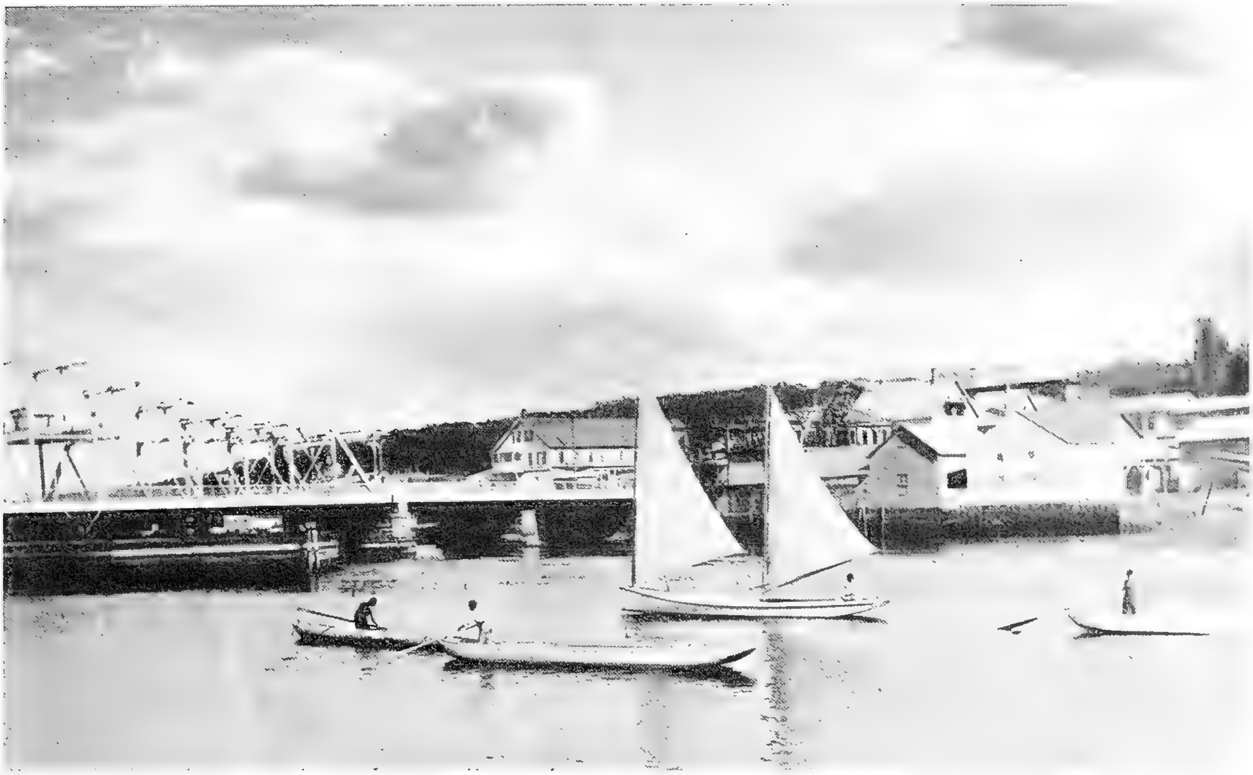

Figure 2.—A New Haven sharpie and dugouts on the Quinnipiac River, New Haven, Connecticut, about the turn of the century.

much weight, the heel of her straight and upright stem was an inch or two above the water. The stern, usually round, was planked with vertical staving that produced a thin counter. The sheer was usually marked and well proportioned. The New Haven sharpie was a handsome and graceful craft, her straight-line sections being hidden to some extent by the flare of her sides and the longitudinal curves of her hull.

The structure of New Haven sharpies was strong and rather heavy, consisting of white pine plank and oak framing. The sides were commonly wide plank. Each side had two or three strakes that were pieced up at the ends to form the sheer. The sides of large sharpies were commonly 1½ inches thick before finishing, while those of the smaller sharpies were 1¼ inches thick. The sharpie's bottom was planked athwartships with planking of the same thickness as the sides and of 6 to 8 inches in width. That part of the bottom that cleared the water, at the bow and under the stern, was often made of tongue-and-groove planking, or else the seams athwartship would be splined. Inside the boat there was a keelson made of three planks, in lamination, standing on edge side by side, sawn to the profile of the bottom, and running about three-fourths to seven-eighths the length of the boat. The middle one of these three planks was omitted at the centerboard case to form a slot. Afore and abaft the slot the keelson members were cross-bolted and spiked. The ends of the keelson were usually extended to the stem and to the stern by flat planks that were scarphed into the bottom of the built-up keelson.

The chines of the sharpie were of oak planks that were of about the same thickness as the side planks and 4 to 7 inches deep when finished. The chine logs were sawn to the profile of the bottom and sprung to the sweep of the sides in plan view. The side frames were mere cleats, 1½ by 3 inches. In the 1880's these cleats were shaped so that the inboard face was 2 inches wide and the outboard face 3 inches wide, but later this shaping was generally omitted.

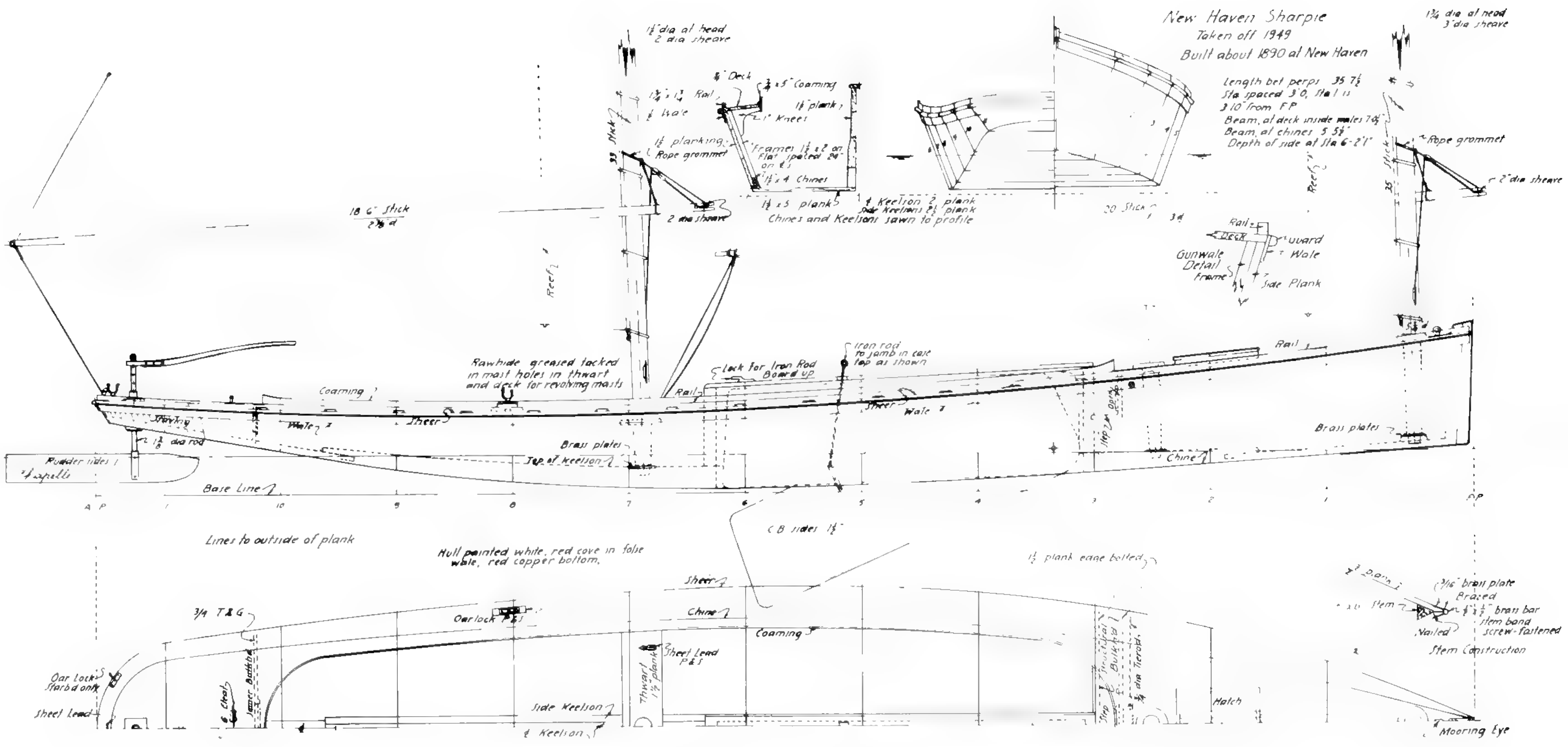
New Haven Sharpie
Taken off 1949
Built about 1890 at New Haven
Length bet perps 35 7½
Sta spaced 3'0, Sta 1 is 3'10" from F.P.
Beam, at deck inside wales 7'4½"
Beam, at chines 5 5½"
Depth of side at Sta 6-2'1"
1¾ dia at head
3" dia sheave
Rope grommet
2" dia sheave
25 Stick
Reef
20 Stick
3d
Rail
Deck
Guard
Wale
Gunwale Detail
Frame
Side Plank
1½" dia at head
2 dia sheave
33 Stick
1¾ x 1¾ Rail
¾ Wale
1½ planking
Rope grommet
2 dia sheave
⅞" Deck
¾ x 5" Coaming
1½" plank
1" Knees
Frames 1½ x 2 on Flat spaced 24" on ℄s
1½ x 4 Chines
1½ x 5 plank
℄ Keelson 2 plank
Side Keelsons 2½ plank
Chines and Keelsons sawn to profile
18' 6" Stick
2⅛ d
Rawhide greased tacked in mast holes in thwart and deck for revolving masts
Lock for Iron Rod
Board up
Iron rod to jamb in case top as shown
Coaming
Rail
Sheer
Wale
Brass plates
Top of Keelson
Chine
Step
Rudder sides 1
Apple
1⅛ dia rod
Base Line
A P
1
10
9
8
7
6
5
4
3
2
1
F.P.
Lines to outside of plank
C B sides 1½
Hull painted white, red cove in false wale, red copper bottom.
1½ plank edge bolted
Sheer
Chine
Coaming
3/4 T & G
Oarlock P & S
Oar Lock Starb'd only
Sheet Lead
6 Cleat
Jumper Bobstay
Side Keelson
℄ Keelson
Thwart 1½ plank
Sheet Lead P & S
Step
Structural Bulkhead
¾ dia Tierod
Hatch
Stem
3/16" brass plate
Brazed
brass bar
Stem band screw-fastened
Nailed
Stem Construction
Mooring Eye

FIGURE 3.—Plan of typical New Haven sharpie showing design and construction characteristics.

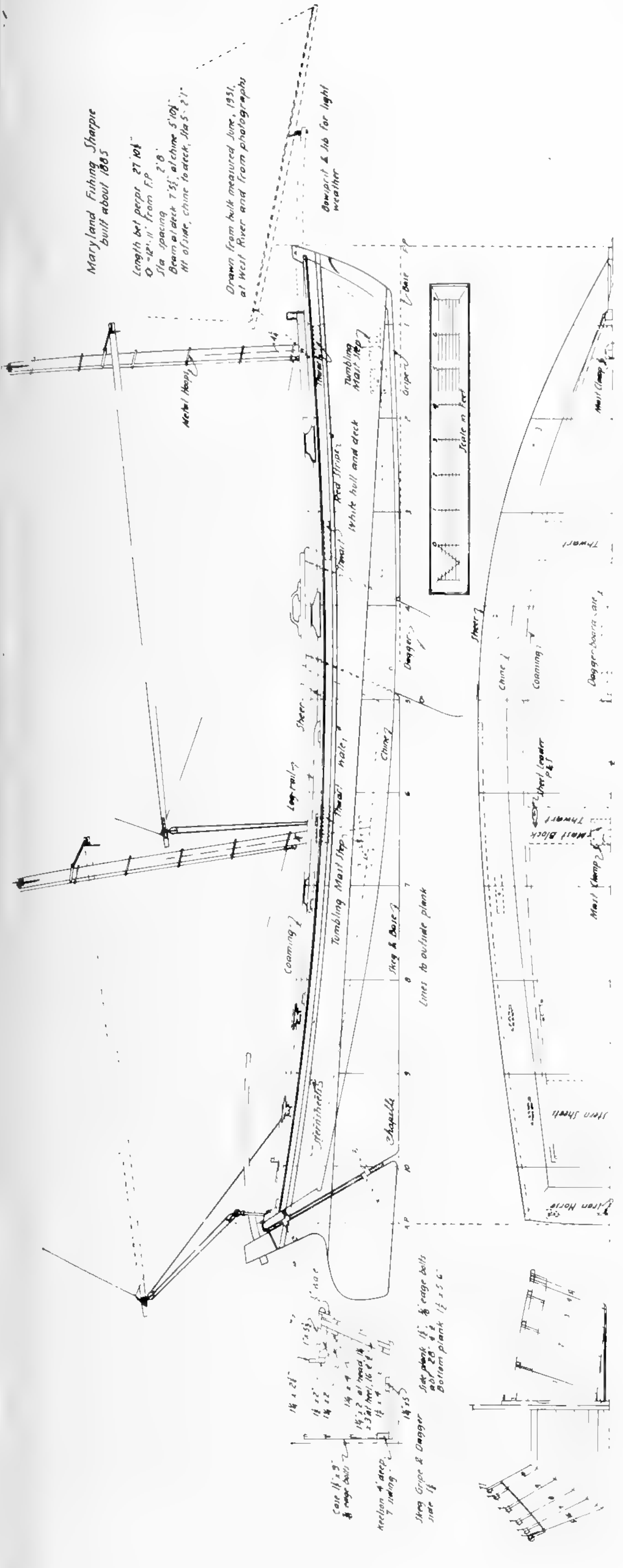
Maryland Fishing Sharpie
built about 1885
Length bet perps 27' 10½"
Drawn from hulk measured June, 1951, at West River and from photographs
Bowsprit & jib for light weather
Metal Hoops
Tumbling Mast Step
Red Stripe
White hull and deck
Sheer
Chine
Coaming
Log rail
Wale
Thwart
Dagger
Gripe
Skeg & Base
Lines to outside plank
Scale in feet
Mast Clamp
Daggerboard case
Sheet leader
Mast Block
Stern Sheets
Stern Horse

FIGURE 4.—Plan of a large Chesapeake Bay sharpie taken from remains of boat.

At the fore end of the sharpie's centerboard case there was an edge-bolted bulkhead of solid white pine, 1¼ or 1½ inches thick, with scuppers cut in the bottom edge. A step about halfway up in this bulkhead gave easy access to the foredeck. In the 1880's that part of the bulkhead above the step was made of vertical staving that curved athwartships, but this feature was later eliminated. In the upper portion of the bulkhead there was often a small rectangular opening for ventilation.

The decking of the sharpie was made of white pine planks 1¼ inches thick and 7 to 10 inches wide. The stem was a triangular-sectioned piece of oak measuring 6 by 9 inches before it was finished. The side plank ran past the forward edge of the stem and was mitered to form a sharp cutwater. The miter was covered by a brass bar stemband to which was brazed two side plates $\frac{3}{32}$ or ¼ inch thick. This stemband, which was tacked to the side plank, usually measured ½ or ⅝ inch by ¾ inch and it turned under the stem, running under the bottom for a foot or two. The band also passed over a stemhead and ran to the deck, having been shaped over the head of the stem by heating and molding over a pattern.

The sharpie's stern was composed of two horizontal oak frames, one at chine and one at sheer; each was about 1½ inches thick. The outer faces of these frames were beveled. The planking around the stern on these frames was vertical staving that had been tapered, hollowed, and shaped to fit the flare of the stern. This vertical staving was usually 1¾ inches thick before it was finished. The raw edges of the deck plank were covered by a false wale ½ to ¾ inch thick and 3 or 4 inches deep, and by an oak guard strip that was half-oval in section and tapered toward the ends. Vertical staving was used to carry the wale around the stern. The guard around the stern was usually of stemmed oak.

The cockpit ran from the bulkhead at the centerboard case to within 4 or 5 feet of the stern, where there was a light joiner bulkhead. A low coaming was fitted around the cockpit and a finger rail ran along the sides of the deck. The boat had a small square hatch in the foredeck and two mast holes, one at the stem and one at the forward bulkhead. A tie rod, ⅜ inch in diameter, passed through the hull athwartships, just forward of the forward bulkhead; the ends of the tie rod were "up-set" or headed over clench rings on the outside of the wale. The hull was usually painted white or gray, and the interior color usually buff or gray.

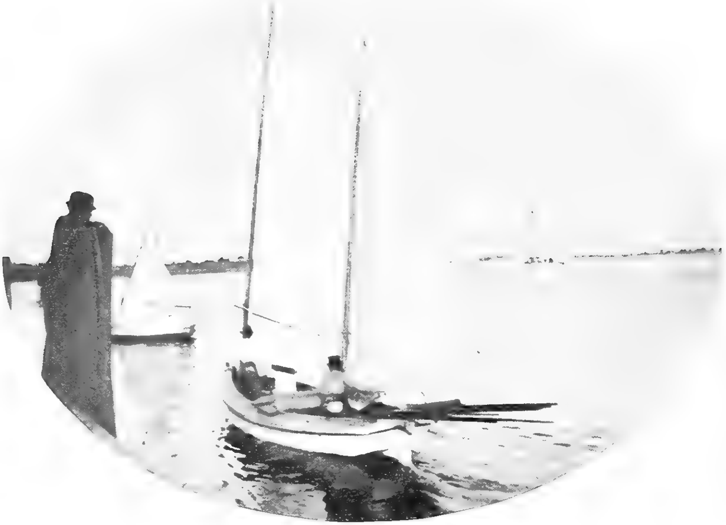

FIGURE 5.—Chesapeake Bay sharpie with daggerboard, about 1885. (Photo courtesy Wirth Munroe.)

The two working masts of a 35- to 36-foot sharpie were made of spruce or white pine and had a diameter of 4½ to 5 inches at deck and 1½ inches at head. Their sail hoists were 28 to 30 feet, and the sail spread was about 65 yards. Instead of booms, sprits were used; these were set up at the heels with tackles to the masts. In most sharpies the sails were hoisted to a single-sheave block at the mast heads and were fitted with wood or metal mast hoops. Because of the use of the sprit and heel tackle, the conventional method of reefing was not possible. The reef bands of the sails were parallel to the masts, and reefing was accomplished by lowing a sail and tying the reef points while rehoisting. The mast revolved in tacking in order to prevent binding of the sprit under the tension of the heel tackle. The tenon at the foot of the mast was round, and to the shoulder of the tenon a brass ring was nailed or screwed. Another brass ring was fastened around the mast step. These rings acted as bearings on which the mast could revolve.

Because there was no standing rigging and the masts revolved, the sheets could be let go when the boat was running downwind, so that the sails would swing forward. In this way the power of the rig could be reduced without the bother of reefing or furling. Sometimes, when the wind was light, tonging was performed while the boat drifted slowly downwind with sails fluttering. The tonger, standing on the side deck or on the stern, could tong or "nip" oysters from a thin bed without having to pole or row the sharpie.

The unstayed masts of the sharpie were flexible and in heavy weather spilled some wind, relieving the heeling moment of the sails to some degree. In summer the 35- to 36-foot boats carried both masts, but in winter, or in squally weather, it was usual to leave the mainmast ashore and step the foremast in the hole just forward of the bulkhead at the centerboard case, thereby balancing the rig in relation to the centerboard. New Haven sharpies usually had excellent balance, and tongers could sail them into a slip, drop the board so that it touched bottom, and, using the large rudders, bring the boats into the wind by spinning them almost within their length. This could be done becaused there was no skeg. When sharpies

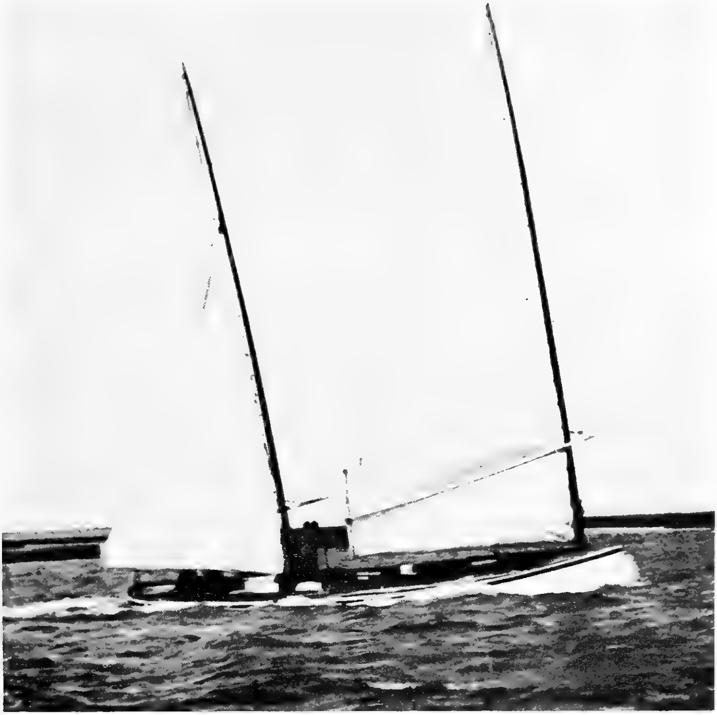

Figure 6.—North Carolina sharpie with one reef in moderate gale, about 1885. (Photo courtesy Wirth Munroe.)

had skegs, as they did in some localities, they were not so sensitive as the New Haven boats. If a sharpie had a skeg, it was possible to use one sail without shifting the mast, but at a great sacrifice in general maneuverability

Kunhardt [5] writing in the mid-1880's, described the New Haven sharpie as being 33 to 35 feet long, about 5 feet 9 inches to 6 feet wide on the bottom, and with a depth of about 36 inches at stem, 24 inches amidships, and 12 inches at stern. The flare increased rapidly from the bow toward amidships, where it became 3½ inches for every 12 inches of depth. The increase of flare was more gradual toward the stern, where the flare was equal to about 4 inches to the foot. According to Kunhardt, a 35-foot sharpie hull weighed 2,000 to 2,500 pounds and carried about 5 short tons in cargo.

The sharpie usually had its round stern carried out quite thin. If the stern was square, the transom was set at a rake of not less than 45°. Although it cost about $15 more than the transom stern, the round stern was favored because tonging from it was easier; also, when the boat was tacked, the round stern did not foul the main sheet and was also less likely to ship a sea than was the square stern. Kunhardt remarks that sharpies lay quiet when anchored by the stern, making the ground tackle easier to handle.

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[5] C. P. Kunhardt, *Small Yachts: Their Design and Construction, Exemplified by the Ruling Types of Modern Practice,* New York, 1886 (rev. ed., 1891, pp. 287–298).

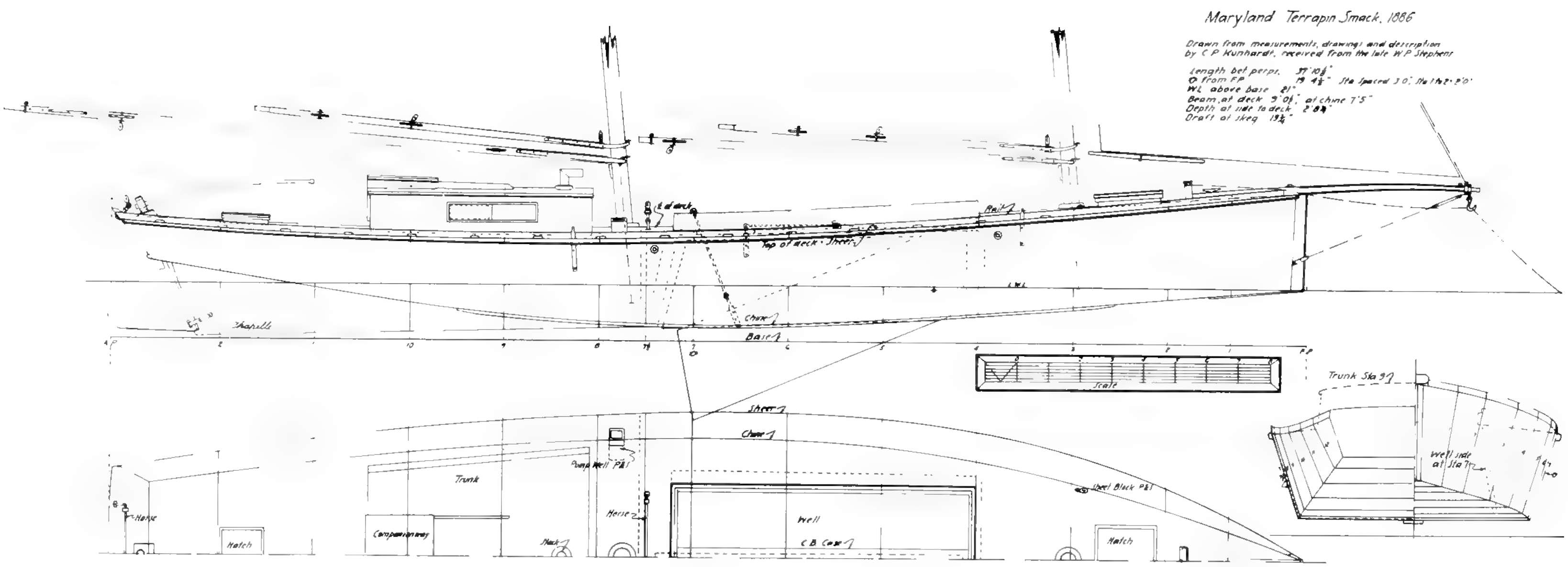
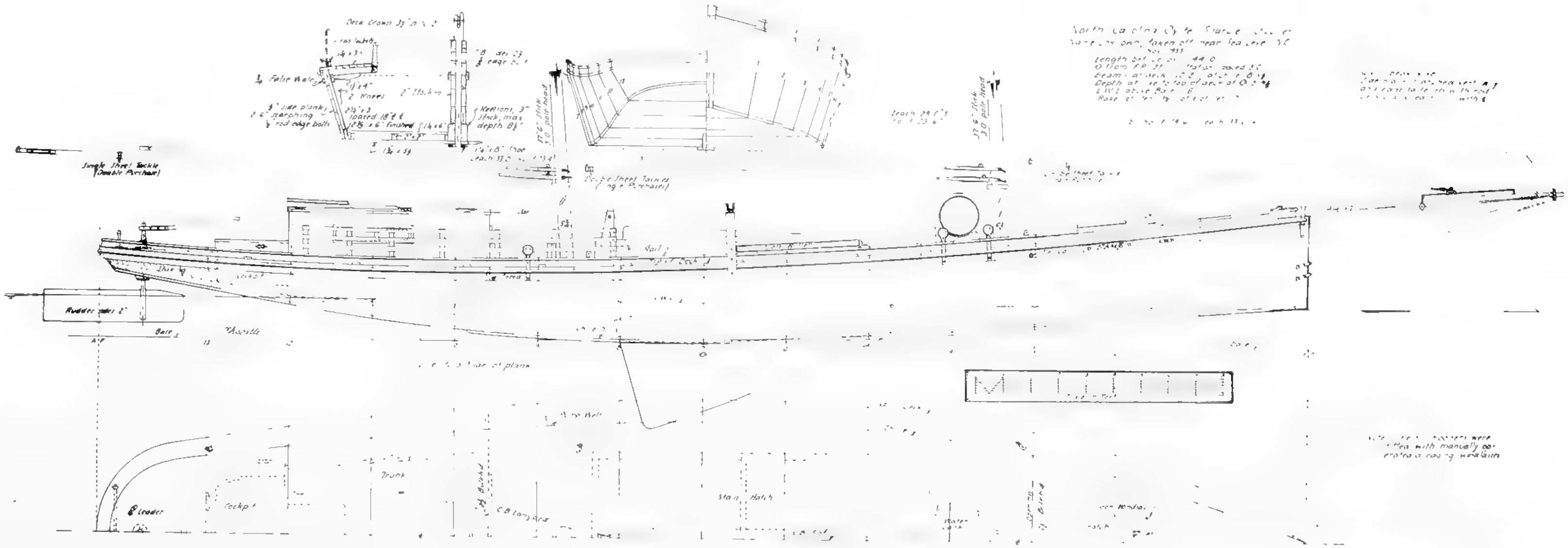

Maryland Terrapin Smack, 1886
Drawn from measurements, drawings and description by C P Kunhardt, received from the late W P Stephens
Length bet. perps. 37'10½"
⊗ from FP 19 4½" Sta spaced 3'0"; Sta 1 to 2 = 2'0"
WL above base 21"
Beam, at deck 9'0½", at chine 7'5"
Depth at side to deck 2'8¾"
Draft at skeg 13¼"
Rail
Top of deck · Sheer
Chine
Base
LWL
Scale
Trunk Sta 9½
Well side at Sta 7½
Sheer
Chine
Trunk
Pump Well P&S
Horse
Horse
Well
C B Case
Companionway
Hatch
Hatch
Mast
Sheet Block P&S

FIGURE 7.—Plan of a Chesapeake Bay terrapin smack based on sketches and dimensions given by C. P. Kunhardt in *Small Yachts: Their Design and Construction, Exemplified by the Ruling Types of Modern Practice*, New York, 1886.

FIGURE 8.—Plan of North Carolina sharpie schooner taken from remains of boat.


Deck Crown 3¾"
False Wale
2 Knees
side plank
Keelsons, 3" thick, max depth 8½"
Shoe
17'6" stick, 3'0" pole head
17'6" stick, 3'0" pole head
Single Sheet Tackle (Double Purchase)
Rudder
Base
Rail
Trunk
C B Lanyard
Hatch
Cockpit
Leader

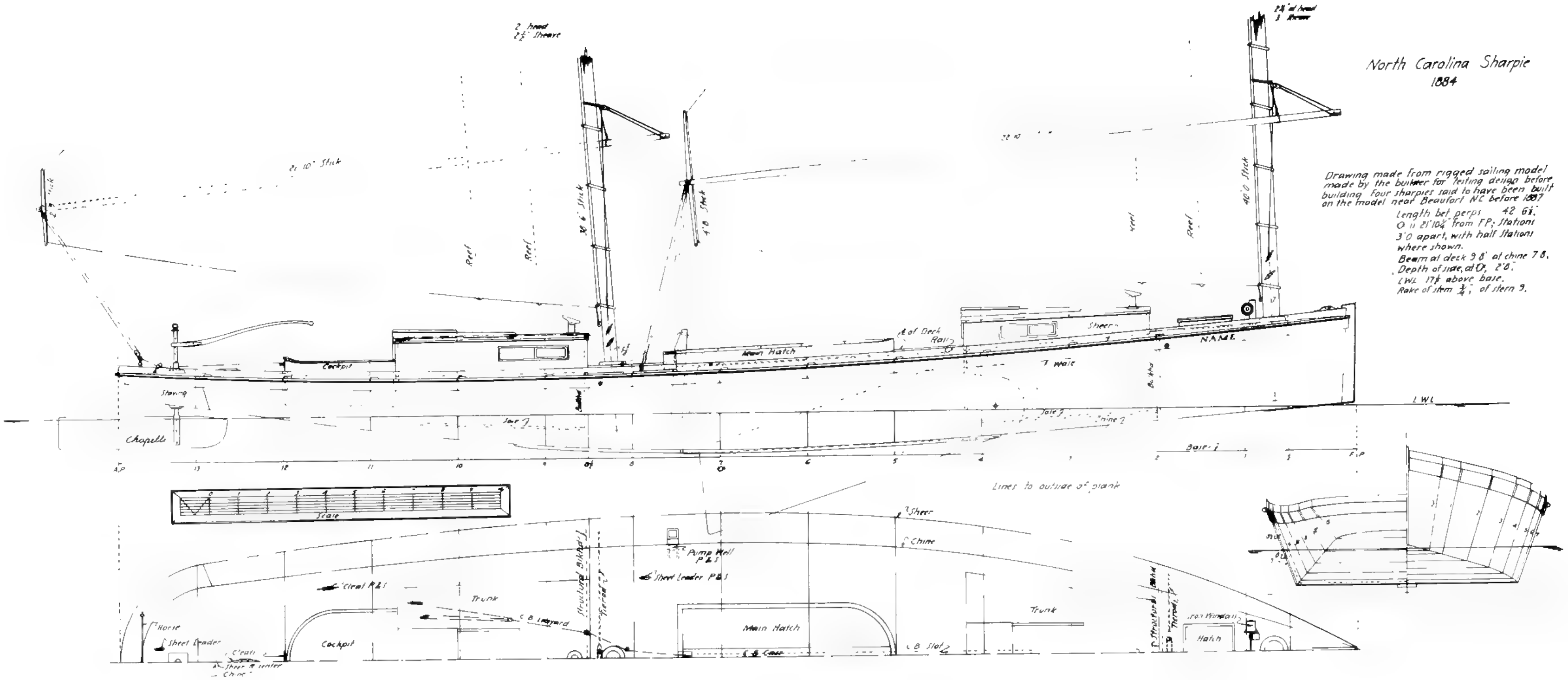

North Carolina Sharpie
1884
Drawing made from rigged sailing model made by the builder for testing design before building. Four sharpies said to have been built on the model near Beaufort NC before 1887
Length bet. perps 42' 6¼"
⊙ is 21' 10¼" from FP; Stations 3' 0 apart, with half Stations where shown.
Beam at deck 9' 8" at chine 7' 8".
Depth of side, at ⊙, 2' 8".
LWL 17½ above base.
Rake of stem ¾"; of stern 9.
2 head
2½" Sheave
2¾" at head
3 Bm
21' 10" Stick
36' 6" Stick
4' 0" Stick
40' 0" Stick
Reef
Reef
Reef
Reef
Cockpit
Main Hatch
℄ of Deck Rail
Sheer
NAME
Wale
Bulkhd
Staving
LWL
Chine
Base
Chapelle
A.P.
F.P.
Scale
Lines to outside of plank
Sheer
℄ Chine
Pump Well P&S
Sheet Leader P&S
Cleat P&S
Trunk
C.B. Lanyard
Structural Bulkhd
Thwart
Main Hatch
C.B. Case
C.B. Slot
Trunk
Structural Bulkhd
Thwart
Iron Windlass
Hatch
Horse
Sheet Leader
Cleats
Sheet & center
Chine
Cockpit

FIGURE 9.—Plan of North Carolina sharpie of the 1880's.

The cost of the New Haven sharpie was very low. Hall stated that in 1880–1882 oyster sharpies could be built for as little as $200, and that large sharpies, 40 feet long, cost less than $400.[6] In 1886 a sharpie with a capacity for 150 to 175 bushels of oysters cost about $250, including spars and sails.[7] In 1880 it was not uncommon to see nearly 200 sharpies longside the wharves at Fairhaven, Connecticut, at nightfall.

The speed of the oyster sharpies attracted attention in the 1870's, and in the next decade many yachts were built on sharpie lines, being rigged either as standard sharpies or as sloops, schooners, or yawls.

Oyster tonging sharpies were raced, and often a sharpie of this type was built especially for racing. One example of a racing sharpie had the following dimensions:

Length:	35′
Width on deck:	8′
Flare, to 1′ of depth:	4′
Width of stern:	4½′
Depth of stern:	10″
Depth at bow:	36″
Sheer:	14″
Centerboard:	11′
Width of washboards or sidedecks:	12″
Length of rudder:	6′
Depth of rudder:	1′ 2″
Height of foremast:	45′
Diameter of foremast:	6″
Head of foremast:	1½″
Height of mainmast:	40′
Diameter of mainmast:	5½″
Head of mainmast:	1½″

The sharpie with the above dimensions was decked-over 10 feet foreward and 4 feet aft. She carried a 17-foot plank bowsprit, to the ends of which were fitted vertical clubs 8 to 10 feet long. When racing, this sharpie carried a 75-yard foresail, a 60-yard mainsail, a 30-yard jib, a 40-yard squaresail, and a 45-yard main staysail; two 16-foot planks were run out to windward and 11 members of the 12-man crew sat on them to hold the boat from capsizing.

Figure 3 shows a plan of a sharpie built at the highest point in the development of this type boat. This plan makes evident the very distinct character of the sharpie in model, proportion, arrangement, construction, and rig.[8] The sharpie represented by the plan is somewhat narrower and has more flare in the sides than indicated by the dimensions given by Kunhardt. The boatmen at New Haven were convinced that a narrow sharpie was faster than a wide one, and some preferred strongly flaring sides, though others thought the upright-sided sharpie was faster. These boatmen also believed that the shape of the bottom camber fore and aft was important, that the heel of the stem should not be immersed, and that the bottom should run aft in a straight line to about the fore end of the centerboard case and then fair in a long sweep into the run, which straightened out before it passed the after end of the waterline. Some racing sharpies had deeper sterns than tonging boats, a feature that produced a faster boat by reducing the amount of bottom camber.

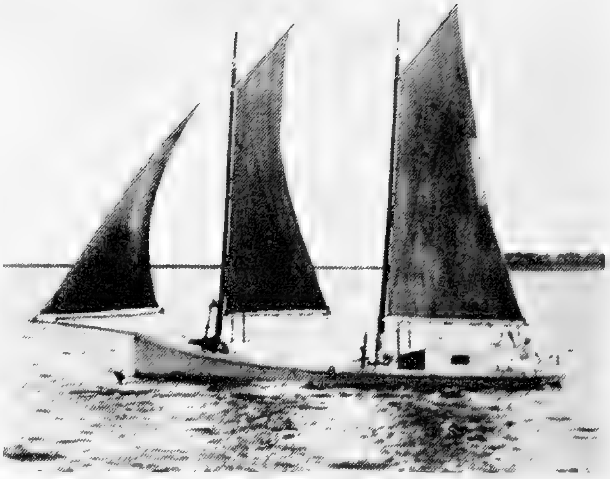


FIGURE 10.—North Carolina sharpie under sail.

The use of the sharpie began to spread to other areas almost immediately after its appearance at New Haven. As early as 1855 sharpies of the 100-bushel class were being built on Long Island across the Sound from New Haven and Bridgeport, and by 1857 there were two-masted, 150-bushel sharpies in lower New York Harbor. Sloop-rigged sharpies 24 to 28 feet long and retaining the characteristics of the New Haven sharpies in construction and most of its basic design features, but with some increase in proportion-

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[6] Hall, *op. cit.* (footnote 3), pp. 30, 32.

[7] Kunhardt, *op. cit.* (footnote 5), pp. 225, 295.

[8] Full-scale examples of sharpies may be seen at the Mariners' Museum, Newport News, Virginia, and at the Mystic Marine Museum, Mystic, Connecticut.

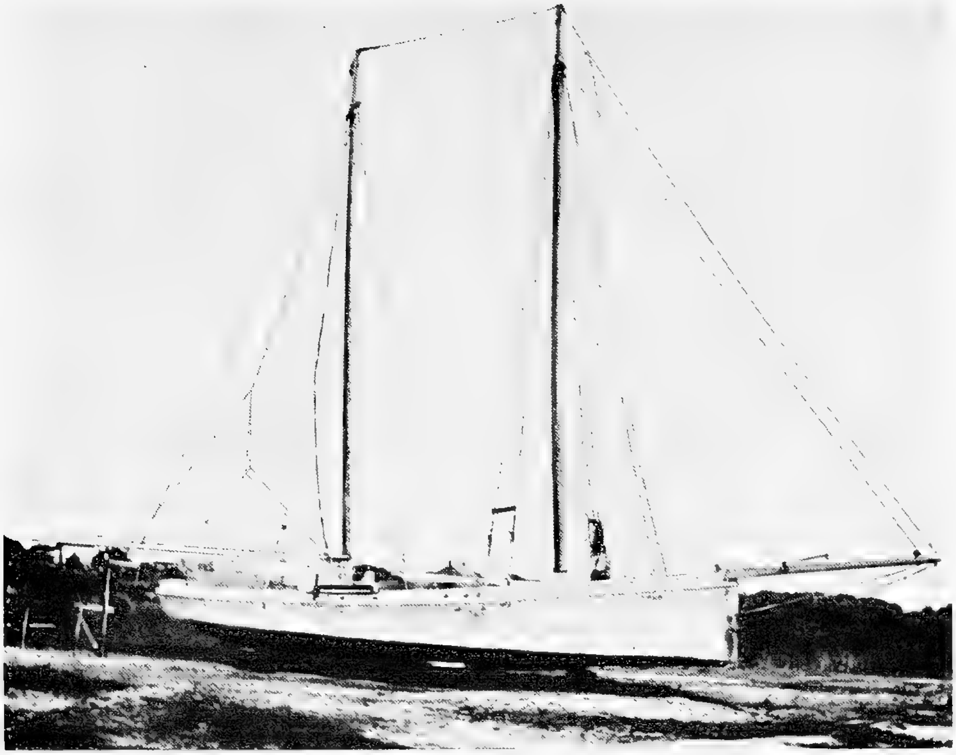

FIGURE 11.—North Carolina sharpie schooner hauled up for painting.

ate beam, were extensively used in the small oyster fisheries west of New Haven. There were also a few sloop-type sharpies in the eastern Sound. In some areas this modification of the sharpie eventually developed its own characteristics and became known as the "flattie," a type that was popular on the north shore of Long Island, on the Chesapeake Bay, and in Florida at Key West and Tampa.

The sharpie's rapid spread in use can be accounted for by its low cost, light draft, speed, handiness under sail, graceful appearance, and rather astonishing seaworthiness. Since oyster tonging was never carried on in heavy weather, it was by chance rather than intent that the seaworthiness of this New Haven tonging boat was discovered. There is a case on record in which a tonging sharpie rescued the crew of a coasting schooner at Branford, Connecticut, during a severe gale, after other boats had proved unable to approach the wreck.

However, efforts to improve on the sharpie resulted in the construction of boats that had neither the beauty nor the other advantages of the original type. This was particularly true of sharpies built as yachts with large cabins and heavy rigs. Because the stability of the sharpie's shoal hull was limited, the added weight of high, long cabin trunks and attendant furniture reduced the boat's safety potential. Windage of the topside structures necessary on sharpie yachts also affected speed, particularly in sailing to windward. Hence, there was an immediate trend toward the addition of deadrise in the bottom of the yachts, a feature that sufficiently increased displacement and draft so that the superstructure and rig could be better carried. Because of its large cabin, the sharpie yacht when under sail was generally less workable than the fishing sharpie. Although it was harmful to the sailing of the boat, many of the sharpie yachts had markedly increased beam. The first sharpie yacht of any size was the *Lucky*, a half-model of which is in the Model Room of the New York Yacht Club. The *Lucky*, built in 1855 from a model by Robert Fish, was 51 feet long with a 13-foot beam; she drew 2 feet 10 inches with her centerboard raised. According to firsthand reports, she was a satisfactory cruiser, except that she was not very weatherly because her centerboard was too small.

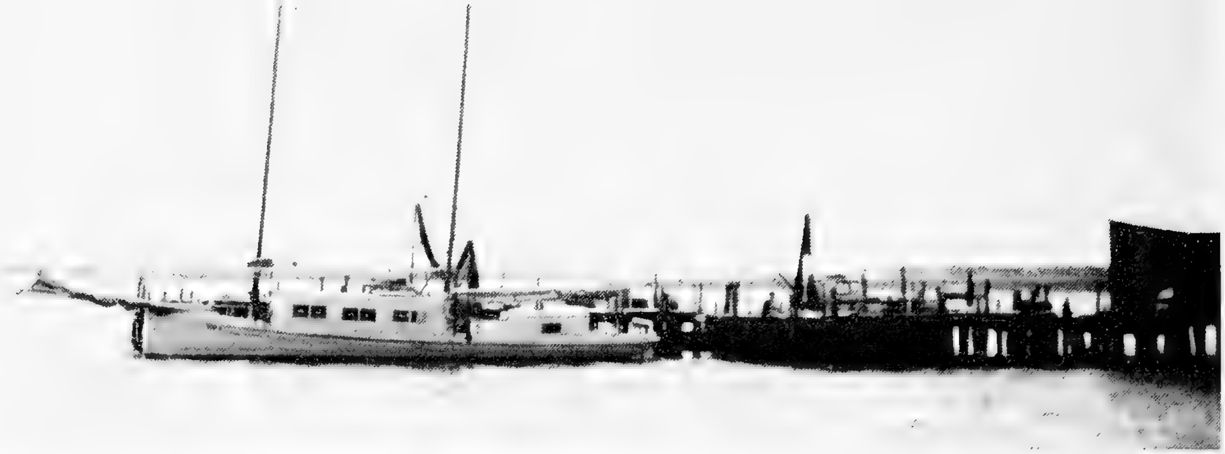

FIGURE 12.—North Carolina sharpie schooner converted to yacht, 1937.

Kunhardt mentions the extraordinary sailing speed of some sharpies, as does certain correspondence in *Forest and Stream*. A large sharpie was reported to have run 11 nautical miles in 34 minutes, and a big sharpie schooner is said to have averaged 16 knots in 3 consecutive hours of sailing. Tonging sharpies with racing rigs were said to have sailed in smooth water at speeds of 15 and 16 knots. Although such reports may be exaggerations, there is no doubt that sharpies of the New Haven type were among the fastest of American sailing fishing boats.

Sharpie builders in New Haven very early developed a "production" method. In the initial stages of building, the hull was upside down. First, the sides

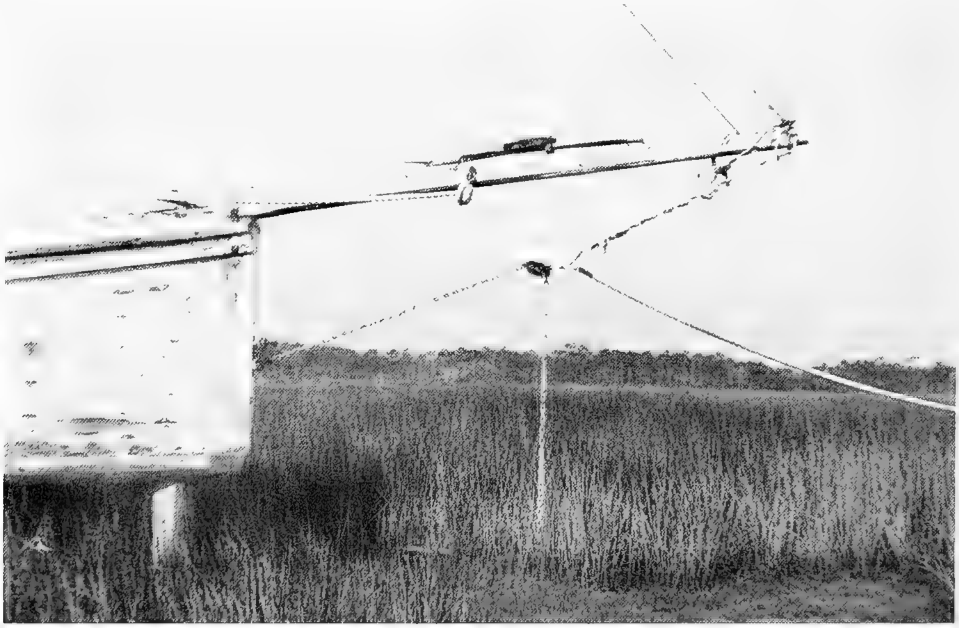

FIGURE 13.—Bow of North Carolina sharpie schooner showing head rigging.

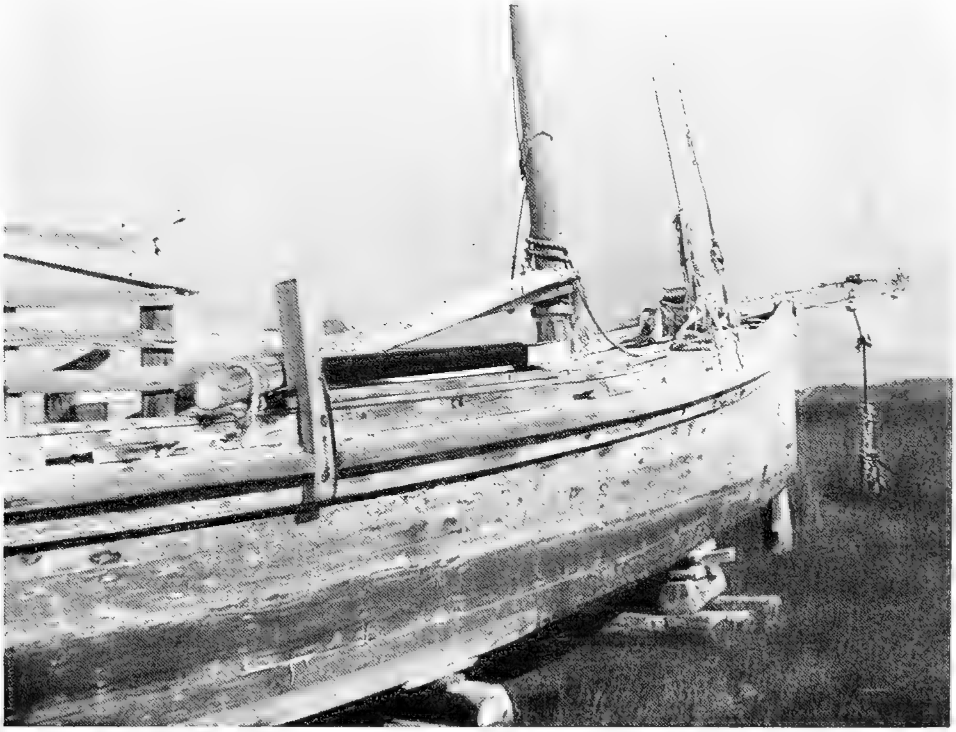

Figure 14.—The entrance of a North Carolina sharpie schooner and details of her sharp lines and planking. Note scarphs in plank.

were assembled and the planking and frames secured; then the inner stem was built, and the sides nailed to it, after which the bulkhead and a few rough temporary molds were made and put in place and the boat's sides bent to the desired curve in plain view. For bending the sides a "Spanish windlass" of rope or chain was used. The chine pieces were inserted in notches in the molds inside the side planking and fastened, then the keelson was made and placed in notches in the molds and bulkhead along the centerline. Next, the upper and lower stern frames were made and secured, and the stern staved vertically. Plank extensions of the keelson were fitted, the bottom laid, and the boat turned over. Sometimes the case was made and fitted with the keelson structure, but sometimes this was not done until the deck and inboard works were finished.

The son of Lester Rowe, a noted sharpie builder at New Haven, told me, in 1925, that it was not uncommon for his father and two helpers to build a sharpie, hull and spars, in 6 working days, and that one year his father and two helpers built 31 sharpies. This was at a time after power saws and planers had come into use, and the heavy cutting and finishing of timber was done at a mill, from patterns.

In spite of Barnegat Bay's extensive oyster beds and its proximity to New Haven, the sharpie never became popular in that region, where a small sailing scow known as the "garvey" was already in favor. The garvey was punt-shaped, with its bow narrower than the stern; it had a sledlike profile with moderately flaring sides and a half-deck; and it was rigged with two spritsails, each with a moderate peak to the head and the usual diagonal sprit.[9] The garvey was as fast and as well suited to oyster tonging as the sharpie, if not so handsome; also, it had an economic advantage over the New Haven boat because it was a little cheaper to build and could carry the same load on

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[9] The foremast of the garvey was the taller and carried the larger sail. At one time garveys had leeboards, but by 1850 they commonly had centerboards and either a skeg aft with a rudder outboard or an iron-stocked rudder, with the stock passing through the stern overhang just foreward of the raking transom. The garvey was commonly 24 to 26 feet long with a beam on deck of 6 feet 4 inches to 6 feet 6 inches and a bottom of 5 feet to 5 feet 3 inches.

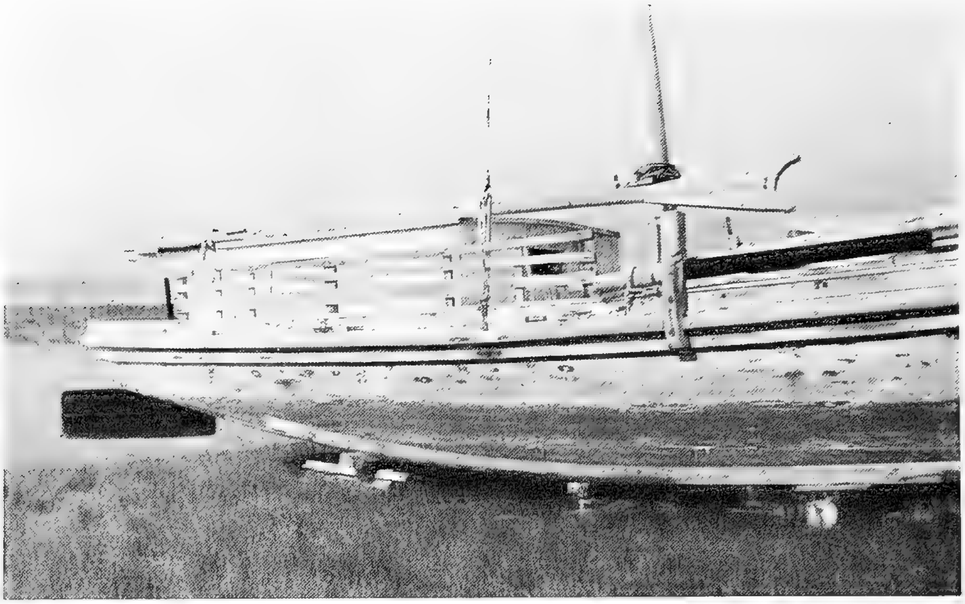

Figure 15.—Midbody and stern of a North Carolina sharpie schooner showing planking, molding, and other details.

shorter length. Probably it was the garvey's relative unattractiveness and the fact that it was a "scow" that prevented it from competing with the sharpie in areas outside of New Jersey.

The Chesapeake Bay Sharpie

The sharpie appeared on the Chesapeake Bay in the early 1870's, but she did not retain her New Haven characteristics very long. Prior to her appearance on the Bay, the oyster fishery there had used several boats, of which the log canoe appears to have been the most popular. Some flat-bottomed skiffs had also been used for tonging. There is a tradition that sometime in the early 1870's a New Haven sharpie named *Frolic* was found adrift on the Bay near Tangier Island. Some copies of the *Frolic* were made locally, and modifications were added later. This tradition is supported by certain circumstantial evidence.

Until 20 years ago Tangier Island skiffs certainly resembled the sharpie above the waterline, being long, rather narrow, straight-stem, round-stern, two-masted craft, although their bottoms were V-shaped rather than flat. The large number of boat types suitable for oyster fishery on the Bay probably prevented the adoption of the New Haven sharpie in a recognizable form. After the Civil War, however, a large sailing skiff did become popular in many parts of the Chesapeake. Boats of this type had a square stern, a curved stem in profile, a strong flare, a flat bottom, a sharply raking transom, and a centerboard of the "daggerboard" form. They were rigged with two leg-of-mutton sails. Sprits were used instead of booms, and there was sometimes a short bowsprit, carrying a jib. The rudder was outboard on a skeg. These skiffs ranged in length from about 18 feet to 28 feet. Those in the 24- to 28-foot range were half-decked; the smaller ones were entirely open.

In the late 1880's or early 1890's the V-bottomed hull became extremely popular on the Chesapeake, replacing the flat-bottom almost entirely, as at Tangier Island. Hence, very few flat-bottomed boats or their remains survive, although a few 18-foot skiffs are still in use.

Characteristics of the large flat-bottomed Chesapeake Bay skiff are shown in figure 4. While it is possible that the narrow beam of this skiff, the straightness of both ends of its bottom camber, and its rig show some New Haven sharpie influence, these characteristics are so similar to those of the flatiron skiff that it is doubtful that many of the Bay sharpies had any real relation to the New Haven boats. As indicated by figures 5 and 7, the Chesapeake flat-bottoms constituted a distinct type of skiff. Except

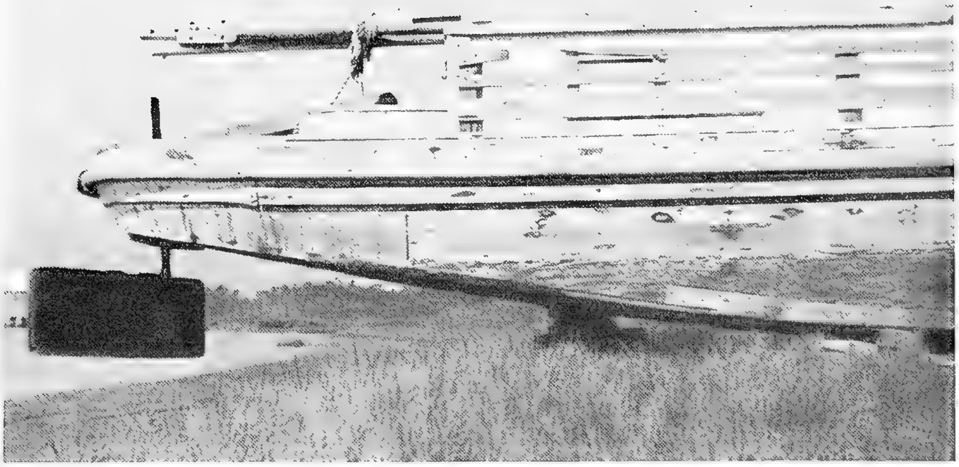

Figure 16.—Stern of a North Carolina sharpie schooner showing planking, staving, molding, and balanced rudder.

for those skiffs used in the Tangier Island area, it is not evident that the Bay skiffs were influenced by the New Haven sharpie to any great degree, in form at least.

Schooner-rigged sharpies developed on Long Island Sound as early as 1870, and their hulls were only slightly modified versions of the New Haven hull in basic design and construction. These boats were, however, larger than New Haven sharpies, and a few were employed as oyster dredges. After a time it was found that sharpie construction proved weak in boats much over 50 feet. However, strong sharpie hulls of great length eventually were produced by edge-fastening the sides and by using more tie rods than were required by a smaller sharpie. Transverse tie rods set up with turnbuckles were first used on the New Haven sharpie, and they were retained on boats that were patterned after her in other areas. Because of this influence, such tie rods finally appeared on the large V-bottomed sailing craft on Chesapeake Bay.

The sharpie schooner seems to have been more popular on the Chesapeake Bay than on Long Island Sound. The rig alone appealed to Bay sailors, who were experienced with schooners. Of all the flat-bottomed skiffs employed on the Bay, only the schooner can be said to have retained much of the appearance of the Connecticut sharpies. Bay sharpie schooners often were fitted with wells and used as terrapin smacks (fig. 7). As a schooner, the sharpie was relatively small, usually being about 30 to 38 feet over-all.

Since the 1880's the magazine *Forest and Stream* and, later, magazines such as *Outing*, *Rudder*, and *Yachting* have been the media by which ideas concerning all kinds of watercraft from pleasure boats to work boats have been transmitted. By studying such periodicals, Chesapeake Bay boatbuilders managed to keep abreast of the progress in boat design being made in new yachts. In fact, it may have been because of articles in these publications that the daggerboard came to replace the pivoted centerboard in Chesapeake Bay skiffs and that the whole V-bottom design became popular so rapidly in the Bay area.

The North Carolina Sharpie

In the 1870's the heavily populated oyster beds of the North Carolina Sounds began to be exploited. Following the Civil War that region had become a depressed area with little boatbuilding industry. The small boat predominating in the area was a modified yawl that had sprits for mainsail and topsail, a jib set up to the stem head, a centerboard, and waterways along the sides. This type of craft, known as the

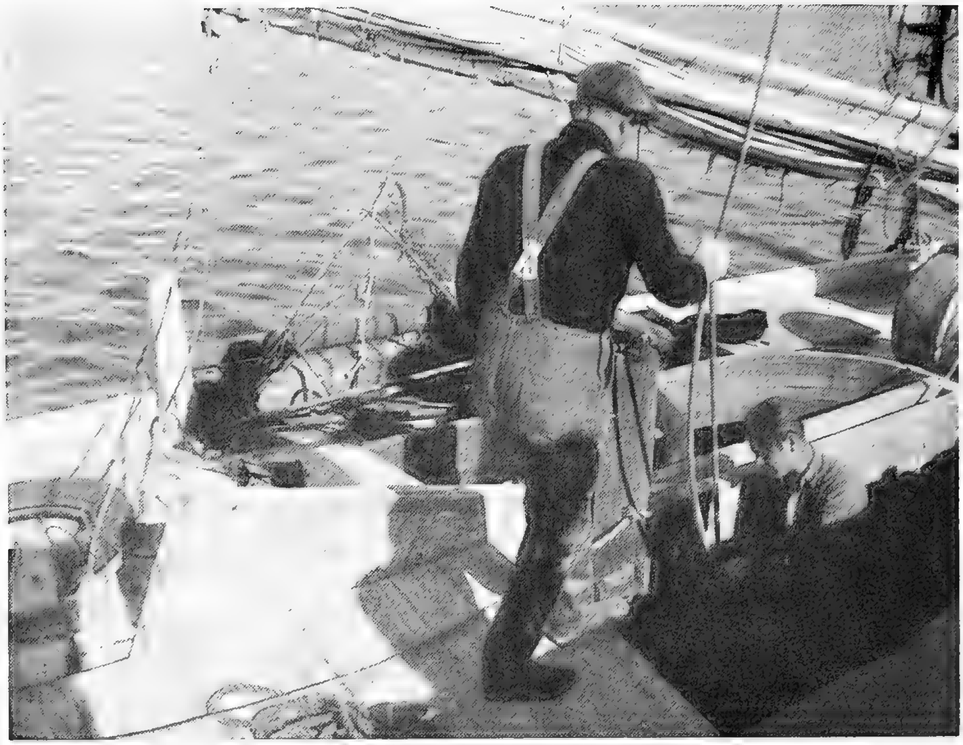

Figure 17.—Deck of a North Carolina sharpie schooner showing U-shaped main hatch typical of sharpies used in the Carolina Sounds.

"Albemarle Sound boat" or "Croatan boat," had been developed in the vicinity of Roanoke Island for the local shad fishery. Although it was seaworthy and fast under sail, this boat was not particularly well suited for the oyster fishery because of its high freeboard and lack of working deck for tonging.

Because the oyster grounds in the Carolina Sounds were some distance from the market ports, boats larger than the standard 34- to 36-foot New Haven sharpie were desirable; and by 1881 the Carolina Sounds sharpie had begun to develop characteristics of its own. These large sharpies could be decked and, when necessary, fitted with a cabin. In all other respects the North Carolina sharpie closely resembled the New Haven boat. Some of the Carolina boats were square-sterned, but, as at New Haven, the round stern apparently was more popular.

Most Carolina sharpies were from 40 to 45 feet long. Some had a cramped forecastle under the foredeck, others had a cuddy or trunk cabin aft, and a few had trunk cabins forward and aft. Figure 6 is a drawing of a rigged model that was built to test the design before the construction of a full-sized boat was attempted.[10] The 1884 North Carolina sharpie shown in this plan has two small cuddies; it also has the U-shaped main hatch typical of the Carolina sharpie. It appears that the clubs shown at the ends of the sprits were very often used on the Carolina sharpies, but they were rarely used on the New Haven tongers except when the craft were rigged for racing. The Carolina Sounds sharpie shown under sail in figure 8 is from 42 to 45 feet long and has no cuddy.

The Carolina Sounds sharpies retained the excellent sailing qualities of the New Haven type and were well finished. The two-sail, two-mast New Haven rig was popular with tongers, but the schooner-rigged sharpie that soon developed (figs. 9, 11–18) was preferred for dredging. It was thought that a schooner rig allowed more adjustment of sail area and thus would give better handling of the boat under all weather condi-

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[10] In building shoal draft sailing vessels, this practice was usually possible and often proved helpful. In the National Watercraft Collection at the United States National Museum there is a rigged model of a Piscataqua gundalow that was built for testing under sail before construction of the full-scale vessel.

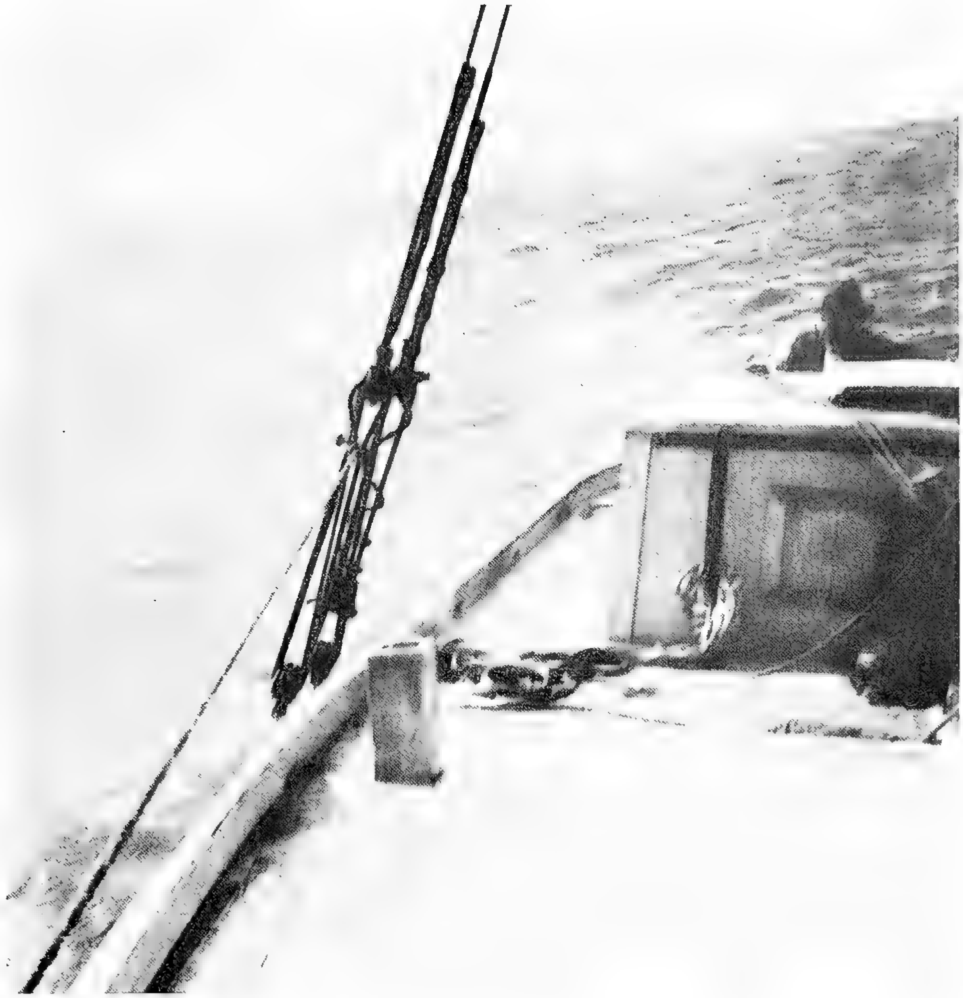

FIGURE 18.—Deck of a North Carolina sharpie schooner under sail showing pump box near rail and portion of afterhouse.

tions. This was important because oyster dredging could be carried on in rough weather when tonging would be impractical. Like the Maryland terrapin smack, the Carolina sharpie schooner adhered closely to New Haven principles of design and construction. However, Carolina sharpie schooners were larger than terrapin smacks, having an over-all length of from 40 to 52 feet. These schooners remained in use well into the 20th century and, in fact, did not go out of use entirely until about 1938. In the 1920's and 1930's many such boats were converted to yachts. They were fast under sail and very stiff, and with auxiliary engines they were equally as fast and required a relatively small amount of power. Large Carolina sharpie schooners often made long coasting voyages, such as between New York and the West Indies.

Sharpies in Other Areas

The Carolina Sounds area was the last place in which the sharpie was extensively employed. However, in 1876 the sharpie was introduced into Florida by the late R. M. Munroe when he took to Biscayne Bay a sharpie yacht that had been built for him by Brown of Tottenville, Staten Island. Afterwards various types of modified sharpies were introduced in Florida. On the Gulf Coast at Tampa two-masted

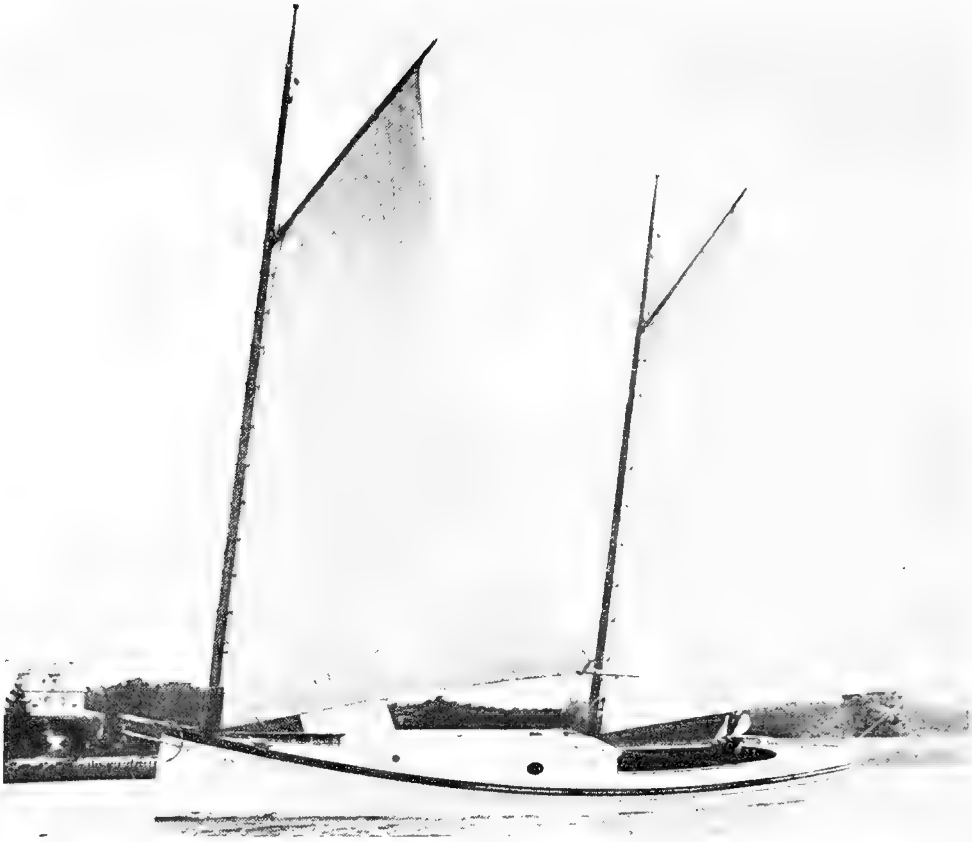

FIGURE 19.—Sharpie yacht *Pelican* built in 1885 for Florida waters. She was a successful shoal-draft sailing cruiser. (Photo courtesy Wirth Munroe.)

sharpies and sharpie schooners were used to carry fish to market, but they had only very faint resemblance to the original New Haven boat.

The sharpie also appeared in the Great Lakes area, but here its development seems to have been entirely independent of the New Haven type. It is possible that the Great Lakes sharpie devolved from the common flatiron skiff.

The sharpie yacht was introduced on Lake Champlain in the late 1870's by Rev. W. H. H. Murray, who wrote for *Forest and Stream* under the pen name of "Adirondack Murray." The hull of the Champlain sharpie retained most of the characteristics of the New Haven hull, but the Champlain boats were fitted with a wide variety of rigs, some highly experimental. A few commercial sharpies were built at Burlington, Vermont, for hauling produce on the lake, but most of the sharpies built there were yachts.

Double-Ended Sharpies

The use of the principles of flatiron skiff design in sharp-stern, or "double-ended," boats has been common. On the Chesapeake Bay a number of small, double-ended sailing skiffs, usually fitted with a centerboard and a single leg-of-mutton sail, were in use in the 1880's. It is doubtful, however, that these skiffs had any real relationship to the New Haven sharpie. They may have developed from the "three-plank" canoe[11] used on the Bay in colonial times.

The "cabin skiff," a double-ended, half-decked, trunk-cabin boat with a long head and a cuddy forward, was also in use on the Bay in the 1880's. This boat, which was rigged like a bugeye, had a bottom of planks that were over 3 inches thick,

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[11] A primitive craft made of three wide planks, one of which formed the entire bottom.

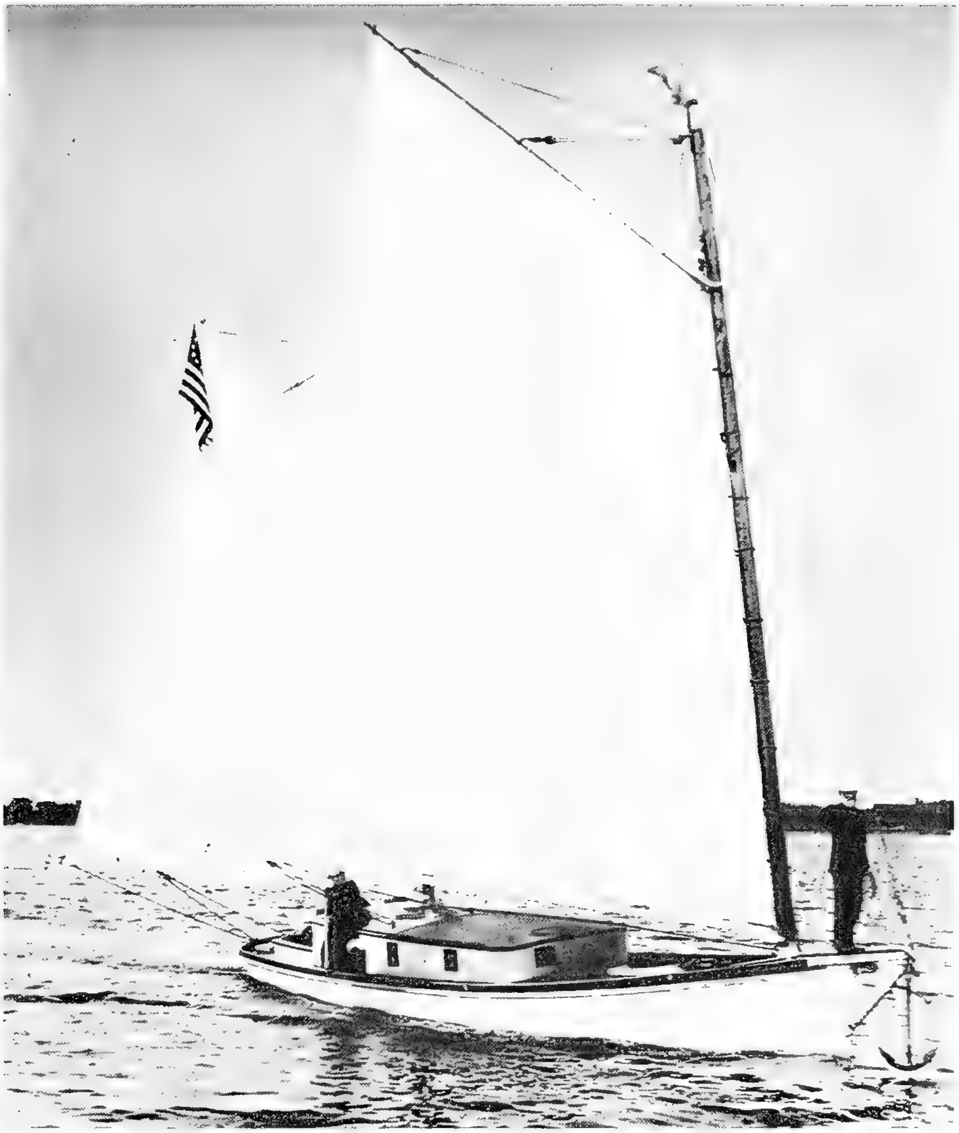

FIGURE 20.—Florida sharpie yacht of about 1890.

laid fore-and-aft, and edge-bolted. The entire bottom was made on two blocks or "sleepers" placed near the ends. The sides were bevelled, and heavy stones were placed amidships to give a slight fore-and-aft camber to the bottom. The sides, washboards, and end decks were then built, the stones removed, and the centerboard case fitted. In spite of its slightly cambered flat bottom, this boat, though truly a flatiron skiff in midsection form, had no real relation to the New Haven sharpie; it probably owed its origin to the Chesapeake log canoe, for which it was an inexpensive substitute.

R. M. Munroe built double-ended sharpies in Florida, and one of these was used to carry mail between Biscayne Bay and Palm Beach. Although Munroe's double-enders were certainly related to the New Haven sharpie, they were markedly modified and almost all were yachts.

A schooner-rigged, double-ended sharpie was used in the vicinity of San Juan Island, Washington, in the 1880's, but since the heels of the stem and stern posts were immersed it is very doubtful that this sharpie was related in any way to the New Haven boats.

Modern Sharpie Development

The story of the New Haven sharpie presents an interesting case in the history of the development of small commercial boats in America. As has been shown, the New Haven sharpie took only about 40 years to reach a very efficient stage of development as a fishing sailboat. It was economical to build, well suited to its work, a fast sailer, and attractive in appearance.

When sailing vessels ceased to be used by the fishing industry, the sharpie was almost forgotten, but some slight evidence of its influence on construction remains. For instance, transverse tie rods are used in the large Chesapeake Bay "skipjacks," and Chesapeak motorboats still have round, vertically staved sterns, as do the "Hatteras boats" used on the Carolina Sounds. But the sharpie hull form has now almost completely disappeared in both areas, except in a few surviving flat-bottomed sailing skiffs.

Recently the flat-bottomed hull has come into use in small, outboard-powered commercial fishing skiffs, but, unfortunately, these boats usually are modeled after the primitive flatiron skiff and are short in length.

The New Haven sharpie proved that a long, narrow hull is most efficient in a flat-bottomed boat, but no utilization has yet been made of its design as the basis for the design of a modern fishing launch.

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HOLCOMB, FITZ, and PEATE:

Three 19th Century American Telescope Makers

Introduction by Robert P. Multhauf

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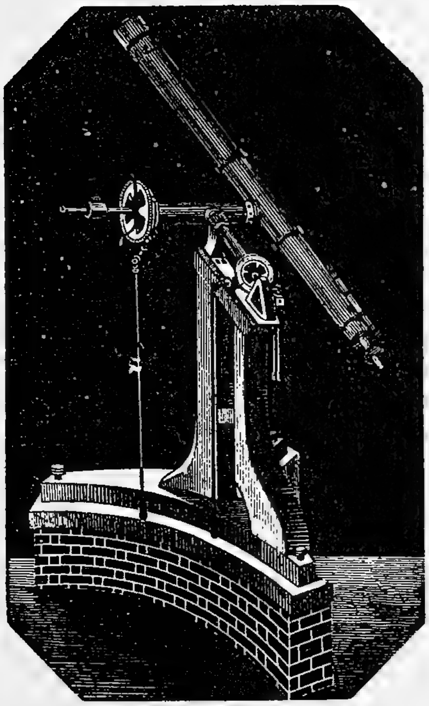

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PAPER 26

HOLCOMB, FITZ, AND PEATE:
THREE 19TH-CENTURY AMERICAN TELESCOPE MAKERS

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HOLCOMB, FITZ, and PEATE:

Three 19th Century American Telescope Makers

Practically all the telescopes used by amateur scientists in 18th-century America were of European origin. Our dependence upon foreign sources for these instruments continued well into the 19th century, and the beginning of telescope making in this country has conventionally been associated with the names of Alvan Clark and John Brashear, whose work dates from the 1860's.

Presented here are biographical sketches of two predecessors and a contemporary of Clark and Brashear whose obscurity is not deserved. The accounts relate some hitherto little-known aspects of telescope making in America as it progressed from mechanic art to science.

THE AUTHOR *of the Introduction, Robert P. Multhauf, is head curator of the department of science and technology in the United States National Museum, Smithsonian Institution.*

INTRODUCTION

Robert P. Multhauf

THE TELESCOPE was invented about 1600. It was brought to America about a half-century later, and within another century had become a commonplace appurtenance to the library of the cultivated gentleman.[1]

Throughout this period, from Galileo to Herschel, the telescope found use in scientific astronomy, although the possibility of contributing to the science of astronomy by simple observation diminished continuously after the time of Galileo. Herschel's work had aimed at the advancement of scientific astronomy through increasing spectacularly our powers of vision, just as had that of Galileo in the 17th century and of Hale in the 20th. But even in Herschel's time the monstrous size of the instrument required made the project something of a national effort. The telescopes of the 18th-century American gentleman were already toys, as far as the astronomer was concerned.

However, the telescope had another, if less glamorous, use in the 18th century. This was its use in positional astronomy, in the ever more precise measurement of the relative positions of objects seen in the heavens. Measurement had been the purpose served by pre-telescopic astronomical instruments, the sighting bars of the Ptolemaic observers of Alexandria and the elegant quadrants of Tycho Brahe. For a time after the invention of the telescope the professional astronomer resisted the innovation, but by the end of the 17th century the new optical instrument was being adapted to the quadrant and other instruments for the precise measurement of the positions of heavenly bodies in relation to the time-honored astronomical coordinates. By the late 18th century telescopes were found serving three relatively distinct purposes: the increased magnification of the sky in general (in which use Herschel's 48-inch reflector had made all others obsolete): the more precise measurement of planetary and stellar positions (and, conversely, of the Earth's shape) by means of the quadrant, vertical circle, zenith sector, and similar instruments; and the simple edification of the educated but not learned classes, who wished not only to see what the astronomer saw, but to have an instrument also useful for looking occasionally at interesting objects on earth.

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[1] Instruments surviving from 18th-century America are almost exclusively of European origin, products of the numerous and famous shops which sprang up, particularly in England and France, to meet the demand occasioned by the popularity of the telescope among amateurs and dilettanti.

Of these three purposes the second was the most unimpeachably scientific. It is remarkable that the earliest American-made telescopes of which we have knowledge were made for this purpose and not for the mere gratification of the curiosity of the educated layman. These are the telescopes of the remarkable Philadelphia mechanic, David Rittenhouse (1732–96). In an atmosphere not unlike the intellectual democracy that characterized the formation of the Royal Society a century earlier in London, Rittenhouse began as a clockmaker and ended as president of the American Philosophical Society, our counterpart of the Royal Society, in Philadelphia. He demonstrated not merely that an instrument-maker was capable of being a scientist, but also that the work of the instrument-maker, as it had developed by the late 18th century, was in itself scientific work. One of several observers assigned by the Society to the observation of the transit of Venus in 1769, he constructed instruments of the most advanced types, apparently employing European lenses, and used the instruments himself. Of these, a 1¾-inch refractor mounted as a transit instrument stands in the hall of the Philosophical Society. It is probably the oldest extant American-made telescope.

Rittenhouse made other telescopes which survive, notably two zenith sectors now in the U.S. National Museum of the Smithsonian Institution,[2] but he does not appear to have made them for commercial sale. In the history of telescope-making in America he seems to have been something of a "sport." Not only were the instruments which still grace the desks of Washington, Jefferson, and others, of European manufacture, but the earliest observatories in the United States (eleven between 1786 and 1840) were outfitted exclusively (except for the Rittenhouse observatory) with European instruments.[3] In its endeavor to establish a permanent observatory even Rittenhouse's own Philosophical Society seems to have thought exclusively in terms of instruments of European manufacture.

It must therefore have required some courage for Amasa Holcomb, 43-year-old Massachusetts surveyor, to approach Professor Silliman of Yale in 1830 with a telescope of his own construction. In the autobiography printed here, Holcomb states that all the telescopes used in this country before 1833 had been obtained in Europe, and indicates that thereafter "the whole market was in his hands during thirteen years," a period which would fall, apparently, between 1833 and 1845. It should be mentioned, although it is no conclusive negation of Holcomb's claim, that the New York instrument-maker Richard Patten in 1830 built a telescopic theodolite that was designed by Ferdinand Hassler for use on the Wilkes Expedition, and was subsequently used at the observatory of the Navy's "Depot of Charts and Instruments" in Washington.[4] We do not know the source of Patten's lenses.

Holcomb would appear to have succeeded as a commercial maker of telescopes. He claims to have sold his instruments "in almost every state in the Union," and also abroad, but we know nothing of what use was made of any of them. The telescope he showed Professor Silliman was a refractor. Another, preserved in the Smithsonian Institution,[5] is like Rittenhouse's 1769 instrument, a transit. But Holcomb seems to have specialized in reflectors of the Herschelean type, *i.e.*, instruments, in which the image is viewed through an eyepiece located at the mouth of the tube. It is probably reasonable to doubt that the serious astronomer of this period shared Holcomb's enthusiasm for this type of difficult-to-adjust instrument in the small sizes he produced (10-inches is the largest reported). In 1834, 1835, and 1836 he presented instruments of this type to the Franklin Institute in Philadelphia, where committees compared them with the best available European refractors and found them more than adequate. One of Holcomb's instruments of 1835, apparently his only surviving reflector, is now in the Smithsonian Institution (see appendix, p. 184).

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[2] U.S. National Museum catalog nos. 152078 and 152079.

[3] W. I. Milham, *Early American Observatories*, Williamstown, Mass., Williams College, 1938.

[4] *Mechanics Magazine*, 1830, vol. 13, pp. 114–115 and frontispiece.

[5] See p. 184 for a list of Holcomb's instruments in the U.S. National Museum.

Toward 1845, Holcomb tells us, "one after another went into the business," and indeed they did. At the American Institute Fair in New York that year a gold medal was given Henry Fitz "for the best achromatic telescope." In Cambridge, Massachusetts, Alvan Clark is supposed to have already taken up the hobby of lens and mirror making. And in McKeesport, Pennsylvania, an amateur telescope-maker now known only as "Squire Wampler" made a small achromatic refractor which he demonstrated in 1849 to a 9-year-old boy named John Brashear, of whom more later.

Some of Holcomb's telescopes must have come to the attention of Henry Fitz during his wide travels as a locksmith after 1830, if, as is reported, he was at that time pursuing his avocational interest in astronomy. It is interesting to note that both Holcomb and Fitz seem to have pursued feverishly the new photographic process of Daguerre in 1839, the former near the end of his career as a telescope-maker, the latter near the beginning of his.

The decade before 1845, when "one after another went into the business," seems to have been marked by the flowering of observational astronomy in the United States. The professional work of the Navy's Depot of Charts and Instruments (forerunner of the Naval Observatory) began about 1838. In 1844 the first instrument larger than 6 inches came to this country, an 11-inch refractor for the Cincinnati Observatory. The Bonds established what was to be the Harvard Observatory in 1839, and by 1847 Harvard had obtained its famous 15-inch refractor from Merz and Mahler.[6] Fitz was to have a more sophisticated market than had Holcomb.

Despite the glowing recommendations of the Franklin Institute committee,[7] no actual use of Holcomb's instruments by astronomers has come to light. We may owe to the rapid progress of American astronomy after 1840 the fact that we have evidence of a more distinguished history for some of Fitz's instruments. It will also be recalled that Holcomb specialized in Herschelian reflectors. Fitz, on the other hand, made few reflectors. He specialized in achromatic telescopes mounted equatorially, the type of instrument which was in greatest demand among professional astronomers at the time.

Some of Fitz's instruments had individual histories and were associated with important events in astronomy. One was taken in 1849 on the Chilean astronomical expedition of Lieut. James M. Gilliss. Another was used by L. M. Rutherfurd in his epochal astronomical photography at Columbia University. One, made for the Allegheny Observatory, is still in use at that institution. It appears from his account book that Fitz made many telescopes, and some have turned up in strange places. The lens of one of his refractors was located a few years ago in South Carolina, in use as substitute for the lens in an automobile headlamp![8] At an eastern university in 1958 the writer saw another of his refractors incorporated into apparatus used in graduate student experimentation.

Among the others who began telescope-making about 1845 was the portrait painter who was to become one of the world's foremost telescope-makers, Alvan Clark. Clark is supposed to have become first interested in lens and mirror making about 1844, and, as a resident of Cambridge, Mass., to have been inspired three years later by the great 15-inch refractor installed at Harvard. His first encouragement came from the British astronomer W. R. Dawes, with whom he had a correspondence on their respective observations and to whom he sold a 7½ inch refractor in 1851. The following year he established, with his sons, the firm of Alvan Clark and Sons, a name which was later to become one of the most famous in the field of telescope making. Whereas Holcomb had demonstrated that telescopes could be made in this country, and Fitz that American instruments were adequate to the needs of the professional astronomer, Clark was to prove that American instruments could compete commercially with the finest made in Europe. In 1862 Alvan Clark and Sons completed an 18½-inch refractor which was long to serve the

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[6] H. C. King, *The History of the Telescope*, London, Charles Griffin, 1955, pp. 246–248. Milham *op. cit.* (footnote 3), p. 10.

[7] As reported in the *Journal of the Franklin Institute* for July 1834, new ser. vol 14 (whole no. 18), pp. 169–172; July 1835, new ser. vol. 16 (whole no. 20), pp. 11–13; and August 1836, new ser. vol. 18 (whole no. 22), p. 110. The first two of these are given in the appendix, pp. 181–184.

[8] Reported by "R. K. M." in *Sky and Telescope*, March 1942, vol. 1, p. 21. The "Catalog of Objectives Made by Henry Fitz," the time span of which is unspecified, lists 428 objectives up to 13 inches and only 6 mirrors. It is not clear, however, that these represent finished units.

Dearborn Observatory. It is now in the Adler Planetarium. The famous Lick Observatory 36-inch refractor was completed in 1887, the year of Clark's death, and his sons went on to build the 40-inch Yerkes refractor, (1897) still the largest refractor ever built. It is no reflection on Clark to note that he was more fortunate than Fitz, in his longer life, his association with Warner and Swasey in the construction of mountings, and in the continuity given to his work by his sons.

Let us return for a moment to the 1840's and John Brashear the 9-year-old Pennsylvania boy who, was given his first opportunity of looking through a small refractor telescope by its maker, Squire Wampler of McKeesport. Brashear became a professional machinist, but retained an interest in astronomy which led him to make a 5-inch achromatic refractor in 1872 and subsequently to show the instrument to Samuel Pierpont Langley,[9] then director of the Allegheny Observatory. With Langley's encouragement Brashear went on to construct a 12-inch reflector and in 1880 decided to make a business of telescope-making. He subsequently made, among other telescopes, a 30-inch refractor in 1906 for the Allegheny Observatory and in 1918 a 72-inch reflector, at Victoria, British Columbia. Brashear's greatest fame, however, came from his accessory instruments—spectroscopes and the like.

Not the least thrilling aspect of the story of the spectacular ascendancy of American-made telescopes is the story of their financing—of the big-telescope era in American philanthropy and the financial giants (Lick, Hooker, Thaw, Yerkes, and others) who peopled it. In the biography of our third telescope-maker, John Peate, we see at once the persistence of the amateur and the difficulty of his position at the end of the 19th century.

Peate, too, may have acquired his interest in astronomy during the years just before 1845. It has been surmised that he was inspired by the sensation created by the comet of 1843, but it is more likely that his interest resulted from visits to European observatories while he was on a walking tour in 1859. Unlike our other amateurs, he did not change his profession (he was a Methodist minister), being certainly at less liberty to do so, but he adapted his hobby to it in an interesting way. Peate was something of a poor man's philanthropist, and his fame would have been no greater than that role customarily brings had he not undertaken in 1893 the astonishingly audacious project of making the largest glass reflector that had ever been built. In this project he assumes, like his English contemporary A. A. Common, a position intermediate between the makers of giant metallic specula, Herschel and Rosse, and the makers of the California glass reflectors of the 20th century.[10] In a professional telescope-maker of the end of the 19th century, Peate's accomplishment would have been remarkable. In an amateur it is amazing. It detracts nothing from Peate to reveal, as does the sketch printed here, that the accolade which this project deserves (but has never received) belongs in part to George Howard and the Standard Plate Glass Company. His example and theirs encourage us to hope that the day of the amateur in science may not be at an end.

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[9] Langley's work at the Allegheny Observatory, particularly his invention of the bolometer, brought him international renown as a scientist. In January 1887 he was appointed assistant secretary of the Smithsonian Institution, and later in that year became its third Secretary, serving from 1887–1906.

[10] The giant mirrors of Herschel (1789) and Rosse (1842) were made of an alloy of 71% copper and 29% tin, and 68½% copper and 31½% tin, respectively. This alloy was known as "speculum metal." The silvered glass mirror was pioneered by Steinhill and Foucault in 1856. In England Dr. A. A. Common made considerable use in the 1870's of silvered glass mirrors made by George Calver. About 1892–97 Common himself made, but never finished, a 60-inch mirror. It was later refigured and is still in use.

On these matters see King, *op. cit.* (footnote 6).

I. Amasa Holcomb

1787–1875

Amasa Holcomb was born in 1787, the year John Fitch demonstrated his steamboat before the Constitutional Convention assembled at Philadelphia, and three years before the death of Benjamin Franklin. Two of Holcomb's telescopes remained in the attic of the family home in Southwick, Massachusetts, until 1933, when they were offered by his descendants to the Smithsonian Institution.[1] *With them came a manuscript book of meteorological and astronomical notes, and the following short sketch of the life of Holcomb, unsigned but almost certainly autobiographical. It appears to have been written when the subject was about 80 years old (1867).*

THE SUBJECT of this notice was born June 18, 1787. The place was Simsbury Connecticut previous to 1768. That year Simsbury was divided and his birth place fell in Granby Con. that being the name of the new town. It remained so until 1804 when the line between Connecticut and Massachusetts was moved further south and his birth place fell in Southwick Massachusetts. The house was about a quarter of a mile north of the new state line, and on a road about half a mile west of the main road from Westfield to Simsbury and Hartford. Here his father and mother lived and died, having lived in three different towns and two different states without changing the place of their residence. Here Amasa was born and past his early youth. His grand father and grand mother on his fathers side lived and died in a house about thirty rods further south, on the same road. His grand fathers name was Elijah, and was a son of Nathaniel Holcomb 3d, and married Violet Cornish of Simsbury Con. daughter of Capt. James Cornish. His fathers name was Elijah Holcomb Junr. He was a farmer and cooper. In the latter part of his life his father became involved in debt, and mortgaged the farm. His son Amasa paid the debt and the father Elijah Holcomb Junr occupied the farm until he died Oct 5th 1841. The grandfather on the mothers side was Silas Holcomb a son of Judah Holcomb 1st and grandson of Nathanial Holcomb 2d[.] He lived in the northwest part of Granby, near Hartland line, where he owned a large farm and beautiful home. He kept a park for deer and cultivated fruit, and made raisins. He married Mary Post of Hebron Connecticut, and in this beautiful place they lived and died. There Lucy Holcomb the mother of Amasa was born in 1767. During her short life, she was one of the excellent ones of the earth, and labored for the welfare of her children by instruction and example, until she died August 31 1800. In a very hot day in 1797, she attempted to get some cattle out a field of wheat. The men were at work in a distant field, too far off to know about it. She became heated, and never recovered, though she lived three years. During the last year of her life she became so reduced, that for a long while she could not speak a loud word, but she could and did whisper some good advice to her children. Her son Amasa never forgot it, and he always remembered his mother with affection and gratitude. She had two sisters but no brother. The house where she was born is still standing, but has passed out of the family. The house where his father and mother [lived and died][2] spent their married life, and where he was born, has been taken down, and a new house built on the same place by his brother Newton Holcomb who now owns the old home stead. Here Amasa spent his early youth and school days. There was not a schoolhouse in the district where he lived, until he was past having any use for a common school. The schools were kept in dwelling houses, one part was occupied by the family, and the other part by the school. In these schools were taught, reading, spelling, writing and the first rules of arithmetic. In some of them a little english grammer was taught. Climena Holcomb, Lois Gains, Bethuel Barber, Samuel Frasier, and James L. Adair, in the order in which they are named, were his teachers. At the age of fifteen he was asked to take a school in Suffield connecticut. He was inspected and passed and

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[1] For a list of these, see appendix, p. 184.

[2] Words crossed out in manuscript. See figure 1.

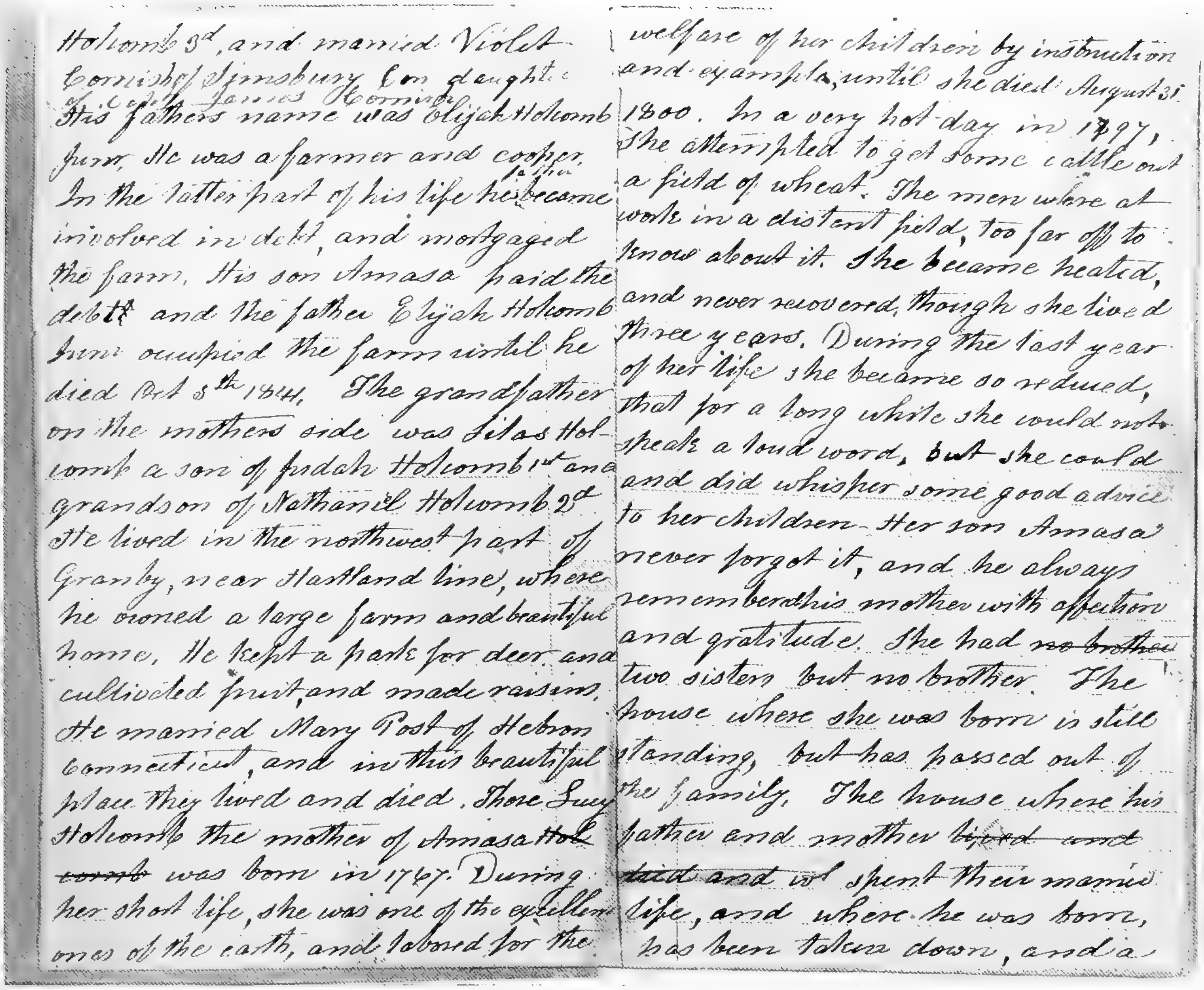

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FIGURE 1.—Page from manuscript sketch of the life of Amasa Holcomb, now in the collections of the U.S. National Museum.

took the school. A large portion of the pupils were older and stouter than he was, but they had the good sense to submit to be governed and taught, and good progress was made. But before this a great impulse had been given to his mind. He had an uncle Abijah Holcomb that went to sea about 1798 and never returned. Abijah had fitted for colledge and left a valuable collection of books. Some of them were classical, and some scientific. Here he found books on Geometry, Navigation, and astronomy. Amasa had free access to these books, and they opened a brighter world before him. He went into these studies with great pleasure, and a mind fully awake, but *alone*[.] None of these branches were taught in any school to which he had access. He had so far progressed without help, in Geometry, Surveying, navigation, Optics and Astronomy, that at the great Solar eclipse in June 1806 he could make astronomical computations, and was prepared to observe the eclipse with instruments of his own making. The stars were visible during about four minutes of total darkness. He computed, and published, an almanac for the next year 1807, and also for the year 1808. He went into the business of surveying land about this time. He loved to climb the mountains, and enjoyed fine health. In the year 1808 he married Miss Gillet Kendall, a daughter of Noadiah Kendall of Granby Connecticut. She was one of the best of women, and had no enemies, but was beloved by every body who was acquainted with her. For a while he took students into his own house, and taught them such branches as each one had engaged to be instructed in. Julius M. Coy of Suffield, studied surveying—Levi —— also from Suffield studied Navigation, and soon went to sea, and after a while command[ed] a vessel. Benoni B. Bacon of Simsbury, studied Surveying and astronomy, Joseph W. King of Suffield, studied surveying—Henry Merwin of Granby studied Surveying, Jefferson Cooley, a graduate of Yale Colledge, studied surveying and civil engineering. He had also students from Granville Mass. But the school interfered with his other business, and he discontinued it. He manufactured about this time a good many sets of surveyors instruments—compasses, chains, scales, protractors, and dividers, some for his pupils and some for others. He also manufactured, magnets, electrical machines, leveling instruments, and some others. He was greatly attached to the business of surveying, and had more applications than he could attend to. He was compelled to leave it in 1825, and go into the business of civil engineering, which also in a few years, gave way for the business of manufacturing telescopes. At the commencement, he never thought of its ever becoming a business of profit. About the year 1830 he had completed an achromatic telescope, which he took to New Haven, and asked Prof. Benjamin Silliman to look at it. He did so, and at once took an interest in it, and published a notice of it in the American Journal of science, of which he was editor. He manufactured principally Reflecting

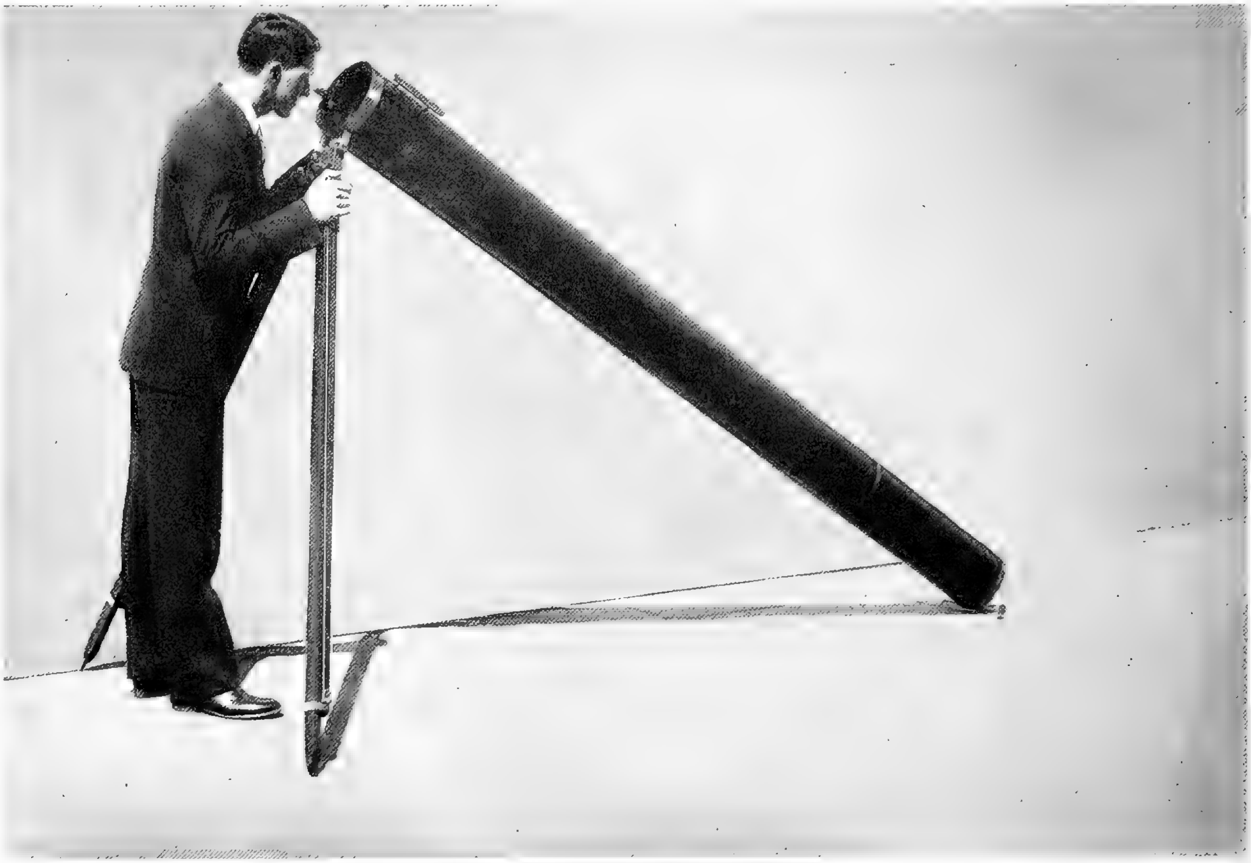

FIGURE 2.—Herschelian reflecting telescope (USNM 310598) built by Amasa Holcomb and shown by him at the Franklin Institute, Philadelphia, in 1835. The Institute's report of the demonstration is given in the appendix (p. 182). (*Smithsonian photo 11000–a*)

telescopes, of the Herschelian kind. About the year 1833, he began to have orders for telescopes. Among these orders was one from William J. Young, a celebrated Philosophical instrument maker of Philadelphia, who wanted two small diagonal metalic reflectors for two Transit instruments that he was making. Mr Holcomb made the articles wanted, and thought he would take them and a telescope and visit Philadelphia. Mr Young introduced him to the late Sears C. Walker, and Mr Walker introduced him to Mr Hamilton, Actuary of the Franklin Institute of the State of Pennsylvania, and the Actuary appointed a committee to examine the telescope. He selected the committee from the standing committee on Science and the Arts of the Institute. Mr Patterson of the Mint, Alexander D. Bach superintendent of the Coast survey, Dr Robert Hare the chemist, James P. Espey, Sears C Walker, Isiah T. Lukens and some others. These were among the first scientific men of America. The committee examined the telescope, and compared it with others of european manufacture. The Report of that committee may be found in the Journal of the Franklin Institute Vol. 14–p–169. The next year 1835 he took a larger telescope to Philadelphia, and offered it to the same committee for examination and comparison with european telescopes. That Report may be found in the Journal of the Franklin Institute Vol 16 p. 11. The next year 1836 he presented a Telescope 14 feet long to the same committee Their report may be found in the Journal of the Franklin Institute Vol. 18–p 312. These Reports furnish the best information in regard to the performance of these telescopes. The committee gave them a high character, and they were sold in almost every state in the Union. One went to Seramp in the East indies, and one to one of the Sandwich islands in the Pacific ocean. While he was pursuing his labors as Engineer, and manufacturing Telescopes, and other instruments, in 1839 the news reached this country from Paris, of Daguerres great discovery of taking pictures on silver plates by solar light.

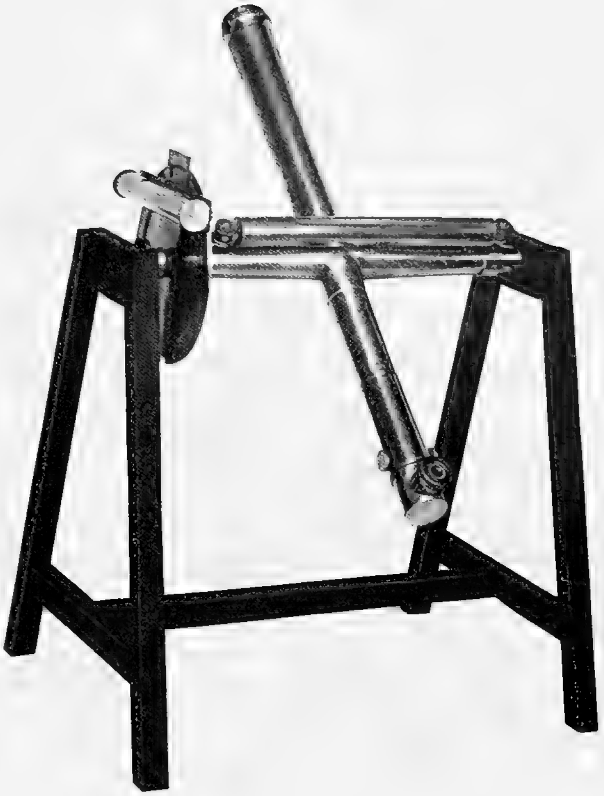

Figure 4.—Transit telescope (USNM 310599) made by Amasa Holcomb. The aperture is 1½ inches, length 21 inches, and axis 14 inches. It lacks the original support. (*Smithsonian photo 43472–c*)

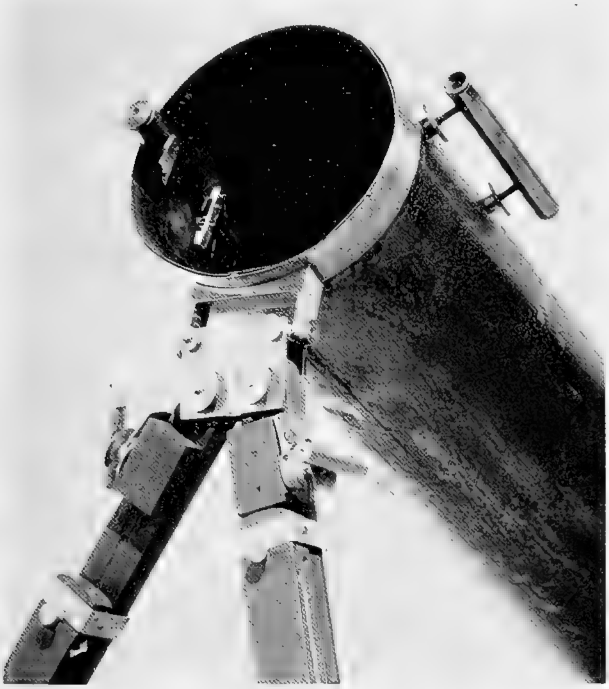

Figure 3.—Eyepiece and tripod head of the Holcomb reflecting telescope shown in figure 2. (*Smithsonian photo 11000*)

The discoverer had not then succeeded in taking likenesses from life. Holcombe immediately commenced experimenting and soon succeeded in taking portraits, on silver plates, made sensitive to light by Iodine. There was soon a great demand for instruments to take portraits. He had for a considerable time as much as he could do to supply the applications he received for these instruments, from 1839 to 1845. As the calls for these instruments lessened he continued the manufacture of telescopes. He was the first that sold a telescope of American manufacture. All the telescopes used in this country before 1833, had been obtained in europe. It had been said that they could not be made in this country. He had been greatly assisted in his sales, by the influence and recommendation of scientific men. It was soon discovered that telescopes could be made in America and about 1845, one after another went into the business, and there is now no further need of going to europe for telescopes, as good ones can be made in the United States as can be made in europe. The whole market was in his hands during thirteen years. During this time the business was good and paid well. The competition afterward reduced the profit. In 1816 he was chosen select man and assessor in his own town, which office he held during four successive years, and held the office occasionally by subsequent elections. In 1832 he was chosen to represent the town in the Legislature of Mass and he was reelected three successive terms. In 1852 he was elected to the State senate. In 1833 he was appointed a Justice of the Peace for the county of Hampden, which office he has held every year since, and his last commission does not expire until May 1875, at which time, if he should live to see it, he will be but a few days less than 88 years old. In 1837 he received from Williams Colledge the Honorary degree of A.M. In 1831 he was ordained a minister in the Methodist Episcopal church. He preached constantly on the sabbath during many years, and afterward occasionally until he was eighty years old.

II. Henry Fitz, 1808–1863

Julia Fitz Howell

Henry Fitz died suddenly through an accident in 1863, when he was in his 55th year. His widow closed his shop in New York City and moved the equipment to Southold, Long Island, where it was used by his son to complete certain contracts in progress. Thereafter it remained essentially as it was until nearly the present time, when the shop was offered to the U.S. National Museum of the Smithsonian Institution by Mrs. Julia Fitz Howell, granddaughter of Fitz. The decision to construct a new Museum of History and Technology made it possible to accept this generous offer, and the complicated project of transferring the shop and reassembling it was accomplished in 1957 through the assistance of Mr. L. C. Eichner.[1]

Although a few duplicate items were eliminated, the shop is essentially complete, including such items as Fitz's account books, the small rouge box he used to polish lenses in the course of a walk, and his door key. Through the assistance of Mr. Eichner and Mr. Arthur V. A. Fitz the Smithsonian has obtained a comet-seeker telescope and Fitz's first instrument, a small draw telescope.

The following biographical sketch was written by Mrs. Howell on the basis of papers in the possession of the family.

Henry Fitz, inventor and telescope maker, was born in Newburyport, Massachusetts, on December 31, 1808. Little is known of his mother, Susan Page Fitz, except that she was probably of Scottish ancestry. His father, Henry Fitz, Sr., was a hatter

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[1] For a list of Fitz material in the U.S. National Museum, see appendix, p. 184.

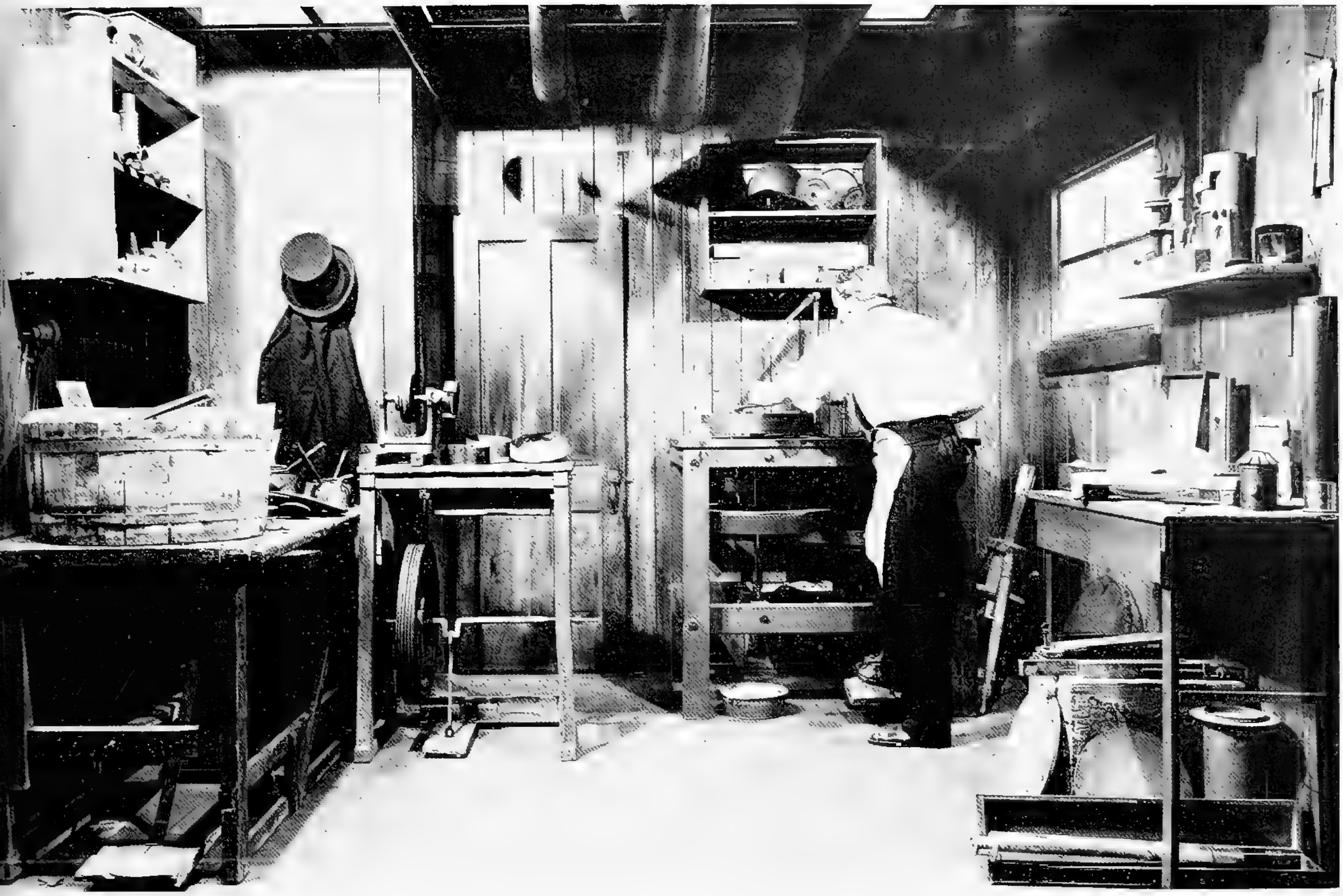

FIGURE 5.—The telescope-maker's shop of Henry Fitz as reconstructed in the U.S. National Museum. (*Smithsonian photo 46545*)

by trade and the youngest son of Mark Fitz, who for several years represented his city in the Massachusetts General Court.

Newburyport was then a prosperous and fast growing maritime community and the Fitzes, though not among its wealthy citizens, were a public spirited and reasonably prosperous family. As in other sections of New England, the War of 1812 made great changes in this pleasing picture. The town's shipping and ship-building had been brought almost to a standstill and all its business suffered disasterously. After the war recovery was very slow. Since few needed or could afford new beaver hats, Henry Fitz in 1819 took his wife and three small children first to Albany, New York, where he worked at his trade for awhile, and later to New York City.

To young Henry, aged eleven, New York was an exciting and stimulating place and he watched all its activities with eager interest. The father found the city stimulating in a different way. An enthusiastic Universalist, he met in New York many persons with similar leanings. He soon established a religious weekly, *The Gospel Herald*, which he edited for several years. It is therefore not suprising that young Henry was set to learning the printer's trade, but although he rapidly became skilled, he didn't especially like the trade. What he most enjoyed about it was tinkering with the machinery of the shop. In this his mechanical ability soon became evident. When his father relinquished his editorship, Henry, then nineteen, gladly turned to different work.

He chose locksmithing, which he learned speedily and well in the shop of William Day of New York. The years 1830 to 1839 found him travelling between

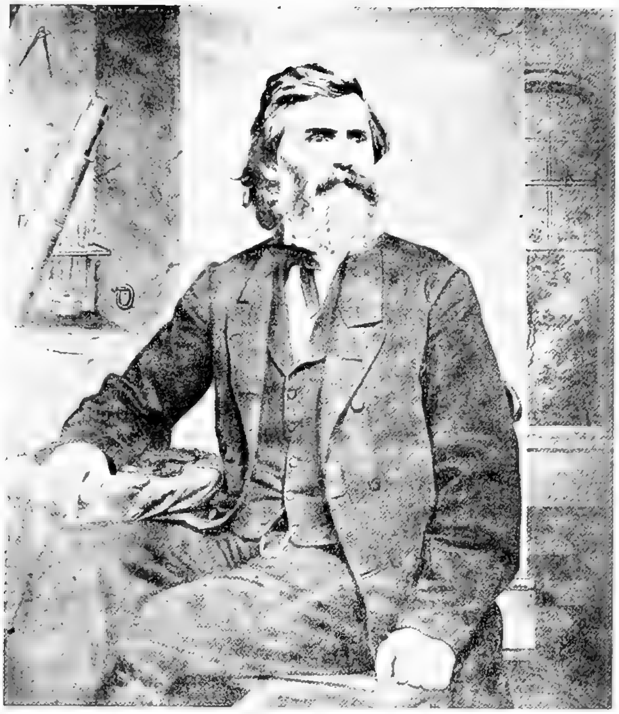

FIGURE 6.—Henry Fitz, from a photograph in the collections of the U.S. National Museum. (*Smithsonian photo 44594–b*)

New York, Philadelphia, Baltimore, and New Orleans, following the activities of the building trades and trying by long hours and austere living to save money for a locksmith shop of his own. For the sake of both health and pocketbook, he never rode if he could walk, neither drank nor smoked, ate little meat, and lived chiefly on graham bread and water.

Evenings were spent in reading, study, and the pursuit of hobbies, chief of which was astronomy. His diaries and letters of this period show him buying telescopes and lenses and carrying them with him on his travels. He first made a telescope in 1838, a reflector, with which he delighted to show the stars and planets to his friends. The well-known Reverend Clapp of New Orleans referred to him in a public address as "the young locksmith who knew more about the heavenly bodies than anyone else in the United States." Henry was pleased with this compliment, even while deprecating the enthusiasm which prompted it.

FIGURE 8.—Advertisement of Henry Fitz, about 1850. (*Smithsonian photo 44594–a*)

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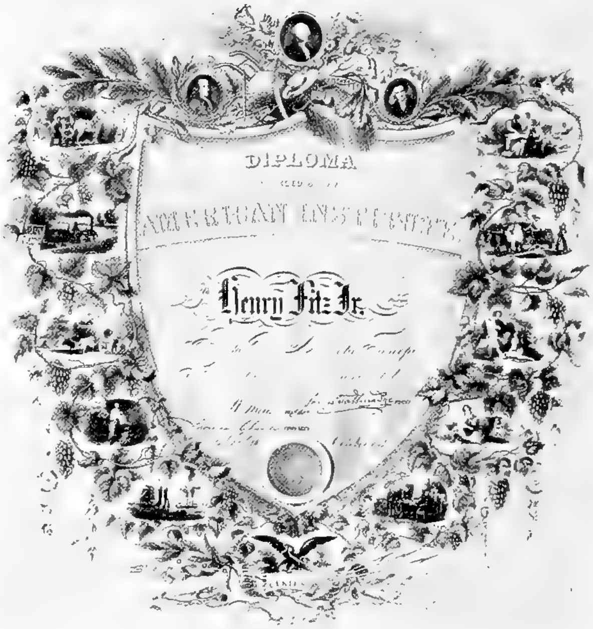
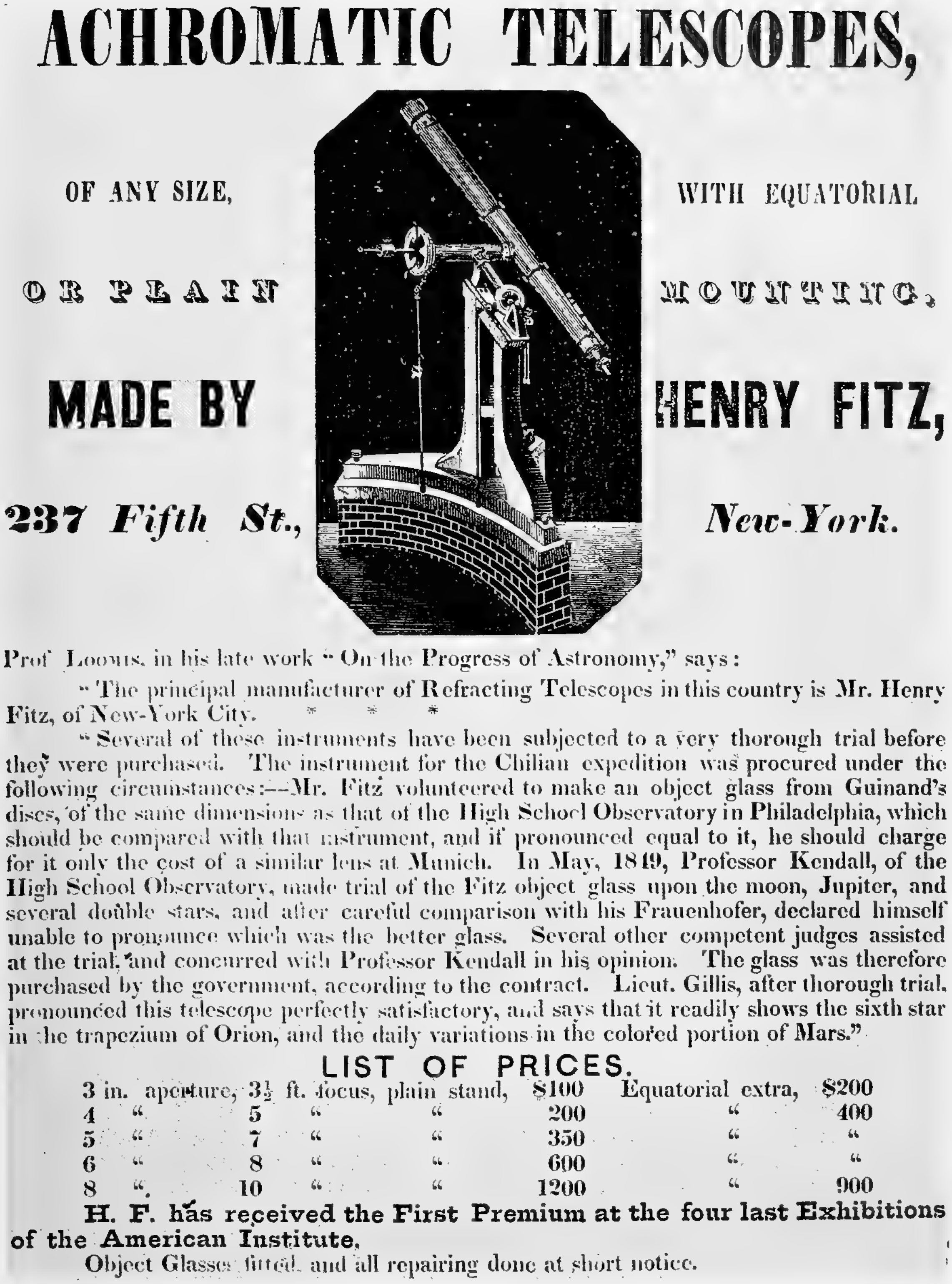
FIGURE 7.—Certificate of award to Henry Fitz, Jr., by the American Institute, 1852, "For the best achromatic telescope." (*Smithsonian photo 46815–a*)



DIPLOMA

AMERICAN INSTITUTE

Henry Fitz Jr.



ACHROMATIC TELESCOPES,

OF ANY SIZE, WITH EQUATORIAL

OR PLAIN MOUNTING,

MADE BY HENRY FITZ,

237 Fifth St., New-York.

Prof. Loomis, in his late work "On the Progress of Astronomy," says:

"The principal manufacturer of Refracting Telescopes in this country is Mr. Henry Fitz, of New-York City. * * *

"Several of these instruments have been subjected to a very thorough trial before they were purchased. The instrument for the Chilian expedition was procured under the following circumstances:—Mr. Fitz volunteered to make an object glass from Guinand's discs, of the same dimensions as that of the High School Observatory in Philadelphia, which should be compared with that instrument, and if pronounced equal to it, he should charge for it only the cost of a similar lens at Munich. In May, 1849, Professor Kendall, of the High School Observatory, made trial of the Fitz object glass upon the moon, Jupiter, and several double stars, and after careful comparison with his Frauenhofer, declared himself unable to pronounce which was the better glass. Several other competent judges assisted at the trial, and concurred with Professor Kendall in his opinion. The glass was therefore purchased by the government, according to the contract. Lieut. Gillis, after thorough trial, pronounced this telescope perfectly satisfactory, and says that it readily shows the sixth star in the trapezium of Orion, and the daily variations in the colored portion of Mars."

LIST OF PRICES.

3 in.	aperture,	3½ ft.	focus,	plain stand,	$100	Equatorial extra,	$200
4	"	5	"	"	200	"	400
5	"	7	"	"	350	"	"
6	"	8	"	"	600	"	"
8	"	10	"	"	1200	"	900

H. F. has received the First Premium at the four last Exhibitions of the American Institute.

Object Glasses fitted, and all repairing done at short notice.

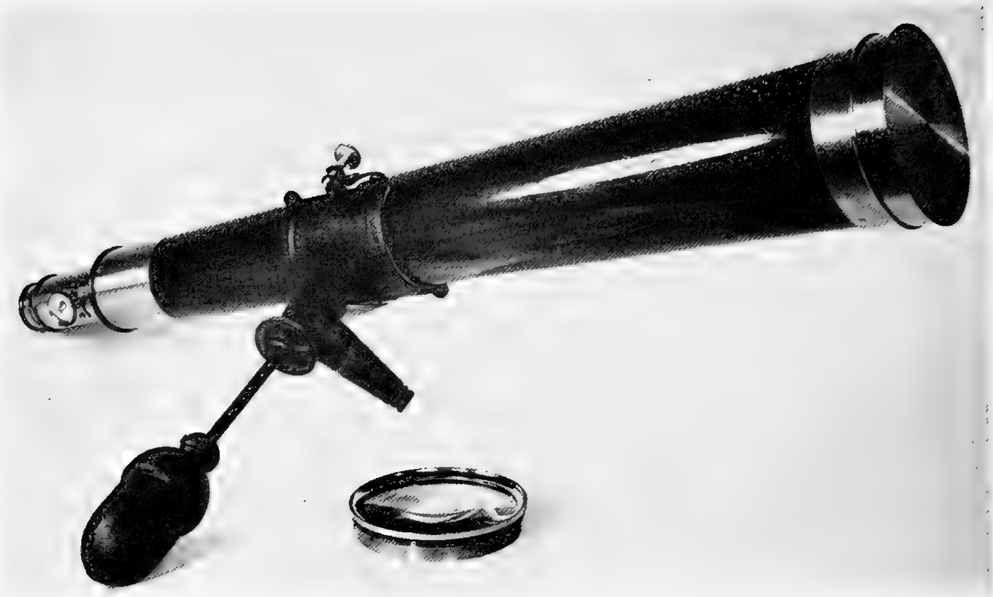


FIGURE 9.—Refracting telescope, comet seeker, (USNM 317027) byHenry Fitz, 8¼-inch aperture, 61-inch tube, fitted for equatorial mounting. The stand is lacking. (*Smithsonian photo 46815*)

Although he saved money, his work did not bring him the financial or other rewards that he had hoped for. In spring of 1839 he appears to have worked as a speculum maker with Wolcott and others—one of them may have been his acquaintance John Johnson—and to have read of Daguerre's work in photography. To learn more of these experiments, as well as to inquire into optics and optical glass, he sailed to Europe in August of that year, taking passage by steerage.

He returned to New York in November 1839 and in that month, according to the testimony of his son Harry, made a portrait with a camera invented by Wolcott. This camera portrait he believed to be the first ever made. In 1840, after more experimenting, he set up a studio in Baltimore, where his father was then living, and spent several years there "taking likenesses." At the same time he continued to work with telescopes and lenses. His first refractors were built there, instruments he later referred to as crude affairs.

While in Baltimore he took a step which marks the beginning of the final phase of his career. In June 1844 he married Julia Ann Wells of Southold, Long Island, whom he had known for about a decade and with whom he had long corresponded. Julia was a woman of unusual ability and personality, less scientific than he but more literary and artistic, and no less intelligent. With her to encourage him, he continued his experiments in telescope building. A year after their marriage they moved to New York, where he was to spend the remainder of his life.

That summer he prepared a 6-inch refracting telescope for exhibition at the Fair of the American Institute, held annually in New York. This carefully constructed instrument, with its ingenious tripod and its achromatic objective—which he had made himself, correcting the curves by a process of his own invention—won the highest award of the Fair, a gold medal. It was the first of many such medals he was to earn. His telescope also received favorable notice from scientists and astronomers, among them Lewis M. Rutherfurd, a wealthy New Yorker and trustee of Columbia College. Rutherfurd immediately ordered a 4-inch refractor for his own observatory. His interest and example soon brought orders from others.

From this time on, Henry Fitz devoted most of his energies to building telescopes. Cameras were not altogether abandoned. He continued to make them and to instruct others in their use. He invented a camera lens that was patented posthumously. He was one of the founders of the American Photo-

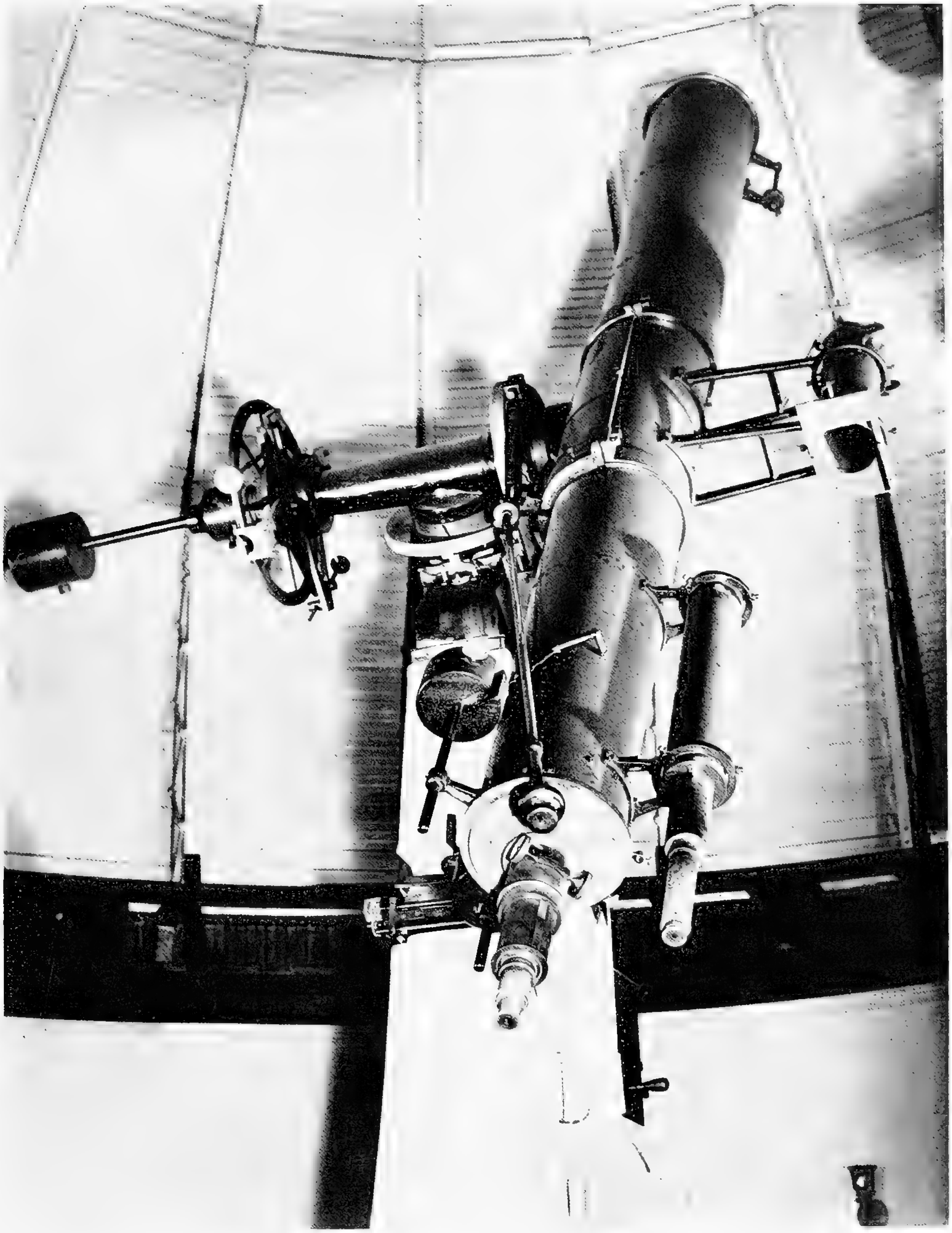


Figure 10.—Henry Fitz made this 13-inch equatorial refractor in 1861 for the Allegheny Observatory. It is still in use. The University of Michigan has in use a Fitz refractor of similar size. (*Photo courtesy Allegheny Observatory*)

graphical Society and remained interested in it all his life. But from 1845 on, cameras became secondary; he built them between telescope orders.

During the years that followed he constantly improved the quality of his lenses and the accuracy and speed with which he could "execute the true curves," as he expressed it. He used better and better glass. In his early experiments he had taken what came to hand—ordinary tumbler bottoms, for instance. In his 1845 prize winner he combined Boston-made flint with French plate glass. But the Boston flint proved too veiny for any but small lenses and he soon was importing both crown and flint. He designed and built machines, run by foot power, on which he could train employees to do much of the labor of lens making, always reserving the final polishing for himself. He increased the size as well as the quality of his lenses. By 1856, he was making 12½-inch refractors, which according to Prof. Loomis, were as large as any that had then been made in Munich. He built later, still larger ones, of which one was a 16-inch instrument made for Mr. Van Duzee of Buffalo. It was his ambition to make a 24-inch one, but this project, for which he had made careful plans, he did not live to complete.

One of his early successes was a 3¾-inch telescope for the Government of Haiti. By a happy accident the objective for this instrument proved to be exceptionally fine and provided a standard which he tried to meet in all his work. The telescopes of European opticians became another measuring stick. It was a matter of both personal and patriotic pride to him that he, an American locksmith untrained in optics, had been able to invent his own process for making so complex and difficult a thing as an achromatic lens, and that he was able to manufacture telescopes to compete with those of European make. He sometimes contracted to make a telescope equal in performance to an imported one of similar size, usually at a lower price. The 6¾-inch telescope made in 1849 for Lt. J. M. Gilliss to use on an astronomical expedition to Chile passed such a test and greatly enhanced Henry Fitz's reputation. Another that met such a test was the 13-inch instrument made for the Allegheny Association at Pittsburgh in 1861.

His telescopes were procured by private observatories not already mentioned, among them that of Van Arsdale, in Newark, and of Campbell, in New York. For Rutherfurd he made several, including a 9- and a 12-inch instrument. The latter is now at Columbia University. Among the telescopes made for colleges were a 12-inch one for Vassar and another for the University of Michigan. Besides these and other important instruments he made many of smaller size—4, 5, 6, and 8 inches.

Most of the time, he was handicapped by lack of capital with which to develop his business. The savings from locksmithing days he had, on his father's advice, invested in Baltimore real estate, but found it difficult to raise cash on this property when he needed it. With the many orders that came in, this situation gradually improved, though he always continued to supervise all phases of the process and to work 12 to 16 hours a day himself. As soon as his eldest son, Harry, was old enough, he taught him all he knew. The boy proved an apt pupil and a great help. By 1863 Henry Fitz felt secure enough to give up renting, and had a house built for his family and business in 11th Street, not many blocks from his friend and patron, Mr. Rutherfurd. Plans for the future looked bright. However, the family had hardly moved into the new home when disaster befell. A heavy chandelier fell on the master of the house, causing injuries which in a few days proved fatal. Henry Fitz died on October 31, 1863, at the height of his career, leaving to carry on his work a widow and six children, the oldest a girl of eighteen, the youngest an infant.

His son Harry, not yet seventeen, was able satisfactorily to fulfill the outstanding contracts. In this he had the backing and advice of Mr. Rutherfurd. In fact, Harry continued the business, though on a smaller scale, for some twenty years. Eventually he became a teacher of drawing, pursuing this occupation for over forty years more.

As soon as possible the widow, Julia Ann Wells Fitz, sold the city house and bought a farm in Peconic, Long Island, near her birthplace, where she managed to raise her family. All the children showed marked ability. Louise, the only daughter, married Silas Overton of Peconic, and used her talents in home and community. The second son, Benjamin, became a noted painter before his early death in 1890. Robert's reputation as a fine mechanic was county-wide. Charles was a prominent business and civic leader in Suffolk County. George became a physician and inventor and was for a time Professor at Harvard. All married, and there are now living in the United States about fifty descendants of Henry Fitz, telescope maker.

A number of his instruments, though made a century ago, are still in use.

III. John Peate, 1820–1903

F. W. Preston and William J. McGrath, Jr.

Although John Peate was born when Holcomb was only 33, and before that pioneer telescope-maker had produced his first instrument, he lived well into the time when American telescope-making had come of age. Before Peate's death George Ellery Hale had begun his career as a promoter of large telescopes; indeed, the Yerkes 40-inch refractor was completed a year prior to Peate's delivery of his own magnum opus, a 62-inch reflector, to The American University. For 34 years the University sought funds to finance the installation of this mirror, until it finally became obsolete as a result of advances in the technology of glass mirror making.

In 1934 it was sent by the American University to the Smithsonian Institution. About this time Dr. F. W. Preston undertook the difficult task of reconstructing Peate's career and particularly the story of the great mirror. His results were published in the Bulletin of the American Ceramic Society *in 1936.*

With the gracious permission of Dr. Preston and the Bulletin, *this article has been condensed, and augmented, for publication here by William J. McGrath, Jr., of the United States National Museum staff.*

JOHN PEATE, bricklayer, Methodist minister, and amateur extraordinary in the art of telescope making, was the first born of Thomas and Mary Peate.[1] He was born on May 6, 1820, in the small northern Irish town of Drumskelt. When John was seven, his father, a mason, emigrated to Quebec, Canada, the first of several moves to cities in Canada and the United States, terminating in 1836 in Buffalo, New York, where the father was to spend the last seven years of his life.[2]

Nothing is known of the circumstances of John's life during these early years, nor of his education. In 1836, at the age of 16, he entered his father's trade as an apprentice bricklayer. He worked at this trade for about sixteen years, apparently intermittently, for he seems to have been a student at Oberlin College part of the time between 1842 and 1845.[3] In the latter year he married Mary Elizabeth Tilden of Buffalo.

Peate's career as a bricklayer ended in 1851, when he became a full-time minister, having been converted to his mother's religion. This came about in consequence of his attendance, when he was about 20 years old, at a Methodist revival. There he was "converted," and, with characteristic energy and enthusiasm, plunged into his new religion. His attendance at Oberlin may have been connected with his preparation for the ministry. In any case, he started to preach in 1849, on trial with the Methodist Erie Conference, was ordained a deacon in 1851, and an elder two years later. From this time until he was made a supernumerary in 1894 he worked full-time as a minister.

The mobility which marked his early life was repeated in his ministerial career. Including his probationary term he held 19 different appointments in 14 cities and towns in northwestern Pennsylvania, northeastern Ohio, and southwestern New York. He was a successful and popular minister, and is said to have converted some 500 persons at one revival in Jamestown, New York. J. N. Fradenburgh, historian of the Erie Conference, begins his sketch of Peate's life with the phrase, "Who has not heard of John Peate?"[4]

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[1] F. W. Preston, "The first big American telescope mirror, John Peate, his lens," *Bulletin of the American Ceramic Society*, 1936, vol. 15, pp. 129–152. Hereafter cited as Preston.

[2] The circumstances of Peate's life and ministerial career are from Preston, supplemented by Dr. Peate's service record, provided by the Erie Conference of the Methodist Church. Dr. Preston's prime sources are: J. N. Fradenburgh, *History of the Erie Conference*, Oil City, Pa., 1907, vol. 2, pp. 204–211; obituary notice by R. N. Stubbs in *Minutes of the Erie Conference*, pl. publ. 1903, p. 90. Other data were obtained by Preston through interviews and letters, all cited in detail in the article.

[3] From information provided by Robert Barr, acting secretary of Oberlin College, February 15, 1960. The college records show a John Peate from Buffalo enrolled in the preparatory department in 1842–43 and 1844–45. The *Encyclopedia Americana* (1924 ed., vol. 21, p. 460) states that Peate attended Oberlin about this time. The Doctorate was an honorary one conferred by Allegheny College.

In 1859 Peate journeyed to Europe, visiting England and Ireland, and making a walking tour of western Europe and the Middle East. His biographer Fradenburgh hints that his interest in astronomy was aroused on this trip. In any event, upon his return home, he took up the study of the science. His fellow minister, R. N. Stubbs reported that "his library reveals that difficult and abstruse works became his delight." At some point in the perusal of these "abstruse works," Peate decided to concentrate on that basic tool, the telescope. It is possible that he first made a telescope, as many amateurs do, to advance himself in the study of astronomy, and only after completing it realized that his primary interest lay in the instruments rather than in the theoretical science. His natural aptitude for craftsmanship probably exerted a strong influence in this decision.

His first instrument was a 3-inch refractor which he made and mounted for his own use. This was about 1870. He next made either a 6-inch refractor or a 6-inch reflector, or perhaps both. One of these, if there were two, was mounted by Peate for use at Chautauqua and Jamestown, New York, and then used in his own observatory at Greenville. After his death it was taken to Salina, Kansas, by W. F. Hoyt, for a small observatory there.[5]

Thereafter Peate made reflectors exclusively. It is possible that he was influenced by the treatise on the making of silvered glass reflectors, by Dr. Henry Draper, published by the Smithsonian Institution in 1865, a work which led to a great improvement in the construction of reflectors in this country.[6]

Attempts to trace Peate's mirrors have been singularly inconclusive. A 7-inch reflector sent to India was still in use in 1903.[7] A 12-inch reflector made for "Harriman University, Tennessee," was evidently mounted, but no record even of the observatory has been found at the present time [1936].[8] A 15-inch mirror in a reflector located at Allegheny College in 1935 was probably made by Peate, although the College records do not show its origin, nor do they mention a 30.5-inch mirror which Peate was making for Allegheny College in 1891, according to an article in *The Scientific American.*[9] Definitely Peate's was a 22-inch reflector found in about 1935, still in its packing case, at Thiel College, Greensville, Pennsylvania.[10]

Altogether, 10 lenses and mirrors (sometimes also described as "lenses") have been traced. As many as 20 were ascribed to him by some sources at the time of his death. Of these only his magnum opus, the 62-inch mirror now in the Smithsonian Institution, can now be found. Most of them seem never to have been used, but this is not necessarily an indication of defects in the instruments. As our consideration of the 62-inch mirror will show, Peate was a competent maker. Nor is it a consequence of his being an amateur. Many of the large telescopes in the world in the mid-nineties had lenses and mirrors made by two other Americans, John Brashear and Alvin Clark, who, like Peate, entered telescope making as amateurs.[11] But they had the fortune to become associated with well known professional astronomers. Peate may have erred in presenting his reflectors to institutions unable to finance their installation. Perhaps his error was in presenting rather than selling them.

We come now to Dr. Peate's greatest mirror, the 62-inch reflector. In September 1893 the annual meeting of the Erie Conference was held at Dubois, Pennsylvania. This was to be Dr. Peate's last meeting as an active minister. In 1894 he would become a supernumerary, a position of semiretirement, after which he would retire. In order to honor the old minister and to mark the opening of a new Methodist university, American University, at Washington, D.C., it was decided to commission Peate to make a telescope mirror for the school. This was to be no ordinary reflector but the largest in the world.

While the facts surrounding this commission and its accomplishment are astounding in themselves it has inspired an even more remarkable legend, which, although rather unjust to the ability and good sense

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[4] Fradenburgh, *op. cit.* (footnote 2), p. 204.

[5] Preston, p. 130, n. 10; p. 131, n. 19; p. 148.

[6] "On the Construction of a Silvered Glass Telescope, Fifteen and a Half Inches in Aperture, and its Use in Celestial Photography," *Smithsonian Contributions to Knowledge*, vol. 14, art. 3, iv+55 pp., 1865 (reprinted in vol. 34 as art. 2, 1904).

[7] Preston, p. 148. From an article in the Greenville, Pa., *Record Argus*, December 17, 1903.

[8] Preston, p. 148. In 1960 it was further learned that an "American Temperance" college or university once existed at Harriman.

[9] *Scientific American*, October 24, 1891, vol. 65, p. 260.

[10] Communication from Thiel College, Preston, p. 131, n. 17

[11] *Popular Astronomy*, July 1898, vol. 6, p. 310.

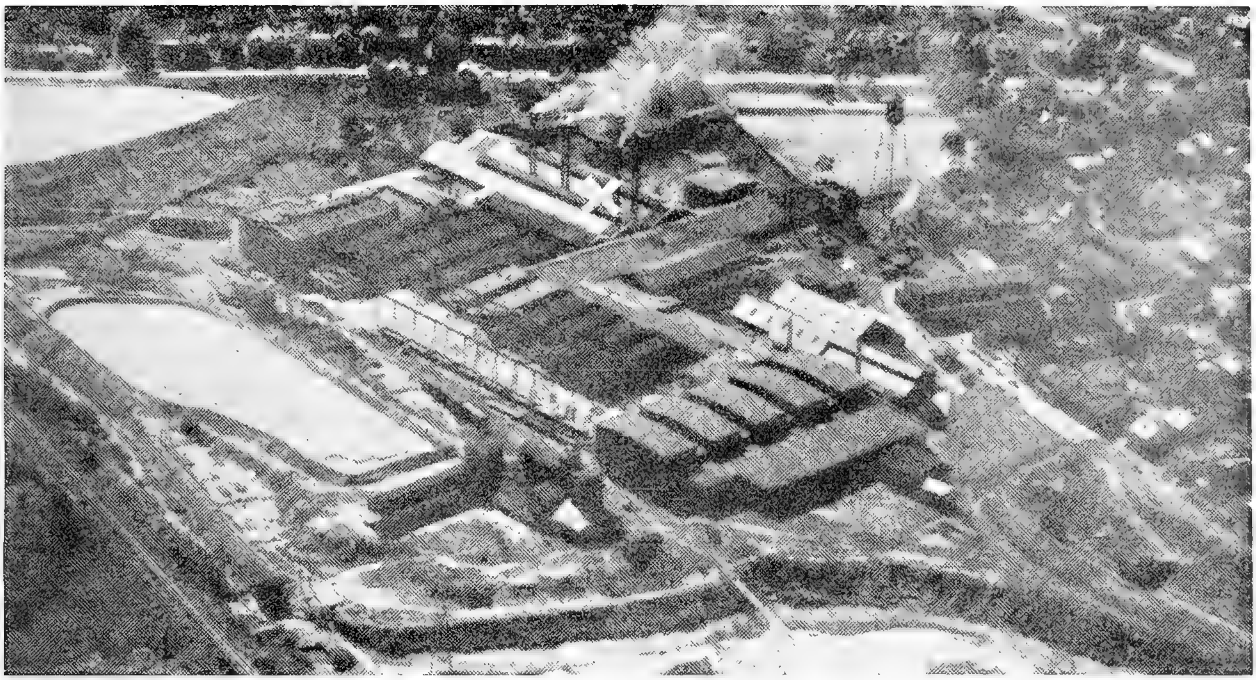

FIGURE 11.—Standard Plate Glass Company, Butler, Pennsylvania, with x marking building where Peate's 62-inch disc was cast. (From Preston, fig. 1.)

of Dr. Peate, indicates the impression his hobby had made on his contemporaries. According to this legend, John suddenly realized at the age of seventy-three that he must have something to occupy his time while retired.

"What am I to do all the rest of my life?" he asked of the presiding officer of the meeting, Bishop Hurst, who was also chancellor of the newly founded University.

"Oh, study astronomy," said the Bishop.

"Make a big telescope lens," said Dr. Wythe.

Dr. Wythe, whose doctorate was in medicine, was a minister well known in the conference as an inventor and technologist. The legend continues that, urged on by Wythe, Peate announced to the conference, "I will make for the new University the largest telescope lens in the world, if you will defray the out of pocket expenses."

"Well, how big a lens can you make?" asked the Bishop.

"Oh, as big as that chart on the wall," said Peate. "Get a rule and measure the chart."

The chart was 62 inches across.

"Offer accepted. One 62-inch reflecting telescope from Dr. Peate," ordered the Bishop.[12]

The minutes of the conference state: [13]

> Proposition of John Peate. . . . John Peate made a proposition to manufacture a large reflecting lens for the University providing material for the same was furnished him . . . a committee of 5 was appointed to take the same into consideration. R. N. Stubbs, G. H. Humason, N. T. Arnold, G. P. Hukill, and G. B. Chase were appointed to that committee.

Although he was 73 years old Peate was in good health and had tremendous vitality for one his age. He had already made a number of large mirrors, so that he could estimate the amount of time and energy he would expend in this work. He knew that if he retained his health for the next few years he could complete it.

With his typical planned enthusiam he started his preparations. He wrote to his usual supplier St. Gobain of France asking the price of a glass blank large enough for a mirror of this size.[14] They quoted a price of $18,000—more, obviously, than he could afford. He then canvassed the glassmakers of Pittsburgh, the center of American glassmaking. However, the Pittsburgh firms had little experience in optical glass, especially of this size, and none would consider making the blank.

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[12] Preston, p. 129, notes 2 & 3. Based on recollections of George Lambert (1895) and John Morrison (1903). That the decision to make the mirror 62 inches in diameter may have had another origin is suggested by the fact that Common, in England, had made two mirrors of 60 and 61 inches in 1886–91.

[13] Minutes of the Erie Conference, 1893, p. 29. Preston, p. 130, n. 4.

Having been rebuffed in Pittsburgh, he approached the Standard Plate Glass Company of Butler, Pennsylvania. Plate glass making, at least profitable plate glass making, was new in America and the Standard was one of the newer companies. Moreover, it was reputed one of the best plate glass makers in the country. Peate wrote to H. C. Tilton, general manager of the plant, asking him for a disc of glass without bubble or flaw 62 inches in diameter and 7 inches thick. He further advised him that he would see him in a few days. Tilton's experience and that of his top supervisors was limited to the business of making ordinary plate glass. Therefore, he sought advice as to the feasibility of this fantastic project. He consulted George Howard, maintenance engineer of the plant, who had graduated from Cornell only a year before. George Howard, later to become noted as an inventor of glassmaking machinery, was at this time simply an optimistic young engineer.

"Howard, here's a man at Greenville who wants us to cast him a disc 62 inches in diameter and 7 inches thick. Is that possible?"

Howard calculated the cubical contents of the proposed disc and replied that it was just barely possible. He didn't see any particular difficulty in it. He thought the first few attempts might fail but felt that they could cast it successfully. Howard was later to ascribe his success more to his optimism and ignorance, rather than to any particular innovation he made. After being reassured by Howard, Tilton continued "Well, this Dr. Peate is coming down here tomorrow and he wants a quotation. How much do you think we ought to ask?"

"We'll have some special apparatus to make and some experimenting to do. Then we'll probably lose two or three pots of glass. I think you'd better ask him $800." Howard thought that this was plenty. Tilton, however, was more cautious and doubled the price. Peate arrived in Butler on schedule. When Tilton named his price, Peate, of course, agreed instantly. Tilton was somewhat shocked and probably would have been more so had he known what St. Goubain had asked. At any rate the contract was placed with Standard, apparently in October 1894.

Having obtained a maker for his disc Peate immediately began making arrangements to prepare the disc. He contracted with the machine shop of a John Hodge for the tools with which the mirror would be worked. This small firm, The Hodge Manufacturing Co., employed only four men besides the owner. Among these was Frank A'Hearn, then just a boy, who became the prime source for details of the tools used by Peate in this work. Starting in November 1894 notes such as, "worked for Dr. Peate 3½ hours" begin to appear in his workbook.[15]

The Hodge company made several (probably three) grinding tools for Peate. One was about 12 inches in diameter, and was to be used by hand. Two of the larger tools were provided with the male member of a ball and socket joint and were to be

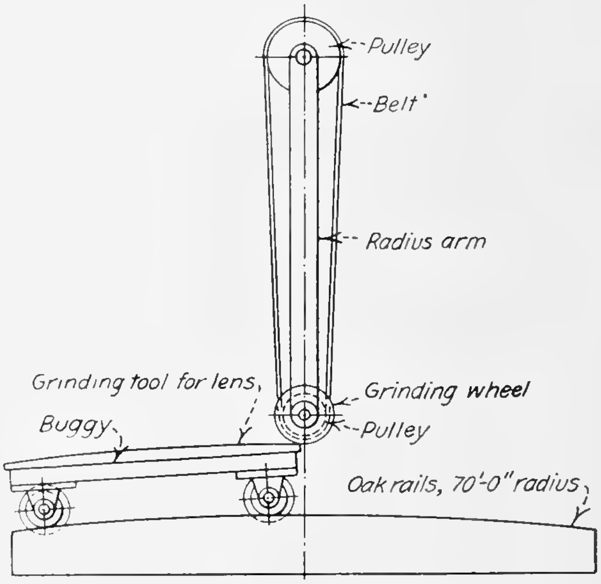

FIGURE 12.—Hodge's method of cutting the checker grooves. (From Preston, fig. 6.)

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[14] Preston has reconstructed the story of the making of the 62-inch mirror from contemporary journals, which will be cited below, and from personal communications with some of the participants, notably George Howard and George Lambert. Detailed citation of these communications are given in Preston. He has also used a brief manuscript account by Peate himself (Preston, p. 142, n. 62).

[15] Communication with Frank A'Hearn and John Hodge. Preston, p. 135.

power driven. They were 30 and 48 inches in diameter, respectively. The largest was grooved to a waffle-like surface on its convex face. These grooves were about ½ inch wide and 3/16 inch deep. This pattern was ground by placing the tool face up on a wheeled buggy, which rode on cambered oak rails. As it was pushed along the length of the rail the grinding wheel on the radius arm cut one groove. When the groove had been cut, the radius arm was moved 2 inches along a line shaft and another groove cut. When all the grooves had been cut in one direction the tool was turned 90 degrees on the buggy and the other set of grooves was ground. The grinding of this tool took many weeks, and making the tools and apparatus for Peate may have kept Hodge busy for nearly six months.[16]

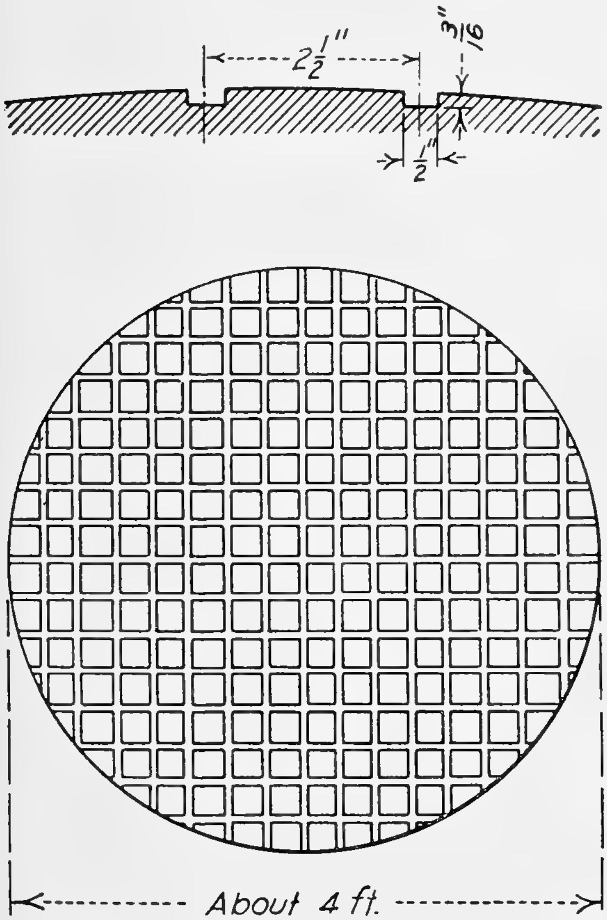

FIGURE 13.—Face of largest grinding tool made by Hodge for Peate. (From Preston, fig. 5b.)

The history of Peate's 62-inch mirror probably would have remained as obscure as that of his others except for the furor which arose over casting the disc. The Erie Conference made no attempt to publicize this project, and both Hodge Manufacturing and Standard Plate Glass accepted Dr. Peate's contracts as somewhat unusual but hardly newsworthy jobs. But when the glass trade became aware of Standard's intention to cast this disc, a mighty outcry arose. Instead of encouraging Standard to complete this novel task the *National Glass Budget*, one of the leading trade journals, reviled them as "bumpkins" for attempting something that even the great glassmakers of Europe would not do.

It is hard to imagine why the trade journal so strenuously objected to Standard's attempt. It has been suggested that it derived from the fact that Standard Plate Glass just previous to that time had refused to join in a combination of Pittsburgh companies which had set up a glass trust.[17] Or it is possible that the young industry was afraid that an overly ambitious project doomed to failure might open American glassmaking to European ridicule and so harm the entire American industry. Whatever the reason, the *Budget* ridiculed Standard Plate Glass, and later Dr. Peate, for the attempt. They argued that it could not be done, but that if it were possible Pittsburgh would be the logical place to try it. Criticism and unfavorable comment came from other sources also, including "university professors from Meadville" (evidently Allegheny College).[18] Nonetheless, Standard Plate Glass started the project.

George Howard was in charge of the casting operation. He planned to use the glass from a pot regularly used in the routine manufacture of plate glass. However, certain modifications were introduced in the procedure. The glass was to be poured on the traveling casting table, upon which was placed a circular mold made up of two semicircles of a special charcoal iron obtained from Philadelphia. This iron was not apt to generate bubbles of gas when in contact with the molten glass.

The iron mold was hinged at one joint of the semicircles, and the other joint was bolted. After the cast was poured it would be allowed to cool somewhat. When it was judged cool enough, it would be pushed into a kiln to be annealed. After it had remained in the kiln a certain length of time—again based simply on judgement—a quantity of pre-heated sand was to be poured over the mold as insulation. A further innovation was the use of a zinc sheet placed on the underside of the mold to avoid the possibility of trouble from grease on the casting table. This was the initial plan of operation.

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[16] Peate's workshop and apparatus is described in detail by Preston, pp. 135–138.

[17] Preston, p. 139.

[18] *Advance Argus*, Greenville, Pa., May 9, 1895. Preston, p. 139.

Sometime early in 1895 the first attempt was made. It was an immediate failure. The zinc sheet, intended to protect the cast from grease, volatilized when the molten glass was poured on it, bubbled up through the glass, and, of course, ruined the cast.

The second attempt was evidently made sometime in March. The casting itself was successful. Sand had been substituted for the zinc sheet. The cast was placed in the kiln, and when it was thought to be set the insulating sand was poured over it. After a time variously estimated at from 4 to 11 days, the cast was considered sufficiently annealed, and was examined.

When the sand was removed, the disc was found in fragments. There was also a large concavity in what would have been the face of the disc. The sand had been poured over it before the glass was sufficiently set. However, the disc had been destroyed by its iron mold. The mold had contracted against the disc, bending the bolt and deforming the hinges, and this trememdous pressure had shattered the glass. The next issue of the trade paper jubilantly noted the failures. They also included Dr. Peate in their derision. They said in effect that at least this experience would save the old preacher the waste of many years of time and effort.[19]

This slur on their most esteemed citizen brought the Greenville papers into the battle. The *Budget* had also made the mistake of implying that any number of Pittsburgh manufacturers were willing and able to make the disc. John Morrison, at that time editor of the Greenville *Advance Argus*, and source of much of our information regarding this controversy, immediately called the bluff of the trade paper, which was able to supply but one name, that of a George A. McBeth Company. This firm promptly declined without qualification. Later the name of the Phillips Semner Co. was given, and this firm guaranteed a perfect disc within 60 days for a "remunerative price," but would not state what this price was.[20] Therefore Dr. Peate could not deal with the firm.

Although the hue and cry continued for a few more weeks, the battle was really over, for Howard was soon to cast his disc. He had replaced the iron bolts in his mold with bolts of red oak dipped in nitric acid and then charred. The purpose of this was to relieve the strain on the glass by having the wooden pegs break as the mold contracted.

The third cast was in the kiln and in process of being annealed when Howard read in the *Budget* an article that set forth the difficulties of successfully casting optical glass. This article was anonymous and was obviously the work of an expert; it is thought to have been written by John Brashear.[21] Although Howard was thoroughly discouraged by this article, the cast had already been made and no harm could be done now by allowing it to cool and be examined.

In May 1895 Howard, with the workmen, opened the kiln. The mold was loose, so the pegs had sheared as expected. When the sand was removed the disc was found to be whole. A close inspection revealed no obvious faults. The disc was gently carried to an inspection room and Dr. Peate was immediately sent for. He arrived, examined the disc for a moment, then said, "Give me a hammer." Before anyone could move he seized a nearby hatchet and knocked off the sprue, or tail left as the pot was removed from the mold. The onlookers feared the lens would "explode," as predicted by its detractors, but the only result was the removal of the tail, as Dr. Peate expected.[22]

The *Budget* was still saying it couldn't be done. Commenting on a May 1, 1895, announcement of the removal of the disc from the kiln, the paper seized on the fact that the disc was still warm to predict that it would be shattered before Peate could examine it, and reiterated its low opinion of Standard Plate. By the time this issue was in the hands of its readers however, the disc had been inspected and approved by Peate.

Newspapers in Pittsburgh and elsewhere carried the news of the great American disc. The embarrassed *Budget* replied that it was not talking about the mere

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[19] Clipping of uncertain data from the *Pittsburgh Leader*, quoting the *National Glass Budget*. Preston, p. 139 and n. 55.

[20] Preston, p. 140.

[21] Preston, p. 139.

[22] Preston, p. 140.

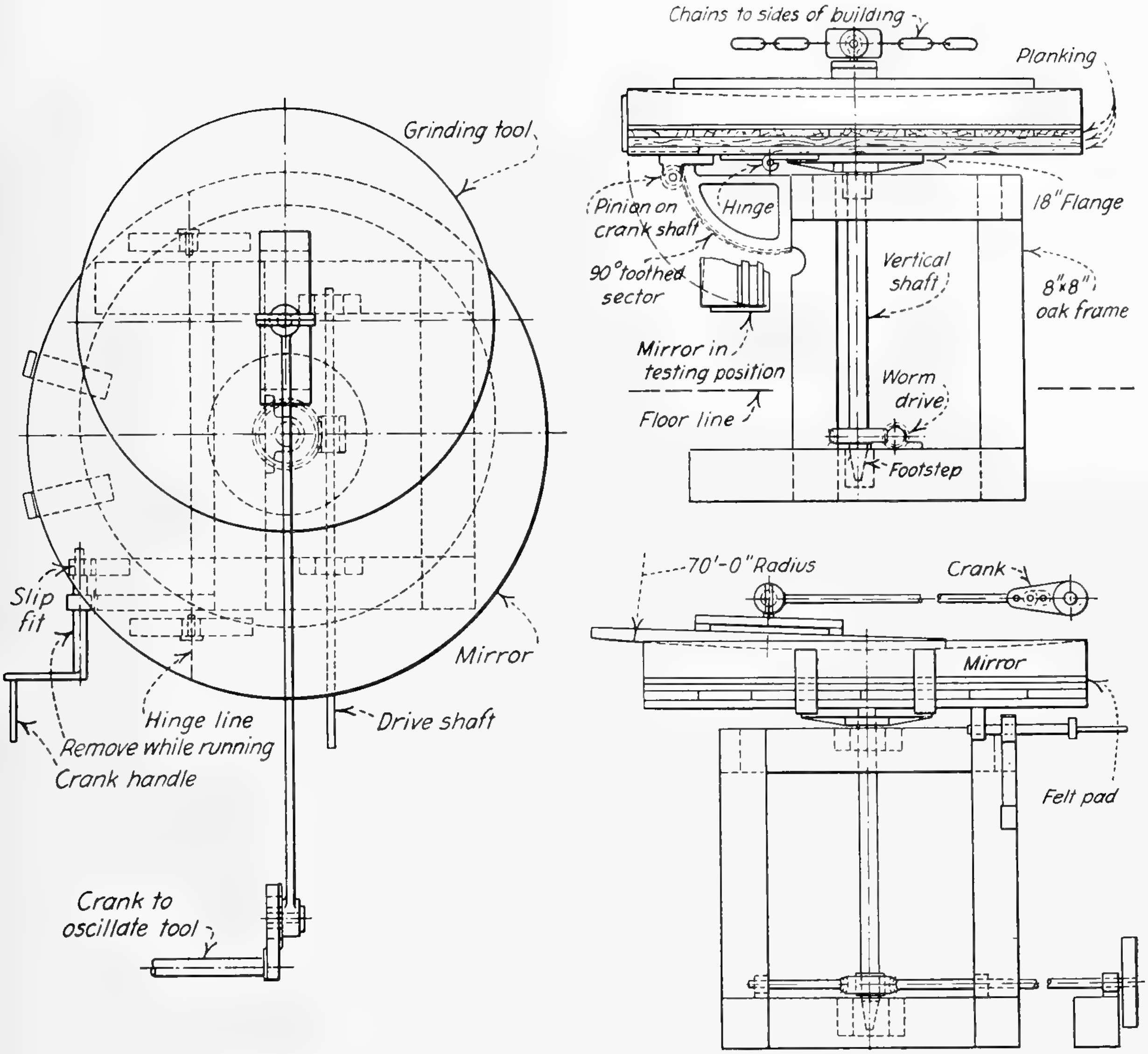
Chains to sides of building
Planking
Pinion on crank shaft
Hinge
18" Flange
90° toothed sector
Vertical shaft
8"×8" oak frame
Mirror in testing position
Floor line
Worm drive
Footstep
Grinding tool
Slip fit
Mirror
Hinge line
Drive shaft
Remove while running
Crank handle
70'-0" Radius
Crank
Mirror
Felt pad
Crank to oscillate tool

FIGURE 14.—Surfacing machine used by Peate. (From Preston, fig. 4.)

casting of the disc but the completion of the mirror. It feigned surprise that this was all that was to be done in Butler. Even as late as May 24, 1895, the *Butler Democratic Herald* was still defending its town. It concluded an editorial on the issue thus:

> . . . we have a feeling he [The *Budget*] has set his foot in it when he goes to poke fun at the Standard about casting the biggest mold on earth, and the end of it may be a repetition of the old saw "he who laughs last laughs best."

A week before this, however, the success of this casting had been made more or less official by an announcement to that effect in the May 17, 1895, issue of *Science*, a publication of the American Association for the Advancement of Science and probably the most highly regarded scientific paper of the time.

On June 1, 1895, Standard Plate rendered Peate an invoice, not for $1600, but for $450. Evidently their work was done at cost. The disc was now removed to Greenville where Dr. Peate had erected a shop to grind, polish, and figure it. As the disc was slightly out of round the first operation was to made it perfectly circular. Peate did this roughly by spalling off pieces of the edge with his bricklayer's hammer. The final rounding was done with the aid of the iron hoops that had made the mold. Dr. Peate fed steel shot between the edge of the disc and the iron semicircles. He rotated the disc on the turntable and thus rounded it off.

After this had been done he commenced the rough grinding. Using the large checkerboard tool, steel shot, and levigated emery Dr. Peate ground out a rough hollow. This took only a few days. George Howard stated that the depth of the concavity was about 5/8 inch and the shape correct to within about 1/10,000 inch. The calculated concavity of the mirror would be 6/10 inch. Peate evidently used the usual method in polishing the large mirror, that is, he covered the tool face with pitch and used rouge (iron oxide) as the abrasive. This method had been used for many years before this time and is still in use today.

The figuring, which consists of removing high spots to achieve a truly parabolic contour, probably took the longest time to complete. A mirror must be continually tested as this polishing is being done, and since the polishing warms the glass and distorts its shape, it is necessary to allow a long time for the glass to cool before it can be tested. Peate estimated that polishing and figuring the mirror took 750 hours.[23]

We do not have a really accurate account of how he tested the mirror. Unfortunately none of the eyewitnesses to these tests had any knowledge of optics or of standard testing procedure. The information of those who had such knowledge is all at least secondhand and sometimes even more remote. J. W. Fecker, successor to Brashear,[24] who was one of a group that examined the mirror in 1923, states that Peate did not use the knife edge test but that he did use a pin with a hole in its head in one of the tests used at that time.

A variety of different tests and diversions with the mirror have been reported. Dr. Peate would entertain visitors in various ways. One of these was to train the mirror on an apple orchard in a valley a few miles away. In another Peate would pull out one of his whiskers and hang it on a fence nearly a quarter of a mile away. Peate himself tells of the time spent in testing the mirror, but does not go into detail about the procedure. He does mention a testing table that stood about 75 feet away from the revolving table on which the mirror rested. He says further that the mirror was tested "in all ways known, in the shop and on a pin and a watch dial a thousand feet distant." Of these only the pin test seems to have been a conventional one.[25]

After the polishing, the mirror was silvered. Said Peate: "It was silvered and tried on the heavens in the starless region under Corvus, and under the very imperfect management of the mirror on telescopic stars, the report was as good as could be expected."[26] Dr. Peate must have spent some time testing it on the stars. The mirror was evidently completed sometime late in summer of 1897, and when Peate was satisfied that it was as perfect as possible, he made arrangements to send it to American University. He also designed the shipping case to protect it on the trip to Washington. It is described in the University paper as follows:[27]

> This consists of a box in which the glass is packed and a wheeled truck in which it is swung. It is swung on its edge by iron bands, which go around it over an iron belt which encircles it.

After waiting for the case, he encountered a further delay by reason of the fact that the express company had no office at Greenville. However the great glass finally was loaded on the train, and on August 24, 1898, it arrived safely at American University.

Although all parties concerned in this project seemed optimistic, no provision for mounting the mirror had yet been made. The University paper which announced the safe arrival of the glass hoped, at a later date, that—

> some day, we trust before long, a noble and generous giver will appear, who will provide for the proper mounting of this mirror and also build a worthy housing.

This donor was never to appear. Five years later, in announcing the death of Peate, the *Courier* was still appealing for funds to mount the mirror. Late in 1903 it announced that a gentleman in Pennsylvania would contribute $100,000 to defray the cost of an observatory to house the mirror, but nothing further was ever heard of this gentleman. Earlier, before the mirror had been made, the Reverend H. G.

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[23] Preston, p. 142.

[24] The Brashear Instrument Company, after the death of its founder John Brashear, became the J. W. Fecker Company, Inc. This concern is now a division of the American Optical Company.

[25] Preston, pp. 142–143.

[26] The mirror is no longer silvered. The silver surface was apparently removed during the inspection by the Bureau of Standards in the 1920's.

[27] Preston, p. 144. Various notices were published in the *American University Courier* in 1898.

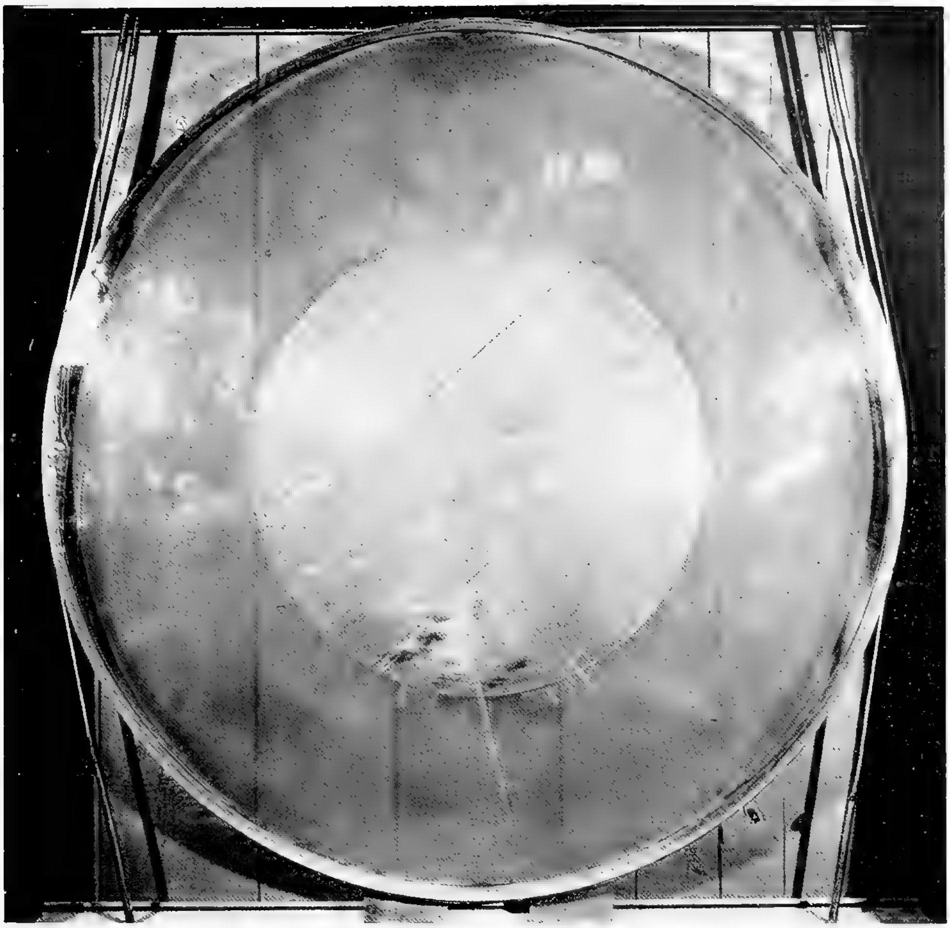

FIGURE 15.—The 62-inch telescope reflector disc (USNM 310899), cast by Standard Plate Glass Company, April 20, 1895, and figured by John Peate. It weighs 2500 pounds. Shown here as it hangs in its protective crate, this clear green glass mirror will be a feature of the exhibit of optics and astronomy now being prepared for the Smithsonian's new Museum of History and Technology, scheduled to open soon after 1962. (*Smithsonian photo 41172*)

Sedgwick of Nashville, Tennessee, had offered to mount and equip the mirror on the same terms under which Peate had made it. That is, he would do the work if someone would donate the cost and the material. But of this offer, too, nothing further was heard. Possibly he died before the mirror was completed.

The mirror was to remain untouched for some 24 years. In 1922 the "Greenville Roundtable," a group reportedly founded by Dr. Peate, allocated $90 to the Reverend H. G. Dodds to investigate the disposition of the mirror. In that same year the Erie Conference appointed Dodds a committee of one to report on the same matter. Dodds visited American University and conferred with the chancellors. They checked the mirror and it seemed to be in good shape. Dodds then went to Warner and Swasey, in Cleveland, Ohio, where he attempted to discover what it would cost to mount the mirror and provide an observatory. But he learned nothing there. Dodds knew nothing either of astronomy or of glass and his lack of knowledge did not inspire confidence in his mission. He did note a peculiar phenomenon, that people seemed suspicious of the mirror in itself without knowing anything about its actual condition.[28]

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[28] Preston, pp. 145–146.

Shortly after Dodd's failure to secure a user for the mirror the Perkins Observatory at Ohio Wesleyan University, which planned to add a large reflecting telescope, became interested in it. Dr. Clifford C. Crump, director of the Perkins Observatory, J. W. Fecker, then president of the J. W. Fecker Company, and A. N. Finn and A. Q. Tool, of the National Bureau of Standards, inspected the glass at American University. They found it remarkably free of bubbles and similar defects. Due to a lack of facilities they were unable to test the mirror optically, so that no comment was made on either the polishing or the correctness of the figure. It was, however, found badly strained due to poor annealing, and Fecker advised against using it, as it would have to be re-annealed. If this were done, some refiguring would also be necessary. After this rather expensive renovation it would remain a rather thin, flexible glass and not equal to modern standards. The Perkins Observatory consequently decided rather to use a mirror cast and finished under the supervision of the Bureau of Standards.[29]

This was the last attempt to use the mirror. It remained at American University until the mid 30's, when it was placed in the Smithsonian Institution. It was still, in February 1935, the largest mirror ever cast and polished in the United States.

Let us return now to Dr. Peate. After seeing the mirror safely stored at American University he returned to Greenville, Pennsylvania. Then 78 years old, still in good health and very active, he was to live for 5 more years.

To the end of his life he maintained his interest in astronomy, and was optimistic about the possibility of his great mirror eventually being mounted and used. In 1900 at the age of 80 he decided to see Europe once again. His prime objective on this trip was undoubtedly the Paris Exposition of 1900, where one of the main attractions was a huge telescope made by Gautier. It had a refracting objective of 49.2 inches, mounted horizontally, the largest refractor yet made. Strangely enough this much publicized telescope was never used either. After the exposition was over the backers became bankrupt and the instrument was dismantled and sold for scrap.

Dr. Peate with his wide range of knowledge and his conversational ability delighted and puzzled his fellow passengers on the boat to and from Europe. They guessed that he was an educator, a scientist, or statesman but he denied all this saying, "no, I'm only a bricklayer."

Dr. Peate lived three years after this trip, dying on March 24, 1903. His good health and physical vigor never left him till almost the moment of his death; as shortly as a week before, he had conducted a funeral service.

It would be rather easy to dismiss him as a harmless fanatic except that everything known of him indicates that he was not. It is reasonable to believe that his mirrors were made more in the hope than in the certain expectation that they would stimulate the study of astronomy in the institutions receiving them. He was probably well aware of the difficulities of establishing so large a telescope at a newly founded institution such as American University, and, content in the knowledge that he had done his part, could only hope that others might be inspired to do likewise.

Dr. Peate's great mirror will shortly be put to use in a manner that could hardly have been predicted by its maker. It has been in the Smithsonian Institution for over 20 years. The huge glass will form a part of the exhibition of optics and astronomy in the new Museum of History and Technology that the Smithsonian Institution will open to the public about 1962. There it will be seen by some millions of persons each year. Because of its spectacular size it should catch the attention of most museum visitors. Surely it will awaken in more than one potentially able worker an interest in astronomy. If so, it will have accomplished Dr. Peate's purpose.

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[29] Preston, p. 146.

Appendix

REPORTS OF COMMITTEES OF THE FRANKLIN INSTITUTE

[From *Journal of the Franklin Institute*, July 1834, new ser. vol. 14 (whole no. 18), pp. 169–172.]

Report on Amasa Holcomb's Reflecting Telescope.

The Committee on Science and the Arts, constituted by the Franklin Institute of the State of Pennsylvania for the promotion of the Mechanic Arts, to whom was referred for examination a Reflecting Telescope, manufactured by Mr Amasa Holcomb, of Southwick, Hampden county, Massachusetts,

REPORT:—

That the following is the description of the instrument as given by Mr. Holcomb.

"The telescope submitted to the examination of the Committee of the Franklin Institute is of the reflecting kind; has a focal length of six feet; the diameter of the speculum is three inches nine-tenths; the rays of light are reflected but once; the image formed in the focus of the speculum is viewed by a common astronomical eye piece, or by a single lens; it has also an eye piece for viewing land objects, which shows them erect. The telescope is of the same construction as those of Sir William Herschell, the observer having his back towards the object and looking directly towards the speculum. It has an advantage over those of the Gregorian and Newtonian forms, by showing the object brighter with the same aperture, there being no light lost by a second reflection. The diameter of the speculum is small in proportion to the length of the instrument; it will bear a diameter of eight inches, with much advantage for viewing very small stars, in consequence of the great increase of the light.

The magnifying powers that are used are, forty, ninety, and two hundred and fifty."

Through the politeness of Prof. A. D. Bache, the committee were permitted to compare the performance of Mr. Holcomb's reflector with that of a five feet achromatic, of four inches aperture, by Dolland, the property of the University of Pennsylvania. The instrument was also compared with a three and a half feet achromatic, by Dolland, and with a Gregorian of four inches aperture, the mirrors of which had been lately repolished in London. The short stay of Mr. Holcomb in Philadelphia, prevented the comparison of it with reflectors in the possession of other members of the committee.

On the evening of the 14th of April, the committee met by adjournment in the open lot south of the Pennsylvania Hospital, the use of which was politely permitted to the committee by the managers of that institution.

The following were the results of the comparisons:—

The moon, nearly full, was at a height to be conveniently viewed with the lower powers of the instruments: with a power of 350 in the five feet achromatic, the moon appeared bright and well defined,—with the same eye-piece, giving a power of 400, in the reflector by Mr. Holcomb, the moon was sufficiently bright, and equally well defined. The same, with the exception that the moon was more brilliant, and the field of view much greater, was remarked with the use of Mr. Holcomb's highest magnifier, giving a power of two hundred and fifty.

As an illustration of their comparative performances, it was remarked that the waved appearance of the outer declivities of the craters of some of the apparently extinct lunar volcanoes, indicating the successive depositions of the lava, was more manifest with a power of four hundred in the reflector.

The immersions of 3 and 4 Geminorum of the sixth and seventh magnitude, were observed at the same instant of time in each.

The same occurred the evening before with a star of the eighth or ninth magnitude.

The immersions, however, of two very small stars, apparently of the tenth or eleventh magnitude, were observed with difficulty in the refractor, but could not be observed at all in the reflector.

The comparison of Polaris was best seen when the moon was up in the refractor, but in the absence of the moon it was readily seen in both.

Castor was easily divided with the lower powers of either, but in the case of this, as well as of other binary and double stars, the dark space between the stars was less disturbed by scattering rays in the reflector than in the refractor.

ϵ Bootes was seen double in each, but more distinctly in the reflector. μ Draconis, γ Leonis, and 4th and 5th ϵ Lyra, were seen distinctly double in both instruments; μ Draconis, from the equality of the disks and softness of light, presented the finest appearance.

γ Virgines, with a power of three hundred and fifty in either telescope, gave no certain indications of being double. Some of the members of the committee were of opinion that it was slightly elongated.

It was stated by the artist that his reflector would divide stars distant 3″ from each other.

Estimating the distance of the stars observed by the late observations of South, Struve, and Herschel, jr., the committee were of opinion that his instrument is adequate to the distinct division of double stars distant from each other 2″.5.

The motion of this instrument, plainly mounted, was steady, and with the finder, even without rack work, objects were easily made to range with the centre, or line of collimation of the instrument.

The position of the observers with the Herschelian telescope, was natural and easy in contemplating objects having seventy or eighty degrees of altitude, though quite constrained and inconvenient in using the achromatic.

The reflector gave a distinct view of land objects, even when within one-fourth of a mile.

Some light was lost by the position of the head, an inconvenience partially obviated by making the end nearest the object three inches greater in aperture.

The Gregorian, which probably was not a very fine instrument of its kind, bore no comparison in distinctness, or in quantity of light, with the Herschelian telescope.

From these trials, the committee are of opinion that Mr. Holcomb has been entirely successful in the difficult art of polishing specula with the true curve, which gives to the objects viewed all the distinctness of figure that is given them by the best refractors by Dolland.

In one respect, the largeness of the field of view, the reflectors by Mr. Holcomb have a decided advantage over achromatics and reflectors of different construction. The apparent diameter of the field of view in the Herschelian being nearly double that of either, with equal freedom from aberration. The quantity of light furnished by the refractor was greater with the same aperture, an important advantage in searching for, and observing very minute objects. This deficiency of light in the Herschelian for viewing faint objects near the moon, or satellites near their primaries, the committee are of opinion may be removed by enlarging the aperture of the Herschelian reflector to five or five and a half inches.

The simplicity of the method of preparing and mounting Mr. Holcomb's telescopes is worthly of notice, since on this plan, the artist is enabled to furnish for an expense of one hundred dollars, with plain mounting, or of one hundred and fifty to two hundred dollars, with more expensive mounting, telescopes whose performance equals that of Gregorians and achromatics hitherto imported into the country at an expense of five hundred dollars.

By order of the committee.

May 8th, 1834. William Hamilton, *Actuary*.

[From *Journal of the Franklin Institute*, July 1835, new ser. vol. 16 (whole no. 20), pp. 11–13]

Report on Holcomb's Reflecting Telescopes.

The Committee on Science and the Arts, constituted by the Franklin Institute of the State of Pennsylvania for the promotion of the Mechanic Arts, to whom was referred for examination, two reflecting telescopes, made by Mr. Amasa Holcomb, of Southwick, Hampden county, Massachusetts, REPORT:—

That the following description of these telescopes is given by Mr. Holcomb:

The two reflecting telescopes now submitted by the subscriber, are constructed on the plan of Sir William Herschel, having the front view. The largest has a focal length of 9½ feet; the diameter of the speculum is 8½ inches, and has five astronomical eye-pieces, and one terrestrial eye-piece, for showing objects erect; the lowest power is 57, the highest 900. The smallest has a focal length of 7 feet 9 inches; the diameter of the speculum is 6½ inches, and has one terrestrial, and four astronomical, eye-pieces; the lowest power is 60, the highest is 600. They are of the same kind as those that were submitted a year ago, except the manner of mounting, which is very different.

Amasa Holcomb.

On the evening of the 4th of May, the committee met, by appointment, in an open lot south of the Pennsylvania Hospital, for the purpose of testing the performance of the telescopes, which had previously been tried by some of the members of the committee, and by other gentlemen, on the evening of the 2d. The result of the examination was highly creditable to Mr. Holcomb, and cannot fail to gratify all who have at heart the advancement of astronomical science in this country.

The instruments, with powers varying from 50 to 600 in the smaller, and to 900 in the larger, gave satisfactory views of the moon with a sufficiency of light.

Mr. Holcomb's ability to manufacture telescopes which should bear a comparison, on favourable terms, with the best four and five feet achromatics now in the country, having been established by the report of the committee in May, 1834, their attention was chiefly directed to ascertaining the degree of perfection to which he has attained in his art, by his persevering efforts during the past year. Accordingly, the remarks which follow are made with reference to the larger telescope, of about ten feet focal length, eight inches aperture, and with a positive eye-piece, giving a power of about 900, and the surface of the field of view nearly twice as great as that of a Gregorian, and one-third greater than that of an achromatic telescope, under similar circumstances.

The view of the moon with its rugged surface, its ridges of mountains, and the endless variety of indentations on its surface, was interesting beyond description, and exceeded any thing of the kind the committee have ever witnessed.

Saturn's ring, though not in a favourable position, was seen manifestly double, for the first time in this country, as far as the information of the committee extends.

The companion of Polaris appeared as a star of the fourth or fifth magnitude, to the unassisted eye.

The double stars, Castor, μ Draconis, 4 and 5 ϵ Lyræ, and 44 Bootes, were distinctly separated, and the dark space between them made evident. The last mentioned, consisting of two stars of the fifth magnitude, distant 3″ made a fine appearance; they were soft, and well defined, and there were no scattering rays of light, as was the case with Castor, in both instruments.

A class of closer doubles stars, of which 6 Coronæ, distant 1″.2., and ζ Bootes, distant 1″.4., may serve as examples, was acknowledged by the artist, last year, to be too difficult for his telescope. This has furnished a stimulus for his exertions, and the complete division of the latter, as witnessed by the committee on the present occasion, has been the reward of his disinterested labours. The discs of the two stars in ζ Bootes appeared to be tangent to each other. The committee have no evidence that the same has been effected by any other telescope in the country.

For the purpose of finding the limit to the power of Mr. Holcomb's telescope, the committee called his attention to a class of still closer stars; among them were mentioned, ζ Cancri, μ^2 Bootes, „ Coronæ, 36 Andromedæ, and ϵ Arietis, the last of which is only divisible by two telescopes now in use, viz.: the Dorpat telescope, and the twenty foot reflector of Sir John Herschel. These stars, distant from 0″.6. to 1″.0., are made to appear with their discs tangent to each other in those celebrated instruments, as appears by their notes appended to the observations contained in their printed catalogues. It is almost needless to add, that Mr. Holcomb acknowledged these stars to be too difficult for any telescopes he has yet made.

It may seem presumptuous to compare the small instrument of Holcomb with the chefs d'oeuvre of British and German genius; but, thanks to the admirable labours of the Herschels, of Struve, and of South, observers are enabled, through their printed catalogues, to compare together the optical capacities of their telescopes in distant regions. Accordingly it appears from an examination of these catalogues, and of Holcomb's instruments, that what the best telescopes in Europe can do upon stars distant 0″.6., can be done upon stars distant 1″.4., by instruments which are the work of an unassisted, and almost neglected, American optician.

Judging from the progress made in his art, by Mr. Holcomb, during the past year, the committee look forward, with confident expectation, to the not far distant period, when, should his health be spared, the country will be in possession of a twenty feet reflector, of native workmanship, rivalling the best European instruments, and that, too, without the patronage of any corporate institution, should all of them be willing to waive the opportunity of sharing with him the merit of such an enterprise.

The committee have been led to enlarge upon this subject, from a knowledge that one of our national institutions has, within a few years, imported into the country, at an expense of $2,500, a telescope which, though excellent in its kind, is inferior to that exhibited by Mr. Holcomb, which was made and mounted to order for an individual in Georgia, at less than the eighth part of the above mentioned sum. It is not probable that a twenty foot instrument from Mr. Holcomb, would cost eight times as much as one of the length of ten feet.

The mode of mounting the instrument appears to be original, and nothing can exceed it in simplicity, or steadiness. Indeed, with a power of 900, no inconvenience was perceived from resting with one hand on the frame, and another on the tube, although the same could not be done with the mounting used by Mr. Holcomb last year, or with that of common achromatics with a power of 200, without serious inconvenience.

In conclusion, the committee beg leave to recommend Mr. Holcomb to the Board of Managers of the Franklin Institute, as a candidate for a premium and medal from the Scott's legacy fund, for his new mode of mounting reflecting telescopes.

By order of the committee.

WILLIAM HAMILTON, *Actuary*.

May 14*th*, 1835.

RELICS OF HOLCOMB, FITZ, AND PEATE IN THE SMITHSONIAN INSTITUTION

(United States National Museum catalog number shown at right)

AMASA HOLCOMB

(All items from Mrs. Grace E. Holcomb Steere and Mrs. Eva C. Holcomb Storey)

1.	Undated and unsigned original autobiographical sketch, ink on notepaper (as published here, p. 160)	
2.	Manuscript notebook on meteorological and astronomical matters, covering the period 1834–41.	310600
3.	Herschelean reflecting telescope, 8½-inch aperture, 9 feet 4 inches long. This is the telescope made by Holcomb and shown at the Franklin Institute in 1835.	310598
4.	Refracting telescope, 1½-inch aperture, 21 inches long, on 14-inch axis for use as a transit telescope, without support.	310599

HENRY FITZ, JR.

(Item 1 from Mr. L. C. Eichner, items 2–4 from Mrs. Julia Fitz Howell, item 5 from Mr. Arthur V. A. Fitz)

1.	Refracting telescope, comet seeker, 8¼-inch aperture, 61-inch wooden tube, fitted for equatorial mounting, but without mount.	317027
2.	Machines, tools, and partially completed instruments from the shop of Henry Fitz, of which the major pieces are:	
	Lens grinding machine	315152
	Lens polishing machine	315153
	Lens edging and testing machine	315151
3.	Manuscript notebook of Fitz accounts from 1851 to 1855.	317026 (2)
4.	Manuscript "Catalogue of Objectives made by Henry Fitz."	317026 (2)
5.	Refracting telescope, 5-section draw, marked "Ta. Long, Royal Exchange, London," 2⅛-inch objective, 42½ inches long, open. Purchased in London by Fitz in 1839. The present objective was made by Fitz.	316706

JOHN PEATE

(From The American University)

1.	Mirror, glass, unsilvered, 62-inch diameter, about 6 inches thick.	310899

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KINEMATICS of Mechanisms from the Time of Watt

by Eugene S. Ferguson

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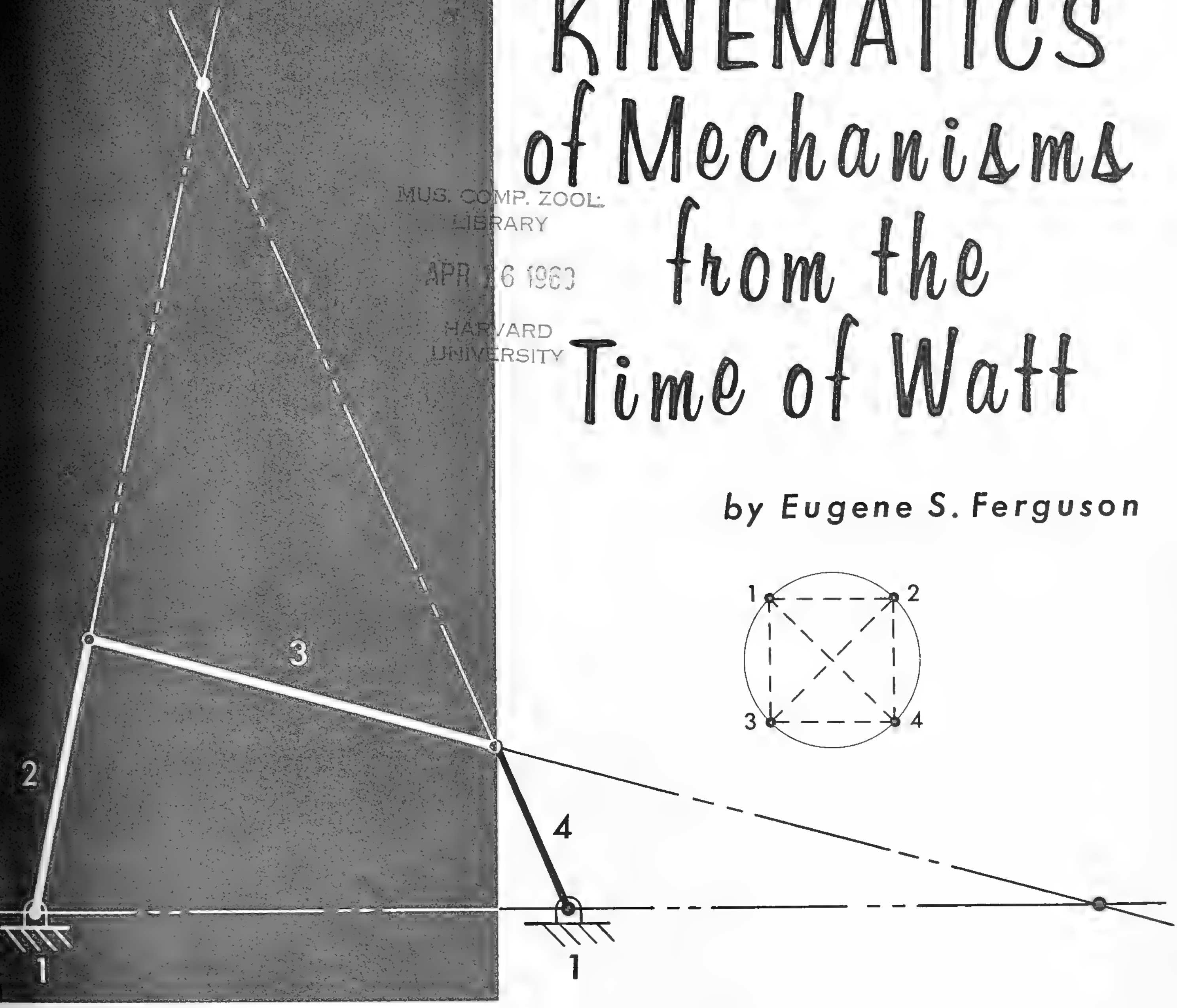

Paper 27, pages 185–230, from

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PAPER 27

KINEMATICS OF MECHANISMS FROM THE TIME OF WATT

Eugene S. Ferguson

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by Eugene S Ferguson

KINEMATICS OF MECHANISMS FROM THE TIME OF WATT

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In an inventive tour de force that seldom, if ever, has been equalled for its brilliance and far-reaching consequences, James Watt radically altered the steam engine not only by adding a separate condenser but by creating a whole new family of linkages. His approach was largely empirical, as we use the word today.

This study suggests that, despite the glamor of today's sophisticated methods of calculation, a highly developed intuitive sense, reinforced by a knowledge of the past, is still indispensable to the design of successful mechanisms.

THE AUTHOR: *Eugene S. Ferguson, formerly curator of mechanical and civil engineering in the United States National Museum, Smithsonian Institution, is now professor of mechanical engineering at Iowa State University of Science and Technology.*

IN ENGINEERING SCHOOLS TODAY, a student is introduced to the kinematics of mechanisms by means of a course of kinematic analysis, which is concerned with principles underlying the motions occurring in mechanisms. These principles are demonstrated by a study of mechanisms already in existence, such as the linkage of a retractable landing gear, computing mechanisms, mechanisms used in an automobile, and the like. A systematic, if not rigorous, approach to the design of gears and cams also is usually presented in such a course. Until recently, however, no serious attempt was made to apply the principles developed in kinematic analysis to the more complex problem of kinematic synthesis of linkages. By kinematic synthesis is meant the designing of a linkage to produce a given series of motions for a particular purpose.

That a rational—numerical or geometrical—approach to kinematic synthesis is possible is a relatively recent idea, not yet fully accepted; but it is this idea that is responsible for the intense scholarly interest in the kinematics of mechanisms that has occurred in this country within the last 10 years.

This scholarly activity has resulted in the rediscovery of many earlier works on the subject, and nearly all the scholars now working in this field have acknowledged in one way or another their debt to those who arrived on the scene at an earlier time than they. There have been occasional reviews of the sequence and nature of developments, but the emphasis naturally has been upon the recent past. It seems to me that there is something to be gained in looking beyond our own generation, or even beyond the time of Franz Reuleaux (1829–1905), who is generally credited with originating many of our modern concepts of mechanism analysis and design, and to inquire into the ideas that made possible Reuleaux's contributions.

While no pretense of completeness is made, I have tried in this paper to trace the high points in the development of kinematic analysis and synthesis,

> *Take to Kinematics. It will repay you. It is more fecund than geometry; it adds a fourth dimension to space.*
>
> —Chebyshev to Sylvester, 1873

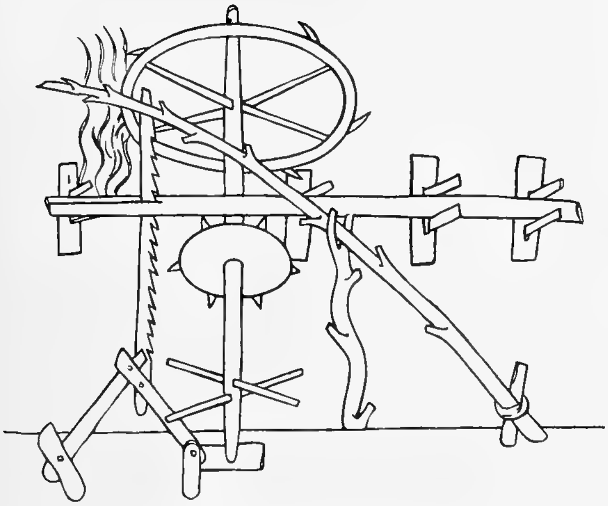


Figure 1.—Up-and-down sawmill of the 13th century. The guide mechanism at lower left, attached to the saw blade, appears to be a 4-bar linkage. After Robert Willis, trans. and ed., *Facsimile of the Sketch-Book of Wilars de Honecort* (London, 1859, pl. 43).

both in academic circles and in the workshop, noting where possible the influence of one upon the other. If I have devoted more space to particular people and episodes than is warranted by their contributions to the modern treatment of the subject, it is because I have found that the history of kinematics of mechanisms, like the history of any other branch of engineering, is more interesting and more plausible if it is recognized that its evolutionary development is the result of human activity. This history was wrought by people like us, no less intelligent and no less subject than we are to environment, to a subjective way of looking at things, and to a heritage of ideas and beliefs.

I have selected the period from the time of Watt because modern mechanisms originated with him, and I have emphasized the first century of the period because by 1885 many of the ideas of modern kinematics of mechanisms were well developed. Linkages are discussed, to the virtual exclusion of gears and cams, because much of the scholarly work in kinematic synthesis is presently directed toward the design of linkages and because linkages provide a convenient thread for a narrative that would have become unnecessarily complex if detailed treatment of gears and cams had been included. I have brought the narrative down to the present by tracing kinematics as taught in American engineering schools, closing with brief mention of the scholarly activity in kinematics in this country since 1950. An annotated list of additional references is appended as an encouragement to further work in the history of the subject.

James Watt, Kinematic Synthesist

James Watt (1736–1819), improver of the steam engine, was a highly gifted designer of mechanisms, although his background included no formal study of mechanisms. Indeed, the study of mechanisms, without immediate regard to the machines in which they were used, was not introduced until after Watt's important work had been completed, while the actual design of mechanisms had been going on for several centuries before the time of Watt.

Mechanisms that employed screws, cams, and gears were certainly in use by the beginning of the Christian era. While I am not aware of unequivocal evidence of the existence of four-bar linkages before the 16th century, their widespread application by that time indicates that they probably originated much earlier. A tantalizing 13th-century sketch of an up-and-down sawmill (fig. 1) suggests, but does not prove, that the four-bar linkage was then in use. Leonardo da Vinci (1452–1519) delineated, if he did not build, a crank and slider mechanism, also for a sawmill (fig. 2). In the 16th century may be found the conversion of rotary to reciprocating motion (strictly speaking, an oscillation through a small arc of a large circle) and vice versa by use of linkages of rigid members (figs. 3 and 4), although the conversion of rotary to reciprocating motion was at that time more frequently accomplished by cams and intermittent gearing. Nevertheless, the idea of linkages was a firmly established part of the repertory of the machine builder before 1600. In fact one might have wondered in 1588, when Agostino Ramelli published his book on machines,[1] whether linkages had not indeed reached their ultimate stage of development. To illustrate my point, I have selected the plate of Ramelli that most appeals to me (fig. 5), although the book exhibits more than 200 other machines of comparable complexity and ingenuity.

There was a vast difference, both in conception and execution, between the linkages of Ramelli and those of James Watt some 200 years later. Watt was responsible for initiating profound changes in mechanical technology, but it should be recognized that the mechanic arts had, through centuries of slow development, reached the stage where his genius could flourish. The knowledge and ability to provide the materials and tools necessary for Watt's researches were at hand, and through the optimism and patient encouragement of his partner, Matthew Boulton, they were placed at his disposal.

---

[1] Agostino Ramelli, *Le Diverse et Artificiose Machine*, Paris, 1588.

Watt's genius was nowhere more evident than in his synthesis of linkages. An essential ingredient in the success of Watt's linkages, however, was his partner's appreciation of the entirely new order of refinement that they called for. Matthew Boulton, who had been a successful manufacturer of buttons and metal novelties long before his partnership with Watt was formed, had recognized at once the need for care in the building of Watt's steam engine. On February 7, 1769, he had written Watt:[2] "I presumed that

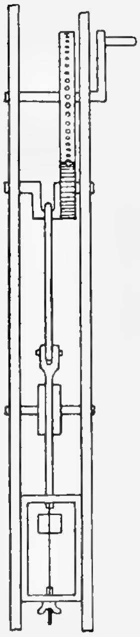
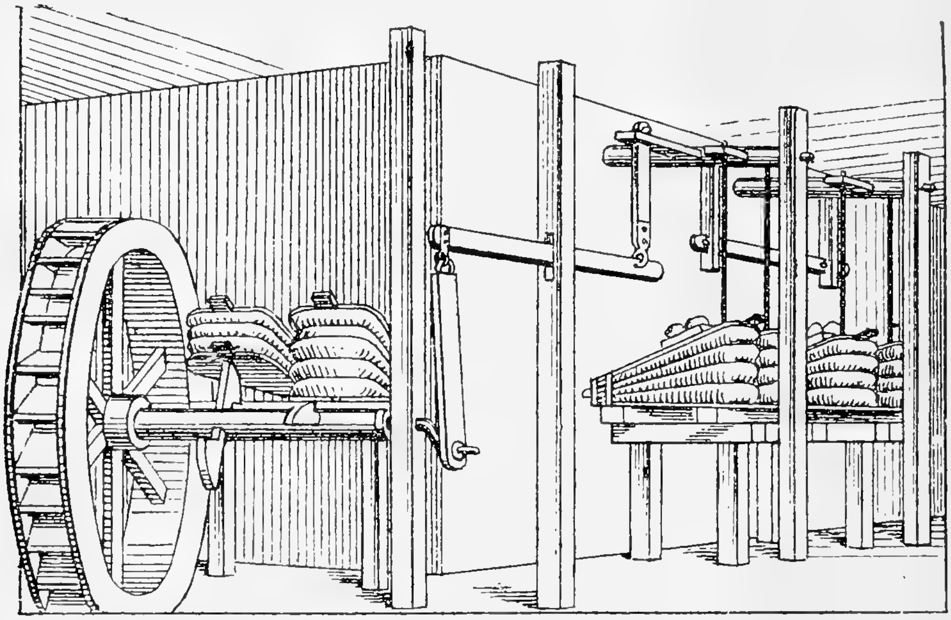


Figure 2.—Slider-crank mechanism of Leonardo da Vinci (1452–1519), redrawn from his manuscript notebooks. A frame saw is depicted at the lower end of the guides. From Theodor Beck, *Beiträge zur Geschichte des Maschinenbaues* (Berlin, 1899, p. 323).

Figure 3.—Blowing engine by Vanuccio Biringuccio, about 1540, showing coversion of motion of the waterwheel shaft from rotation to oscillation. From Theodor Beck, *Beiträge zur Geschichte des Maschinenbaues* (Berlin, 1899 p. 120).



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[2] Henry W. Dickinson, *James Watt, Craftsman & Engineer*, Cambridge, Cambridge University Press, 1936, pp. 52–53.

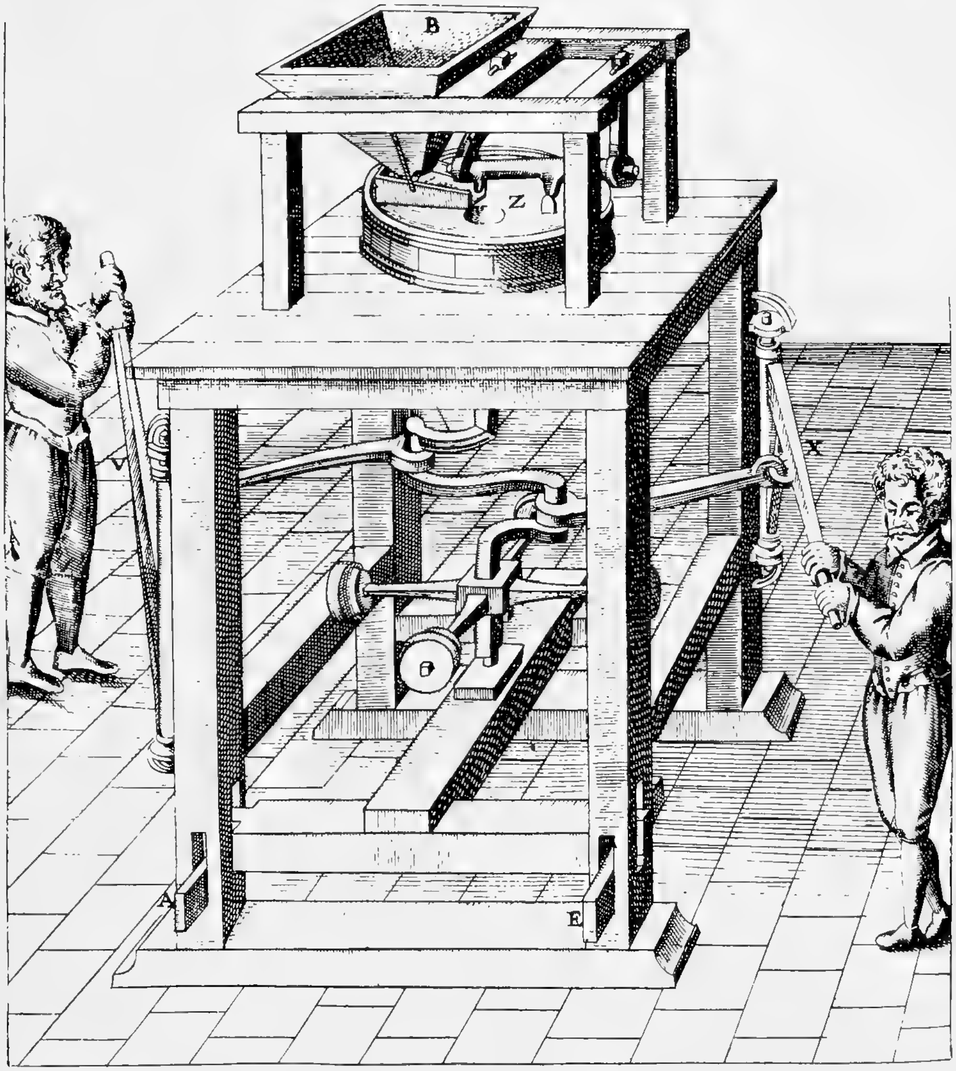

Figure 4.—Grain mill, 1588, showing conversion of motion of the operating bars from oscillation to rotation. Note the fly-weights, predecessors of the flywheel. From Agostino Ramelli, *Le Diverse et Artificiose Machine* (Paris, 1588, pl. opposite p. 199).

your engine would require money, very accurate workmanship and extensive correspondence to make it turn out to the best advantage and that the best means of keeping up the reputation and doing the invention justice would be to keep the executive part of it out of the hands of the multitude of empirical engineers, who from ignorance, want of experience and want of necessary convenience, would be very liable to produce bad and inaccurate workmanship; all of which deficiencies would affect the reputation of the invention." Boulton expected to build the engines in his shop "with as great a difference of accuracy as there is between the blacksmith and the mathematical instrument maker." The Soho Works of Boulton and Watt, in Birmingham, England, solved for Watt the problem of producing "in great" (that is, in sizes large enough to be useful in steam engines) the mechanisms that he devised.[3]

The contributions of Boulton and Watt to practical mechanics "in great" cannot be overestimated. There were in the 18th century instrument makers

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[3] James P. Muirhead, *The Origin and Progress of the Mechanical Inventions of James Watt*, London, 1854, vol. 1, pp. 56, 64. This work, in three volumes, contains letters, other documents, and plates of patent specification drawings.

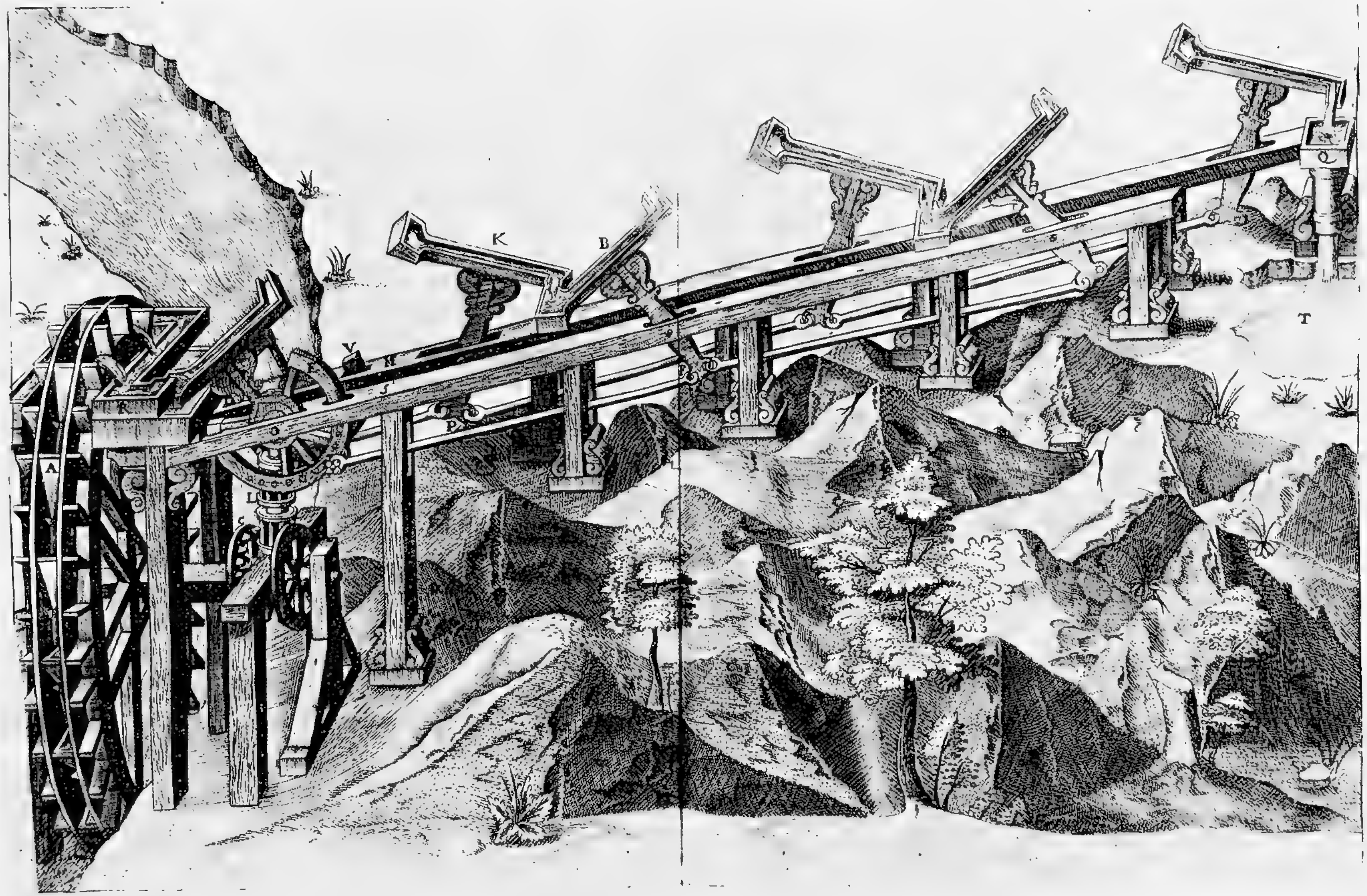

Figure 5.—Machine for raising water. Such a machine was built in Spain during the 16th century and was operated for some 80 years. From Agostino Ramelli, *Le Diverse et Artificiose Machine* (Paris, 1588, p. 199).

and makers of timekeepers who had produced astonishingly accurate work, but such work comprised relatively small items, all being within the scope of a bench lathe, hand tools, and superb handwork. The rapid advancement of machine tools, which greatly expanded the scope of the machine-building art, began during the Boulton and Watt partnership (1775–1800).

In April 1775 the skirmish at Concord between American colonists and British redcoats marked the beginning of a war that was to determine for the future the course of political events in the Western Hemisphere.

Another event of April 1775 occurring in Birmingham now appears to have been one that marked the beginning of a new era of technological advance. It was near the end of this month that Boulton, at the Soho Works, wrote to his partner and commented upon receiving the cast iron steam engine cylinder that had been finished in John Wilkinson's boring mill:

> . . . it seems tolerably true, but is an inch thick and weighs about 10 cwt. Its diameter is about as much above 18 inches as the tin one was under, and therefore it is become necessary to add a brass hoop to the piston, which is made almost two inches broad.[4]

This cylinder indeed marked the turning point in the discouragingly long development of the Watt steam engine, which for 10 years had occupied nearly all of Watt's thoughts and all the time he could spare from the requirements of earning a living. Although there were many trials ahead for the firm of Boulton and Watt in further developing and perfecting the steam engine, the crucial problem of leakage of steam past the piston in the cylinder had now been solved by Wilkinson's new boring mill, which was the first large machine tool capable of boring a cylinder both round and straight.

The boring mill is pertinent to the development of linkages "in great," being the first of a new class of machine tools that over the next 50 or 60 years came to include nearly all of the basic types of heavy chip-removing tools that are in use today. The development of tools was accelerated by the inherent accuracy required of the linkages that were originated by Watt. Once it had been demonstrated that a large and complex machine, such as the steam engine, could be built accurately enough so that its operation would be relatively free of trouble, many outstanding minds became engaged in the development of machines and tools. It is interesting, however, to see how Watt and others grappled with the solutions of problems that resulted from the advance of the steam engine.

During the 1770's the demand for continuous, dependable power applied to a rotating shaft was becoming insistent, and much of Boulton's and Watt's effort was directed toward meeting this demand. Mills of all kinds used water or horses to turn "wheel-work," but, while these sources of power were adequate for small operations, the quantity of water available was often limited, and the use of enormous horse-whims was frequently impracticable.

The only type of steam engine then in existence was the Newcomen beam engine, which had been introduced in 1712 by Thomas Newcomen, also an Englishman. This type of engine was widely used, mostly for pumping water out of mines but occasionally for pumping water into a reservoir to supply a waterwheel. It was arranged with a vertical steam cylinder located beneath one end of a large pivoted working beam and a vertical plunger-type pump beneath the other end. Heavy, flat chains were secured to a sector at each end of the working beam and to the engine and pump piston rods in such a way that the rods were always tangent to a circle whose center was at the beam pivot. The weight of the reciprocating pump parts pulled the pump end of the beam down; the atmosphere, acting on the open top of the piston in the steam cylinder, caused the engine end of the beam to be pulled down when the steam beneath the piston was condensed. The chains would of course transmit force from piston to beam only in tension.

It is now obvious that a connecting rod, a crank, and a sufficiently heavy flywheel might have been used in a conventional Newcomen engine in order to supply power to a rotating shaft, but contemporary evidence makes it clear that this solution was by no means obvious to Watt nor to his contemporaries.

At the time of his first engine patent, in 1769, Watt had devised a "steam wheel," or rotary engine, that used liquid mercury in the lower part of a toroidal chamber to provide a boundary for steam spaces successively formed by flap gates within the chamber. The practical difficulties of construction finally ruled out this solution to the problem of a rotating power source, but not until after Boulton and Watt had spent considerable effort and money on it.[5]

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[4] *Ibid.*, vol. 2, p. 84.

In 1777 a speaker before the Royal Society in London observed that in order to obtain rotary output from a reciprocating steam engine, a crank "naturally occurs in theory," but that in fact the crank is impractical because of the irregular rate of going of the engine and its variable length of stroke. He said that on the first variation of length of stroke the machine would be "either broken to pieces, or turned back."[6] John Smeaton, in the front rank of English steam engineers of his time, was asked in 1781 by His Majesty's Victualling-Office for his opinion as to whether a steam-powered grain mill ought to be driven by a crank or by a waterwheel supplied by a pump. Smeaton's conclusion was that the crank was quite unsuited to a machine in which regularity of operation was a factor. "I apprehend," he wrote, "that no motion communicated from the reciprocating beam of a fire engine can ever act perfectly equal and steady in producing a circular motion, like the regular efflux of water in turning a waterwheel." He recommended, incidentally, that a Boulton and Watt steam engine be used to pump water to supply the waterwheel.[7] Smeaton had thought of a flywheel, but he reasoned that a flywheel large enough to smooth out the halting, jerky operation of the steam engines that he had observed would be more of an encumbrance than a pump, reservoir, and waterwheel.[8]

The simplicity of the eventual solution of the problem was not clear to Watt at this time. He was not, as tradition has it, blocked merely by the existence of a patent for a simple crank and thus forced to invent some other device as a substitute.

Matthew Wasbrough, of Bristol, the engineer commonly credited with the crank patent, made no mention of a crank in his patent specification, but rather intended to make use of "racks with teeth," or "one or more pullies, wheels, segments of wheels, to which are fastened rotchets and clicks or palls. . . ." He did, however, propose to "add a fly or flys, in order to render the motion more regular and uniform." Unfortunately for us, he submitted no drawings with his patent specification.[9]

James Pickard, of Birmingham, like Boulton, a buttonmaker, in 1780 patented a counterweighted crank device (fig. 6) that was expected to remove the objection to a crank, which operated with changing leverage and thus irregular power. In figure 6, the counterweighted wheel, revolving twice for each revolution of the crank (A), would allow the counterweight to descend while the crank passed the dead-center position and would be raised while the crank had maximum leverage. No mention of a flywheel was made in this patent.[10]

Wasbrough, finding that his "rotchets and clicks" did not serve, actually used, in 1780, a crank with a flywheel. Watt was aware of this, but he remained unconvinced of the superiority of the crank over other devices and did not immediately appreciate the regulating ability of a flywheel.[11] In April 1781 Watt wrote to Boulton, who was then out of town: "I know from experiment that the other contrivance, which you saw me try, performs at least as well, and has in fact many advantages over the crank."[12] The "other contrivance" probably was his swash wheel which he built and which appeared on his next important patent specification (fig. 7a). Also in this patent were four other devices, one of which was easily recognizable as a crank, and two of which were eccentrics (fig. 7a, b). The fourth device was the well-known sun-and-planet gearing (fig. 7e).[13] In spite of the similarity of the simple crank to the several variations devised by Watt, this patent drew no fire from Wasbrough or Pickard, perhaps because no reasonable person would contend that the crank itself was a patentable feature, or perhaps because the similarity was not at that time so obvious. However, Watt steered clear of directly discernible application of cranks because he preferred to avoid a suit that might overthrow his or other patents. For example, if the Wasbrough and Pickard patents had been voided, they would have become public property;

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[5] Henry W. Dickinson and Rhys Jenkins, *James Watt and the Steam Engine*, Oxford, Clarendon Press, 1927, pp. 146–148, pls. 14, 31. This work presents a full and knowledgeable discussion, based on primary material, of the development of Watt's many contributions to mechanical technology. It is ably summarized in Dickinson, *op. cit.* (footnote 2).

[6] John Farey, *A Treatise on the Steam Engine*, London, 1827, pp. 408–409.

[7] *Reports of the Late John Smeaton, F.R.S.*, London, 1812, vol. 2, pp. 378–380.

[8] Farey, *op. cit.* (footnote 6), p. 409.

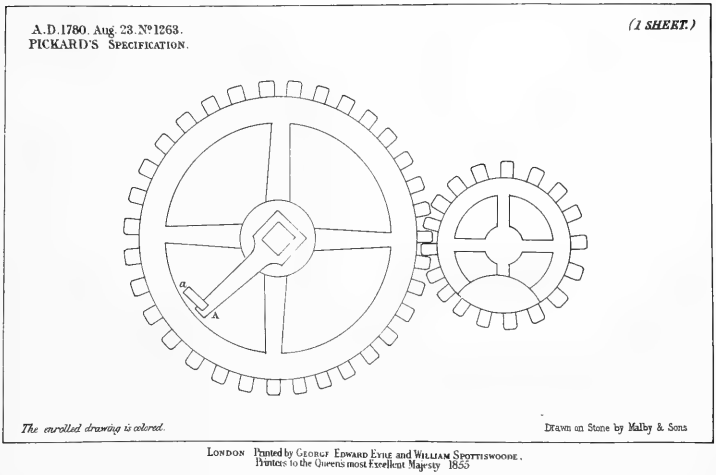
[9] British Patent 1213, March 10, 1779.

[10] British Patent 1263, August 23, 1780.

[11] Dickinson and Jenkins, *op. cit.* (footnote 5), pp. 150, 154.

[12] *Ibid.*, p. 154.

[13] William Murdock, at this time a Boulton and Watt erector, may have suggested this arrangement. *Ibid.*, p. 56.


A.D.1780. Aug. 23. No 1263.
PICKARD'S SPECIFICATION.
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LONDON Printed by George Edward Eyre and William Spottiswoode,
Printers to the Queen's most Excellent Majesty 1855

Figure 6.—One of the steam engine "Crank Patents" that hindered James Watt's progress. This patent, granted to James Pickard in 1780, claimed only the arrangement of counterweights, not the crank. The crank pin to which the connecting rod was attached is at *Aa*. From British Patent 1263, August 23, 1780.

and Watt feared that they might "get into the hands of men more ingenious," who would give Boulton and Watt more competition than Wasbrough and Pickard.[14]

The sun-and-planet arrangement, with gears of equal size, was adopted by Watt for nearly all the rotative engines that he built during the term of the "crank patents." This arrangement had the advantage of turning the flywheel through two revolutions during a single cycle of operation of the piston, thus requiring a flywheel only one-fourth the size of the flywheel needed if a simple crank were used. The optional link (JK of fig. 7e) was used in the engines as built.

From the first, the rotative engines were made double-acting—that is, work was done by steam alternately in each end of the cylinder. The double-acting engine, unlike the single-acting pumping engine, required a piston rod that would push as well as pull. It was in the solution of this problem that Watt's originality and sure judgment were most clearly demonstrated.

A rack and sector arrangement (fig. 8) was used on some engines. The first one, according to Watt, "has broke out several teeth of the rack, but works steady." [15] A little later he told a correspondent that his double-acting engine "acts so powerfully that it has broken all its tackling repeatedly. We have now tamed it, however." [16]

It was about a year later that the straight-line linkage [17] was thought out. "I have started a new

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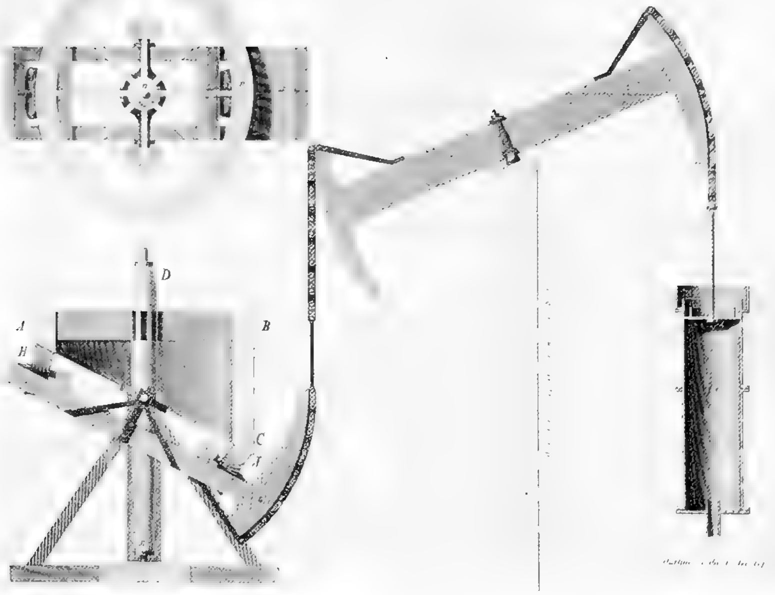
[14] Muirhead, *op. cit.* (footnote 3), vol. 3, note on p. 39.

[15] James Watt, March 31, 1783, quoted in Dickinson and Jenkins, *op. cit.* (footnote 5), p. 140.

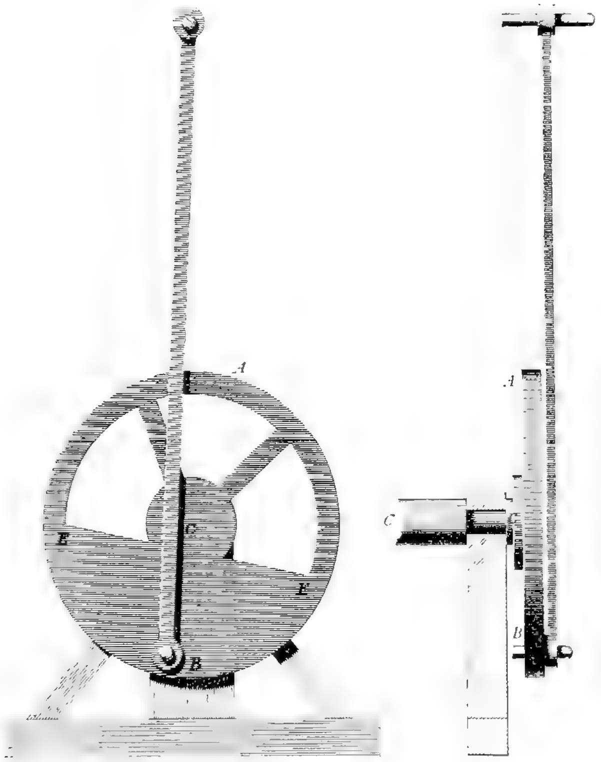
[16] Watt to De Luc, April 26, 1783, quoted in Muirhead, *op. cit.* (footnote 3), vol. 2, p. 174.

[17] Watt's was a four-bar linkage. All four-bar straight-line linkages that have no sliding pairs trace only an approximately straight line. The exact straight-line linkage in a single plane was not known until 1864 (see p. 204). In 1853 Pierre-Frédéric Sarrus (1798–1861), a French professor of mathematics at Strasbourg, devised an accordion-like spatial linkage that traced a true straight line. Described but not illustrated (Académie des Sciences, Paris, *Comptes rendus*, 1853, vol. 36, pp. 1036–1038, 1125), the mechanism was forgotten and twice reinvented; finally, the original invention was rediscovered by an English writer in 1905. For chronology, see Florian Cajori, *A History of Mathematics*, ed. 2, New York, 1919, p. 301.



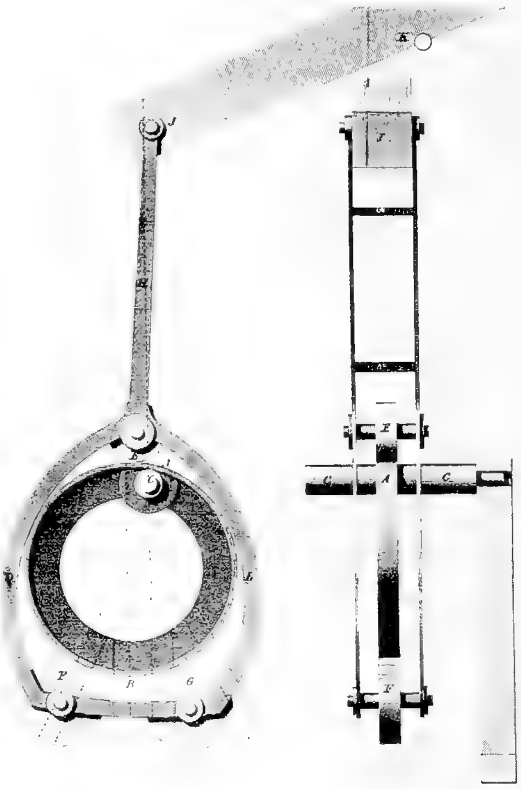
(a)

"Inclined wheel." The vertical shaft at *D* is rotated by action of wheels *H* and *J* on cam, or swash plate, *ABC*. Boulton and Watt tried this device but discarded it.



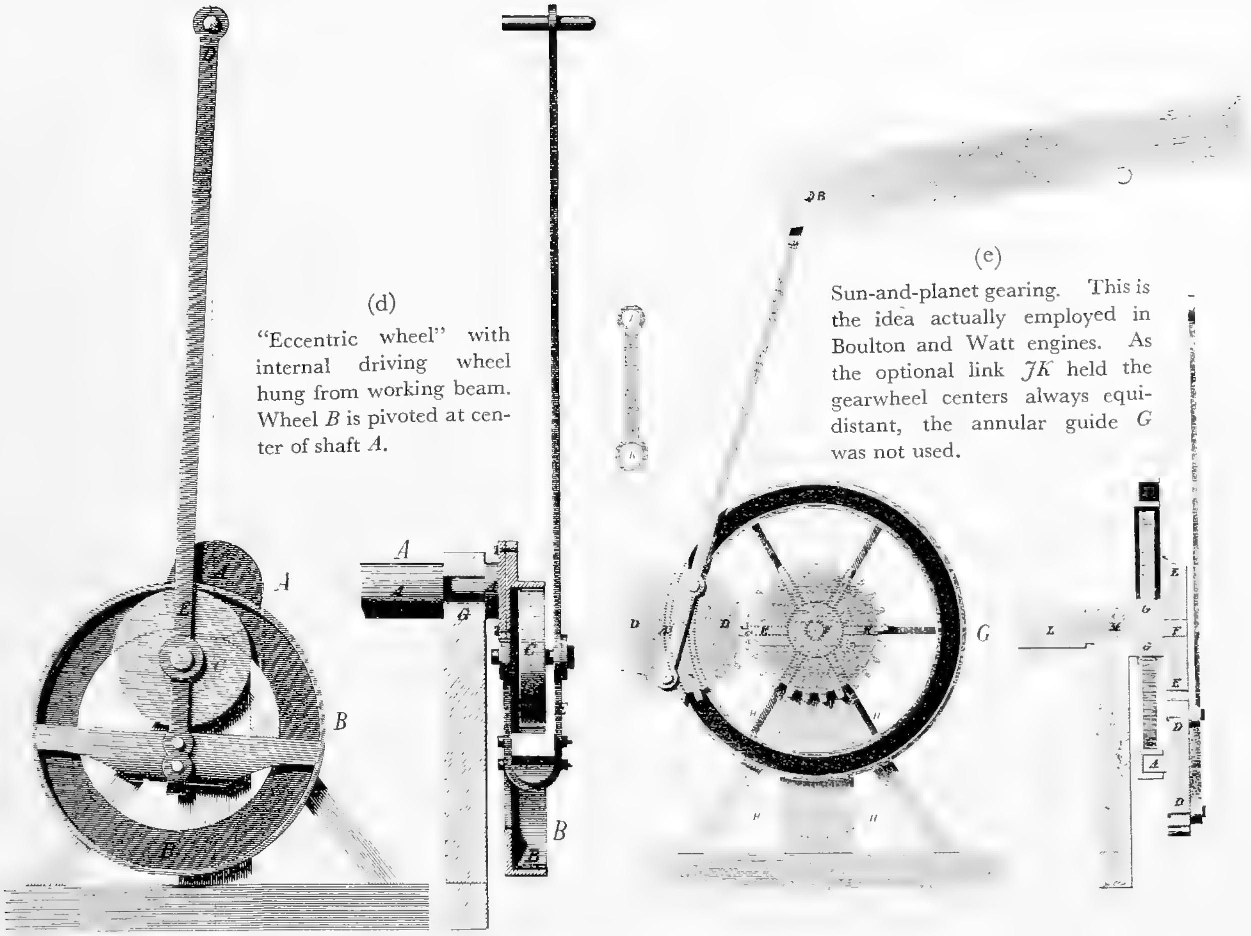
(b)

Counterweighted crank wheel.



(c)

"Eccentric wheel" with external yoke hung from working beam. The wheel pivots at *C*.



(d)
"Eccentric wheel" with internal driving wheel hung from working beam. Wheel *B* is pivoted at center of shaft *A*.

(e)
Sun-and-planet gearing. This is the idea actually employed in Boulton and Watt engines. As the optional link *JK* held the gearwheel centers always equidistant, the annular guide *G* was not used.

Figure 7.—James Watt's five alternative devices for the conversion of reciprocating motion to rotary motion in a steam engine. (British Patent 1306, October 25, 1781). From James P. Muirhead, *The Origin and Progress of the Mechanical Inventions of James Watt* (London, 1854, vol. 3, pls. 3–5, 7).

hare," Watt wrote to his partner. "I have got a glimpse of a method of causing the piston-rod to move up and down perpendicularly, by only fixing it to a piece of iron upon the beam, without chains, or perpendicular guides, or untowardly frictions, arch-heads, or other pieces of clumsiness . . . . I have only tried it in a slight model yet, so cannot build upon it, though I think it a very probable thing to succeed, and one of the most ingenious simple pieces of mechanism I have contrived . . . ." [18]

Watt's marvelously simple straight-line linkage was incorporated into a large beam engine almost immediately, and the usually pessimistic and reserved inventor was close to a state of elation when he told Boulton that the "new central perpendicular motion answers beyond expectation, and does not make the shadow of a noise." [19] This linkage, which was included in an extensive patent of 1784, and two alternative devices are illustrated here (fig. 9). One of the alternatives is a guided crosshead (fig. 9, top right).

Brilliant as was the conception of this linkage, it was followed up by a synthesis that is very little short of incredible. In order to make the linkage attached to the beam of his engines more compact, Watt had

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[18] Muirhead, *op. cit.* (footnote 3), vol. 2, pp. 191–192.

[19] *Ibid.*, p. 202.

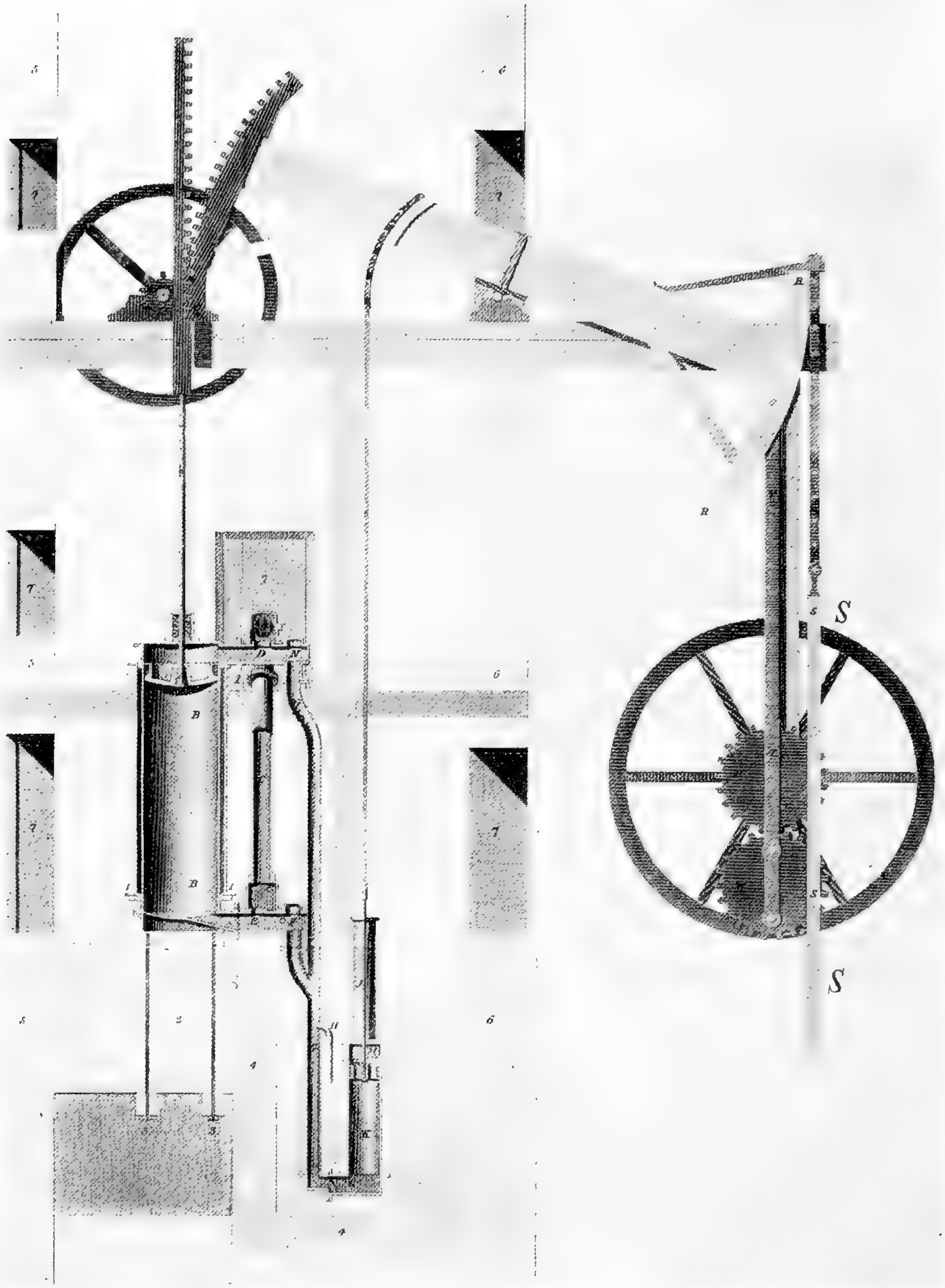

Figure 8.—Watt engine of 1782 (British Patent 1321, March 12, 1782) showing the rack and sector used to guide the upper end of the piston rod and to transmit force from piston to working beam. This engine, with a 30-inch cylinder and an 8-foot stroke, was arranged for pumping. Pump rod *SS* is hung from sector of the working beam. From James P. Muirhead, *The Origin and Progress of the Mechanical Inventions of James Watt* (London, 1854, vol. 3, pl. 15).

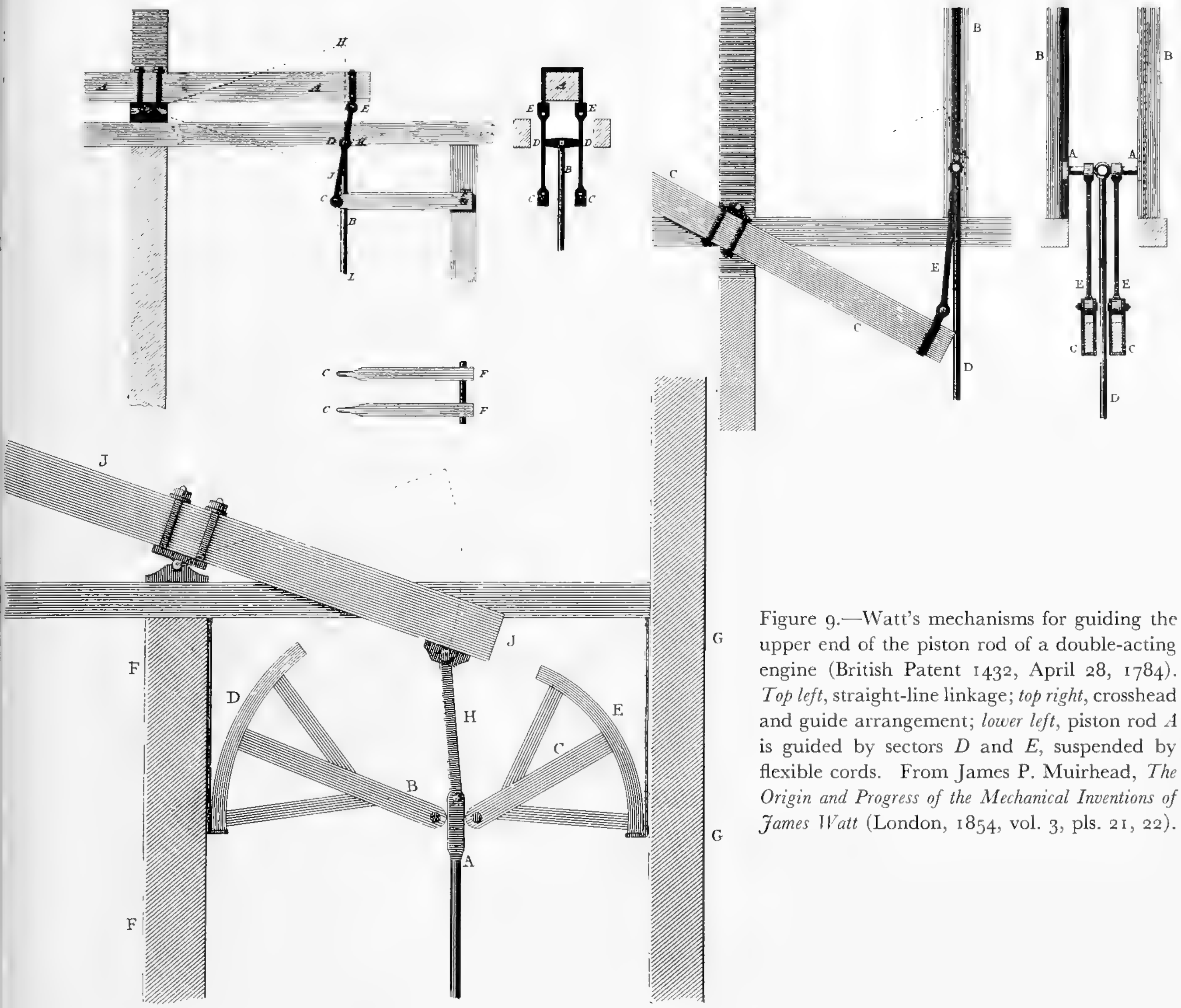

Figure 9.—Watt's mechanisms for guiding the upper end of the piston rod of a double-acting engine (British Patent 1432, April 28, 1784). *Top left*, straight-line linkage; *top right*, crosshead and guide arrangement; *lower left*, piston rod *A* is guided by sectors *D* and *E*, suspended by flexible cords. From James P. Muirhead, *The Origin and Progress of the Mechanical Inventions of James Watt* (London, 1854, vol. 3, pls. 21, 22).

plumbed his experience for ideas; his experience had yielded up the work done much earlier on a drafting machine that made use of a pantograph.[20] Watt combined his straight-line linkage with a pantograph, one link becoming a member of the pantograph.

The length of each oscillating link of the straight-line linkage was thus reduced to one-fourth instead of one-half the beam length, and the entire mechanism could be constructed so that it would not extend beyond the end of the working beam. This arrangement soon came to be known as Watt's "parallel motion" (fig. 10).[21] Years later Watt told his son: "Though I am not over anxious after fame, yet

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[20] "It has only one fault," he had told a friend on December 24, 1773, after describing the drafting machine to him, "which is, that it will not do, because it describes conic sections instead of straight lines." *Ibid.*, p. 71.

[21] Throughout the 19th century the term "parallel motion" was used indiscriminately to refer to any straight-line linkage. I have not discovered the origin of the term. Watt did not use it in his patent specification, and I have not found it in his writings or elsewhere before 1808 (see footnote 22). *The Cyclopaedia* (Abraham Rees, ed., London, 1819, vol. 26) defined parallel motion as "a term used among practical mechanics to denote the rectilinear motion of a piston-rod, &c.

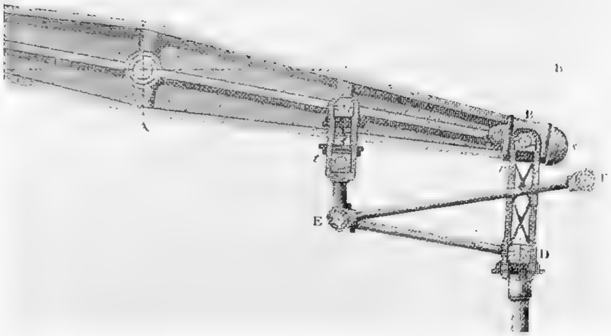

Figure 10.—Watt's "parallel motion." Engine's working beam is pivoted at *A*. Pivot *F* is attached to the engine frame. From Dyonysius Lardner, *The Steam Engine* (Philadelphia, 1852), pl. 5 (American ed. 5 from London ed. 5).

I am more proud of the parallel motion than of any other mechanical invention I have ever made."[22]

The Watt four-bar linkage was employed 75 years after its inception by the American Charles B. Richards when, in 1861, he designed his first high-speed engine indicator (fig. 11). Introduced into England the following year, the Richards Indicator was an immediate success, and many thousands were sold over the next 20 or 30 years.[23]

In considering the order of synthetic ability required to design the straight-line linkage and to combine it with a pantograph, it should be kept in mind that this was the first one of a long line of such mechanisms.[24] Once the idea was abroad, it was only to be expected that many variations and alternative solutions should appear. One wonders, however, what direction the subsequent work would have taken if Watt had not so clearly pointed the way.

In 1827 John Farey, in his exhaustive study of the steam engine, wrote perhaps the best contemporary view of Watt's work. Farey as a young man had several times talked with the aging Watt, and he had reflected upon the nature of the intellect that had caused Watt to be recognized as a genius, even within his own lifetime. In attempting to explain Watt's genius, Farey set down some observations that are pertinent not only to kinematic synthesis but to the currently fashionable term "creativity."

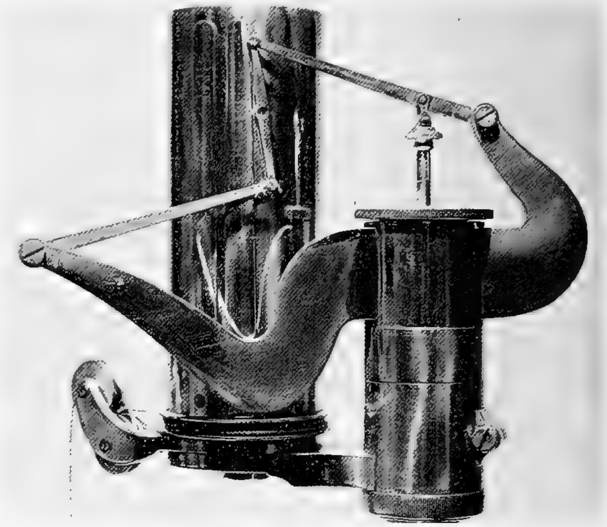

Figure 11.—Richards high-speed engine indicator of 1861, showing application of the Watt straight-line linkage. (*USNM* 307515; *Smithsonian photo* 46570).

In Farey's opinion Watt's inventive faculty was far superior to that of any of his contemporaries; but his many and various ideas would have been of little use if he had not possessed a very high order of judgment, that "faculty of distinguishing between ideas; decomposing compound ideas into more

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in the direction of its length; and contrivances, by which such alternate rectilinear motions are converted into continuous rotatory ones, or *vice versa* . . . ." Robert Willis in his *Principles of Mechanism* (London, 1841, p. 399) described parallel motion as "a term somewhat aukwardly applied to a combination of jointed rods, the purpose of which is to cause a point to describe a straight line . . . ." A. B. Kempe in *How to Draw a Straight Line* (London, 1877, p. 49) wrote: "I have been more than once asked to get rid of the objectionable term 'parallel motion.' I do not know how it came to be employed, and it certainly does not express what is intended. The expression, however, has now become crystallised, and I for one cannot undertake to find a solvent."

[22] Muirhead, *op. cit.* (footnote 3), vol. 3, note on p. 89.

[23] Charles T. Porter, *Engineering Reminiscences*, New York, 1908, pp. 58–59, 90.

[24] At least one earlier straight-line linkage, an arrangement later ascribed to Richard Roberts, had been depicted before Watt's patent (Pierre Patte, *Mémoirs sur les objets les plus importans de l'architecture*, Paris, 1769, p. 229 and pl. 11). However, this linkage (reproduced here in figure 18) had no detectable influence on Watt or on subsequent practice.

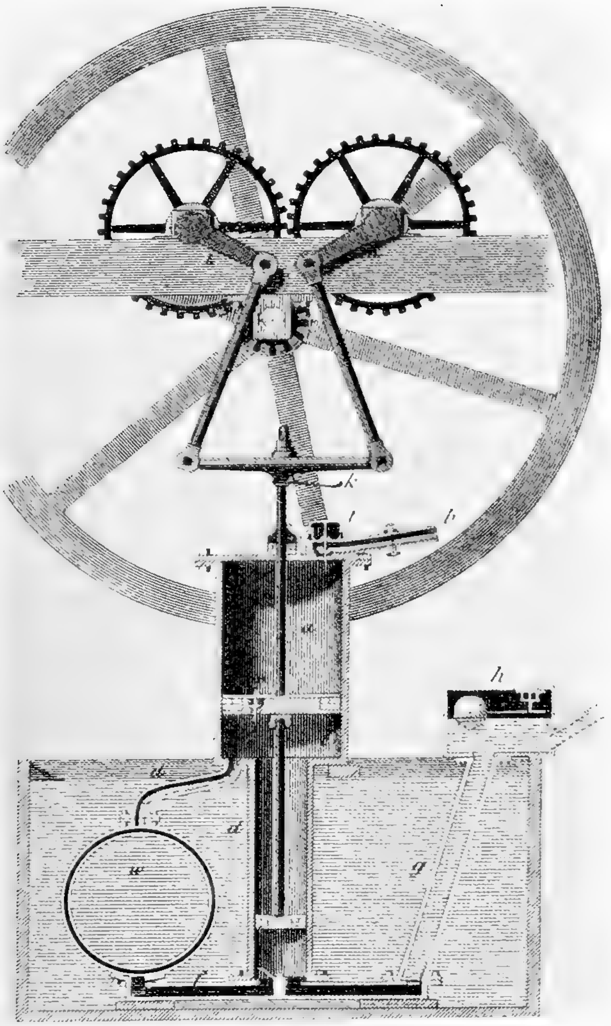

Figure 12.—Cartwright's geared straight-line mechanism of about 1800, From Abraham Rees, *The Cyclopaedia* (London, 1819, "Steam Engine," pl. 5).

simple elements; arranging them into classes, and comparing them together . . . ."

Farey was of the opinion that while a mind like Watt's could produce brilliant new ideas, still the "common stock of ideas which are current amongst communities and professions, will generally prove to be of a better quality than the average of those new ideas, which can be produced by any individual from the operation of his own mind, without assistance from others." Farey concluded with the observation that "the most useful additions to that common stock, usually proceed from the individuals who are well acquainted with the whole series." [25]

To Draw a Straight Line

During most of the century after James Watt had produced his parallel motion, the problem of devising a linkage, one point of which would describe a straight line, was one that tickled the fancies of mathematicians, of ingenious mechanics, and of gentlemanly dabblers in ideas. The quest for a straight-line mechanism more accurate than that of Watt far outlasted the pressing practical need for such a device. Large metal planing machines were well known by 1830, and by midcentury crossheads and crosshead guides were used on both sides of the Atlantic in engines with and without working beams.

By 1819 John Farey had observed quite accurately that, in England at least, many other schemes had been tried and found wanting and that "no methods have been found so good as the original engine; and we accordingly find, that all the most established and experienced manufacturers make engines which are not altered in any great feature from Mr. Watt's original engine . . . ." [26]

Two mechanisms for producing a straight line were introduced before the Boulton and Watt monopoly ended in 1800. Perhaps the first was by Edmund Cartwright (1743–1823), who is said to have had the original idea for a power loom. This geared device (fig. 12), was characterized patronizingly by a contemporary American editor as possessing "as much merit as can possibly be attributed to a gentleman engaged in the pursuit of mechanical studies for his own amusement." [27] Only a few small engines were made under the patent.[28]

The properties of a hypocycloid were recognized by James White, an English engineer, in his geared design which employed a pivot located on the pitch circle of a spur gear revolving inside an internal gear. The diameter of the pitch circle of the spur gear was one-half that of the internal gear, with the

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[25] Farey, *op. cit.* (footnote 6), pp. 651, 652.

[26] In Rees, *op. cit.* (footnote 21), vol. 34 ("Steam Engine"). John Farey was the writer of this article (see Farey, *op. cit.*, p. vi).

[27] *Emporium of Arts and Sciences*, December 1813, new ser., vol. 2, no. 1, p. 81.

[28] Farey, *op. cit.* (footnote 6), p. 666.

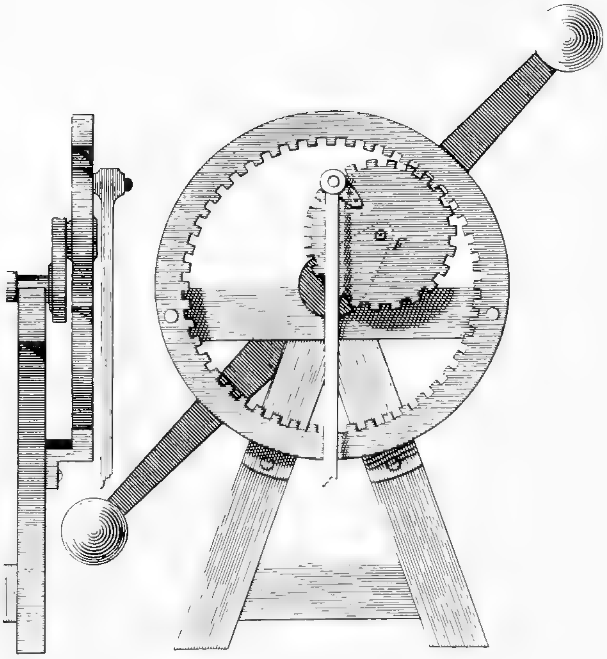

Figure 13.—James White's hypocycloidal straight-line mechanism, about 1800. The fly-weights (at the ends of the diagonal arm) functioned as a flywheel. From James White, *A New Century of Inventions* (Manchester, 1822, pl. 7).

result that the pivot, to which the piston rod was connected, traced out a diameter of the large pitch circle (fig. 13). White in 1801 received from Napoleon Bonaparte a medal for this invention when it was exhibited at an industrial exposition in Paris.[29] Some steam engines employing White's mechanism were built, but without conspicuous commercial success. White himself rather agreed that while his invention was "allowed to possess curious properties, and to be a *pretty* thing, opinions do not all concur in declaring it, essentially and generally, a *good* thing."[30]

The first of the non-Watt four-bar linkages appeared shortly after 1800. The origin of the grasshopper beam motion is somewhat obscure, although

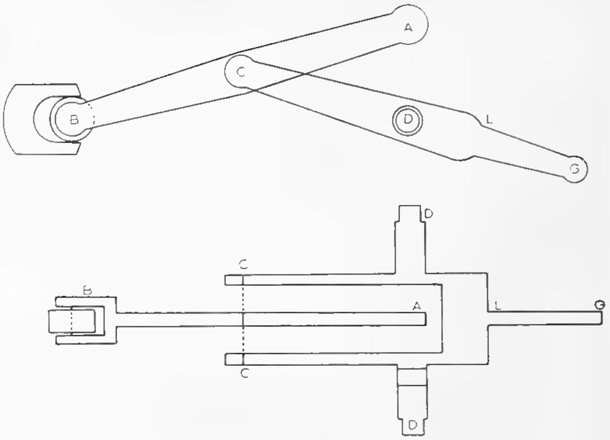

Figure 14.—Freemantle straight-line linkage, later called the Scott Russell linkage. From British Patent 2741, November 17, 1803.

it came to be associated with the name of Oliver Evans, the American pioneer in the employment of high-pressure steam. A similar idea, employing an isosceles linkage, was patented in 1803 by William Freemantle, an English watchmaker (fig. 14).[31] This is the linkage that was attributed much later to John Scott Russell (1808–1882), the prominent naval architect.[32] An inconclusive hint that Evans had devised his straight-line linkage by 1805 appeared in a plate illustrating his *Abortion of the Young Steam Engineer's Guide* (Philadelphia, 1805), and it was certainly used on his Columbian engine (fig. 15), which was built before 1813. The Freemantle linkage, in modified form, appeared in Rees's *Cyclopaedia* of 1819 (fig. 16), but it is doubtful whether even this would have been readily recognized as identical with the Evans linkage, because the connecting rod was at the opposite end of the working beam from the piston rod, in accordance with established usage, while in the Evans linkage the crank and connecting rod were at the same end of the beam. It is possible that Evans got his idea from an earlier English periodical, but concrete evidence is lacking.

If the idea did in fact originate with Evans, it is strange that he did not mention it in his patent claims, or in the descriptions that he published of his

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[29] H. W. Dickinson, "James White and His 'New Century of Inventions,'" *Transactions of the Newcomen Society*, 1949–1951, vol. 27, pp. 175–179.

[30] James White, *A New Century of Inventions*, Manchester, 1822, pp. 30–31, 338. A hypocycloidal engine used in Stourbridge, England, is in the Henry Ford Museum.

[31] British Patent 2741, November 17, 1803.

[32] William J. M. Rankine, *Manual of Machinery and Millwork*, ed. 6, London, 1887, p. 275.

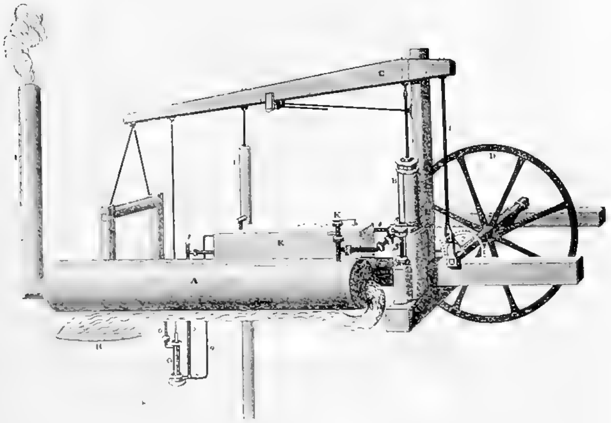

Figure 15.—Oliver Evans' "Columbian" engine, 1813, showing the Evans, or "grasshopper," straight-line linkage. From *Emporium of Arts and Sciences* (new ser., vol. 2, no. 3, April 1814, pl. opposite p. 380).

engines.[33] The practical advantage of the Evans linkage, utilizing as it could a much lighter working beam than the Watt or Freemantle engines, would not escape Oliver Evans, and he was not a man of excessive modesty where his own inventions were concerned.

Another four-bar straight-line linkage that became well known was attributed to Richard Roberts of Manchester (1789–1864), who around 1820 had built one of the first metal planing machines, which machines helped make the quest for straight-line linkages largely academic. I have not discovered what occasioned the introduction of the Roberts linkage, but it dated from before 1841. Although Roberts patented many complex textile machines, an inspection of all of his patent drawings has failed to provide proof that he was the inventor of the Roberts linkage.[34] The fact that the same linkage is shown in an engraving of 1769 (fig. 18) further confuses the issue.[35]

The appearance in 1864 of Peaucellier's exact straight-line linkage went nearly unnoticed. A

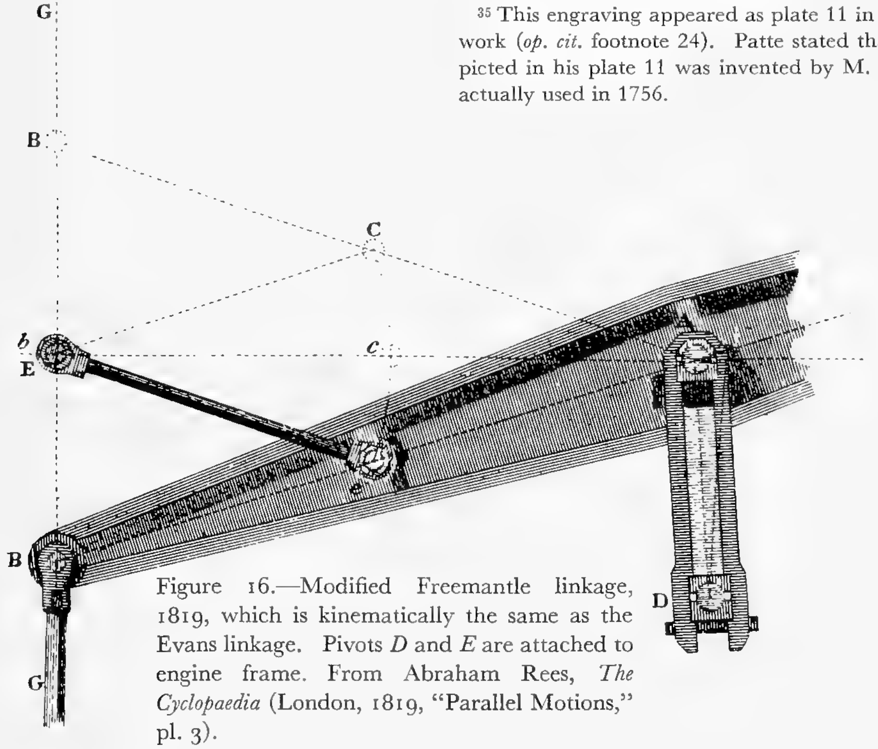

Figure 16.—Modified Freemantle linkage, 1819, which is kinematically the same as the Evans linkage. Pivots *D* and *E* are attached to engine frame. From Abraham Rees, *The Cyclopaedia* (London, 1819, "Parallel Motions," pl. 3).

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[33] Greville and Dorothy Bathe, *Oliver Evans*, Philadelphia, 1935, pp. 88, 196, and *passim.*

[34] Robert Willis (*op. cit.* [footnote 21] p. 411) credited Richard Roberts with the linkage. Roberts' 15 British patent drawings exhibit complex applications of cams, levers, guided rods, cords, and so forth, but no straight-line mechanism. In his patent no. 6258 of April 13, 1832, for a steam engine and locomotive carriage, Roberts used Watt's "parallel motion" on a beam driven by a vertical cylinder.

[35] This engraving appeared as plate 11 in Pierre Patte's 1769 work (*op. cit.* footnote 24). Patte stated that the machine depicted in his plate 11 was invented by M. de Voglie and was actually used in 1756.

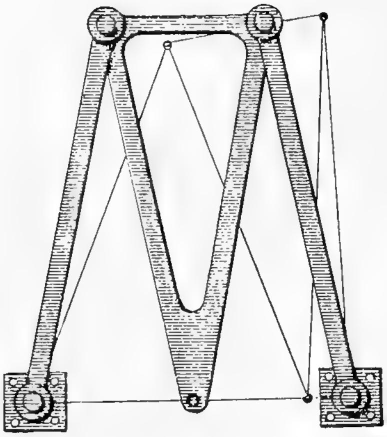
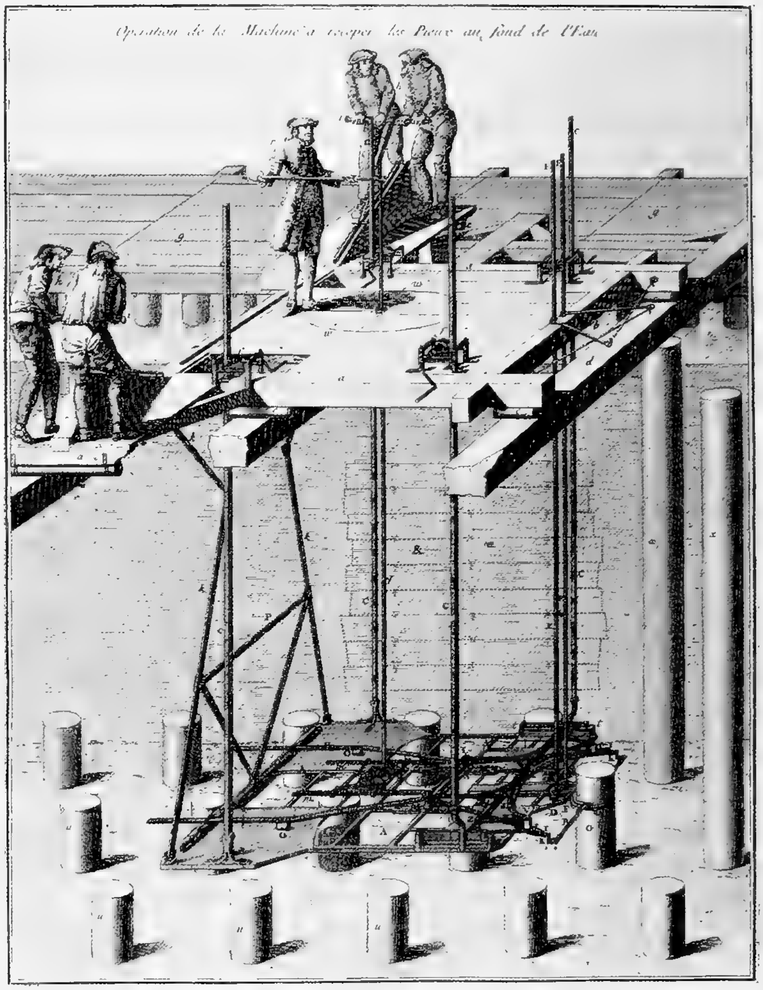


Figure 17.—Straight-line linkage (before 1841) attributed to Richard Roberts by Robert Willis. From A. B. Kempe, *How to Draw a Straight Line* (London, 1877, p. 10).

decade later, when news of its invention crossed the Channel to England, this linkage excited a flurry of interest, and variations of it occupied mathematical minds for several years. For at least 10 years before and 20 years after the final solution of the problem, Professor Chebyshev,[36] a noted mathematician of the University of St. Petersburg, was interested in the matter. Judging by his published works and his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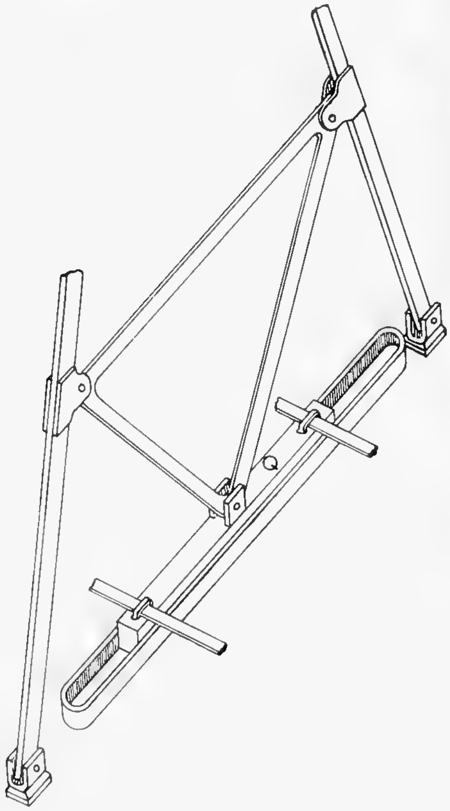

Figure 18.—Machine for sawing off pilings under water, about 1760, designed by De Voglie. The Roberts linkage operates the bar (*Q* in detailed sketch) at the rear of the machine below the operators. The significance of the linkage apparently was not generally recognized. A similar machine depicted in Diderot's *Encyclopédie*, published several years later, did not employ the straight-line linkage. From Pierre Patte, *Memoirs sur les objets plus importants de l'architecture* (Paris, 1769, pl. 11).

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[36] This is the Library of Congress spelling

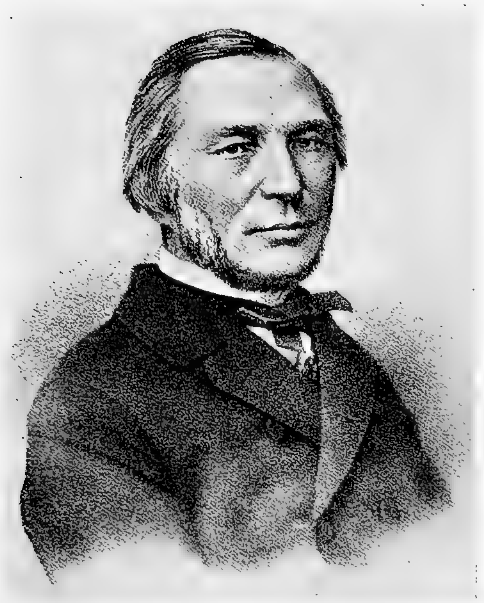

Figure 19.—Pafnutiĭ L'vovich Chebyshev (1821–1894), Russian mathematician active in analysis and synthesis of straight-line mechanisms. From *Ouvres de P. L. Tchebychef* (St. Petersburg, 1907, vol. 2, frontispiece).

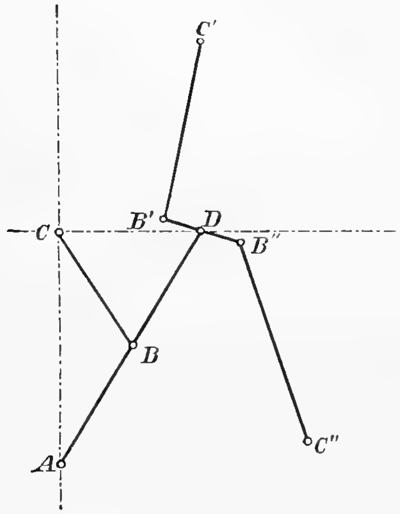

Figure 20.—Chebyshev's combination (about 1867) of Watt's and Evans' linkages to reduce errors inherent in each. Points *C*, *C'*, and *C''* are fixed; *A* is the tracing point. From *Oeuvres de P. L. Tchebychef* (St. Petersburg, 1907, vol. 2, p. 93).

reputation abroad, Chebyshev's interest amounted to an obsession.

Pafnutiĭ L'vovich Chebyshev was born in 1821, near Moscow, and entered the University of Moscow in 1837. In 1853, after visiting France and England and observing carefully the progress of applied mechanics in those countries, he read his first paper on approximate straight-line linkages, and over the next 30 years he attacked the problem with new vigor at least a dozen times. He found that the two principal straight-line linkages then in use were Watt's and Evans'. Chebyshev noted the departure of these linkages from a straight line and calculated the deviation as of the fifth degree, or about 0.0008 inch per inch of beam length. He proposed a modification of the Watt linkage to refine its accuracy but found that he would have to more than double the length of the working beam. Chebyshev concluded ruefully that his modification would "present great practical difficulties."[37]

At length an idea occurred to Chebyshev that would enable him to approach if not quite attain a true straight line. If one mechanism was good, he reasoned, two would be better, *et cetera, ad infinitum.* The idea was simply to combine, or compound, four-link approximate linkages, arranging them in such a way that the errors would be successively reduced. Contemplating first a combination of the Watt and Evans linkages (fig. 19), Chebyshev recognized that if point D of the Watt linkage followed nearly a straight line, point A of the Evans linkage would depart even less from a straight line. He calculated the deviation in this case as of the 11th degree. He then replaced Watt's linkage by one that is usually called the Chebyshev straight-line mechanism (fig. 20), with the result that precision was increased to the 13th degree.[38] The steam engine that he displayed at the Vienna Exhibition in 1873 employed this linkage—the Chebyshev mechanism compounded with the Evans, or approximate isosceles, linkage. An English visitor to the exhibition commented that

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[37] *Oeuvres de P. L. Tchebychef*, 2 vols., St. Petersburg, 1899–1907, vol. 1, p. 538; vol. 2, pp. 57, 85.

[38] *Ibid.*, vol. 2, pp. 93, 94.

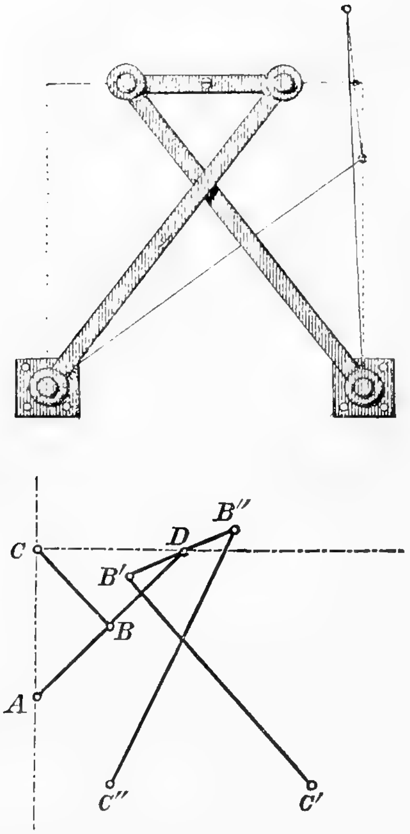

Figure 21.—*Top:* Chebyshev straight-line linkage, 1867; from A. B. Kempe, *How to Draw a Straight Line* (London, 1877, p. 11). *Bottom:* Chebyshev-Evans combination, 1867; from *Oeuvres de P. L. Tchebychef* (St. Petersburg, 1907, vol. 2, p. 94). Points *C*, *C*', and *C*'' are fixed. *A* is the tracing point.

"the motion is of little or no practical use, for we can scarcely imagine circumstances under which it would be more advantageous to use such a complicated system of levers, with so many joints to be lubricated and so many pins to wear, than a solid guide of some kind; but at the same time the arrangement is very ingenious and in this respect reflects great credit on its designer." [39]

There is a persistent rumor that Professor Chebyshev sought to demonstrate the impossibility of constructing any linkage, regardless of the number of links, that would generate a straight line; but I have found only a dubious statement in the *Grande Encyclopédie*[40] of the late 19th century and a report of a conversation with the Russian by an Englishman, James Sylvester, to the effect that Chebyshev had "succeeded in proving the nonexistence of a five-bar link-work capable of producing a perfect parallel motion. . . ."[41] Regardless of what tradition may have to say about what Chebyshev said, it is of course well known that Captain Peaucellier was the man who finally synthesized the exact straight-line mechanism that bears his name.

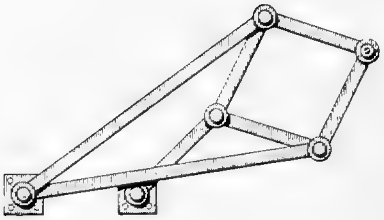

Figure 22.—Peaucellier exact straight-line linkage, 1873. From A. B. Kempe, *How to Draw a Straight Line* (London, 1877, p. 12).

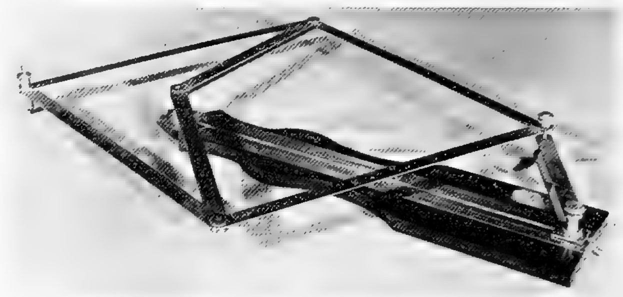

Figure 23.—Model of the Peaucellier "Compas Composé," deposited in Conservatoire National des Arts et Métiers, Paris, 1875. Photo courtesy of the Conservatoire.

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[39] *Engineering,* October 3, 1873, vol. 16, p. 284.

[40] *La Grande Encyclopédie,* Paris, 1886 ("Peaucellier").

[41] James Sylvester, "Recent Discoveries in Mechanical Conversion of Motion," *Notices of the Proceedings of the Royal Institution of Great Britain,* 1873–1875, vol. 7, p. 181. The fixed link was not counted by Sylvester; in modern parlance this would be a six-link mechanism.

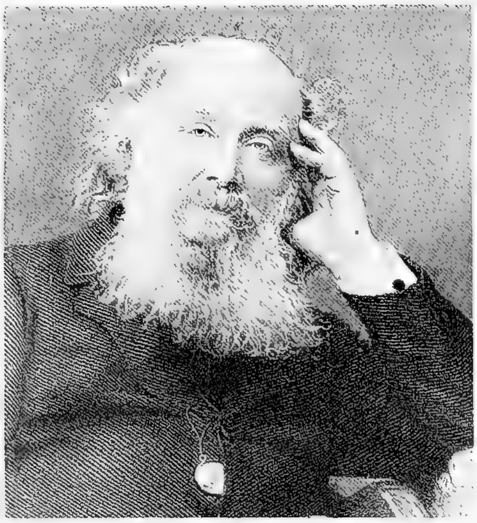

Figure 24.—James Joseph Sylvester (1814–1897), mathematician and lecturer on straight-line linkages. From *Proceedings of the Royal Society of London* (1898, vol. 63, opposite p. 161).

Charles-Nicolas Peaucellier, a graduate of the Ecole Polytechnique and a captain in the French corps of engineers, was 32 years old in 1864 when he wrote a short letter to the editor of *Nouvelles Annales de mathématiques* (ser. 2, vol. 3, pp. 414–415) in Paris. He called attention to what he termed "compound compasses," a class of linkages that included Watt's parallel motion, the pantograph, and the polar planimeter. He proposed to design linkages to describe a straight line, a circle of any radius no matter how large, and conic sections, and he indicated in his letter that he had arrived at a solution.

This letter stirred no pens in reply, and during the next 10 years the problem merely led to the filling of a few academic pages by Peaucellier and Amédée Mannheim (1831–1906), also a graduate of Ecole Polytechnique, a professor of mathematics, and the designer of the Mannheim slide rule. Finally, in 1873, Captain Peaucellier gave his solution to the readers of the *Nouvelles Annales.* His reasoning, which has a distinct flavor of discovery by hindsight, was that since a linkage generates a curve that can be expressed algebraically, it must follow that any algebraic curve can be generated by a suitable linkage—it was only necessary to find the suitable linkage. He then gave a neat geometric proof, suggested by Mannheim, for his straight-line "compound compass."[42]

On a Friday evening in January 1874 Albemarle Street in London was filled with carriages, each

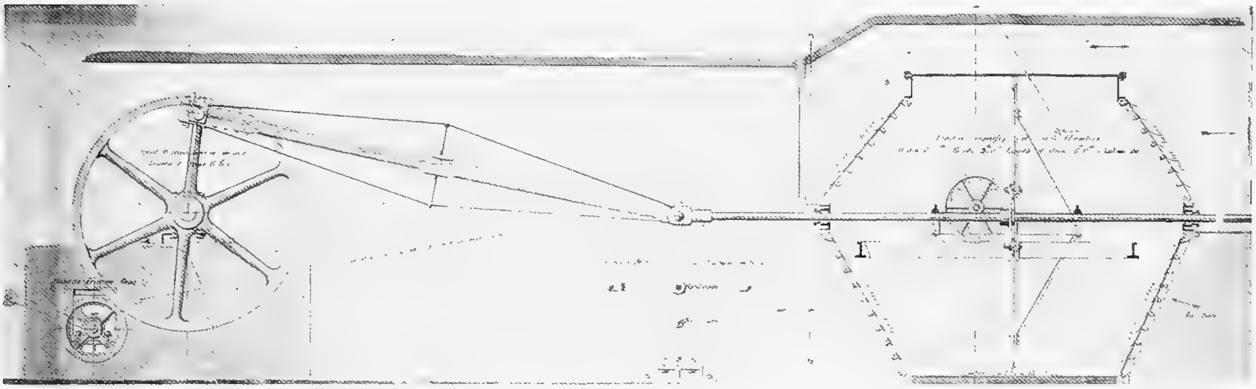

Figure 25.—Mr. Prim's blowing engine used for ventilating the House of Commons, 1877. The crosshead of the reciprocating air pump is guided by a Peaucillier linkage shown at the center. The slate-lined air cylinders had rubber-flap inlet and exhaust valves and a piston whose periphery was formed by two rows of brush bristles. Prim's machine was driven by a steam engine. Photograph by Science Museum, London.

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[42] Charles-Nicholas Peaucellier, "Note sur une question de geométrie de compas," *Nouvelles Annales de mathématiques,* 1873, ser. 2, vol. 12, pp. 71–78. A sketch of Mannheim's work is in Florian Cajori, *A History of the Logarithmic Slide Rule,* New York, about 1910, reprinted in *String Figures and Other Monographs,* New York, Chelsea Publishing Company, 1960.

maneuvering to unload its charge of gentlemen and their ladies at the door of the venerable hall of the Royal Institution. Amidst a "mightly rustling of silks," the elegant crowd made its way to the auditorium for one of the famous weekly lectures. The speaker on this occasion was James Joseph Sylvester, a small intense man with an enormous head, sometime professor of mathematics at the University of Virginia, in America, and more recently at the Royal Military Academy in Woolwich. He spoke from the same rostrum that had been occupied by Davy, Faraday, Tyndall, Maxwell, and many other notable scientists. Professor Sylvester's subject was "Recent Discoveries in Mechanical Conversion of Motion."[43]

Remarking upon the popular appeal of most of the lectures, a contemporary observer noted that while many listeners might prefer to hear Professor Tyndall expound on the acoustic opacity of the atmosphere, "those of a higher and drier turn of mind experience ineffable delight when Professor Sylvester holds forth on the conversion of circular into parallel motion."[44]

Sylvester's aim was to bring the Peaucellier linkage to the notice of the English-speaking world, as it had been brought to his attention by Chebyshev—during a recent visit of the Russian to England—and to give his listeners some insight into the vastness of the field that he saw opened by the discovery of the French soldier.[45]

"The perfect parallel motion of Peaucellier looks so simple," he observed, "and moves so easily that people who see it at work almost universally express astonishment that it waited so long to be discovered." But that was not his reaction at all. The more one reflects upon the problem, Sylvester continued, he "wonders the more that it was ever found out, and can see no reason why it should have been discovered for a hundred years to come. Viewed *a priori* there was nothing to lead up to it. It bears not the remotest analogy (except in the fact of a double centring) to Watt's parallel motion or any of its progeny."[46]

It must be pointed out, parenthetically at least, that James Watt had not only had to solve the problem as best he could, but that he had no inkling, so far as experience was concerned, that a solvable problem existed.

Sylvester interrupted his panegyric long enough to enumerate some of the practical results of the Peaucellier linkage. He said that Mr. Penrose, the eminent architect and surveyor to St. Paul's Cathedral, had "put up a house-pump worked by a negative Peaucellier cell, to the great wonderment of the plumber employed, who could hardly believe his senses when he saw the sling attached to the piston-rod moving in a true vertical line, instead of wobbling as usual from side to side." Sylvester could see no reason "why the perfect parallel motion should not be employed with equal advantage in the construction of ordinary water-closets." The linkage was to be employed by "a gentleman of fortune" in a marine engine for his yacht, and there was talk of using it to guide a piston rod "in certain machinery connected with some new apparatus for the ventilation and filtration of the air of the Houses of Parliament." In due course, Mr. Prim, "engineer to the Houses," was pleased to show his adaptation of the Peaucellier linkage to his new blowing engines, which proved to be exceptionally quiet in their operation (fig. 25).[47] A bit on the ludicrous side, also, was Sylvester's 78-bar linkage that traced a straight line along the line connecting the two fixed centers of the linkage.[48]

Before dismissing with a smile the quaint ideas of our Victorian forbears, however, it is well to ask, 88 years later, whether some rather elaborate work reported recently on the synthesis of straight-line mechanisms is more to the point, when the principal objective appears to be the moving of an indicator on a "pleasing, expanded" (i.e., squashed flat) radio dial.[49]

But Professor Sylvester was more interested, really, in the mathematical possibilities of the Peaucellier linkage, as no doubt our modern investigators are. Through a compounding of Peaucellier mechanisms,

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[43] Sylvester, *op. cit.* (footnote 41), pp. 179–198. It appears from a comment in this lecture that Sylvester was responsible for the word "linkage." According to Sylvester, a linkage consists of an even number of links, a "link-work" of an odd number. Since the fixed member was not considered as a link by Sylvester, this distinction became utterly confusing when Reuleaux's work was published in 1876. Although "link" was used by Watt in a patent specification, it is not probable that he ever used the term "link-work"—at any rate, my search for his use of it has been fruitless. "Link work" is used by Willis (*op. cit.* footnote 21), but the term most likely did not originate with him. I have not found the word "linkage" used earlier than Sylvester.

[44] Bernard H. Becker, *Scientific London*, London, 1874, pp. 45, 50, 51.

[45] Sylvester, *op. cit.* (footnote 41), p. 183; *Nature*, November 13, 1873, vol. 9, p. 33.

[46] Sylvester, *op. cit.* (footnote 41), p. 181.

[47] *Ibid.*, pp. 182, 183, 188, 193.

[48] Kempe, *op. cit.* (footnote 21), p. 17.

[49] *Machine Design*, December 1954, vol. 26, p. 210.

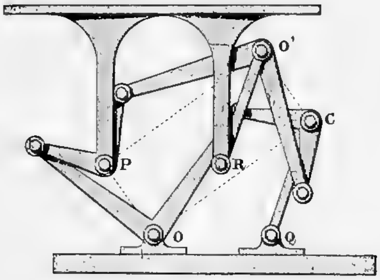

Figure 26.—Sylvester-Kempe translating linkage, 1877. The upper and lower plates remain parallel and equidistant. From A. B. Kempe, *How to Draw a Straight Line* (London, 1877, p. 37).

Figure 27.—Gaspard Monge (1746–1818), professor of mathematics at the Ecole Polytechnique from 1794 and founder of the academic discipline of machine kinematics, From *Livre du Centenaire, 1794–1894, Ecole Polytechnique* (Paris, 1895, vol. 1, frontispece).

he had already devised square-root and cube-root extractors, an angle trisector, and a quadratic-binomial root extractor, and he could see no limits to the computing abilities of linkages as yet undiscovered.[50]

Sylvester recalled fondly, in a footnote to his lecture, his experience with a little mechanical model of the Peaucellier linkage at an earlier dinner meeting of the Philosophical Club of the Royal Society. The Peaucellier model had been greeted by the members with lively expressions of admiration "when it was brought in with the dessert, to be seen by them after dinner, as is the laudable custom among members of that eminent body in making known to each other the latest scientific novelties." And Sylvester would never forget the reaction of his brilliant friend Sir William Thomson (later Lord Kelvin) upon being handed the same model in the Athenaeum Club. After Sir William had operated it for a time, Sylvester reached for the model, but he was rebuffed by the exclamation "No! I have not had nearly enough of it—it is the most beautiful thing I have ever seen in my life." [51]

The aftermath of Professor Sylvester's performance at the Royal Institution was considerable excitement amongst a limited company of interested mathematicians. Many alternatives to the Peaucellier straight-line linkage were suggested by several writers of papers for learned journals.[52]

In the summer of 1876, after Sylvester had departed from England to take up his post as professor of mathematics in the new Johns Hopkins University in Baltimore, Alfred Bray Kempe, a young barrister who pursued mathematics as a hobby, delivered at London's South Kensington Museum a lecture with the provocative title "How to Draw a Straight Line." [53]

In order to justify the Peaucellier linkage, Kempe belabored the point that a perfect circle could be generated by means of a pivoted bar and a pencil, while the generation of a straight line was most difficult if not impossible until Captain Peaucellier came

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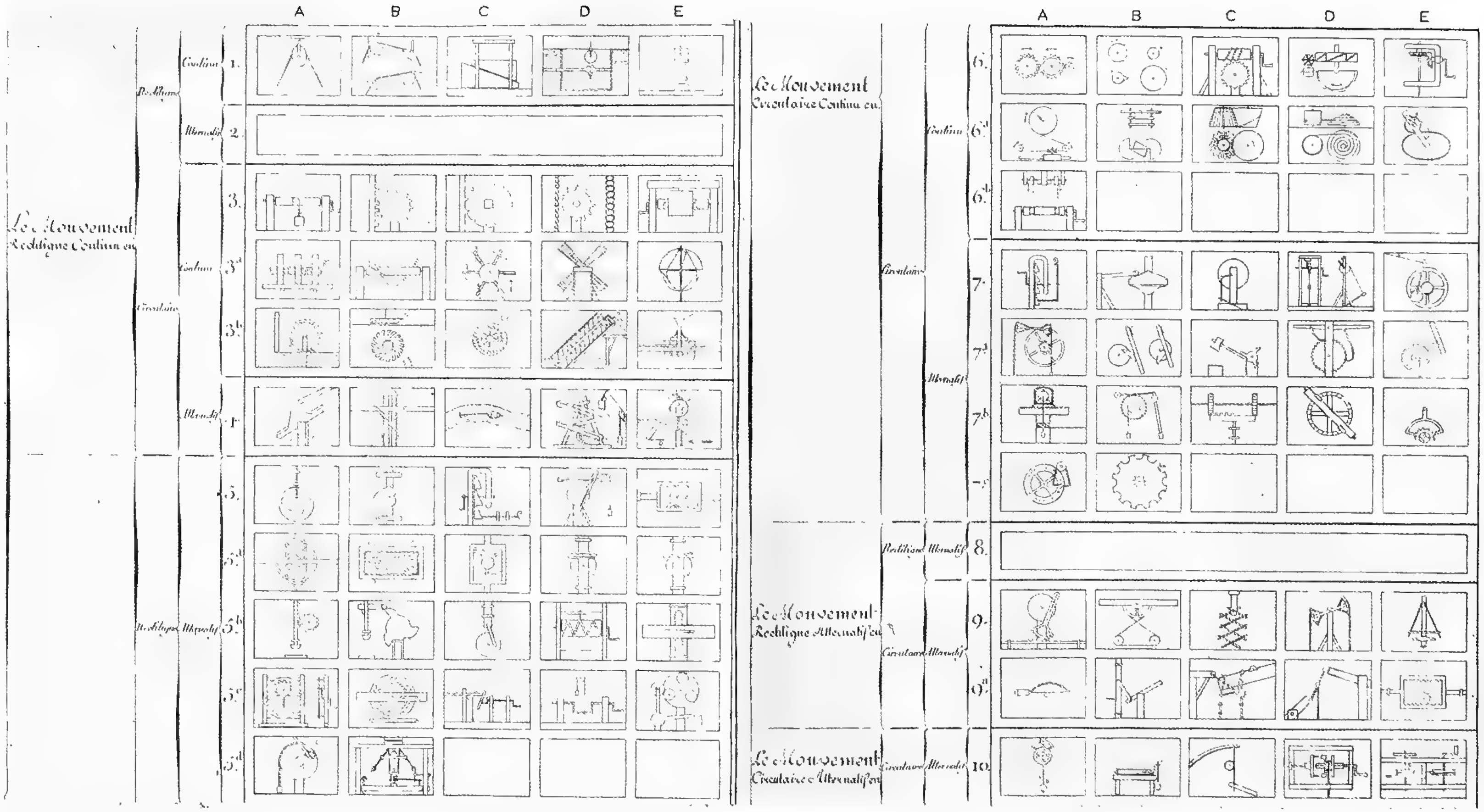
[50] Sylvester, *op. cit.* (footnote 41), p. 191.

[51] *Ibid.*, p. 183.

[52] For a summary of developments and references, see Kempe, *op. cit.* (footnote 21), pp. 49–51. Two of Hart's six-link exact straight-line linkages referred to by Kempe are illustrated in Henry M. Cundy and A. P. Rollett, *Mathematical Models*, Oxford, Oxford University Press, 1952, pp. 204–205. Peaucellier's linkage was of eight links.

[53] Kempe, *op. cit.* (footnote 21), p. 26.


A
B
C
D
E
Le Mouvement
Rectiligne Continu en
Le Mouvement
Circulaire Continu en
Le Mouvement
Rectiligne Alternatif en
Le Mouvement
Circulaire Alternatif en
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1.
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7b
7c
8.
9.
9a
10.

Figure 28.—Hachette's synoptic chart of elementary mechanisms, 1808. This was the first of many charts of mechanical movements that enjoyed wide popularity for over 100 years. From Jean N. P. Hachette, *Traité Elémentaire des Machines* (Paris, 1811, pl. 1).

along. A straight line could be drawn along a straight edge; but how was one to determine whether the straight edge was straight? He did not weaken his argument by suggesting the obvious possibility of using a piece of string. Kempe had collaborated with Sylvester in pursuing the latter's first thoughts on the subject, and one result, that to my mind exemplifies the general direction of their thinking, was the Sylvester-Kempe "parallel motion" (fig. 26).

Enthusiastic as Kempe was, however, he injected an apologetic note in his lecture. "That these results are valuable cannot I think be doubted," he said, "though it may well be that their great beauty has led some to attribute to them an importance which they do not really possess. . . ." He went on to say that 50 years earlier, before the great improvements in the production of true plane surfaces, the straight-line mechanisms would have been more important than in 1876, but he added that "linkages have not at present, I think, been sufficiently put before the mechanician to enable us to say what value should really be set upon them." [54]

It was during this same summer of 1876, at the Loan Exhibition of Scientific Apparatus in the South Kensington Museum, that the work of Franz Reuleaux, which was to have an important and lasting influence on kinematics everywhere, was first introduced to English engineers. Some 300 beautifully constructed teaching aids, known as the Berlin kinematic models, were loaned to the exhibition by the Royal Industrial School in Berlin, of which Reuleaux was the director. These models were used by Prof. Alexander B. W. Kennedy of University College, London, to help explain Reuleaux's new and revolutionary theory of machines.[55]

Scholars and Machines

When, in 1829, André-Marie Ampère (1775–1836) was called upon to prepare a course in theoretical and experimental physics for the Collège de France, he first set about determining the limits of the field of physics. This exercise suggested to his wide-ranging intellect not only the definition of physics but the classification of all human knowledge. He prepared his scheme of classification, tried it out on his physics students, found it incomplete, returned to his study, and produced finally a two-volume work wherein the province of kinematics was first marked out for all to see and consider.[56] Only a few lines could be devoted to so specialized a branch as kinematics, but Ampère managed to capture the central idea of the subject.

Cinématique (from the Greek word for movement) was, according to Ampère, the science "in which movements are considered in themselves [independent of the forces which produce them], as we observe them in solid bodies all about us, and especially in the assemblages called machines." [57] Kinematics, as the study soon came to be known in English,[58] was one of the two branches of elementary mechanics, the other being statics.

In his definition of kinematics, Ampère stated what the faculty of mathematics at the Ecole Polytechnique, in Paris, had been groping toward since the school's opening some 40 years earlier. The study of mechanisms as an intellectual discipline most certainly had its origin on the left bank of the Seine, in this school spawned, as suggested by one French historian,[59] by the great *Encyclopédie* of Diderot and d'Alembert.

Because the Ecole Polytechnique had such a far-reaching influence upon the point of view from which mechanisms were contemplated by scholars for nearly a century after the time of Watt, and by compilers of dictionaries of mechanical movements for an even longer time, it is well to look for a moment at the early work that was done there. If one is interested in origins, it might be profitable for him to investigate the military school in the ancient town of Mézières, about 150 miles northeast of Paris. It was here that Lazare Carnot, one of the principal founders of the Ecole Polytechnique, in 1783 published his essay on machines,[60] which was concerned, among other things, with showing the impossibility of "perpetual motion"; and it was from Mézières that Gaspard Monge and Jean Hachette [61] came to Paris to work out the system of mechanism classification that has come to be associated with the names of Lanz and Bétancourt.

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[54] *Ibid.*, pp. 6–7. I have not pursued the matter of cognate linkages (the Watt and Evans linkages are cognates) because the Roberts-Chebyshev theorem escaped my earlier search, as it had apparently escaped most others until 1958. See R. S. Hartenberg and J. Denavit, "The Fecund Four-Bar," *Transactions of the Fifth Conference on Mechanisms*, Cleveland, Penton Publishing Company, 1958, pp. 194–206, reprinted in *Machine Design*, April 16, 1959, vol. 31, pp. 149–152. See also A. E. R. de Jonge, "The Correlation of Hinged Four-Bar Straight-Line Motion Devices by Means of the Roberts Theorem and a New Proof of the Latter," *Annals of the New York Academy of Sciences*, March 18, 1960, vol. 84, art. 3, pp. 75–145 (published separately).

[55] Alexander B. W. Kennedy, "The Berlin Kinematic Models," *Engineering*, September 15, 1876, vol. 22, pp. 239–240.

[56] André-Marie Ampère, *Essai sur la philosophie des sciences, une exposition analytique d'une classification naturelle de toutes les connaissances humaines*, 2 vols., Paris, 1838 (for origin of the project, see vol. 1, pp. v, xv).

[57] *Ibid.*, vol. 1, pp. 51–52.

[58] Willis (*op. cit.* footnote 21) adopted the word "kinematics," and this Anglicization subsequently became the standard term for this branch of mechanics.

[59] G. Pinet, *Histoire de l'Ecole Polytechnique*, Paris, 1887, pp. viii-ix. In their forthcoming book on kinematic synthesis, R. S. Hartenberg and J. Denavit will trace the germinal ideas of Jacob Leupold and Leonhard Euler of the 18th century.

Gaspard Monge (1746–1818), who while a draftsman at Mézières originated the methods of descriptive geometry, came to the Ecole Polytechnique as professor of mathematics upon its founding in 1794, the second year of the French Republic. According to Jean Nicolas Pierre Hachette (1769–1834), who was junior to Monge in the department of descriptive geometry, Monge planned to give a two-months' course devoted to the elements of machines. Having barely gotten his department under way, however, Monge became involved in Napoleon's ambitious scientific mission to Egypt and, taking leave of his family and his students, embarked for the distant shores.

"Being left in charge," wrote Hachette, "I prepared the course of which Monge had given only the first idea, and I pursued the study of machines in order to analyze and classify them, and to relate geometrical and mechanical principles to their construction." Changes of curriculum delayed introduction of the course until 1806, and not until 1811 was his textbook ready, but the outline of his ideas was presented to his classes in chart form (fig. 28). This chart was the first of the widely popular synoptical tables of mechanical movements.[62]

Hachette classified all mechanisms by considering the conversion of one motion into another. His elementary motions were continuous circular, alternating circular, continuous rectilinear, and alternating rectilinear. Combining one motion with another—for example, a treadle and crank converted alternating circular to continuous circular motion—he devised a system that supplied a frame of reference for the study of mechanisms. In the U.S. Military Academy at West Point, Hachette's treatise, in the original French, was used as a textbook in 1824, and perhaps earlier.[63]

Lanz and Bétancourt, scholars from Spain at the Ecole Polytechnique, plugged some of the gaps in Hachette's system by adding continuous and alternating curvilinear motion, which doubled the number of combinations to be treated, but the advance of their work over that of Hachette was one of degree rather than of kind.[64]

Giuseppe Antonio Borgnis, an Italian "engineer and member of many academies" and professor of mechanics at the University of Pavia in Italy, in his monumental, nine-volume *Traité complet de méchanique appliquée aux arts*, caused a bifurcation of the structure built upon Hachette's foundation of classification when he introduced six orders of machine elements and subdivided these into classes and species. His six orders were *récepteurs* (receivers of motion from the prime mover), *communicateurs*, *modificateurs* (modifiers of velocity), *supports* (e.g., bearings), *regulateurs* (e.g.,

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[60] Lazare N. M. Carnot, *Essai sur les machines en général*, Mézières, 1783 (later published as *Principes fondamentaux de l'equilibre et du mouvement*, Paris, 1803).

[61] Biographical notices of Monge and Hachette appear in *Encyclopaedia Britannica*, ed. 11. See also *L'Ecole Polytechnique, Livre du Centenaire*, Paris, 1895, vol. 1, p. 11ff.

[62] Jean N. P. Hachette, *Traité élémentaire des machines*, Paris, 1811, p. v.

[63] This work was among the books sent back by Sylvanus Thayer when he visited France in 1816 to observe the education of the French army cadets. Thayer's visit resulted in his adopting the philosophy of the Ecole Polytechnique in his reorganization of the U.S. Military Academy and, incidentally, in his inclusion of Hachette's course in the Academy's curriculum (U.S. Congress, *American State Papers*, Washington, 1832–1861, Class v, Military Affairs, vol. 2, p. 661: Sidney Forman, *West Point*, New York, 1950, pp. 36–60). There is a collection of miscellaneous papers (indexed under Sylvanus Thayer and William McRee, U.S. National Archives, RG 77, Office, Chief of Engineers, Boxes 1 and 6) pertaining to the U.S. Military Academy of this period, but I found no mention of kinematics in this collection.

[64] Phillipe Louis Lanz and Augustin de Bétancourt, *Essai sur la composition des machines*, Paris, 1808. Hachette's chart and an outline of his elementary course on machines is bound with the Princeton University Library copy of the Lanz and Bétancourt work. This copy probably represents the first textbook of kinematics. Bétancourt was born in 1760 in Teneriffe, attended the military school in Madrid, and became inspector-general of Spanish roads and canals. He was in England before 1789, learning how to build Watt engines, and he introduced the engines to Paris in 1790 (see Farey, *op. cit.*, p. 655). He entered Russian service in 1808 and died in St. Petersburg in 1826 (J. C. Poggendorff, *Biographisches-literarisches Handwörterbuch für Mathematik . . .* , Leipzig, 1863, vol. 1.

Figure 29.—Robert Willis (1800–1875), Jacksonian Professor, Cambridge University, and author of *Principles of Mechanism*, one of the landmark books in the development of kinematics of mechanisms. Photo courtesy Gonville and Caius College, Cambridge University.

governors), and *operateurs*, which produced the final effect.[65]

The brilliant Gaspard-Gustave de Coriolis (1792–1843)—remembered mainly for a paper of a dozen pages explaining the nature of the acceleration that bears his name[66]—was another graduate of the Ecole Polytechnique who wrote on the subject of machines. His book,[67] published in 1829, was provoked by his recognition that the designer of machines needed more knowledge than his undergraduate work at the Ecole Polytechnique was likely to give him. Although he embraced a part of Borgnis' approach, adopting *récepteurs*, *communicateurs*, and *operateurs*, Coriolis indicated by the title of his book that he was more concerned with forces than with relative displacements. However, the attractively simple three-element scheme of Coriolis became well fixed in French thinking.[68]

Michel Chasles (1793–1880), another graduate of the Ecole Polytechnique, contributed some incisive ideas in his papers on instant centers[69] published during the 1830's, but their tremendous importance in kinematic analysis was not recognized until much later.

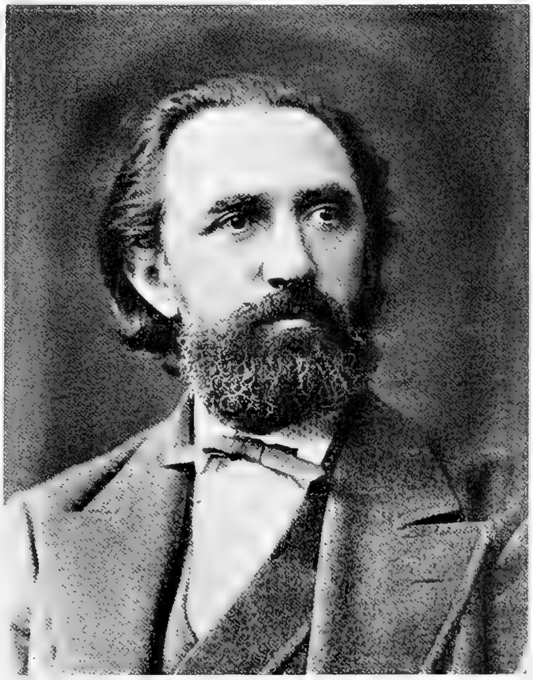

Figure 30.—Franz Reuleaux (1829–1905). His *Theoretische Kinematik*, published in 1875, provided the basis for modern kinematic analysis. Photo courtesy Deutsches Museum, Munich.

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[65] Giuseppe Antonio Borgnis, *Théorie de la mécanique usuelle* in *Traité complet de mécanique appliquée aux arts*, Paris, 1818, vol. 1, pp. xiv-xvi.

[66] Gaspard-Gustave de Coriolis, "Memoire sur les equations du mouvement relatif des systèmes de corps," *Journal de l'Ecole Polytechnique*, 1835, vol. 15, pp. 142–154.

[67] Gaspard-Gustave de Coriolis, *De Calcul de l'effet des machines*, Paris, 1829. In this book Coriolis proposed the now generally accepted equation, work=force X distance (pp. iii, 2).

[68] The renowned Jean Victor Poncelet lent weight to this scheme. (See Franz Reuleaux, *Theoretische Kinematik: Grundzüge einer Theorie des Maschinenwesens*, Braunschweig, 1875, translated by Alexander B. W. Kennedy as *The Kinematics of Machinery: Outlines of a Theory of Machines*, London, 1876, pp. 11, 487. I have used the Kennedy translation in the Reuleaux references throughout the present work.)

[69] The instant center was probably first recognized by Jean Bernoulli (1667–1748) in his "De Centro Spontaneo Rotationis" (*Johannis Bernoulli . . . Opera Omnia . . .* , Lausanne, 1742, vol. 4, p. 265ff.).

Acting upon Ampère's clear exposition of the province of kinematics and excluding, as Ampère had done, the consideration of forces, an Englishman, Robert Willis, made the next giant stride forward in the analysis of mechanisms. Willis was 37 years old in 1837 when he was appointed professor of natural and experimental philosophy at Cambridge. In the same year Professor Willis—a man of prodigious energy and industry and an authority on archeology and architectural history as well as mechanisms—read his important paper "On the Teeth of Wheels" before the Institution of Civil Engineers[70] and commenced at Cambridge his lectures on kinematics of mechanisms that culminated in his 1841 book *Principles of Mechanism.*[71]

It seemed clear to Willis that the problem of devising a mechanism for a given purpose ought to be attacked systematically, perhaps mathematically, in order to determine "all the forms and arrangements that are applicable to the desired purpose," from which the designer might select the simplest or most suitable combination. "At present," he wrote, "questions of this kind can only be solved by that species of intuition which long familiarity with a subject usually confers upon experienced persons, but which they are totally unable to communicate to others."

In analyzing the process by which a machine was designed, Willis observed: "When the mind of a mechanician is occupied with the contrivance of a machine, he must wait until, in the midst of his meditations, some happy combination presents itself to his mind which may answer his purpose." He ventured the opinion that at this stage of the design process "the motions of the machine are the principal subject of contemplation, rather than the forces applied to it, or the work it has to do." Therefore he was prepared to adopt without reservation Ampère's view of kinematics, and, if possible, to make the science useful to engineers by stating principles that could be applied without having to fit the problem at hand into the framework of the systems of classification and description that had gone before. He appraised the "celebrated system" of Lanz and Bétancourt as "a merely popular arrangement, notwithstanding the apparently scientific simplicity of the scheme." He rejected this scheme because "no attempt is made to subject the motions to calculation, or to reduce these laws to general formulas, for which indeed the system is totally unfitted."

Borgnis had done a better job, Willis thought, in actually describing machinery, with his "orders" based upon the functions of machine elements or mechanisms within the machine, but again there was no means suggested by which the kinematics of mechanisms could be systematically investigated.

Although Willis commenced his treatise with yet another "synoptical table of the elementary combinations of pure mechanism," his view shifted quickly from description to analysis. He was consistent in his pursuit of analytical methods for "pure mechanism," eschewing any excursions into the realm of forces and absolute velocities. He grasped the important concept of relative displacements of machine elements, and based his treatment upon "the proportions and relations between the velocities and directions of the pieces, and not upon their actual and separate motions."[72]

That he did not succeed in developing the "formulas" that would enable the student to determine "all the forms and arrangements that are applicable to the desired purpose"—that he did not present a rational approach to synthesis—is not to be wondered at. Well over a century later we still are nibbling at the fringes of the problem. Willis did, nonetheless, give the thoughtful reader a glimpse of the most powerful tool for kinematic synthesis that has yet been devised; namely, kinematic analysis, in which the argument is confined to the relative displacements of points on links of a mechanism, and through which the designer may grasp the nature of the means at his disposal for the solution of any particular problem.

As remarked by Reuleaux a generation later, there was much in Professor Willis's book that was wrong, but it was an original, thoughtful work that departed in spirit if not always in method from its predecessors. *Principles of Mechanism* was a prominent landmark along the road to a rational discipline of machine-kinematics.

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[70] Robert Willis, "On the Teeth of Wheels," *Transactions of the Institution of Civil Engineers of London,* 1838, vol. 2, pp. 89–112.

[71] Willis, *op. cit.* (footnote 21). Through the kindness of its owner (Mr. Warren G. Ogden of North Andover, Massachusetts), I have had access to Willis' own copy of his 1841 edition of *Principles of Mechanism.* The book is interleaved, and it contains notes made by Willis from time to time until at least 1870, when the second edition was issued. Corrections, emendations, notations of some of his sources (for example, the De Voglie linkage mentioned in footnote 35 above), notes to himself to "examine the general case" and "examine the modern forms" of straight-line devices are interspersed with references to authors that had borrowed from his work without acknowledgment. Of one author Willis writes an indignant "He ignores my work."

[72] *Ibid.,* pp. iv, x–xii, xxi, 15.

A phenomenal engineer of the 19th century was the Scottish professor of civil engineering at the University of Glasgow, William John MacQuorn Rankine. Although he was at the University for only 17 years—he died at the age of 52, in 1872—he turned out during that time four thick manuals on such diverse subjects as civil engineering, ship-building, thermodynamics, and machinery and mill-work, in addition to literally hundreds of papers, articles, and notes for scientific journals and the technical press. Endowed with apparently boundless energy, he found time from his studies to command a battalion of rifle volunteers and to compose and sing comic and patriotic songs. His manuals, often used as textbooks, were widely circulated and went through many editions. Rankine's work had a profound effect upon the practice of engineering by setting out principles in a form that could be grasped by people who were dismayed by the treatment usually found in the learned journals.

When Rankine's book titled *A Manual of Machinery and Millwork* was published in 1869 it was accurately characterized by a reviewer as "dealing with the *principles* of machinery and millworks, and as such it is entirely distinct from [other works on the same subject] which treat more of the practical applications of such principles than of the principles themselves."[73]

Rankine borrowed what appeared useful from Willis' *Principles of Mechanism* and from other sources. His treatment of kinematics was not as closely reasoned as the later treatises of Reuleaux and Kennedy, which will be considered below. Rankine did, however, for the first time show the utility of instant centers in velocity analysis, although he made use only of the instant centers involving the fixed link of a linkage. Like others before him, he considered the fixed link of a mechanism as something quite different from the movable links, and he did not perceive the possibilities opened up by determining the instant center of two movable links.

Many other books dealing with mechanisms were published during the middle third of the century, but none of them had a discernible influence upon the advance of kinematical ideas.[74] The center of inquiry had by the 1860's shifted from France to Germany. Only by scattered individuals in England, Italy, and France was there any impatience with the well-established, general understanding of the machine-building art.

In Germany, on the other hand, there was a surge of industrial activity that attracted some very able men to the problems of how machines ought to be built. Among the first of these was Ferdinand Redtenbacher (1809–1863), professor of mechanical engineering in the polytechnic school in Karlsruhe, not far from Heidelberg. Redtenbacher, although he despaired of the possibility of finding a "true system on which to base the study of mechanisms," was nevertheless a factor in the development of such a system. He had young Franz Reuleaux in his classes for two years, from 1850. During that time the older man's commanding presence, his ability as a lecturer, and his infectious impatience with the existing order influenced Reuleaux to follow the scholar's trail that led him to eminence as an authority of the first rank.[75]

Before he was 25 years old Franz Reuleaux published, in collaboration with a classmate, a textbook whose translated title would be *Constructive Lessons for the Machine Shop*.[76] His several years in the workshop, before and after coming under Redtenbacher's influence, gave his works a practical flavor, simple and direct. According to one observer, Reuleaux's book exhibited "a recognition of the claims of practice such as Englishmen do not generally associate with the writings of a German scientific professor."[77]

Reuleaux's original ideas on kinematics, which are responsible for the way in which we look at mechanisms today, were sufficiently formed in 1864 for him to lecture upon them.[78] Starting in 1871, he published his findings serially in the publication of the Verein zur Beförderung des Gewerbefleisses in Preussen (Society for the Advancement of Industry in Prussia), of which he was editor. In 1875 these articles were brought together in the book that established his fame—*Theoretische Kinematik* . . .[79]

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[73] *Engineering*, London, August 13, 1869, vol. 8, p. 111.

[74] Several such books are referred to by Reuleaux, *op. cit.* (footnote 68), pp. 12–16.

[75] See Carl Weihe, "Franz Reuleaux und die Grundlagen seiner Kinematik," Deutsches Museum, Munich, *Abhandlung und Berichte*, 1942, p. 2; Friedrich Klemm, *Technik: Eine Geschichte ihrer Probleme*, Freiburg and Munich, Verlag Karl Alber, 1954, translated by Dorothea W. Singer as *A History of Western Technology*, New York, Charles Scribner's Sons, 1959, p. 317.

[76] See Weihe, *op. cit.* (footnote 75), p. 3; Hans Zopke, "Professor Franz Reuleaux," *Cassier's Magazine*, December 1896, vol. 11, pp. 133–139; *Transactions of the American Society of Mechanical Engineers*, 1904–1905, vol. 26, pp. 813–817.

[77] *Engineering*, London, September 8, 1876, vol. 22, p. 197.

[78] A. E. Richard de Jonge, "What is Wrong with Kinematics and Mechanisms?" *Mechanical Engineering*, April 1942, vol. 64, pp. 273–278 (comments on this paper are in *Mechanical Engi-*

In the introduction of this book, Reuleaux wrote:

> In the development of every exact science, its substance having grown sufficiently to make generalization possible, there is a time when a series of changes bring it into clearness. This time has most certainly arrived for the science of kinematics. The number of mechanisms has grown almost out of measure, and the number of ways in which they are applied no less. It has become absolutely impossible still to hold the thread which can lead in any way through this labyrinth by the existing methods.[80]

Reauleaux's confidence that it would be his own work that would bring order out of confusion was well founded. His book had already been translated into Italian and was being translated into French when, only a year after its publication, it was presented by Prof. Alexander B. W. Kennedy in English translation.[81]

The book was enthusiastically reviewed by the weekly London journal *Engineering*,[82] and it was given lengthy notice by the rival journal, *The Engineer*. The editor of *The Engineer* thought that the mechanician would find in it many new ideas, that he would be "taught to detect hitherto hidden resemblances, and that he must part—reluctantly, perhaps—with many of his old notions." "But," added the editor with considerable justice, "that he [the mechanician] would suddenly recognize in Professor Reuleaux's 'kinematic notation,' 'analysis,' and 'synthesis,' the long-felt want of his professional existence we do not for a moment believe." [83] Indeed, the fresh and sharp ideas of Reuleaux were somewhat clouded by a long (600-page) presentation; and his kinematic notation, which required another attempt at classification, did not simplify the presentation of radically new ideas.[84]

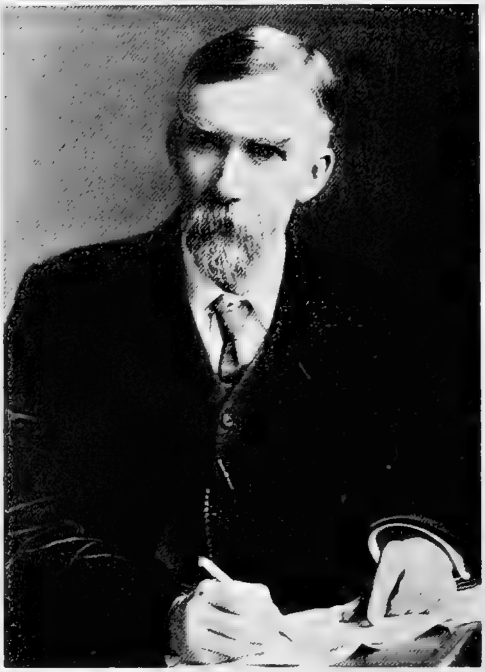

Figure 31.—Alexander Blackie William Kennedy (1847–1928), translator of Reuleaux' *Theoretische Kinematik* and discoverer of Kennedy's "Law of Three Centers." From *Minutes of the Proceedings of the Institution of Civil Engineers* (1907, vol. 167, frontispiece).

Nevertheless, no earlier author had seen the problem of kinematic analysis so clearly or had introduced so much that was fresh, new, and of lasting value.

Reuleaux was first to state the concept of the pair; by his concept of the expansion of pairs he was able to show similarities in mechanisms that had no apparent relation. He was first to recognize that the fixed link of a mechanism was kinematically the same as the movable links. This led him to the important notion of inversion of linkages, fixing successively the various links and thus changing the function of the mecha-

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neering, October 1942, vol. 64, pp. 744–751); Zopke, *op. cit.* (footnote 76), p. 135.

[79] Reuleaux, *op. cit.* (footnote 68). This was not the last of Reuleaux's books. His trilogy on kinematics and machine design is discussed by De Jonge, *op. cit.* (footnote 78).

[80] Reuleaux, *op. cit.* (footnote 68), p. 23.

[81] *Ibid.*, p. iii.

[82] *Engineering*, *loc. cit.* (footnote 77).

[83] *The Engineer*, London, March 30 and April 13, 1877, vol. 43, pp. 211–212, 247–248.

[84] It is perhaps significant that the first paper of the First Conference on Mechanisms at Purdue University was Allen S. Hall's "Mechanisms and Their Classification," which appeared in *Machine Design*, December 1953, vol. 25, pp. 174–180. The place of classification in kinematic synthesis is suggested in Ferdinand Freudenstein's "Trends in Kinematics of Mechanisms," *Applied Mechanics Reviews*, September 1959, vol. 12, pp. 587–590.

nism. He devoted 40 pages to showing, with obvious delight, the kinematic identity of one design after another of rotary steam engines, demolishing for all time the fond hopes of ingenious but ill-informed inventors who think that improvements and advances in mechanism design consist in contortion and complexity.

The chapter on synthesis was likewise fresh, but it consisted of a discussion, not a system; and Reuleaux stressed the idea that I have mentioned above in connection with Willis' book, that synthesis will be successful in proportion to the designer's understanding and appreciation of analysis. Reuleaux tried to put the designer on the right track by showing him clearly "the essential simplicity of the means with which we have to work" and by demonstrating to him "that the many things which have to be done can be done with but few means, and that the principles underlying them all lie clearly before us."[85]

It remained for Sir Alexander Blackie William Kennedy (1847–1928) and Robert Henry Smith (1852–1916) to add to Reuleaux's work the elements that would give kinematic analysis essentially its modern shape.

Kennedy, the translator of Reuleaux's book, became professor of engineering at the University College in London in 1874, and eventually served as president both of the Institution of Mechanical Engineers and of the Institution of Civil Engineers. Smith, who had taught in the Imperial University of Japan, was professor of engineering at Mason College, now a part of Birmingham University, in England.

While Reuleaux had used instant centers almost exclusively for the construction of centrodes (paths of successive positions of an instant center), Professor Kennedy recognized that instant centers might be used in velocity analysis. His book, *Mechanics of Machinery*, was published in 1886 ("partly through pressure of work and partly through ill-health, this book appears only now"). In it he developed the law of three centers, now known as Kennedy's theorem. He noted that his law of three centers "was first given, I believe, by Aronhold, although its previous publication was unknown to me until some years after I had given it in my lectures."[86] In fact, the law had been published by Siegfried Heinrich Aronhold (1819–1884) in his "Outline of Kinematic Geometry," which appeared in 1872 alongside Reuleaux's series in the journal that Reuleaux edited. Apparently Reuleaux did not preceive its particular significance at that time.[87]

Figure 32.—Robert Henry Smith (1852–1916), originator of velocity and acceleration polygons for kinematic analysis. Photo courtesy the Librarian, Birmingham Reference Library, England.

Kennedy, after locating instant centers, determined velocities by calculation and accelerations by graphical differentiation of velocities, and he noted in his preface that he had been unable, for a variety of reasons, to make use in his book of Smith's recent work. Professor Kennedy at least was aware of Smith's surprisingly advanced ideas, which seem to have been generally ignored by Americans and Englishmen alike.

Professor Smith, in a paper before the Royal Society of Edinburgh in 1885, stated clearly the ideas and methods for construction of velocity and acceleration diagrams of linkages.[88] For the first time, velocity and acceleration "images" of links (fig. 33) were presented. It is unfortunate that Smith's ideas were permitted to languish for so long a time.

By 1885 nearly all the tools for modern kinematic analysis had been forged. Before discussing subsequent developments in analysis and synthesis, however, it will be profitable to inquire what the mechanician—designer and builder of machines—was doing while all of this intellectual effort was being expended.

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[85] Reuleaux, *op. cit.* (footnote 68), p. 582.

[86] Alexander B. W. Kennedy, *The Mechanics of Machinery*, ed. 3, London, 1898, pp. vii, x.

[87] Siegfried Heinrich Aronhold, "Outline of Kinematic Geometry," *Verein zur Beförderung des Gewerbefleisses in Preussen*, 1872, vol. 51, pp. 129–155. Kennedy's theorem is on pp. 137–138.

[88] Robert H. Smith, "A New Graphic Analysis of the Kinematics of Mechanisms," *Transactions of the Royal Society of Edinburgh*, 1882–1885, vol. 32, pp. 507–517, and pl. 82. Smith used

Mechanicians and Mechanisms

While the inductive process of recognizing and stating true principles of the kinematics of mechanisms was proceeding through three generations of French, English, and finally German scholars, the actual design of mechanisms went ahead with scant regard for what the scholars were doing and saying.

After the demonstration by Boulton and Watt that large mechanisms could be wrought with sufficient precision to be useful, the English tool builders Maudslay, Roberts, Clement, Nasmyth, and Whitworth developed machine tools of increasing size and truth. The design of other machinery kept pace with—sometimes just behind, sometimes just ahead of—the capacity and capability of machine tools. In general, there was an increasing sophistication of mechanisms that could only be accounted for by an increase of information with which the individual designer could start.

Reuleaux pointed out in 1875 that the "almost feverish progress made in the regions of technical work" was "not a consequence of any increased capacity for intellectual action in the race, but only the perfecting and extending of the tools with which the intellect works." These tools, he said, "have increased in number just like those in the modern mechanical workshop—the men who work them remain the same." Reuleaux went on to say that the theory and practice of machine-kinematics had "carried on a separate existence side by side." The reason for this failure to apply theory to practice, and vice versa, must be sought in the defects of the theory, he thought, because "the mechanisms themselves have been quietly developed in practical machine-design, by invention and improvement, regardless of whether or not they were accorded any direct and proper theoretical recognition." He pointed out that the theories had thus far "furnished no new mechanisms." [89]

It is reasonable, therefore, to ask what was responsible for the appearance of new mechanisms, and then to see what sort of mechanisms had their origins in this period.

It is immediately evident to a designer that the progress in mechanisms came about through the spread of knowledge of what had already been done; but designers of the last century had neither the leisure nor means to be constantly visiting other workshops, near and far, to observe and study the latest developments. In the 1800's, as now, word must in the main be spread by the printed page.

Hachette's chart (fig. 28) had set the pattern for display of mechanical contrivances in practical journals and in the large number of mechanical dictionaries that were compiled to meet an apparent demand for such information. It is a little surprising, however, to find how persistent were some of Hachette's ideas that could only have come from the uppermost superficial layer of his cranium. See, for example, his "anchored ferryboat" (fig. 34). This device, employed by Hachette to show conversion of continuous rectilinear motion into alternating circular motion, appeared in one publication after another throughout the 19th century. As late as 1903 the ferryboat was still anchored in Hiscox's *Mechanical Movements*, although the tide had changed (fig. 35).[90]

During the upsurge of the Lyceum—or workingman's institute—movement in the 1820's, Jacob Bigelow, Rumford professor of applied science at Harvard University, gave his popular lectures on the "Elements of Technology" before capacity audiences in Boston. In preparing his lecture on the elements of machinery, Bigelow used as his authorities Hachette, Lanz and Bétancourt, and Olinthus Gregory's mechanical dictionary, an English work in which

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this paper as the basis for a chapter in his *Graphics or the Art of Calculating by Drawing Lines*, London, 1889, pp. 144–162. In a footnote of his paper, Smith credited Fleeming Jenkin (1833–1885) with suggesting the term "image." After discarding as "practically useless" Kennedy's graphical differentiation, Smith complained that he had "failed to find any practical use" for Reuleaux's "method of centroids, more properly called axoids." Such statements were not calculated to encourage Kennedy and Reuleaux to advertise Smith's fame; however, I found no indication that either one took offense at the criticism. Smith's velocity and acceleration diagrams were included (apparently embalmed, so far as American engineers were concerned) in *Encyclopaedia Britannica*, ed. 11, 1910, vol. 17, pp. 1008–1009.

[89] Reuleaux, *op. cit.* (footnote 68), p. 8.

[90] Gardner D. Hiscox, ed., *Mechanical Movements*, ed. 10, New York, 1903, p. 151. The ferryboat did not appear in the 1917 edition.

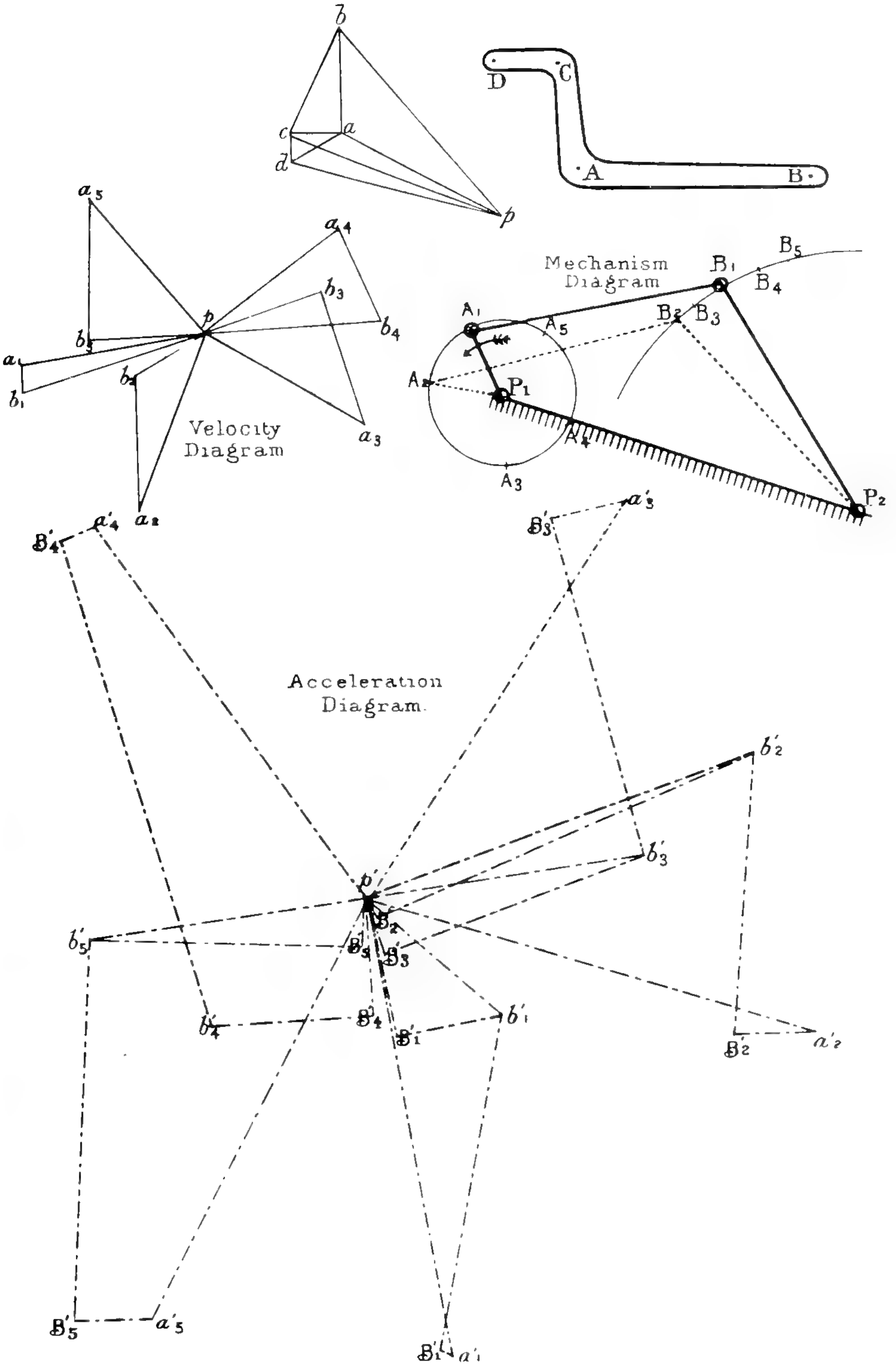
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Figure 33.—Smith's velocity image (the two figures at top), and his velocity, mechanism, and acceleration diagrams, 1885. The image of link BACD is shown as figure *bacd*. The lines *pa*, *pb*, *pc*, and *pd* are velocity vectors. This novel, original, and powerful analytical method was not generally adopted in English or American schools until nearly 50 years after its inception. From *Transactions of the Royal Society of Edinburgh* (1882–1885, vol. 32, pl. 82).

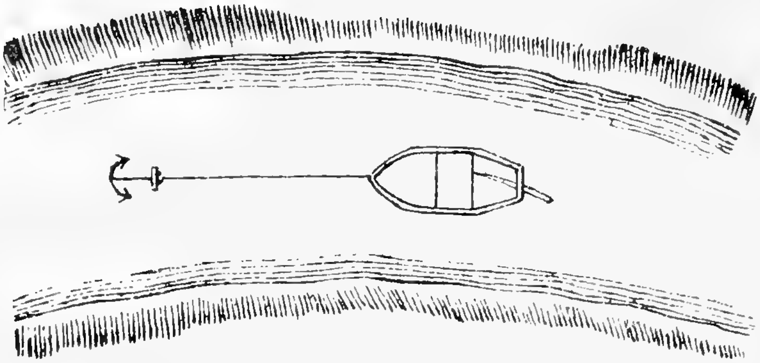

Figure 34.—Hachette's ferryboat of 1808, a "machine" for converting continuous rectilinear motion into alternating circular motion. From Phillipe Louis Lanz and Augustin de Bétancourt, *Essai sur la composition des machines* (Paris, 1808, pl. 2).

Hachette's classification scheme was copied and his chart reproduced.[91]

A translation of the work of Lanz and Bétancourt [92] under the title *Analytical Essay on the Construction of Machines*, was published about 1820 at London by Rudolph Ackermann (for whom the Ackermann steering linkage was named), and their synoptic chart was reprinted again in 1822 in Durham.[93] In the United States, *Appleton's Dictionary of Machines* [94] (1851) adopted the same system and used the same figures. Apparently the wood engraver traced directly onto his block the figures from one of the reprints of Lanz and Bétancourt's chart because the figures are in every case exact mirror images of the originals.

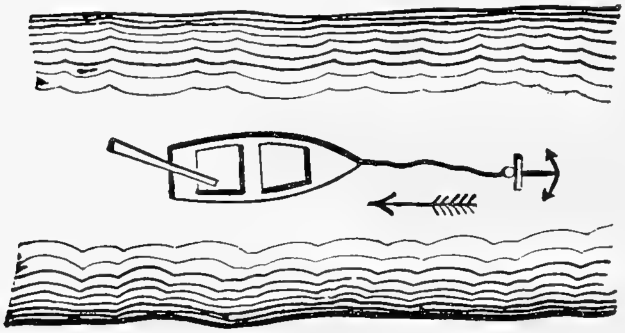

Figure 35.—Ferryboat from Gardner D. Hiscox, ed., *Mechanical Movements* (ed. 10, New York, 1903, p. 151).

In the *Dictionary of Engineering* [95] (London, 1873), the figures were redrawn and dozens of mechanisms were added to the repertory of mechanical motions; the result was a fair catalog of sound ideas. The ferryboat still tugged at its anchor cable, however.[96] *Knight's American Mechanical Dictionary*,[97] a classic of detailed pictorial information compiled by a U.S. patent examiner, contained well over 10,000 finely detailed figures of various kinds of mechanical contrivances. Knight did not have a separate section on mechanisms, but there was little need for one of the Hachette variety, because his whole dictionary was a huge and fascinating compendium of ideas to be filed away in the synthetic mind. One reason for the popularity and usefulness of the various pictorial works was the peculiar ability of a wood or steel engraving to convey precise mechanical information, an advantage not possessed by modern halftone processes.

Many patent journals and other mechanical periodicals concerned with mechanics were available in English from the beginning of the 19th century, but few of them found their way into the hands of American mechanicians until after 1820. Oliver Evans (1755–1819) had much to say about "the difficulties inventive mechanics labored under for want of published records of what had preceded them, and for works of reference to help the be-

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[91] Jacob Bigelow, *Elements of Technology*, ed. 2, Boston, 1831, pp. 231–256; Olinthus Gregory, *A Treatise of Mechanics*, 3 vols., ed. 3, London, 1815.

[92] Rudolph Ackermann, *Analytical Essay on the Construction of Machines*, London, about 1820, a translation of Lanz and Bétancourt, *op. cit.* (footnote 64).

[93] Thomas Fenwick, *Essays on Practical Mechanics*, ed. 3, Durham, England, 1822.

[94] *Appleton's Dictionary of Machines, Mechanics, Engine-Work, and Engineering*, 2 vols., New York, 1851 ("Motion").

[95] E. F. and N. Spon, *Dictionary of Engineering*, London 1873, pp. 2421–2452.

[96] *Ibid.*, p. 2447.

[97] Edward H. Knight, *Knight's American Mechanical Dictionary*, 3 vols., New York 1874–1876.

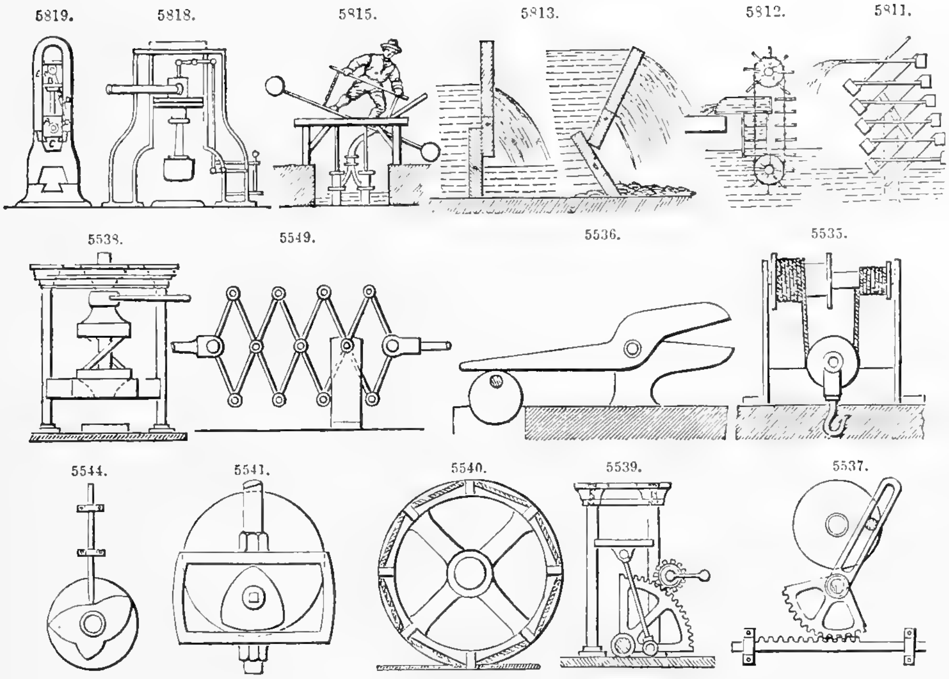

Figure 36.—Typical mechanisms from E. F. and N. Spon, *Dictionary of Engineering* (London, 1873, pp. 2426, 2478).

ginner."[98] In 1817 the *North American Review* also remarked upon the scarcity of engineering books in America.[99]

The *Scientific American*, which appeared in 1845 as a patent journal edited by the patent promoter Rufus Porter, carried almost from its beginning a column or so entitled "Mechanical Movements," in which one or two mechanisms—borrowed from an English work that had borrowed from a French work—were illustrated and explained. The *American Artisan* began a similar series in 1864, and in 1868 it published a compilation of the series as *Five Hundred and Seven Mechanical Movements*, "embracing all those which are most important in dynamics, hydraulics, hydrostatics, pneumatics, steam engines . . . and miscellaneous machinery."[100] This collection went through many editions; it was last revived in 1943 under the title *A Manual of Mechanical Movements.* This 1943 edition included photographs of kinematic models.[101]

Many readers are already well acquainted with the three volumes of *Ingenious Mechanisms for Designers and Inventors*,[102] a work that resulted from a contest, announced by *Machinery* (vol. 33, p. 405) in 1927, in which seven prizes were offered for the seven best articles on unpublished ingenious mechanisms.

There was an interesting class of United States patents called "Mechanical Movements" that comprised scores of patents issued throughout the middle decades of the 19th century. A sampling of these patents shows that while some were for devices used in particular machines—such as a ratchet device for a numbering machine, a locking index for gunmaking machinery, and a few gear trains—the great majority were for converting reciprocating motion to rotary motion. Even a cursory examination of these patents reveals an appalling absence of sound mechanical sense, and many of them appear to be attempts at

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[98] George Escol Sellers in *American Machinist*, July 12, 1884, vol. 7, p. 3.

[99] *North-American Review and Miscellaneous Journal*, 1819, new ser., vol. 8, pp. 13–15, 25.

[100] Henry T. Brown, ed., *Five Hundred and Seven Mechanical Movements*, New York, 1868.

[101] Will M. Clark, *A Manual of Mechanical Movements*, Garden City, New York, 1943.

[102] *Ingenious Mechanisms for Designers and Inventors* (vols. 1 and 2 edited by F. D. Jones, vol. 3 edited by H. L. Horton), New York, Industrial Press, 1930–1951.

"perpetual motion," in spite of an occasional disclaimer of such intent.

Typical of many of these patented devices was a linkage for "multiplying" the motion of a flywheel, proposed in 1841 by Charles Johnson of Amity, Illinois (fig. 37). "It is not pretended that there is any actual gain of power," wrote Mr. Johnson; and probably he meant it. The avowed purpose of his linkage was to increase the speed of a flywheel and thus decrease its size.[103]

An Englishman who a few years earlier had invented a "new Motion" had claimed that his device would supersede the "ordinary crank in steam engines," the beam, parallel motion, and "external flywheel," reduce friction, neutralize "all extra contending power," and leave nothing for the piston to do "but the work intended to be done."

A correspondent of the *Repertory of Patent Inventions* made short work of this device: "There is hardly one assertion that can be supported by proof," he wrote, "and most of them are palpable misstatements." The writer attacked "the 'beetle impetus wheel,' which he [the inventor] thinks us all so beetle-headed, as not to perceive to be a flywheel," and concluded with the statement: "In short the whole production evinces gross ignorance either of machinery, if the patentee really believed what he asserted, or of mankind, if he did not." [104]

Although many of the mechanisms for which patents were taken out were designed by persons who would make no use of the principles involved even if such principles could at that time have been clearly stated, it is a regrettable fact that worthless mechanisms often got as much space as sound ones in patent journals, and objections such as the one above were infrequent. The slanted information thus conveyed to the young mechanician, who was just accumulating his first kinematic repertory, was at times sadly misleading.

From even this sketchy outline of the literature on the subject, it should be fairly evident that there has been available to the mechanician an enormous quantity of information about mechanical linkages and other devices. Whatever one may think of the quality of the literature, it has undoubtedly had influence not only in supplying designers with information but in forming a tradition of how one ought to supply the background that will enable the mind to assemble and synthesize the necessary mechanism for a given purpose.[105]

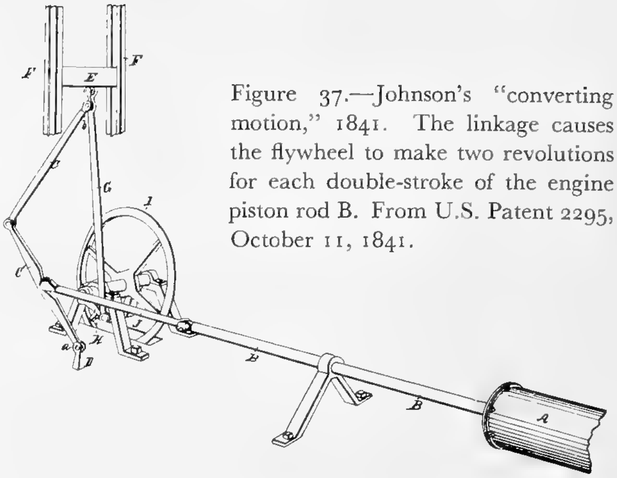

Figure 37.—Johnson's "converting motion," 1841. The linkage causes the flywheel to make two revolutions for each double-stroke of the engine piston rod B. From U.S. Patent 2295, October 11, 1841.

Some of the mechanisms that have been given names—such as the Watt straight-line linkage and the Geneva stop—have appeared in textbook after textbook. Their only excuse for being seems to be that the authors must include them or risk censure by colleagues. Such mechanisms are more interesting to a reader, certainly, when he has some idea of what the name has to do with the mechanism, and who originated it. One such mechanism is the drag link.

After I had learned of the drag link (as most American engineering students do), I wondered for awhile, and eventually despaired of making any sense out of the term. What, I wanted to know, was being dragged? Recently, in Nicholson's *Operative Mechanic and British Machinist* (1826), I ran across the sketch reproduced here as figure 38. This figure, explained Mr. Nicholson (in vol. 1, p. 32) "represents the coupling link used by Messrs. Boulton and Watt in their portable steam engines. A, a strong iron pin, projecting from one of the arms of the fly-wheel B; D, a crank connected with the shaft C; and E, a link to couple the pin A and the crank D together, so the motion may be communicated to the shaft C." So the drag link was actually a link of a coupling. Nothing could be more logical. A drag link mechanism now makes sense to me.

Directly related to the drag link coupling were the

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[103] U.S. Patent 2295, October 11, 1841.

[104] *Repertory of Patent Inventions*, ser. 3, October 1828, vol. 7, pp. 196–200, and December 1828, vol. 7, pp. 357–361.

[105] Some additional catalogs of "mechanical movements" are listed in the selected references at the end of this paper.

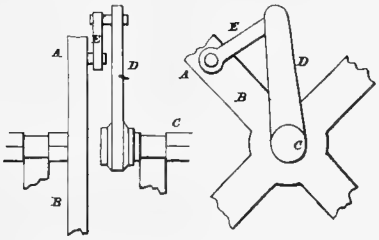

Figure 38.—Drag link coupling used on Boulton and Watt portable engines. The link E drags one shaft when the other turns. From John Nicholson, *The Operative Mechanic, and British Machinist* (Philadelphia, 1826, vol. 1, pl. 5).

patents of John Oldham (1779–1840), an Irish engineer who is remembered mainly for the coupling that bears his name (fig. 39). His three patents, which were for various forms of steamboat feathering paddle wheels, involved linkages kinematically similar to the drag link coupling, although it is quite unlikely that Oldham recognized the similarity. However, for his well-known coupling, which employs an inversion of the elliptical trammel mechanism, I have found no evidence of a patent. Probably it was part of the machinery that he designed for the Bank of Ireland's printing house, of which Oldham was manager for many years. "Mr. Oldham and his beautiful system" were brought to the Bank of England in 1836, where Oldham remained until his death in 1840.[106]

The Geneva stop mechanism (fig. 40) was properly described by Willis as a device to permit less than a full revolution of the star wheel and thus to prevent overwinding of a watch spring. It was called Geneva stop because it was used in Geneva watches. The Geneva wheel mechanism, which permits full rotation of the star wheel and which is frequently used for

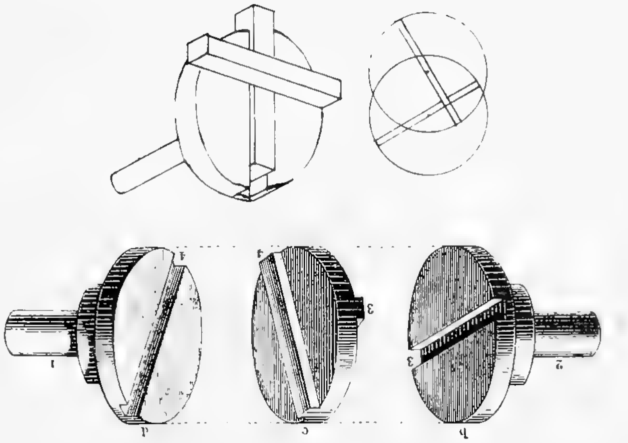

Figure 39.—*Top*, Original Oldham coupling built before 1840, using a cross (instead of a center disk), as sketched by Robert Willis in personal copy of his *Principles of Mechanism* (London, 1841, p. 167). *Bottom*, Oldham coupling as illustrated in Alexander B. W. Kennedy, *Kinematics of Machinery*, a translation of Franz Reuleaux' *Theoretishe Kinematik* (London, 1876, pp. 315–316).

intermittent drives, was improperly called a Geneva stop in a recent textbook probably because the logical origin of the term had been lost.

The name for the Scotch yoke seems to be of fairly recent origin, the linkage being called by a Scotsman in 1869 a "crank and slot-headed sliding rod" (fig. 41). I suppose that it is now known as a Scotch yoke because, in America at least, a "Scotch" was a slotted bar that was slipped under a collar on a string of well-drilling tools to support them while a section was being added (fig. 42).

It was surprising to me to find that the Ackermann steering linkage, used today on most automobiles, was patented in 1818 when Detroit was still a frontier town.[107] Furthermore, the man who took out the patent described himself as Rudolph Ackermann, publisher and printseller. I thought I had the necessary clue to the linkage's origin when I noticed that the first English translation of the Lanz and Bétancourt treatise was published by Ackermann, but the connection finally proved to be more logical, if less direct. Ackermann (1764–1834), son of a Bavarian coach builder, had spent a number of

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[106] Oldham's paddle-wheel patents were British Patents 4169 (October 10, 1817), 4429 (January 15, 1820), and 5445 (February 1, 1827). Robert Willis (*op. cit.* footnote 21, p. 167) noticed the existence of the coupling. Drawings or descriptions of the banknote machinery apparently have not been published though they probably still exist in the banks' archives. The quotation is from Frederick G. Hall, *The Bank of Ireland 1783–1946*, Dublin, 1949. John Francis in his *History of the Bank of England* (London, 1848, vol. 2, p. 232) wrote: "The new machinery for printing the notes, which was introduced by Mr. Oldham . . . is well worthy of a visit, but would be uninteresting to delineate."

[107] British Patent 4212, January 27, 1818.

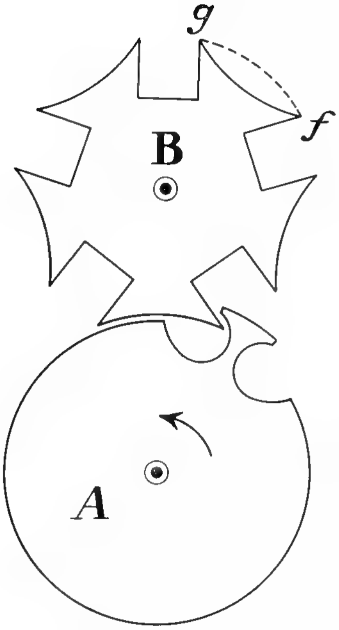

Figure 40.—Geneva stop mechanism first used in Geneva watches to prevent overwinding. The starwheel B had one convex surface (*g-f*, dotted) so the wheel could be turned less than a full revolution. After Robert Willis, *Principles of Mechanism* (London, 1841, p. 266).

years designing coaches for English gentlemen in London, where he made his home. One of his more notable commissions was for the design of Admiral Nelson's funeral car in 1805. The Ackermann steering linkage was not actually Ackermann's invention, although he took out the British patent in his name and promoted the introduction of the running gear of which the linkage was a part (fig. 43). The actual inventor was Ackermann's friend George Lankensperger of Munich, coachmaker to the King of Bavaria. The advantage of being able to turn a carriage around in a limited area without danger of oversetting was immediately obvious, and while there was considerable opposition by English coachmakers to an innovation for which a premium had to be paid, the invention soon "made its way from its own intrinsic merit," as Ackermann predicted it would.[108]

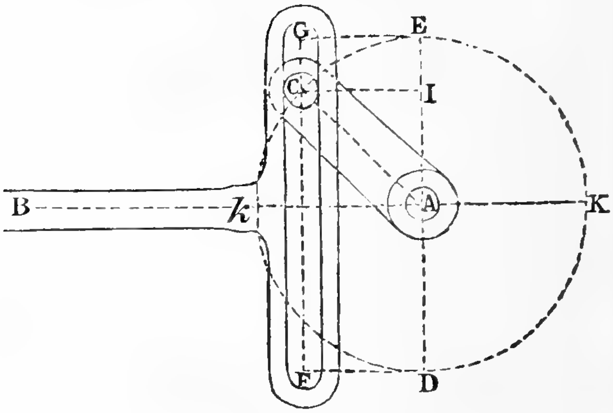

Figure 41.—Scotch yoke, described as a "crank and slot-headed sliding rod." From W. J. M. Rankine, *A Manual of Machinery and Millwork* (ed. 6, London, 1887, p. 169).

The Whitworth quick-return mechanism (fig. 44) was first applied to a slotter, or vertical shaper, in 1849, and was exhibited in 1851 at the Great Exhibi-

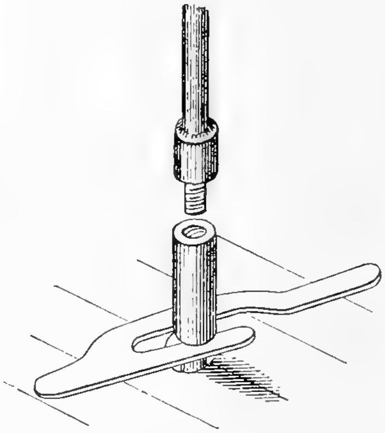

Figure 42.—A "Scotch" supporting the top member of a string of well-drilling tools while a section is being added, 1876. From Edward H. Knight, *Knight's American Mechanical Dictionary* (New York, 1876, p. 2057).

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[108] Rudolph Ackermann, *Observations on Ackermann's Patent Moveable Axles*, London, 1819. It was interesting to me to note an abstract of W. A. Wolfe's paper "Analytical Design of an Ackermann Steering Linkage" in *Mechanical Engineering*, September 1958, vol. 80, p. 92.

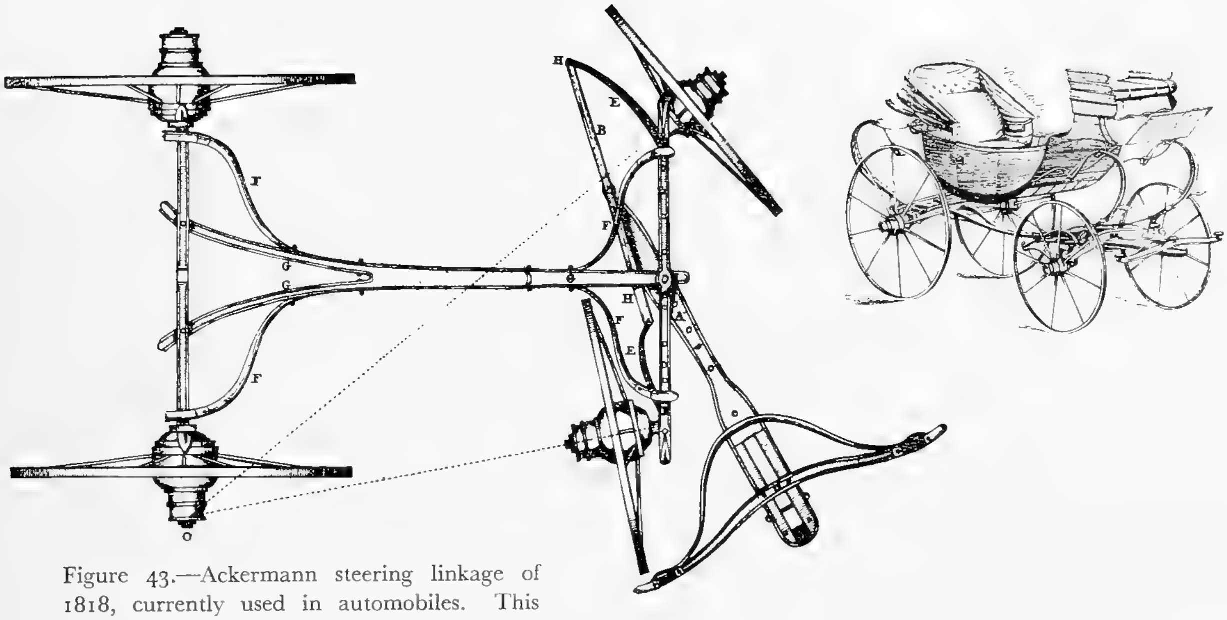

Figure 43.—Ackermann steering linkage of 1818, currently used in automobiles. This linkage was invented by George Lankensperger, coachmaker to the King of Bavaria. From *Dinglers Polytechnisches Journal* (1820, vol. 1, pl. 7).

tion in London.[109] Willis' comments on the mechanism are reproduced in figure 44. I hope that Sir Joseph Whitworth (1803–1887) will be remembered for sounder mechanical contrivances than this.

Mechanisms in America, 1875-1955

Engineering colleges in the United States were occupied until the late 1940's with extending, refining, and sharpening the tools of analysis that had been suggested by Willis, Rankine, Reuleaux, Kennedy, and Smith. The actual practice of kinematic synthesis went on apace, but designers often declined such help as the analytical methods might give them and there was little exchange of ideas between scholars and practitioners.

The capability and precision of machine tools were greatly enhanced during this period, although, with the exception of the centerless grinder, no significant new types of tools appeared. The machines that were made with machine tools increased in complexity and, with the introduction of ideas that made mass production of complex mechanical products economically feasible, there was an accelerating increase in quantity. The adoption of standards for all sorts of component parts also had an important bearing upon the ability of a designer economically to produce mechanisms that operated very nearly as he hoped they would.

The study of kinematics has been considered for nearly 80 years as a necessary part of the mechanical engineer's training, as the dozens of textbooks that have been published over the years make amply clear. Until recently, however, one would look in vain for original work in America in the analysis or rational synthesis of mechanisms.

One of the very earliest American textbooks of kinematics was the 1883 work of Charles W. MacCord (1836–1915), who had been appointed professor of mechanical drawing at Stevens Institute of Technology in Hoboken after serving John Ericsson, designer of the *Monitor*, as chief draftsman during the Civil War.[110] Based upon the findings of Willis and Rankine, MacCord's *Kinematics* came too early to be influenced by Kennedy's improvements upon Reuleaux's work.

When the faculty at Washington University in St. Louis introduced in 1885 a curriculum in "dynamic

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[109] The quick-return mechanism (British Patent 12907, December 19, 1849) was perhaps first publicly described in Charles Tomlinson, ed., *Cyclopaedia of Useful Arts and Manufactures*, London, 1854, vol. 1, p. cxliv.

[110] A biographical notice and a bibliography of MacCord appears in *Morton Memorial: A History of the Stevens Institute of Technology*, Hoboken, 1905, pp. 219–222.

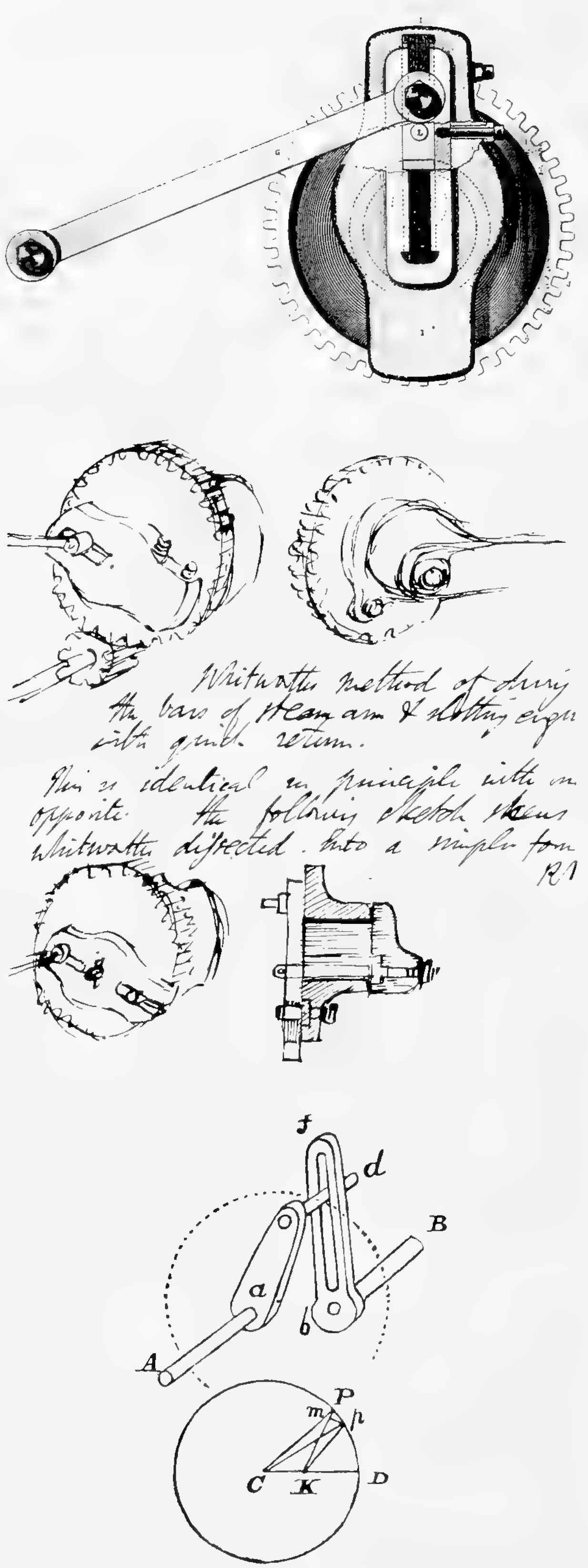
Whitworths method of driving
the bars of steam arm & slotting engine
with quick return.
This is identical in principle with one
opposite. the following sketch shews
whitworths dissected into a simpler form
RW
f
d
B
a
b
A
P
m
p
C
K
D

Figure 44.—Quick-return mechanism. *Top*, Early representation of the quick-return mechanism patented by Whitworth in 1849, from William Johnson, ed., *The Imperial Cyclopaedia of machinery* (Glasgow, about 1855, pl. 88). *Middle*, Sketch by Robert Willis from his copy of *Principles of Mechanism* (London, 1841, p. 264), which "shews Whitworth dissected into a simpler form"; it is as obscure as most subsequent attempts have been to explain this mechanism without a schematic diagram. *Bottom*, Linkage that is kinematically equivalent to Whitworth's, from Robert Willis, *Principles of Mechanism* (London, 1841, p. 264).

engineering," reflecting a dissatisfaction with the traditional branches of engineering, kinematics was a senior subject and was taught from Rankine's *Machinery and Millwork*.[111]

At Massachusetts Institute of Technology, Peter Schwamb, professor of machine design, put together in 1885 a set of printed notes on the kinematics of mechanisms, based on Reuleaux's and Rankine's works. Out of these notes grew one of the most durable of American textbooks, first published in 1904.[112] In the first edition of this work, acceleration was mentioned only once in passing (on p. 4). Velocities in linkages were determined by orthogonal components transferred from link to link. Instant centers were used only to determine velocities of various points on the same link. Angular velocity ratios were frequently noted. In the third edition, published in 1921, linear and angular accelerations were defined, but no acceleration analyses were made. Velocity analyses were altered without essential change. The fourth edition (1930) was essentially unchanged from the previous one. Treatment of velocity analysis was improved in the fifth edition (1938) and acceleration analysis was added. A sixth edition, further revised by Prof. V. L. Doughtie of the University of Texas, appeared in 1947.

Before 1900, several other books on mechanisms had been published, and all followed one or another of the patterns of their predecessors. Professors Woods and Stahl, at the Universities of Illinois and Purdue, respectively, who published their *Elementary Mechanism* in 1885, said in their preface what has been said by many other American authors and what should have been said by many more. "We make little claim to originality of the subject-matter," wrote Woods and Stahl, "free use having been made of all available matter on the subject . . . . Our claim to consideration is based almost entirely on the manner in which the subject has been presented." Not content with this disclaimer, they continued: "There is, in fact, very little room for such originality, the ground having been almost completely covered by previous writers." [113]

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[111] *Transactions of the American Society of Mechanical Engineers*, 1885–1886, vol. 7, p. 757.

[112] Peter Schwamb and Allyne L. Merrill, *Elements of Mechanism*, New York, 1904. In addition to the work of Reuleaux and Rankine, the authors acknowledged their use of the publications of Charles MacCord, Stillman W. Robinson, Thomas W. Goodeve, and William C. Unwin. For complete titles see the list of selected references.

The similarity and aridity of kinematics textbooks in this country from around 1910 are most striking. The generation of textbook writers following MacCord, Woods and Stahl, Barr of Cornell, Robinson of Ohio State, and Schwamb and Merrill managed to squeeze out any remaining juice in the subject, and the dessication and sterilization of textbooks was nearly complete when my generation used them in the 1930's. Kinematics was then, in more than one school, very nearly as it was characterized by an observer in 1942—"on an intellectual par with mechanical drafting." [114] I can recall my own naïve belief that a textbook contained all that was known of the subject; and I was not disabused of my belief by my own textbook or by my teacher. I think I detect in several recent books a fresh, less final, and less tidy treatment of the kinematics of mechanisms, but I would yet recommend that anyone who thinks of writing a textbook take time to review, carefully and at first hand, not only the desk copies of books that he has accumulated but a score or more of earlier works, covering the last century at least. Such a study should result in a better appreciation of what constitutes a contribution to knowledge and what constitutes merely the ringing of another change.

The author of the contentious article that appeared in *Mechanical Engineering* in 1942 under the title "What is Wrong with Kinematics and Mechanisms?" made several pronouncements that were questioned by various readers, but his remarks on the meagerness of the college courses of kinematics and the "curious fact" that the textbooks "are all strangely similar in their incompleteness" went unchallenged and were, in fact, quite timely.[115]

It appears that in the early 1940's the general classroom treatment of accelerations was at a level well below the existing knowledge of the subject, for in a series of articles by two teachers at Purdue attention was called to the serious consequences of errors in acceleration analysis occasioned by omitting the Coriolis component.[116] These authors were reversing a trend that had been given impetus by an article written in 1920 by one of their predecessors, Henry N. Bonis. The earlier article, appearing in a practical-and-proud-of-it technical magazine, demonstrated how the acceleration of a point on a flywheel governor might be determined "without the use of the fictitious acceleration of Coriolis." The author's analysis was right enough, and he closed his article with the unimpeachable statement that "it is better psychologically for the student and practically for the engineer to understand the fundamentals thoroughly than to use a complex formula that may be misapplied." However, many readers undoubtedly read only the lead paragraph, sagely nodded their heads when they reached the word "fictitious," which confirmed their half-formed conviction that anything as abstruse as the Coriolis component could have no bearing upon a practical problem, and turned the page to the "practical kinks" section.[117]

Less than 20 years ago one might have read in *Mechanical Engineering* that "Practical machinery does not originate in mathematical formulas nor in beautiful vector diagrams." While this remark was in a letter evoked by an article, and was not a reflection of editorial policy, it was nevertheless representative of an element in the American tradition of engineering. The unconscious arrogance that is displayed in this statement of the "practical" designer's creed is giving way to recognition of the value of scholarly work. Lest the scholar develop arrogance of another sort, however, it is well to

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[113] Arthur T. Woods and Albert W. Stahl, *Elementary Mechanism*, New York, 1885.

[114] *Mechanical Engineering*, October 1942, vol. 64, p. 745.

[115] De Jonge, *op. cit.* (footnote 78).

[116] A. S. Hall and E. S. Ault, "How Acceleration Analysis Can Be Improved," *Machine Design*, February 1943, vol. 15, pp. 100–102, 162, 164; and March 1943, vol. 15, pp. 90–92, 168, 170. See also A. S. Hall, "Teaching Coriolis' Law," *Journal of Engineering Education*, June 1948, vol. 38, pp. 757–765.

[117] Henry N. Bonis, "The Law of Coriolis," *American Machinist*, November 18, 1920, vol. 53, pp. 928–930. See also "Acceleration Determinations," *American Machinist*, November 25 and December 2, 1920, vol. 53, pp. 977–981 and 1027–1029.

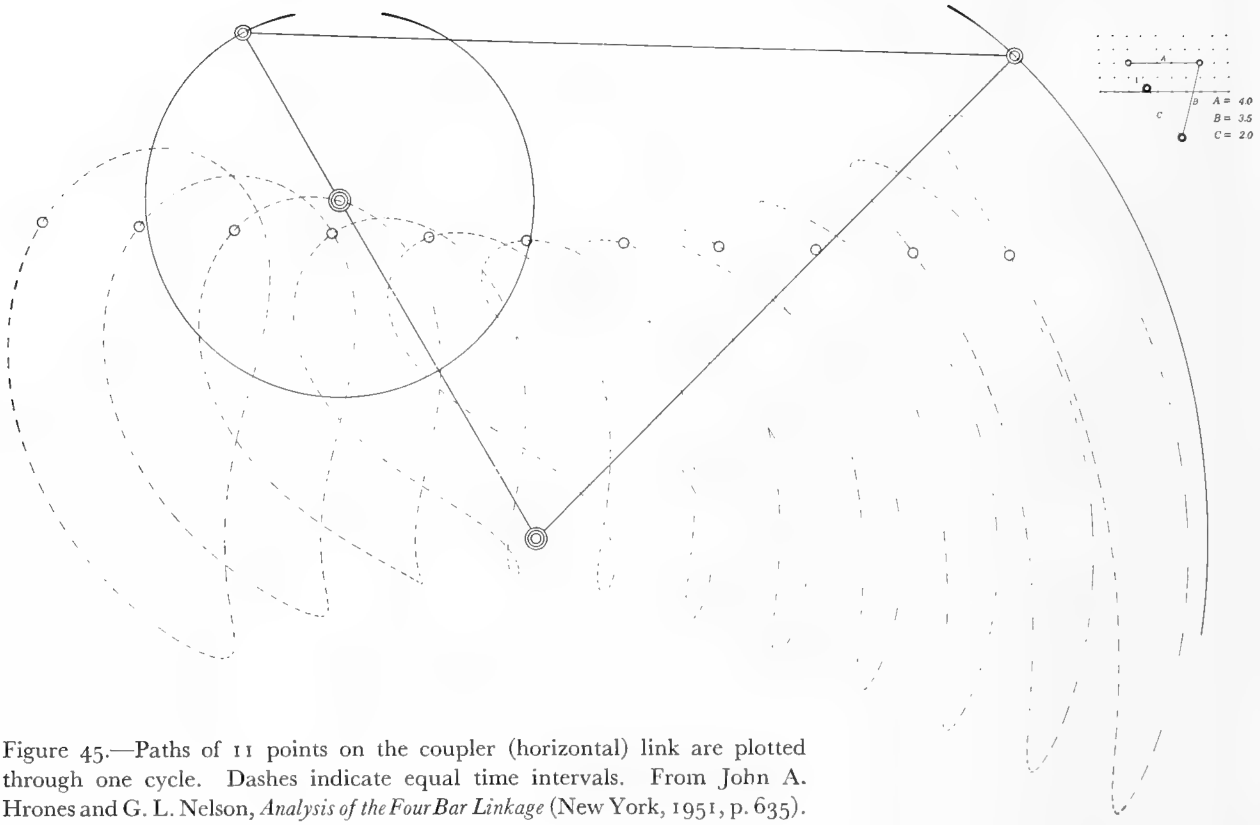

Figure 45.—Paths of 11 points on the coupler (horizontal) link are plotted through one cycle. Dashes indicate equal time intervals. From John A. Hrones and G. L. Nelson, *Analysis of the Four Bar Linkage* (New York, 1951, p. 635).

hear the author of the statement out. "A drafting machine is a useful tool," he wrote. "It is not a substitute for a draftsman."[118]

The scholarly interest in a subject is fairly represented by the papers that are published in the transactions of professional societies and, more recently, by original papers that appear in specialized magazines. From 1900 to 1930 there were few papers on mechanisms, and most of those that did appear were concerned with descriptions of new "mechanical motions." In the 1930's the number of papers reported in *Engineering Index* increased sharply, but only because the editors had begun to include foreign-language listings.

There has been in Germany a thread of continuity in the kinematics of mechanisms since the time of Reuleaux. While most of the work has had to do with analysis, the teasing question of synthesis that Reuleaux raised in his work has never been ignored. The developments in Germany and elsewhere have been ably reviewed by others,[119] and it is only to be noted here that two of the German papers, published in 1939 in *Maschinenbau*, appear to have been the sparks for the conflagration that still is increasing in extent and intensity. According to summaries in *Engineering Index*, R. Kraus, writing on the synthesis of the double-crank mechanism, drew fire from the Russian Z. S. Bloch, who, in 1940, discussed critically Kraus's articles and proceeded to give the outline of the "correct analysis of the problem" and a general numerical solution for the synthesis of "any four-bar linkage."[120] Russian work in mechanisms, dating back to Chebyshev and following the "Chebyshev theory of synthesis" in which algebraic methods are used to determine paths of minimum deviation from a

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[118] *Mechanical Engineering*, October 1942, vol. 64, p. 746.

[119] Grodzinski, Bottema, De Jonge, and Hartenberg and Denavit. For complete titles see list of selected references.

[120] My source, as noted, is *Engineering Index*. Kraus's articles are reported in 1939 and Bloch's in 1940, both under the section heading "Mechanisms."

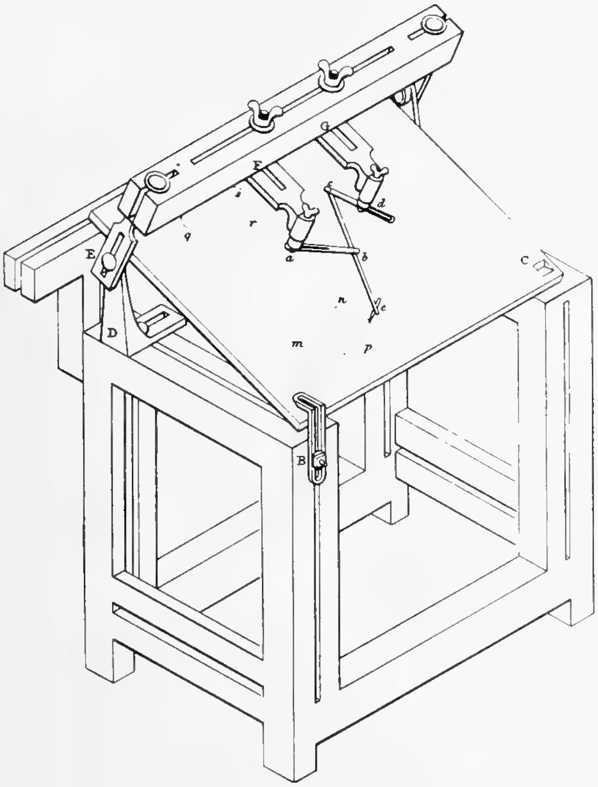

Figure 46.—Coupler-point path-generating machine for four-bar linkage. This device, built by Professor Willis as a teaching aid for demonstrating straight-line linkages, could have been adapted to produce a plate like the one shown in figure 45. From Robert Willis, *A System of Apparatus for the Use of Lecturers and Experimenters* . . . (London 1851, pl. 3).

given curve, has also been reviewed elsewhere,[121] and I can add nothing of value.

When, after World War II, some of the possibilities of kinematic synthesis were recognized in the United States, a few perceptive teachers fanned the tinder into an open flame.

The first publication of note in this country on the synthesis of linkages was a practical one, but in conception and undertaking it was a bold enterprise. In a book by John A. Hrones and G. L. Nelson, *Analysis of the Four Bar Linkage* (1951), the four-bar crank-and-rocker mechanism was exhaustively analyzed mechanically and the results were presented graphically. This work was faintly praised by a Dutch scholar, O. Bottema, who observed that the "complicated analytical theory of the three-bar [sic] curve has undoubtedly kept the engineer from using it" and who went on to say that "we fully understand the publication of an atlas by Hrones and Nelson containing thousands of trajectories which must be very useful in many design problems."[122] Nevertheless, the authors furnished designers with a tool that could be readily, almost instantly, understood (fig. 45), and the atlas has enjoyed wide circulation.[123] The idea of a geometrical approach to synthesis has been exploited by others in more recent publications,[124] and it is likely that many more variations on this theme will appear.

Pursuit of solutions to the "complicated analytical theory" of linkages was stimulated by publication of Ferdinand Freudenstein's "Analytical Approach to the Design of Four-Link Mechanisms" in 1954,[125] and an increasing interest in the problem is indicated by the extensive literature that has appeared in the last five years.

The proper role of rational methods in the synthesis of mechanisms is not yet clear. "While we may talk about kinematic synthesis," wrote two of today's leaders in the field, "we are really talking about a hope for the future rather than a great reality of the present."[126] When the mental equipment and the enthusiasm of scholars who are devoting their time to the problems of kinematic synthesis are considered, however, it is difficult to see how important new ideas can fail to be produced.

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[121] A. E. Richard de Jonge, "Are the Russians Ahead in Mechanism Analysis?" *Machine Design*, September 1951, vol. 23, pp. 127, 200–208; O. Bottema, "Recent Work on Kinematics," *Applied Mechanics Reviews*, April 1953, vol. 6, pp. 169–170.

[122] Bottema, *op. cit.* (footnote 121).

[123] In 1851 Robert Willis had designed a coupler-point path-generating machine (fig. 46) that could have been used to produce a work similar to that of Hrones and Nelson.

[124] R. S. Hartenberg and J. Denavit, "Systematic Mechanism Design," *Machine Design*, September 1954, vol. 26, pp. 167–175, and October 1954, vol. 26, pp. 257–265; A. S. Hall, A. R. Holowenko, and H. G. Laughlin, "Four-Bar Lever Crank Mechanism," *Design News*, September 15, 1957, vol. 12, pp. 130–139, October 1, 1957, vol. 12, pp. 145–154, and October 15, 1957, vol. 12, pp. 132–141. For a nomographic approach, with particular application to computers, see Antonin Svoboda, *Computing Mechanisms and Linkages*, New York, 1948.

[125] *Transactions of the American Society of Mechanical Engineers*, 1954, vol. 76, pp. 483–492. See also *Transactions of the American Society of Mechanical Engineers*, 1955, vol. 77, pp. 853–861, and 1956, vol. 78, pp. 779–787.

[126] R. S. Hartenberg and J. Denavit, "Kinematic Synthesis," *Machine Design*, September 6, 1956, vol. 28, pp. 101–105.

An annual Conference on Mechanisms, sponsored by Purdue University and *Machine Design*, was inaugurated in 1953 and has met with a lively response. Among other manifestations of current interest in mechanisms, the contributions of Americans to international conferences on mechanisms reflects the growing recognition of the value of scholarly investigation of the kind that can scarcely hope to yield immediately tangible results.

While we look to the future, one may ask how a lengthy view of the past can be justified. It seems to me that there is inherent in the almost feverish activity of the present the danger of becoming so preoccupied with operational theory that the goals may become clouded and the synthesis (let us put it less elegantly: the design) of mechanisms may never quite come into focus. If one knows nothing of the past, I wonder how he can with any confidence decide in what direction he must turn in order to face the future.

Acknowledgment

I am grateful to Professors Richard S. Hartenberg and Allen S. Hall, Jr., for reading the manuscript, making helpful comments, and suggesting material that I had not found. The errors, however, are mine.

Additional References

The following list of additional reference material on kinematics may be of help to readers who desire to do independent research. The material is listed according to the section headings in the text of the present article.

TO DRAW A STRAIGHT LINE

KEMPE, A. B. *How to Draw a Straight Line.* London, 1877.

Contains a useful bibliography. Reprinted in *Squaring the Circle and Other Monographs*, New York, Chelsea Publishing Company, 1953.

Much attention has been given to straight-line mechanisms since the time of Kempe; at least a half dozen articles have appeared in the United States since 1950, but I did not investigate the literature published after 1877.

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BECK, THEODOR. *Beiträge zur Geschichte des Maschinenbaues.* Berlin, 1899.

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This subject index was started in 1908, and by 1914 three volumes (the third in two parts) had been published; however, this subject index was never completed. Volume 2, titled *Mechanics*, has some 200 entries under "Linkages." It is interesting to note that both of the Royal Society's monumental catalogs grew out of a suggestion made by Joseph Henry at a British Association meeting in Glasgow in 1855.

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MECHANISMS IN AMERICA, 1875–1955

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Contains a bibliography that includes works not mentioned in the present paper.

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An early textbook. The author taught at Cornell University.

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Contains an extensive and useful bibliography.

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Conference on Mechanisms.

This conference was sponsored by Purdue University and *Machine Design.* Transactions of the first two conferences appeared as special sections in *Machine Design*, December 1953, vol. 25, pp. 173–220, December 1954, vol. 26, pp. 187–236, and in collected reprints. Papers of the third and fourth conferences (May 1956 and October 1957) appeared in *Machine Design* over several months following each conference and in collected reprints. Papers of the fifth conference (October 1958) were collected and preprinted for conference participants; subsequently, all papers appeared in *Machine Design.* Collected reprints and preprints are available (May 1960) from Penton Publishing Company, Cleveland, Ohio.

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An early textbook.

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This article evoked interesting discussion. It is unfortunate that Grodzinski's periodical, *Mechanism, An International Bibliography*, which was published in London in 1956–1957 and which terminated shortly after his death, has not been revived. Grodzinski's incisive views and informative essays are valuable and interesting.

Hartenberg, R. S. "Complex Numbers and Four-Bar Linkages," *Machine Design*, March 20, 1958, vol. 30, pp. 156–163.

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PAPER 28

THE DEVELOPMENT OF ELECTRICAL TECHNOLOGY IN THE 19TH CENTURY:

1. THE ELECTROCHEMICAL CELL AND THE ELECTROMAGNET

W. James King

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THE DEVELOPMENT OF ELECTRICAL TECHNOLOGY IN THE 19th CENTURY:

1. The Electrochemical Cell and the Electromagnet

by W. James King

This paper—first in a series tracing the early history of electrical invention—deals with two devices basic to most of the later inventions in this field.

Starting with the early researches of Luigi Galvani and Alessandro Volta in the late 1700's, it highlights developments involving the electrochemical cell and the electromagnet during the period that culminated in the invention of various electric motors in the mid-19th century.

Among the devices described and illustrated are objects in the collections of the Smithsonian. They include the 1831 electromagnet of Joseph Henry, later to become first head of the Institution, and the U.S. Patent Office model of Thomas Davenport's electric motor, the first to be patented in America.

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MUCH of electrical technology depends upon an understanding of the properties of a coil of wire about an iron core. When an electric current is sent through a coil, the coil becomes an electromagnet that produces a mechanical force which may be turned on and off; moreover, this mechanical force may be controlled at a distance and in any arbitrary manner. On the other hand, an electric current is induced in the coil if a magnet is moved near it. Almost all electrical machinery with moving parts depends on these simple properties.

Static electricity had been known for some time before electromagnetism was discovered. However, it was not until the chemical cell was devised and made practical that electromagnets could be applied to invention. The first part of this article deals with the story of the chemical cell, together with some of its first commercial applications; the second part concerns electromagnets and how they were first applied to motors.

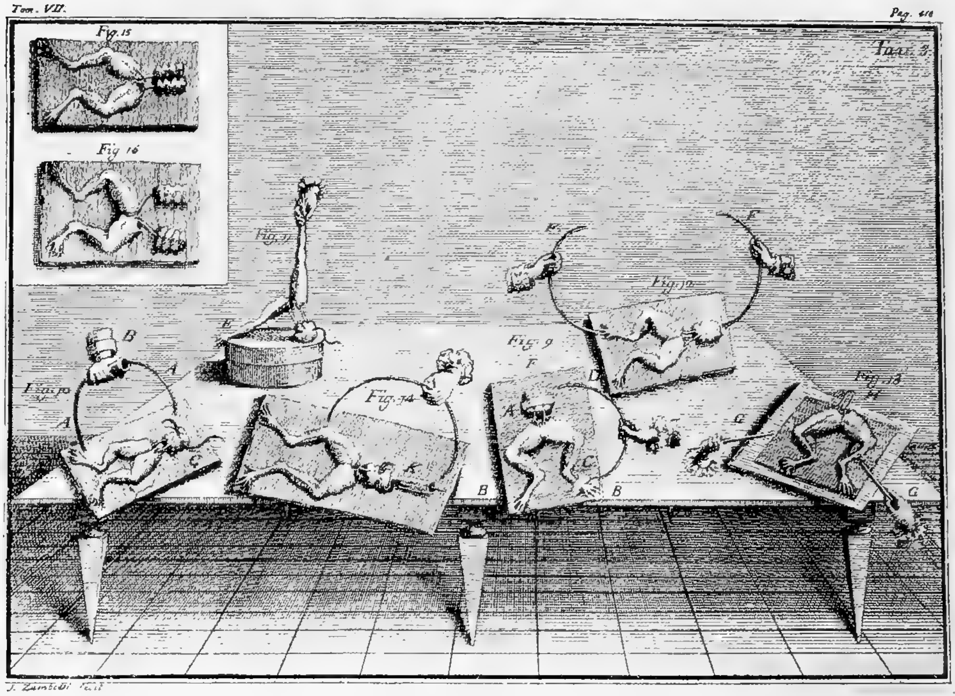

Figure 1.—Galvani's experiments in animal electricity. From Luigi Galvani, *De Viribus Electricitatis in Motu Musculari Commentarius*, Bologna, 1791, translated by Margaret Foley, Norwalk, Connecticut, 1953, pl. 3.

The Electrochemical Cell

Luigi Galvani, professor of anatomy at Bologna, was studying the relation between electricity and muscular tissue when he discovered that if the exposed nerve of a frog's leg were touched by metals under certain conditions, a contraction of the muscle would result (figs. 1, 2). This discovery led Galvani to explain muscular contractions in terms of an electrical nervous fluid being conducted, stored, and discharged.[1] Tissue, living or dead, was the receptacle of this fluid, and so could act as a kind of Leyden jar. Previous experience had shown that a Leyden jar could produce a spark only after "electrical fluid" had been condensed in it; however, an electrical effect could be detected in the tissue each time. Because of this, the suspicion arose that perhaps the electrical fluid might be some kind of life force.

Galvani's explanation was first elaborated[2] and then contested[3] by Alessandro Volta, who finally concluded that animal tissue was not necessary to produce the electrical effect and that all that was needed was two dissimilar metals separated by a poor conductor.[4] As a result of his research, Volta was able to design his famous voltaic pile (figs. 3, 4), which multiplied the effect of a single pair of dissimilar metals. The pile was formed by stacking pairs of metals separated by disks of paper moistened with salt water in the sequence: silver-paper-zinc-silver-paper-zinc, etc. These piles were found to increase their

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[1] Luigi Galvani, *De Viribus Electricitatis in Motu Musculari Commentarius*, Bologna, 1791, translated by Margaret Foley, Burndy Library Publication No. 10, Norwalk, Connecticut, 1953.

[2] Alessandro Volta, "Account of Some Discoveries Made by Mr. Galvani, of Bologna; with Experiments and Observations on Them," *Philosophical Transactions of the Royal Society of London* (hereinafter referred to as *Philosophical Transactions*), 1793, vol. 83, pp. 10–44.

[3] Allesandro Volta, "Observations on Animal Electricity; Being the Substance of Two Letters from A. Volta to Professor Gren," *Philosophical Magazine*, 1799, vol. 4, pp. 59–68, 163–171, 306–312.

[4] Alessandro Volta, "On the Electricity Excited by the Mere Contact of Conducting Substances of Different Kinds," *Philosophical Magazine*, 1800, vol. 7, pp. 289–311.

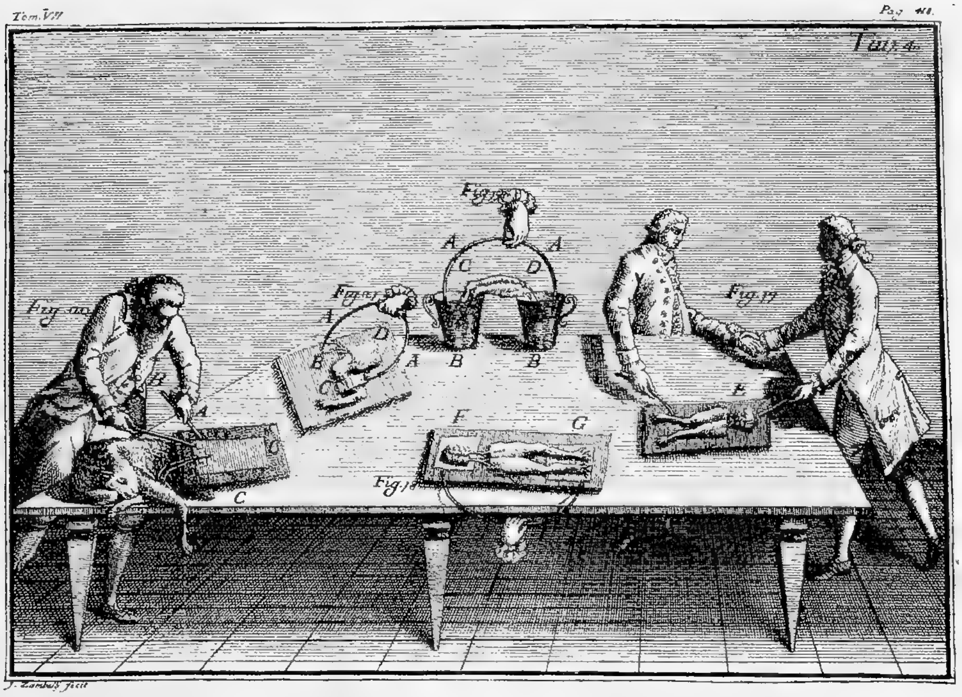

Figure 2.—Galvani's experiments in animal electricity. From Luigi Galvani, *De Viribus Electricitatis in Motu Musculari Commentarius*, Bologna, 1791, translated by Margaret Foley, Norwalk, Connecticut, 1953, pl. 4.

effects if more or larger plates were used; but, of course, the heavier the plates, the faster the paper dried out and the faster the pile ceased working. Such dehydration could be avoided by dividing the pile in half and connecting several piles together. Even so, the pile usually was effective for only a couple of days; then it had to be taken apart and cleaned before further use. Such devices (fig. 5) were in use during the first quarter of the 19th century. Volta devised a battery with a longer life in his "crown of cups." [5] This innovation consisted of a number of cups filled with a saline solution and with a pair of dissimilar metals in each cup. One metal electrode was joined to its opposite mate in the next cup, and so on, until a complete circuit was made. However, the "crown of cups" was much bulkier than the pile.

Volta's results were communicated in two well known letters to England, where they promptly stimulated further work. Even before the publication of the second letter, William Nicholson and Anthony Carlisle made a pile of 17 silver half-crowns and as many zinc disks.[6] This pile was not powerful enough for their electrochemical experiments, so they made another pile of 36 pairs, and then one of 100 pairs.[7]

Dissatisfied with the arrangement of the metals in a pile, William Cruickshanks devised his "trough" battery.[8] For this battery, 60 pairs of zinc and silver plates measuring about 1½ inches square were cemented with rosin and beeswax in a trough so that all the zinc plates faced one way and all the silver plates the other way. The cells formed by these metal partitions were "charged" by a dilute solution of ammonium chloride. Trough batteries (such as shown in figs. 6–8) might last several weeks instead of only a couple of days, but even so the

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[5] *Ibid.*

[6] William Nicholson, "Account of the New Electrical or Galvanic Apparatus of Sig. Alex. Volta, and Experiments Performed with the Same," *Journal of Natural Philosophy, Chemistry, and the Arts* (hereinafter referred to as Nicholson's *Journal*), 1800, vol. 4, pp. 179–187.

[7] William Nicholson, Anthony Carlisle, William Cruickshanks, et al. "Experiments in Galvanic Electricity," *Philosophical Magazine*, 1800, vol. 7, pp. 337–347.

[8] William Cruickshanks, "Additional Remarks on Galvanic Electricity," Nicholson's *Journal*, 1801, vol. 4, pp. 254–264.

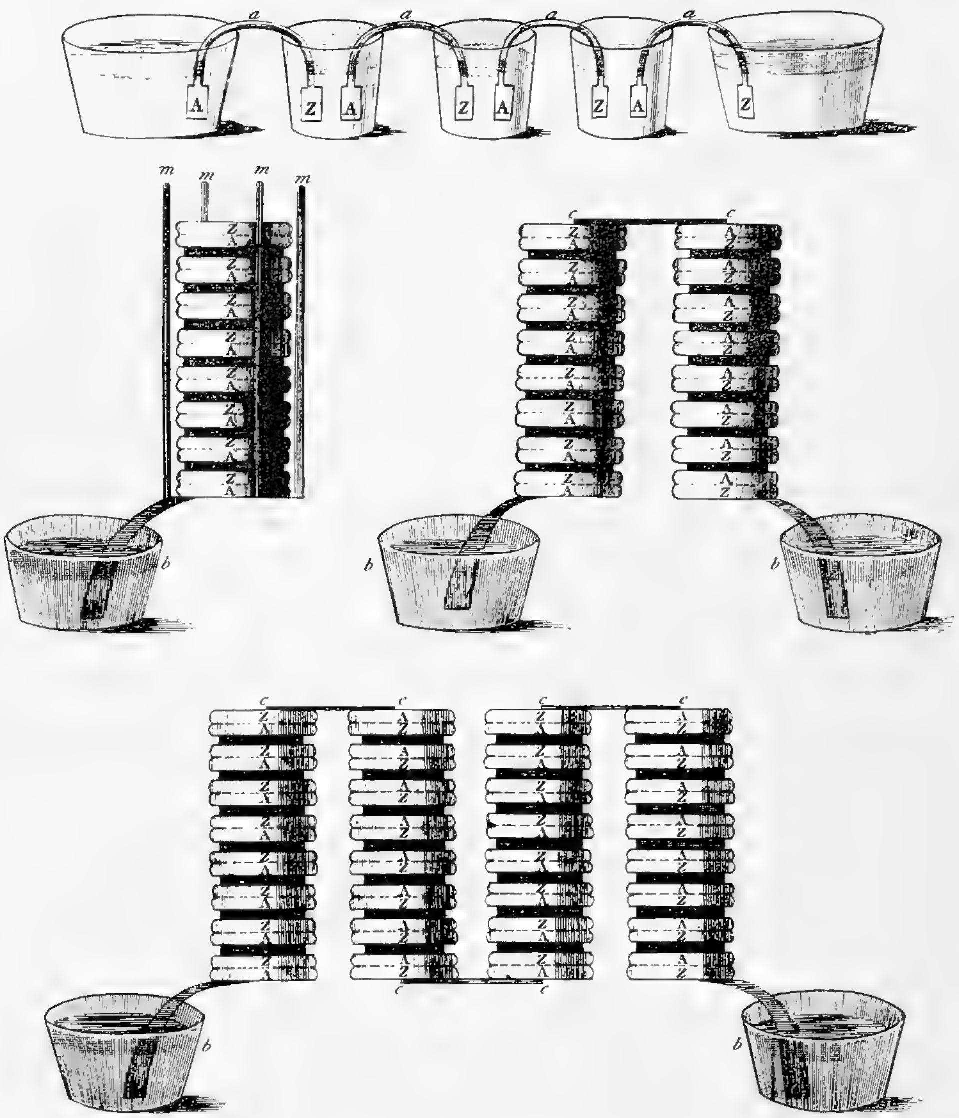

Figure 3.—Volta's "crown of cups" (at top) and his voltaic pile. From *Philosophical Transactions of the Royal Society of London*, 1800, vol. 90, plate opposite p. 430.

experimenter had "to hasten to complete his experiments before the power had materially declined." [9] Two years later William Pepys built two troughs (fig. 9) with 130 pairs of zinc and copper plates, each plate being 6 inches square.[10] Each trough was charged with dilute "nitrous acid." In 1807 Humphrey Davy used three such batteries to separate sodium and potassium from their compounds.[11] One battery had 24 pairs of copper and zinc plates 12 inches square;

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[9] Benjamin Silliman, *First Principles of Chemistry*, Philadelphia, 1847, p. 115.

[10] William Cruickshanks, "Description of Mr. Pepys' Large Galvanic Apparatus," *Philosophical Magazine*, 1803, vol. 15, pp. 94–96.

[11] Humphrey Davy, "On Some New Phenomena of Chemical Changes Produced by Electricity, Particularly the Decomposition of the Fixed Alkalies, and the Exhibition of the New Substances which Constitute Their Bases; and on the General Nature of Alkaline Bodies," *Philosophical Transactions*, 1808, vol. 98, pp. 1–44.

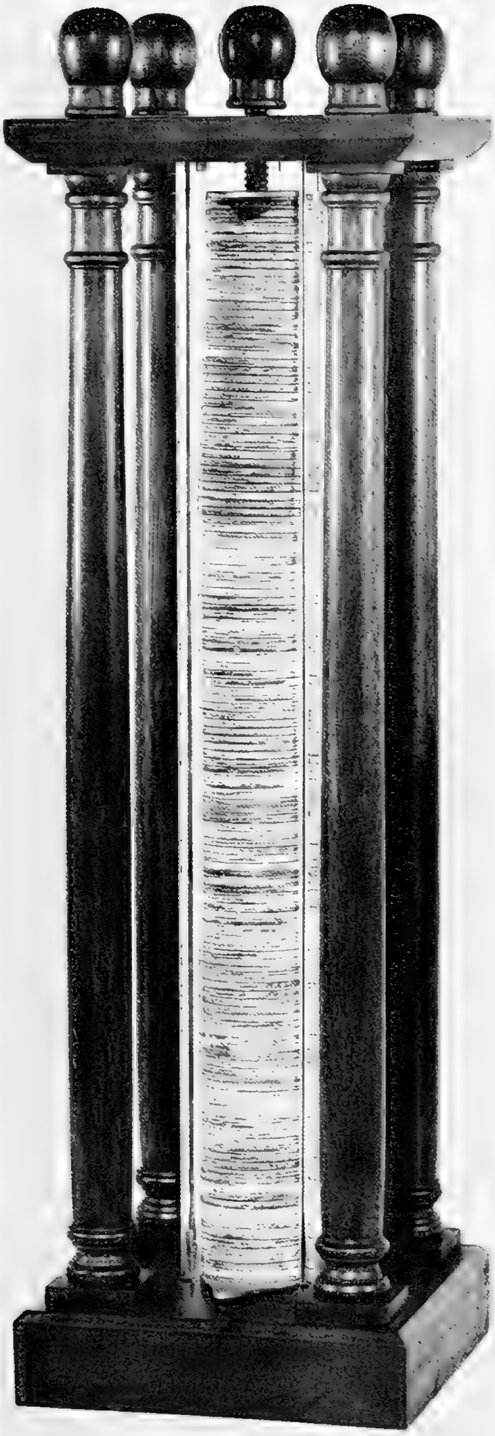


Figure 4.—Reproduction of voltaic pile of about 1810. The stand is about 4 feet high. (*USNM 315049; Smithsonian photo 47048-D.*)

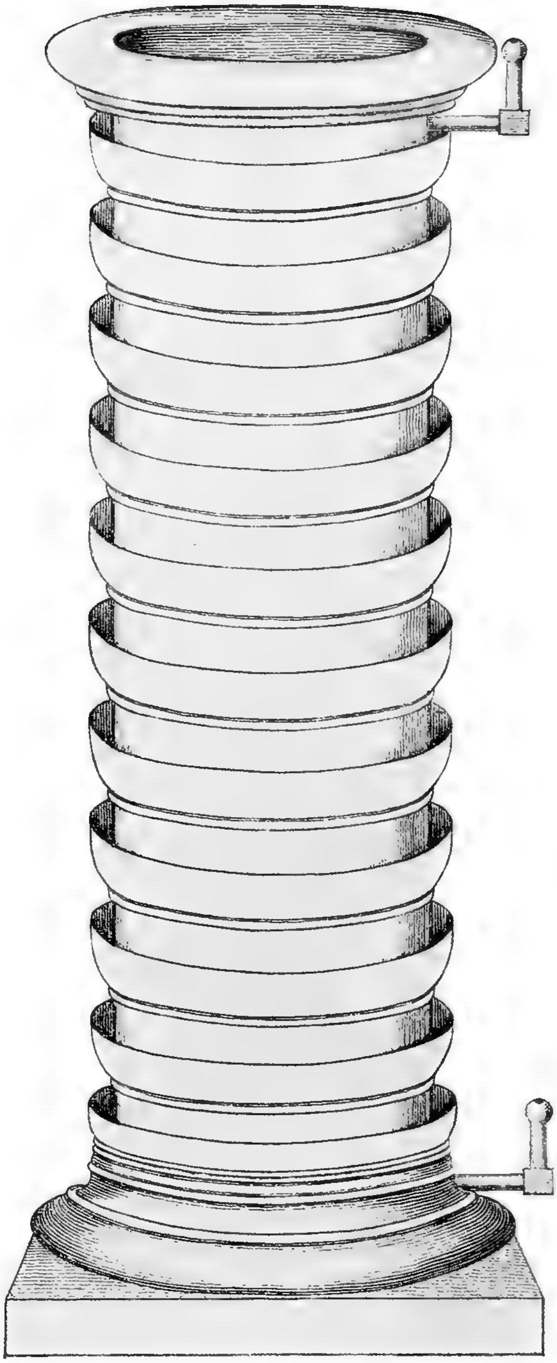
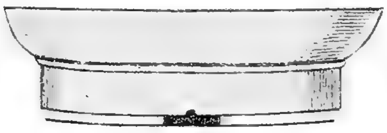


Figure 5.—Kemp's voltaic pile of 1828. From *Edinburgh New Philosophical Journal*, 1828, vol. 6, pl. 2, p. 71.



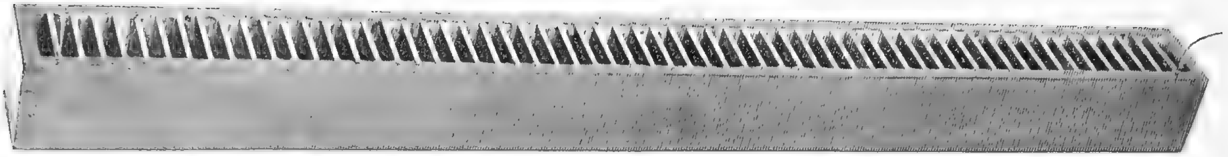


Figure 6.—Joseph Priestley's trough battery. (*USNM 315114; Smithsonian photo 47048-A.*)

one had 100 pairs of plates 6 inches square, and one had 150 pairs of plates 4 inches square. Alum and "nitrous acid" were used to charge the cells.

A trough battery could not be cleaned without some difficulty; and as long as the charge was in the battery it tended to dissolve any corrodible electrode. C. H. Wilkinson's "plunge" battery [12] avoided this dissolution by suspending the electrodes from a rod so that all the electrodes could be immersed at the same time and could be removed from the corrosive acid when not in use. In addition, both sides of an electrode were used, increasing the current output for a given amount of metal. A similar form of such a plunge battery was constructed by Pepys (fig. 10). J. G. Children made a plunge battery of 20 pairs of copper and zinc plates, each 4 feet high and 2 feet wide, with a "charging" fluid of dilute nitrous and sulfuric acid.[13] In the following year, the "Great Battery" [14] of the Royal Institution of Great Britain was constructed on a similar plan (fig. 11). In this battery there were 200 porcelain troughs, each of which constituted a plunge battery of 10 pairs of electrodes that were 4 inches square. With the use of this battery Davy isolated the alkaline earth metals.[15]

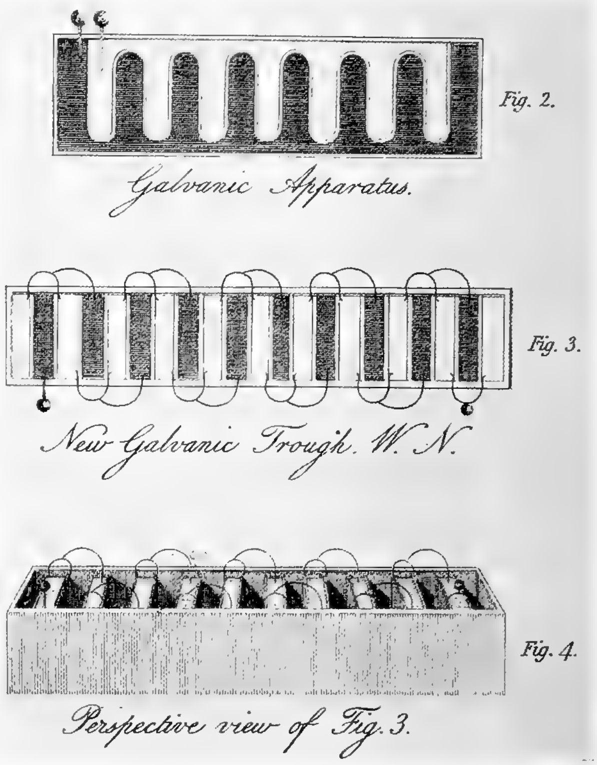


Figure 7.—Nicholson's trough battery. From Nicholson, ed., *A Journal of Natural Philosophy, Chemistry, and the Arts,* 1804, vol. 8, p. 64, pl. 3.

Volta's pile of *n* pairs of metals increased what he

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[12] C. H. Wilkinson, "On the Means of Simplifying and Improving the Galvanic Apparatus," Nicholson's *Journal*, 1804, vol. 8, pp. 1–5; "Facts upon which Deductions Are Made to Show the Law of Galvanism in Burning the Metals, According to the Disposition of Equal Surfaces of Charged Metallic Plates," Nicholson's *Journal*, 1804, vol. 7, pp. 206–209; "Description of an Improved Galvanic Trough," *Philosophical Magazine*, 1807, vol. 29, pp. 243–244.

[13] John G. Children, "An Account of Some Experiments, Performed with a View to Ascertain the Most Advantageous Method of Constructing a Voltaic Apparatus, for the Purpose of Chemical Research," *Philosophical Transactions*, 1809, vol. 99, pp. 32–38.

[14] Humphrey Davy, "On Some New Electrochemical Researches, on Various Objects, Particularly the Metallic Bodies, from the Alkalies and Earths, and on Some Combinations of Hydrogene," *Philosophical Transactions*, 1810, vol. 100, pp. 16–74.

[15] Humphrey Davy, "Electro-Chemical Researches on the Decomposition of the Earths; with Observations on the Metals Obtained from the Alkaline Earths, and on the Amalgam Procured from Ammonia," *Philosophical Transactions*, 1808, vol. 98, pp. 333–370.

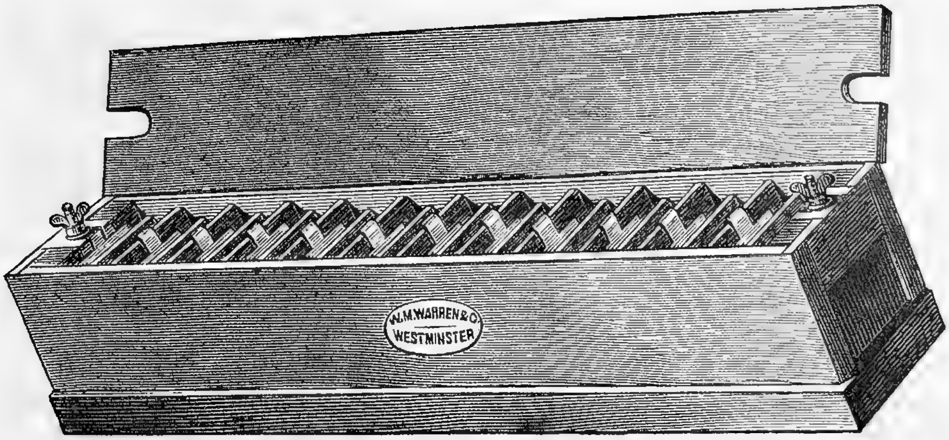

Figure 8.—Fuller's trough battery, a Daniell cell battery that was used in the early days of British telegraphy. From R. Wormell, *Electricity in the Service of Man*, London and New York, 1886, p. 397.

called the "intensity of the electrical force" (that is, the voltage) *n*-fold over that produced by a single pair of electrodes, but the quantity of electricity (that is, the current) was the same whether the pile had one pair or *n* pairs. Davy argued that the intensity of electricity increased with the number of pairs and the quantity increased with the area of these pairs.[16] In 1815 J. G. Children [17] published the results of a number of experiments made to prove Davy's hypothesis. He improved the trough battery by applying a suggestion by William Wollaston to increase the area of one electrode by folding it into a U-shape about the other (fig. 12). Two years later Hans Oersted [18] reported he had increased the effective area of a battery by replacing the wooden trough with a copper one (fig. 13). This copper trough served as one electrode; the electrodes of the other metal were placed in the trough. Such a design greatly increased the heating and sparking power of the battery.

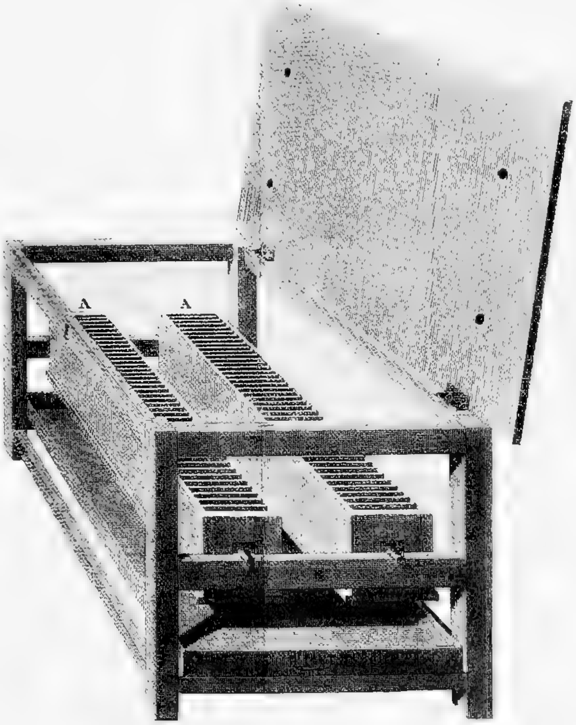

Figure 9.—Pepys' trough battery. From *Philosophical Magazine*, 1803, vol. 15, pl. 1.

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[16] Humphrey Davy, "On Some Chemical Agencies of Electricity," *Philosophical Transactions*, 1807, vol. 97, pp. 1–56.

[17] John G. Children, "An Account of Some Experiments with a Large Voltaic Battery," *Philosophical Transactions*, 1815, vol. 105, pp. 363–374.

[18] Hans C. Oersted, "Bemerkungen hinsichtlich auf Contactelektrizität," *Journal für Chemie und Physik* (hereinafter referred to as Schweigger's *Journal*), 1817, vol. 20, pp. 205–212.

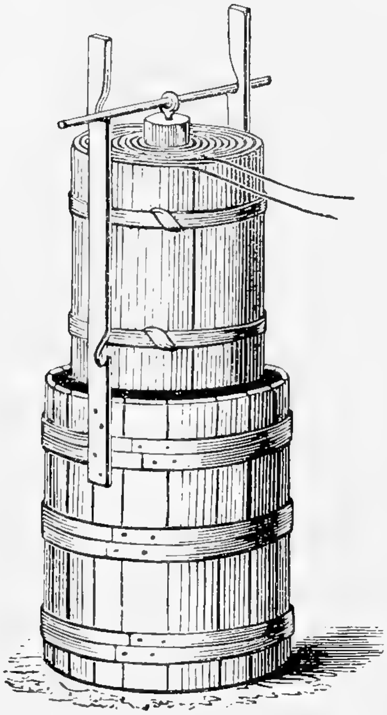

Figure 10.—Pepys' plunge battery as constructed for the Royal Institution. From H. M. Noad, *Student's Textbook of Electricity*, London, 1867, p. 168.

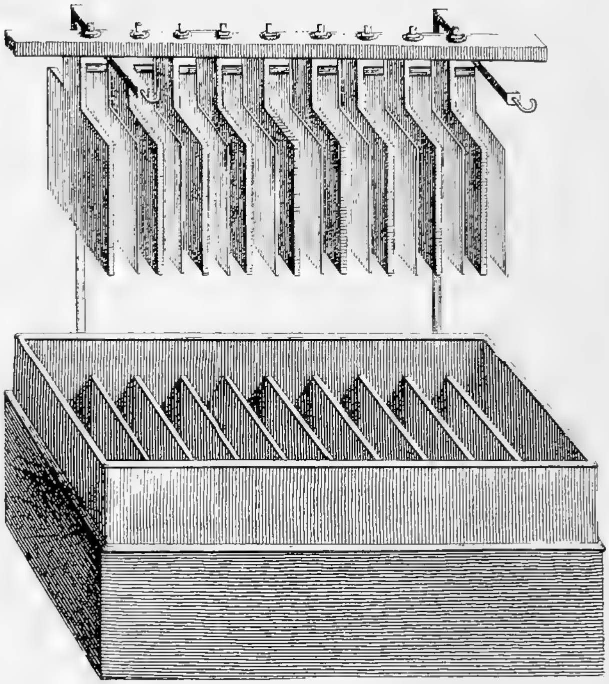

Figure 11.—One of the 200 plunge batteries in the "Great Battery" of the Royal Institution. From *Philosophical Transactions of the Royal Society of London*, 1810, vol. 100, pl. 2, fig. 6.

Robert Hare[19] tried to attack the problem on a more general basis. He made what he called a "calorimotor" by connecting all the copper plates together and all the zinc plates together, so that "instead of multiplying the pairs of galvanic plates [he increased the effect] by enlarging one pair" (fig. 14). He further increased the area of the electrodes that would fit in a given volume by rolling them up in a close spiral. His "galvanic deflagrator"[20] simplified battery construction in the same manner as had Oersted's copper trough battery. Instead of a cell for each pair of elements, only one trough was used. Michael Faraday, Peter Barlow, and Joseph Henry all used batteries based on the construction of Hare's calorimotor for their experiments.

Due to the nullifying chemical reactions of polarization and local action, both the trough battery and the plunge battery had extremely limited lives. Local action results from the use of impure metals, where the impurity forms a voltaic pair with the material of the electrode and prevents the affected portion of the electrode from contributing to the electrical output of the cell. Since over half the energy, and in some cases as much as three-quarters of the energy, of the zinc electrode could be wasted in local action, the impure zinc that was available commercially at the time led to considerable inefficiency.

Auguste de la Rive found that electrodes made from distilled zinc would eliminate local action, but the method was too expensive for ordinary purposes. However, the application of mercury to the zinc electrode permitted the zinc to interact with the electrolyte and at the same time prevented the im-

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[19] Robert Hare, "A New Theory of Galvanism, Supported by Some Experiments and Observations Made by Means of the Calorimotor, a New Galvanic Instrument," *American Journal of Science*, 1819, vol. 1, pp. 413–423.

[20] Robert Hare, "A Memoir on Some New Modifications of Galvanic Apparatus, with Observations in Support of His New Theory of Galvanism," *American Journal of Science*, 1821, vol. 3, pp. 105–117. "Correspondence between Robert Hare . . . and the Editor, on the Subject of Dr. Hare's Calorimotor and Deflagrator, and the Phenomena Produced by Them," *American Journal of Science*, 1822, vol. 5, pp. 94–112.

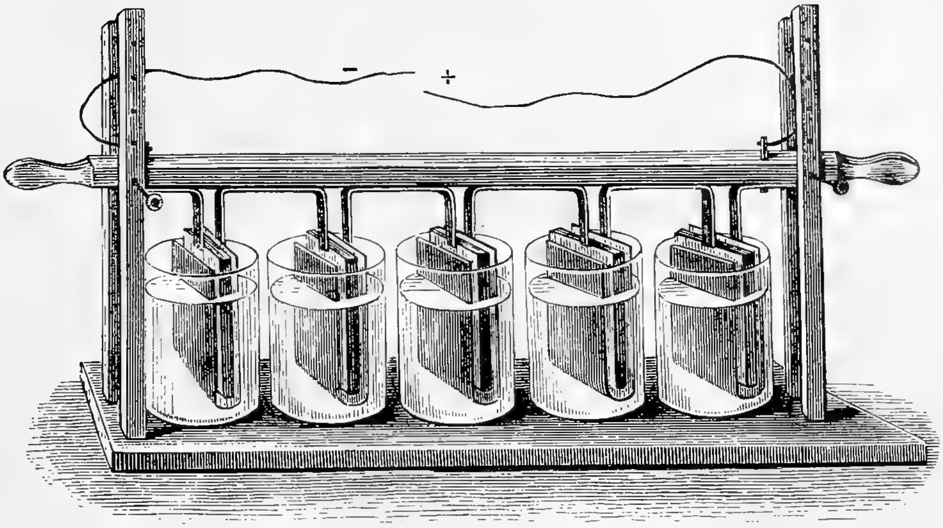

Figure 12.—Plunge battery using Wollaston's U-shaped electrodes. From T. Karass, *Geschichte der Telegraphie*, Braunschweig, 1909, p. 55.

purities from doing so. Although Davy casually mentioned the use of such an amalgamated electrode in his Bakerian Lecture[21] of 1826, De la Rive was the first to examine and explain the relation between amalgamation and local action.[22] (It may be that Davy was led to try such electrodes by analogy with the use of amalgamated electrodes in the usual electrostatic machine.) K. T. Kemp[23] and William Sturgeon[24] were the first to use amalgamation regularly in their experiments.

Polarization results from the formation of a gaseous or solid film at an electrode. This film may prevent chemical interaction between the electrode and the electrolyte and may cause a current in the direction opposite to the normal flow.

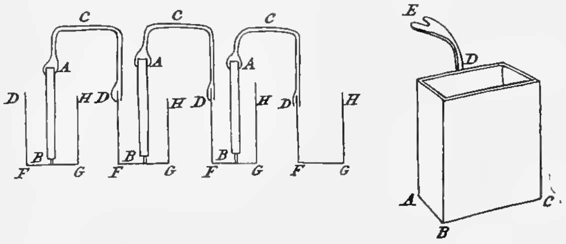

Figure 13.—Oersted's trough battery. From Schweigger's *Journal für Chemie und Physik*, 1817, vol. 20, fig. 2 of plate in Heft 2.

One of the first practical answers to the problem of gaseous polarization was found by J. Frederic Daniell, who in 1836 constructed a cell that used not one electrolyte but two.[25] As early as 1801 Davy had devised a two-solution cell to demonstrate his theory that electricity was the result of chemical oxidation rather

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[21] Humphrey Davy, "On the Relations of Electrical and Chemical Changes," *Philosophical Transactions*, 1826, vol. 116, pp. 383–422.

[22] Auguste de la Rive, "Note relative à l'action qu'exerce sur le zinc l'acide sulfurique étendu d'eau," *Bibliothèque universelle, sciences et arts*, 1830, vol. 43, pp. 391–411.

[23] K. T. Kemp, "Description of a New Kind of Galvanic Pile, and also of Another Galvanic Apparatus in the Form of a Trough," *Edinburgh New Philosophical Journal*, 1828, vol. 6, pp. 70–77; "Voltaic Batteries with Amalgamated Zinc," *Annals of Electricity, Magnetism and Chemistry* (hereinafter referred to as Sturgeon's *Annals of Electricity*), 1837, vol. 1, pp. 81–88.

[24] William Sturgeon, "On Electro-Magnets," *Philosophical Magazine*, 1832, vol. 11, pp. 194–205.

[25] J. Frederic Daniell, "On Voltaic Combinations," *Philosophical Transactions*, 1836, vol. 126, pp. 107–124; "Additional Observations on Voltaic Combinations," *Philosophical Transactions*, 1836, vol. 126, pp. 125–129; "Further Observations on Voltaic Combinations," *Philosophical Transactions*, 1837, vol. 127, pp. 141–150.

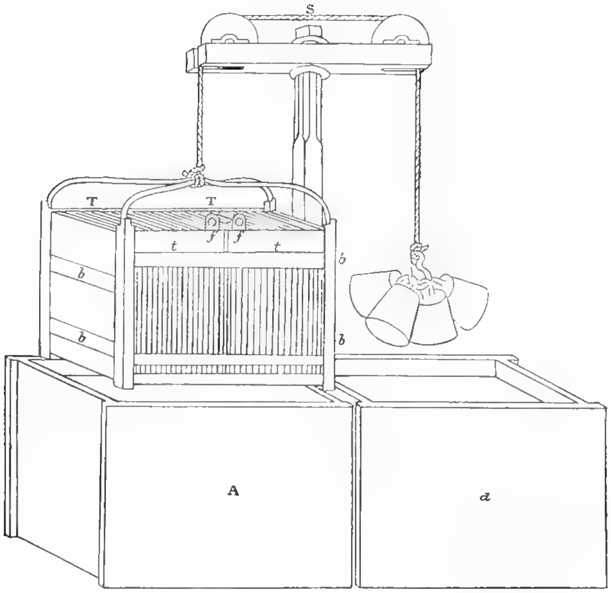
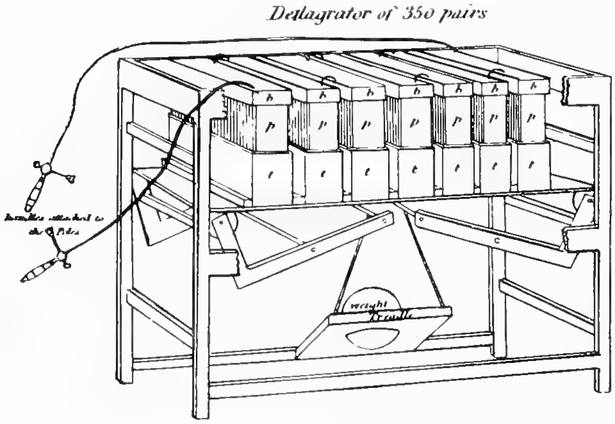


Figure 14.—Robert Hare's calorimotor (top) and galvanic deflagrator. From *American Journal of Science*, 1819, vol. 1, plate opposite p. 413, and 1822, vol. 5, plate opposite p. 95.



than of physical contact,[26] and Antoine Becquerel had devised another such cell[27] in the 1820's as a result of Davy's theories. Daniell set out to test Faraday's electrochemical theories, and he devised his nonpolarizable "Constant Battery" on the results (figs. 15, 16, and 17). In Daniell's cell an amalgamated zinc electrode in a weak solution of sulfuric acid was separated by an ox gullet from a copper electrode in a copper sulfate solution. John Gassiot made a more durable cell by replacing the gullet by an unglazed

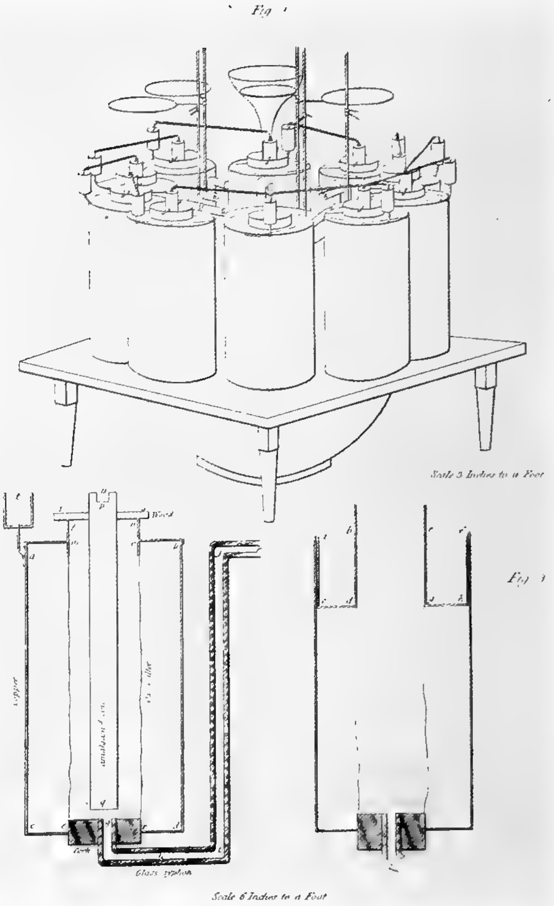


Figure 15.—Daniell's "constant" battery. From *Philosophical Transactions of the Royal Society of London*, 1836, vol. 126, p. 117, pl. 9.

porcelain cylinder.[28] While the high internal resistance of the Daniell cell limited the current consider-

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[26] Humphrey Davy, "An Account of Some Galvanic Combinations, Formed by the Arrangement of Single Metallic Plates and Fluids, Analogous to the New Galvanic Apparatus of Mr. Volta," *Philosophical Transactions*, 1801, vol. 91, pp. 397–402.

[27] Antoine Becquerel, "Nouveaux Résultats électro-chimiques," *Annales de chimie et de physique*, 1823, vol. 23, pp. 259–260; "De l' Etat de l'électricité développée pendant les actions chimiques, et de la mesure de ces dernières au moyen des effets électriques qui en résultent," *Annales de chimie et de physique*, 1823, vol. 24, pp. 192–205; "Mémoire sur l'électrochimie et l'emploi de l'électricité pour opérer des combinaisons," *Annales de chimie et de physique*, 1829, vol. 41, pp. 5–45.

[28] John P. Gassiot, "Account of Experiments with Voltameters, Having Electrodes Exposing Different Surfaces," *London and Edinburgh Philosophical Magazine and Journal of Science* (title varies, hereinafter referred to as *Philosophical Magazine*), 1839, vol. 13, pp. 436–439.

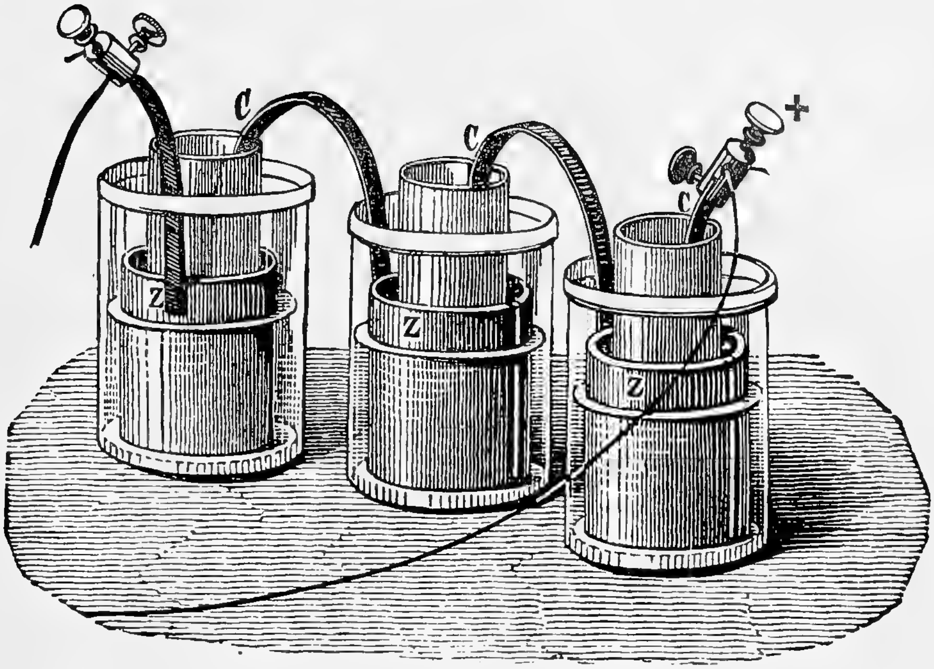

Figure 16.—Laboratory battery of Daniell cells. From A. Niaudet, *Electric Batteries*, New York, 1880, p. 86.

ably and the potential was only 1.1 volts, this voltage was so reliable and unchanging that it was used as a standard up through the 1870's. A simpler version of the Daniell cell, the "gravity" cell, was worked out in the 1850's by Cromwell F. Varley in England and by Heinrich Meidinger[29] in Germany. Meidinger's three forms of the Daniell cell are shown in figure 18. In these later cells the different densities of the two fluids prevented them from mixing. A. Callaud[30] reduced the cell to its simplest form (fig. 19), and a version of this, called the "crowfoot" cell, was occasionally seen until quite recently. The gravity cell was used in the early days of telegraphy and railroad signaling where there were closed circuits with a constant but light drain on the cell.

William Grove[31] devised another variation of a cell of two solutions separated by a porous diaphragm (figs. 20, 21). He used zinc in dilute sulfuric acid and platinum in strong nitric acid. The 1.9-volt output of the Grove cell was almost double the output of the Daniell cell, and its low internal resistance enabled it to give currents as high as 10 amperes. However, the Grove cell was expensive to make, and it gave off highly corrosive fumes. It occurred to a number of researchers[32] to replace the platinum electrode by a cheaper material, but credit for this innovation is usually given to the German chemist Robert Bunsen[33] who modified the Grove cell by replacing the platinum electrode with a charcoal rod and by replacing the nitric acid with fuming nitric acid (fig. 22). The Bunsen cell's voltage was slightly less than that of the Grove cell, but its current was doubled, and it was much cheaper to make.

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[29] French Patent 38820, November 22, 1858; Heinrich Meidinger, "Über eine völlig konstante galvanische Batterie," *Annalen der Physik und Chemie* (title varies, hereinafter referred to as *Annalen der Physik*), 1859, vol. 108, pp. 602–610.

[30] French Patent 36643, May 19, 1858.

[31] W. R. Grove, "On a New Voltaic Combination," *Philosophical Magazine*, 1838, vol. 13, pp. 430–431; "On a Small Voltaic Battery of Great Energy; Some Observations on Voltaic Combinations and Forms of Arrangement; and on the Inactivity of a Copper Positive Electrode in Nitro-Sulfuric Acid," *ibid.*, 1839, vol. 15, pp. 287–293.

[32] For example, J. T. Cooper, "On the Employment of Carbon in Voltaic Combinations," *Philosophical Magazine*, 1840, vol. 16, pp 35–37; and Silliman, *op. cit.* (footnote 9).

[33] Robert Bunsen, "Ueber die Anwendung der Kohle zur Volta'schen Batterie," *Annalen der Physik*, 1841, vol. 54, pp. 417–420; "Ueber Bereitung einer das Platin in der Grove'schen Kette ersetzenden Kohle," *Annalen der Physik*, 1842, vol. 55, pp. 265–276.

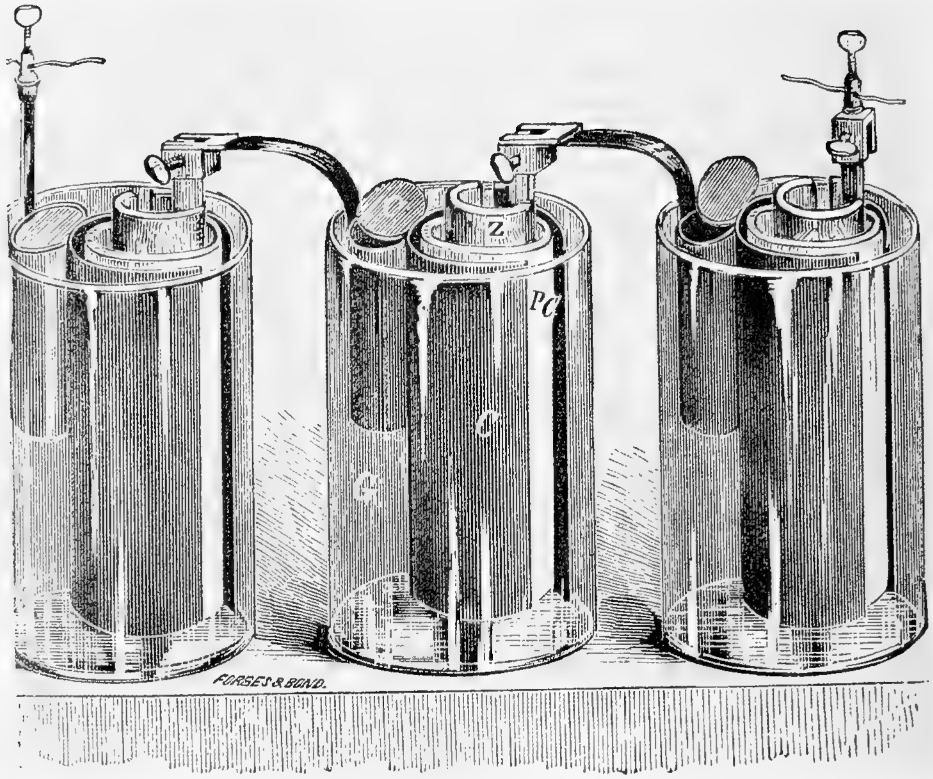
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Figure 17.—Battery of Daniell cells as used in American telegraphy. From G. B. Prescott, *History, Theory, and Practice of the Electric Telegraph,* Boston, 1860, p. 27.

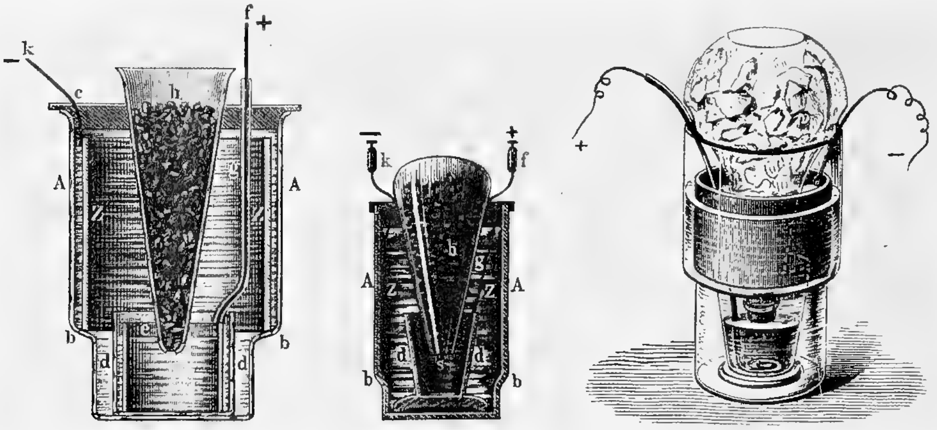
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Figure 18.—Meidinger's three forms of the Daniell cell. From T. Karass, *Geschichte der Telegraphie,* Braunschweig, 1909, p. 68.

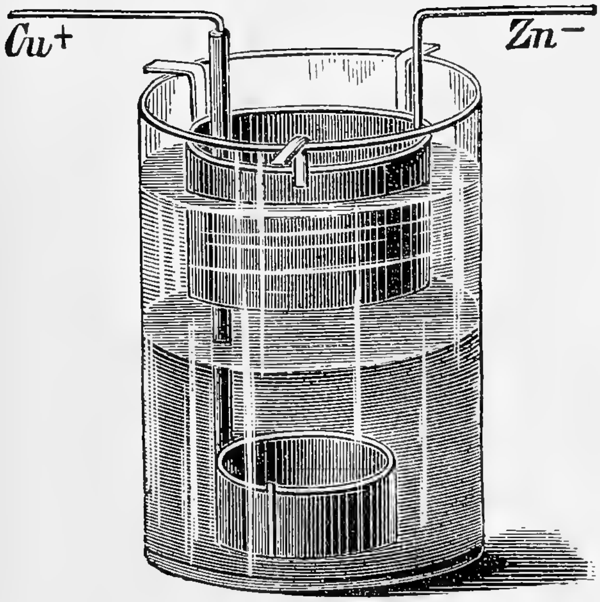

Figure 19.—Callaud's version of the Daniell cell. From R. Wormell, *Electricity in the Service of Man*, London and New York, 1886, p. 401.

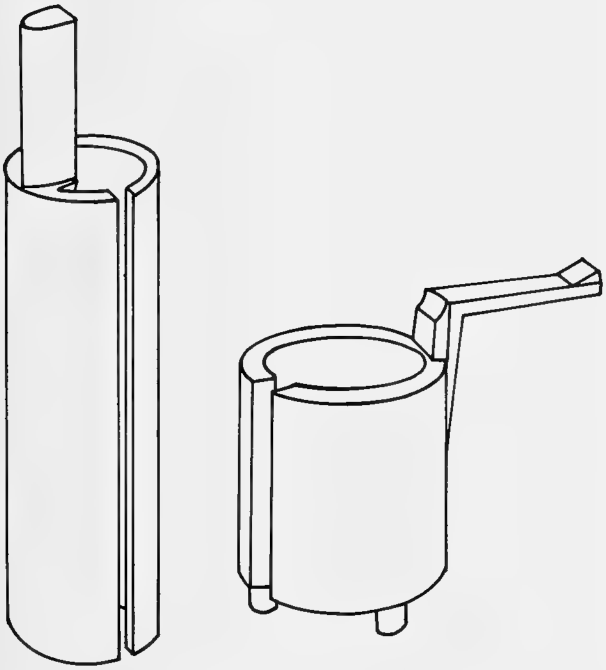

Figure 20.—Shape of the electrodes in a Grove cell. After G. B. Prescott, *History, Theory, and Practice of the Electric Telegraph*, Boston, 1860, p. 29, fig. 9.

Despite its strong fumes, the Bunsen cell was widely used.

The Daniell and Grove cells avoided polarization by the use of two solutions. Other nonpolarizing cells using only a single solution also were invented. Alfred Smee [34] made such a single-solution cell by placing a pair of amalgamated zinc plates in dilute sulfuric acid with a platinum (later silver) plate covered with finely divided platinum (figs. 23, 24). While the voltage of Smee's cell was only about half a volt, it had the advantage of a low cost of maintenance and could be used for open-circuit work where there was a very light drainage of current. Bunsen in 1841 [35] and R. Warrington in 1842 [36] invented one-solution cells that eliminated polarization by using zinc and carbon electrodes in a bichromate and sulfuric acid solution (fig. 25). About the same time J. C. Poggendorff tried a chromic acid cell in his laboratory.[37] The Poggendorff cell gave about two volts, and its low internal resistance enabled it to give high currents for a short period of time. The cell recovered its low resistance on open circuit. Grenet, a Frenchman, devised a bottle version of the chromic acid cell that was widely used in the 1860's (fig. 26). This is the cell that one sees in so many of the physics textbooks of the second half of the 19th century.

After midcentury, when electricity was beginning to pass from the laboratory stage to that of industrial application, more rugged versions of the voltaic cell appeared. The development of a storage battery began in 1859 when Gaston Planté decided to compare the polarization resulting from solid films on electrodes of various metals.[38] With his discovery that lead electrodes gave a more intense and longer-lasting secondary current than electrodes of other metals,

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[34] Alfred Smee, "On the Galvanic Properties of the Metallic Elementary Bodies, with a Description of a New Chemico-Mechanical Battery," *Philosophical Magazine*, 1840, vol. 16, pp. 315–321.

[35] Bunsen, *op. cit.* (footnote 33), and "Spectralanalytische Untersuchungen," *Annalen der Physik*, 1875, vol. 155, pp. 230–252.

[36] R. Warrington, "On the Employment of Chromic Acid as an Agent in Voltaic Arrangements," *Philosophical Magazine*, 1842, vol. 20, pp. 393–395; Leeson, in *Philosophical Magazine*, 1842, vol. 20, p. 262.

[37] J. C. Poggendorff, "Über die mit Chromsäure konstruirten galvanischen Ketten," *Annalen der Physik*, 1842, vol. 57, pp. 101–111.

[38] Gaston Planté "Note sur la polarisation voltaïque," Académie des Sciences, Paris, *Comptes rendus*, 1859, vol. 49, pp. 402–405.

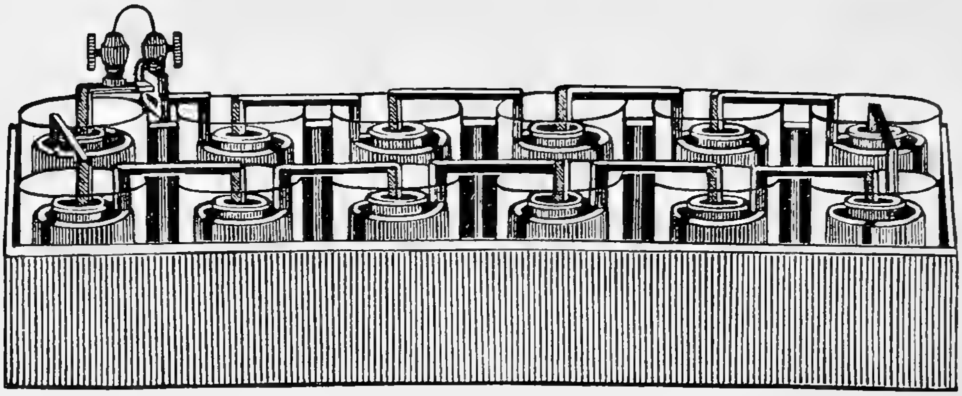

Figure 21.—Grove battery as used in American telegraphy. From G. B. Prescott, *History, Theory, and Practice of the Electric Telegraph*, Boston, 1860, p. 68, fig. 7.

Planté was able to turn the disadvantage of polarization into an advantage, and, using solid electrodes—Grove's 1839 cell had gas electrodes—he created the first "storage" (secondary) cell.[39] By electrolyzing dilute sulfuric acid with lead electrodes, Planté formed a layer of lead oxide on lead. The charging batteries were then removed, and the secondary cell could return the stored energy. If not too much current was required, Planté's cell gave a somewhat constant potential of 1.5 volts. (Figs. 27–31).

Camille Faure modified the secondary cell by applying a paste of the red oxide of lead directly to the plates.[40] The cell was charged by electrolyzing dilute sulfuric acid with these preformed electrodes. This process converted the red oxide to lead dioxide, and the cell was ready for use (fig. 32). The Faure cell gave two volts and had a more stable operation than did the Planté cell. It appeared at a very opportune time, for it found immediate application in telegraphy; later it was particularly important in the production of electrical power. Use of the secondary battery to store electricity when the load was light and to deliver it to the system when the load was heavy resulted in a one-third reduction in the cost of electrical power.

Since secondary cells using acid electrolytes were difficult to work with, some inventors turned to alkaline electrolytes. Felix de Lalande and G. Chaperon invented a cell that used iron or copper for one electrode and zinc for the other, copper oxide as a depolarizer, and a caustic soda or potash solution for the electrolyte.[41] The potential was only about one volt, but the low internal resistance of this cell enabled it to produce high currents.

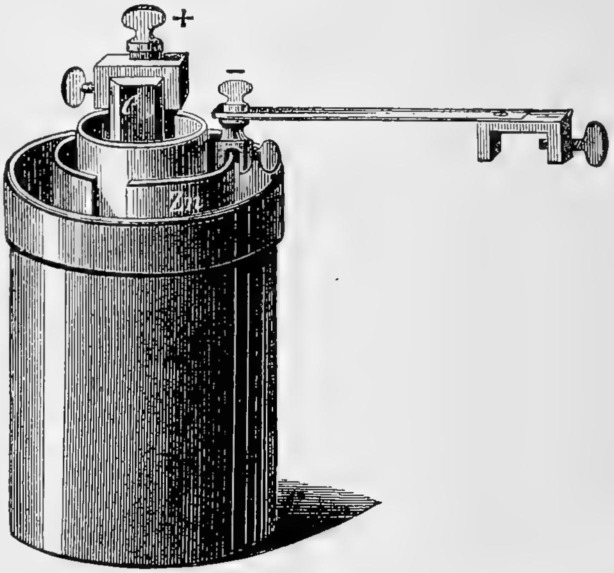

Figure 22.—Bunsen cell. From R. Wormell, *Electricity in the Service of Man*, London and New York, 1886, p. 404.

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[39] Gaston Planté, "Nouvelle Pile secondaire d'une grande puissance," Académie des Sciences, Paris, *Comptes rendus*, 1860, vol. 50, pp. 640–642; "Recherches sur les courants secondaires et leurs applications," *Annales de chimie et de physique*, 1868, vol. 15, pp. 5–30; *Recherches sur l'électricité*, Paris, 1879.

[40] C. A. Faure, "Sur La Pile secondaire de M. C. Faure," Académie des Sciences, Paris, *Comptes rendus*, 1881, vol. 92, pp. 951–953.

[41] Félix de Lalande and G. Chaperon, "Nouvelle Pile à oxyde de cuivre," Académie des Sciences, Paris, *Comptes rendus*, 1883, vol. 97, pp. 164–166.

Thomas A. Edison designed a variation of the Lalande-Chaperon cell in 1889,[42] but later he invented another form of alkaline accumulator (fig. 34). Nickel-plated steel electrodes were covered with nickel peroxide and graphite to form the anode, and with finely divided iron and graphite to form the cathode. The electrolyte was again a solution of caustic potash. The very high currents that could be drawn by the Edison cell made it practical for use in electric traction. In Edison's cell—a form of which is still used—the voltage was about 1.3 volts, and the current was even higher than that of the Lalande-Chaperon cell.

The dry cell began with the 1868 cell of Georges Leclanché,[43] which used a solid depolarizer (figs. 33, 35). In the Leclanché cell, a carbon electrode was inserted into a pasty mixture of manganese dioxide and other materials. A zinc electrode in a sal ammonic solution was separated from this mixture by a ceramic cylinder. This cell gave 1.5 volts, but its pasty texture and its high internal resistance limited it to intermittent use, and its current strengths were not too high. However, it was used extensively in the 19th century for telegraph and telephone lines and for other signaling systems. The ancestor of the modern dry cell was C. Gassner's modification[44] (fig. 36) of the Leclanché cell. The electrical characteristics and uses of the Gassner cell were similar to those of the Leclanché cell. A paste of zinc oxide, sal ammoniac, plaster, and zinc chloride formed the electrolyte; and the zinc electrode formed the container. Commercial production of such dry cells began about 1890.

After the middle of the 19th century, standardization of voltages became an increasingly important and, at the same time, difficult problem. At first the Daniell cell was used to provide a reference voltage, but in 1873 J. Latimer Clark[45] devised an even more stable cell (fig. 37). The potential of the Clark cell was reproducible to an accuracy of one-tenth of 1 percent, and its use slowly spread. However, by the turn of the century the Clark cell began to be supplanted by E. Weston's standard cell,[46] which finally replaced

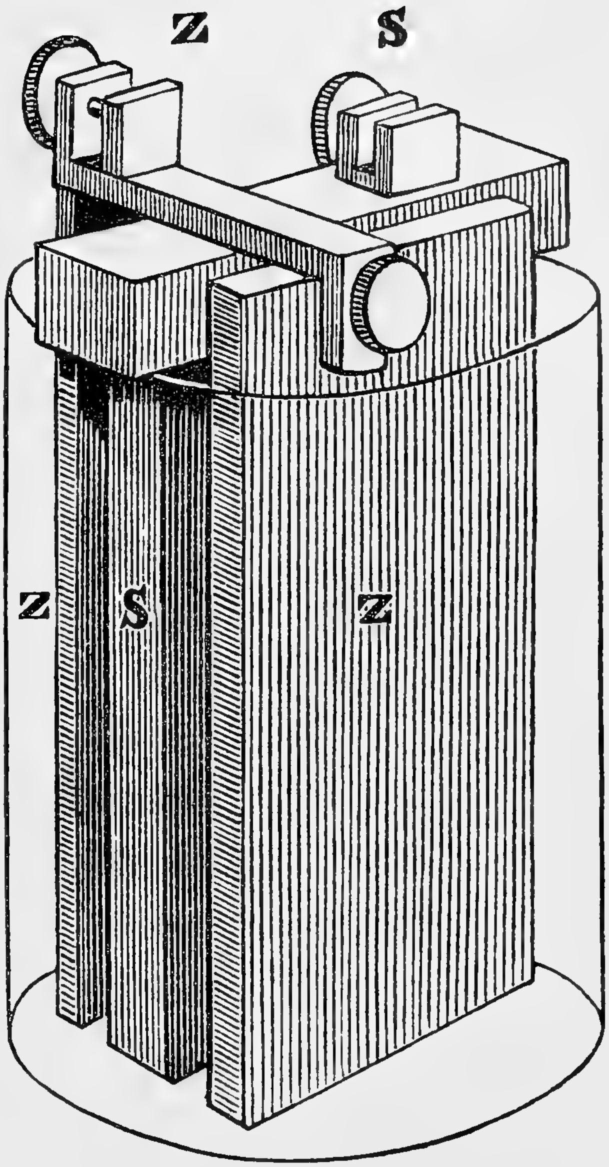

Figure 23.—Smee cell. From F. C. Bakewell, *Manual of Electricity*, London and Glasgow, 1859, p. 147.

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[42] U.S. Patent 430279, June 15, 1889; A. E. Kennelly, "The New Edison Storage Battery," *Electrical World*, 1901, vol. 37, pp. 867–869.

[43] Georges Leclanché, "Pile au peroxyde de manganèse à seul liquide," *Les Mondes*, 1868, vol. 16, pp. 532–535.

[44] German Patent 45251, 1887. See also, "Gassner's Dry Battery" in *Electrician*, 1888, vol. 21, pp. 245–246, 703–704; 1889, vol. 24, p. 185; 1890, vol. 25, p. 508; 1892, vol. 28, pp. 643–644; and Heinrich Krehbiel, "Vergleichende Untersuchung von Trockenelementen," *Elektrotechnische Zeitschrift*, 1890, vol. 11, pp. 422–427.

[45] J. Latimer Clark, "On a Voltaic Standard of Electromotive Force," *Proceedings of the Royal Society of London*, 1872, vol. 20, pp. 444–448; "On a Standard Voltaic Battery," *Philosophical Transactions*, 1874, vol. 164, pp. 1–14; Lord Rayleigh and Mrs. Sidgwick, "On the Electro-Chemical Equivalent of Silver and on the Absolute Electro-Magnetic Force of Clark Cells," *Philosophical Transactions*, 1884, vol. 175, pp. 411–460.

[46] U.S. Patent 494827, April 4, 1893.

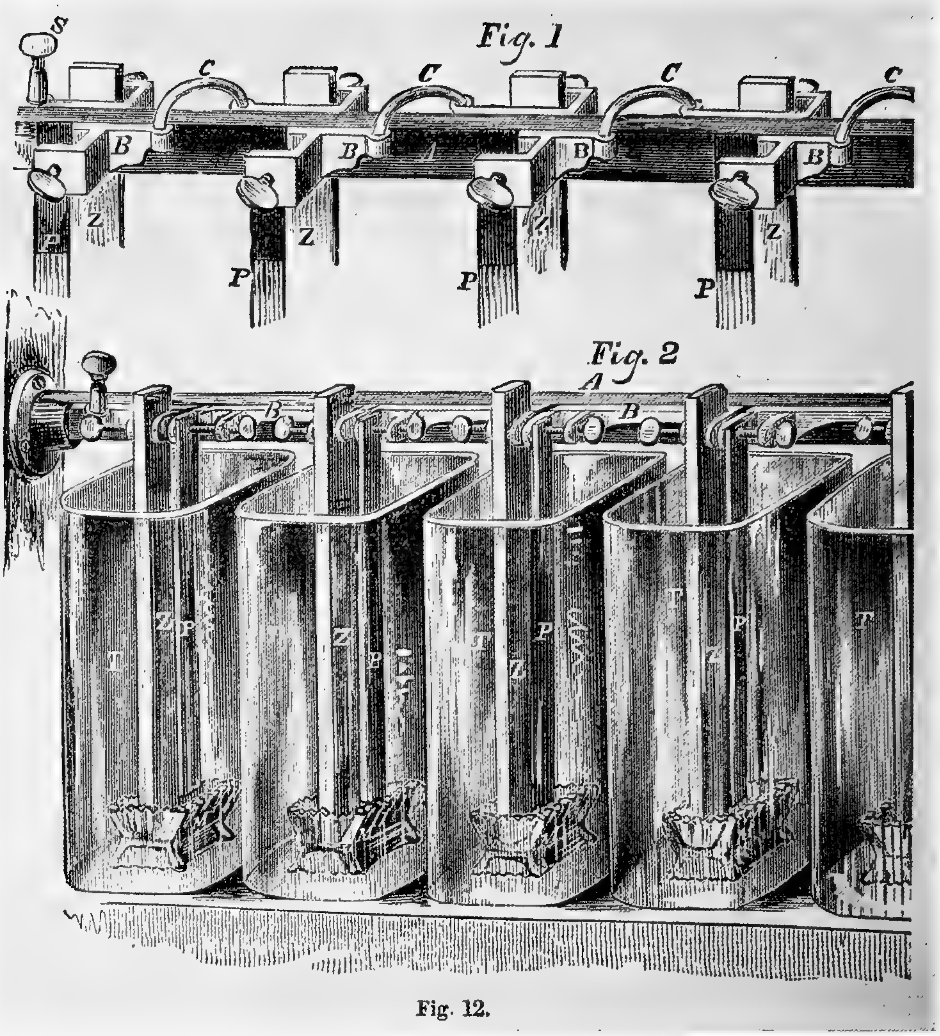

Figure 24.—Battery of Smee cells as used in American telegraphy. From G. F. Prescott, *History, Theory, and Practice of the Electric Telegraph*, Boston, 1860, p. 33.

the Clark cell entirely. One of the earliest Weston cells used by the National Bureau of Standards is shown in figure 38.

ELECTROCHEMISTRY

Almost as soon as a source of electrical current was invented by Volta, the chemical effects of this current were noticed. Among the first to remark these effects were Nicholson and Carlisle, in 1800.[47] They used a drop of water on the top of their pile to ensure a good electrical contact and noticed that gases were evolved in the drop. On the basis of the odors (!) of the gases they identified them as hydrogen and oxygen. They then went on to obtain silver, lead and copper from solutions of the compounds of these metals. In the same year, and independently, the Bavarian Johann

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[47] Nicholson, *op. cit.* (footnote 6); Carlisle, Cruickshanks, Nicholson, *et al.*, "Experiments in Galvanic Electricity," *Philosophical Magazine*, 1800, vol. 7, pp. 337–347.

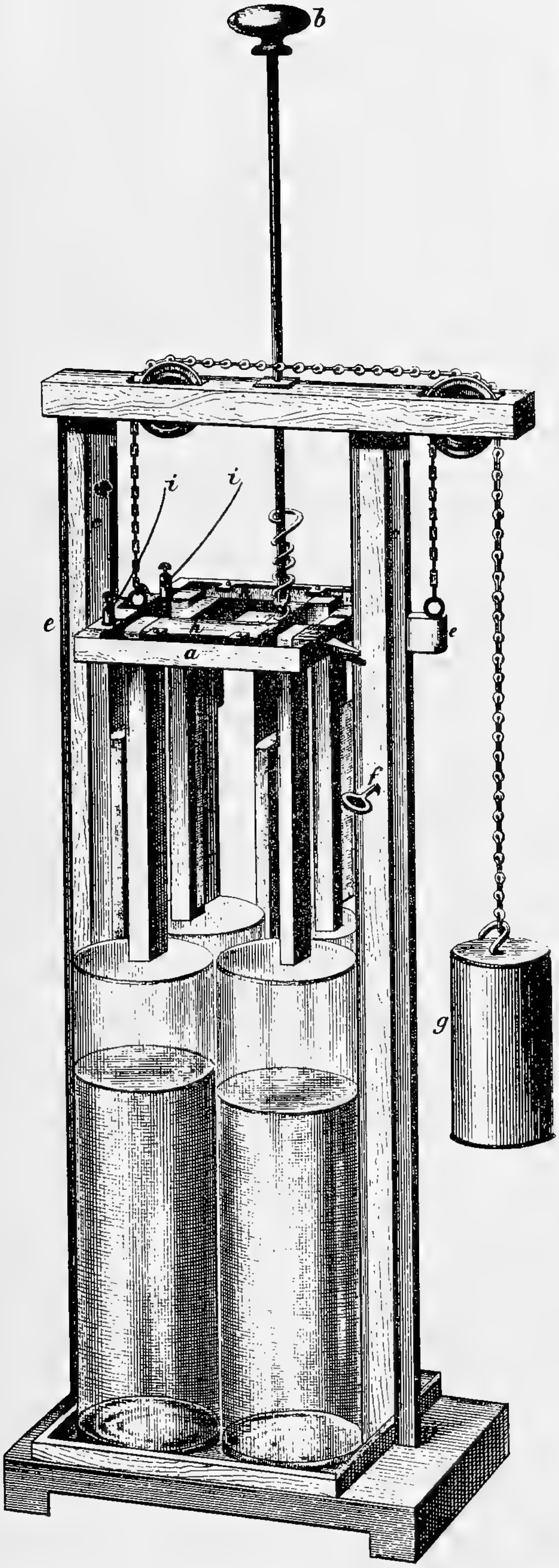

Figure 25.—Battery of Bunsen's chromic acid cells. From *Annalen der Physik*, 1875, vol. 155, pl. 8, fig. 2.

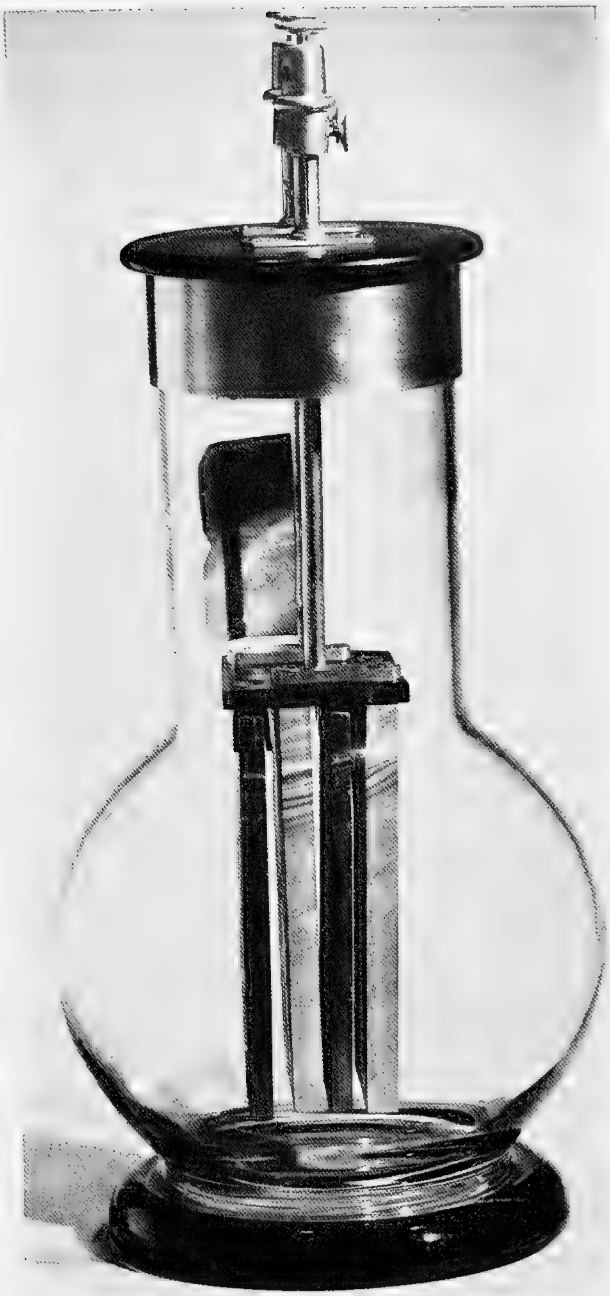

Figure 26.—Grenet cell. (*USNM 315801, Smithsonian photo* 47106.)

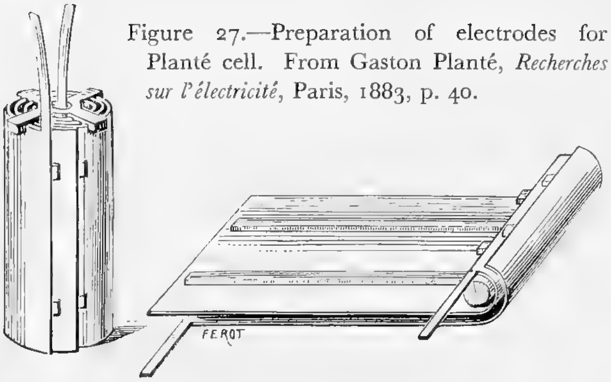

Figure 27.—Preparation of electrodes for Planté cell. From Gaston Planté, *Recherches sur l'électricité*, Paris, 1883, p. 40.

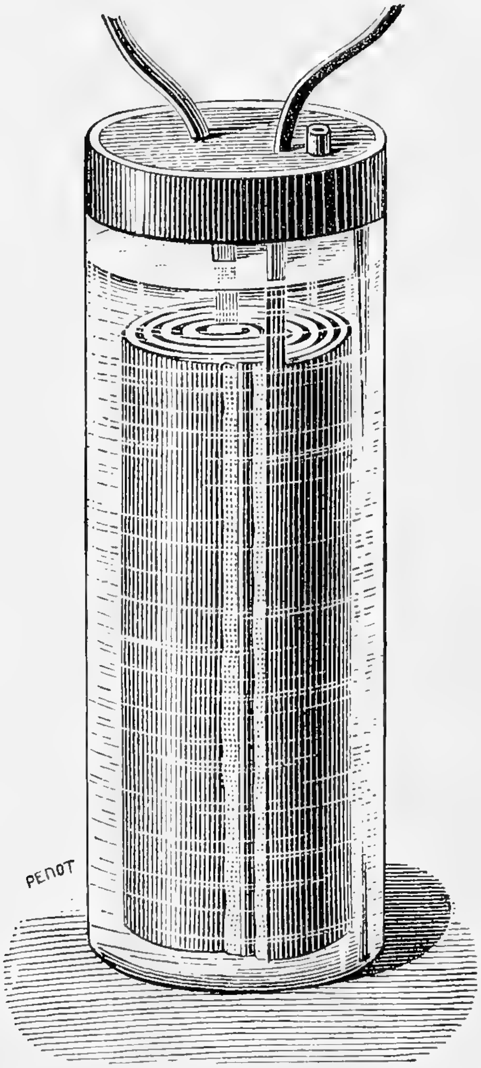

Figure 28.—Planté cell. From Gaston Planté, *Recherches sur l'électricité*, Paris, 1883, p. 35.

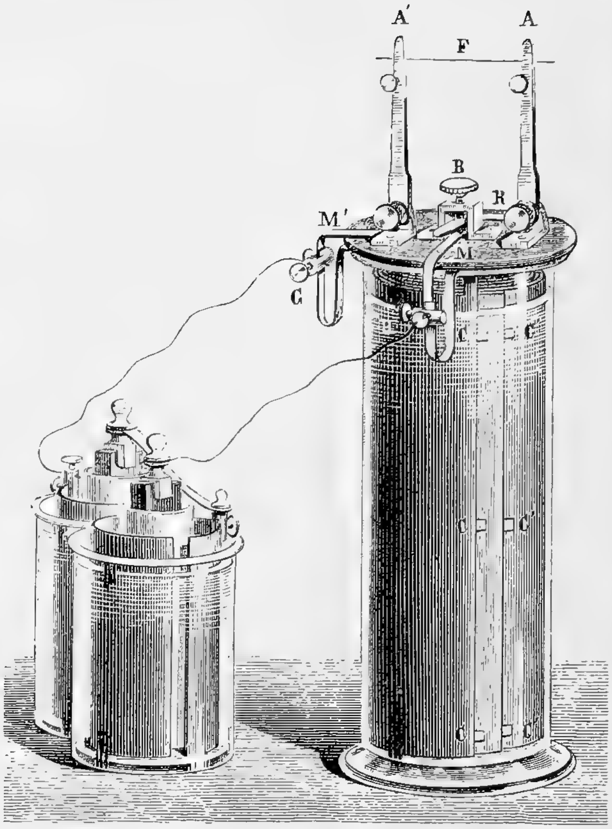

Figure 29.—Charging a Planté cell with a Bunsen battery. From Gaston Planté, *Recherches sur l'électricité*, Paris, 1883, p. 43.

Ritter, using the galvanic current, electrolyzed water and precipitated metals from their solution.[48]

The interesting results of Nicholson and Carlisle led to similar experiments on a larger scale, and it was not long before the new force of electricity was replacing fire as a means of analyzing a chemical compound into its elements. In 1807 Humphrey Davy,[49] as mentioned earlier, tried the action of the voltaic current on soda and potash and so discovered two new metals—sodium and potassium. In order to prove his results, Davy successfully reversed this analysis with a synthesis of these oxides. The next year other new elements were discovered: calcium, barium, strontium, and magnesium.[50]

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[48] Johann Ritter, "Über den elektrischen oder galvanischen Apparat Volta's und über die chemische Wirkungen der galvanischen Elektrizität, von Nicholson, Cruickshanks und Henry," *Annalen der Physik*, 1800, vol. 6, pp. 468–472.

[49] Davy, *op. cit.* (footnote 11).

[50] Davy, *op. cit.* (footnote 15).

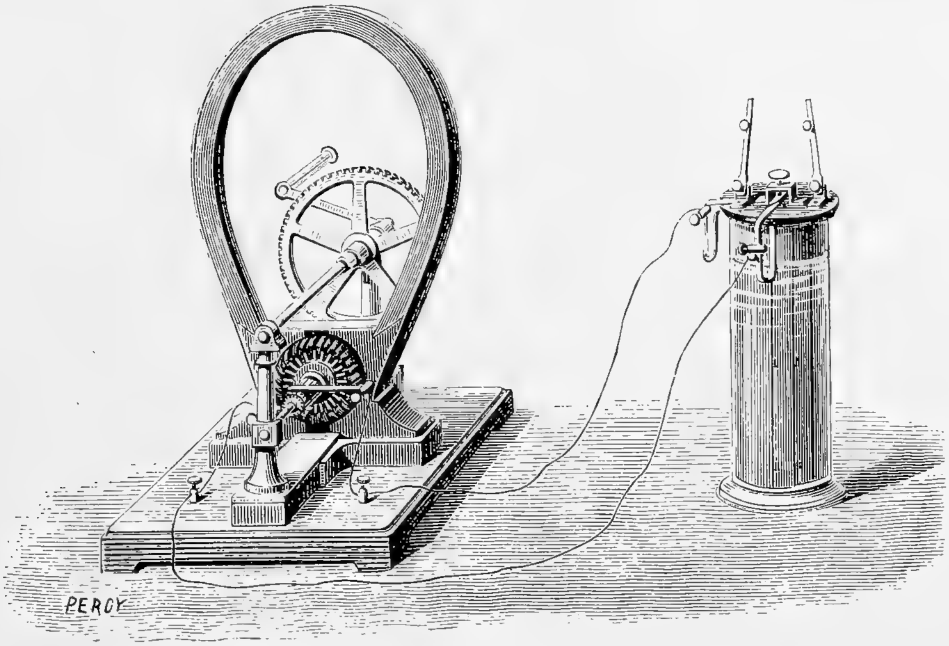

Figure 30.—Charging a Planté cell with a Gramme magneto generator. From Gaston Planté, *Recherches sur l'électricité*, Paris, 1883, p. 80.

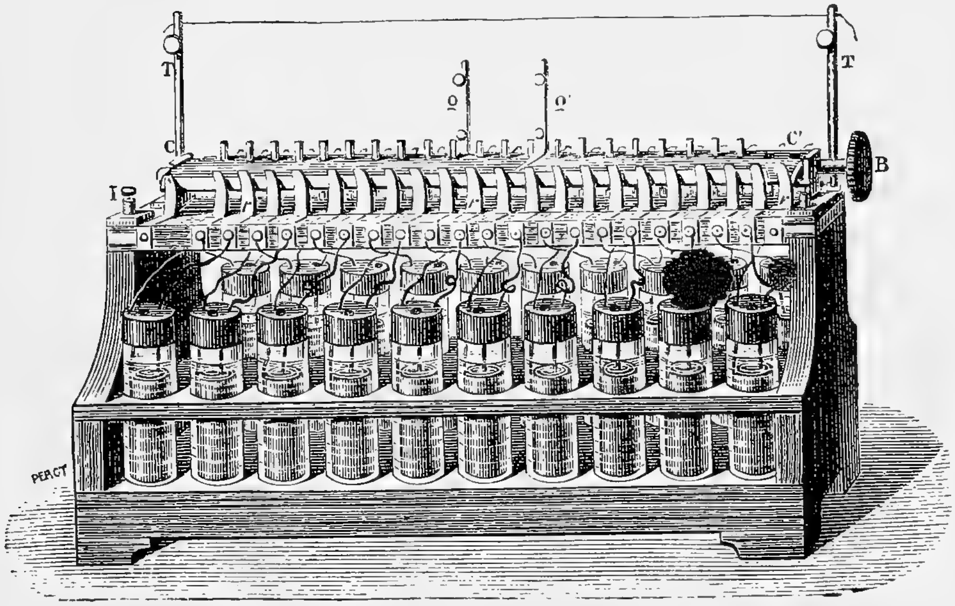

Figure 31.—Battery of Planté cells arranged for high-voltage experiments. From Gaston Planté, *Recherches sur l'Electricité*, Paris, 1883, p. 97.

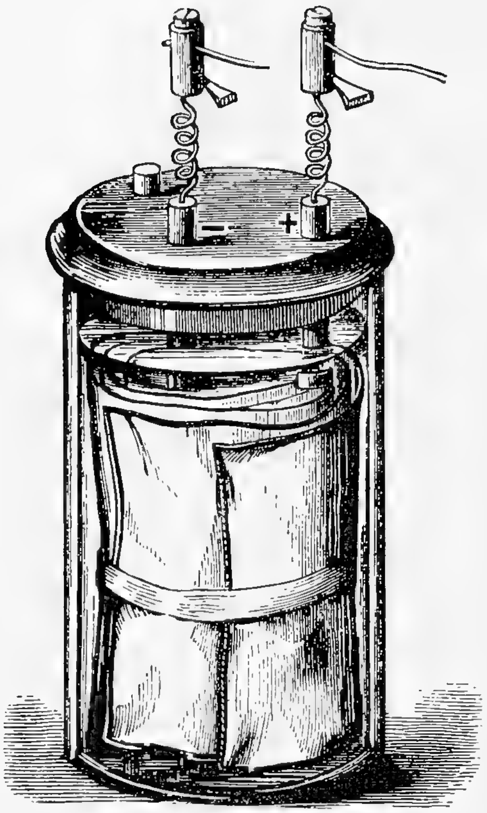

Figure 32.—Faure cell, as modified by Reynier. From R. Wormell, *Electricity in the Service of Man*, London and New York, 1886, p. 438.

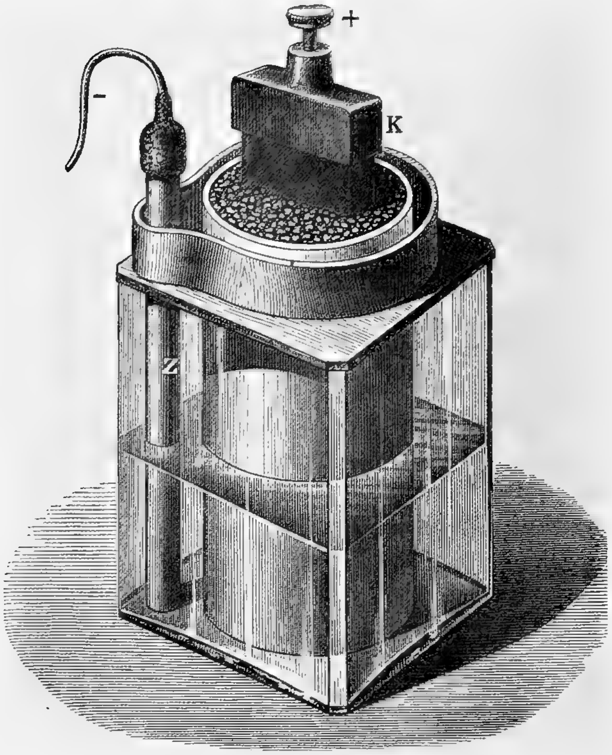

Figure 33.—Leclanché cell. From T. Karass, *Geschichte der Telegraphie*, Braunschweig, 1909, p. 77.

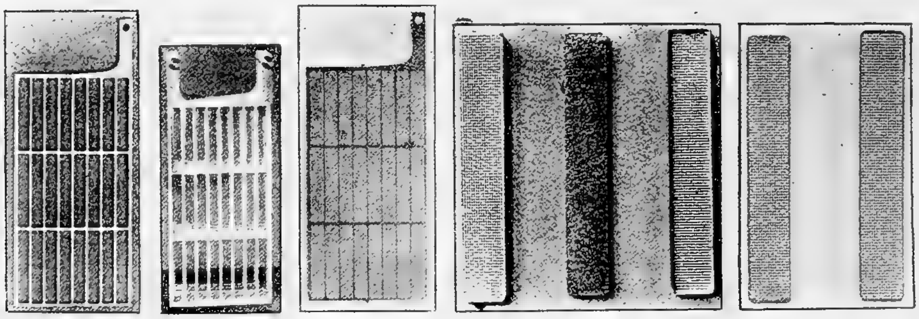

Figure 34.—Electrodes and inserts for Edison storage battery of 1900. From *Electrical World*, 1901, vol. 37, p. 867.

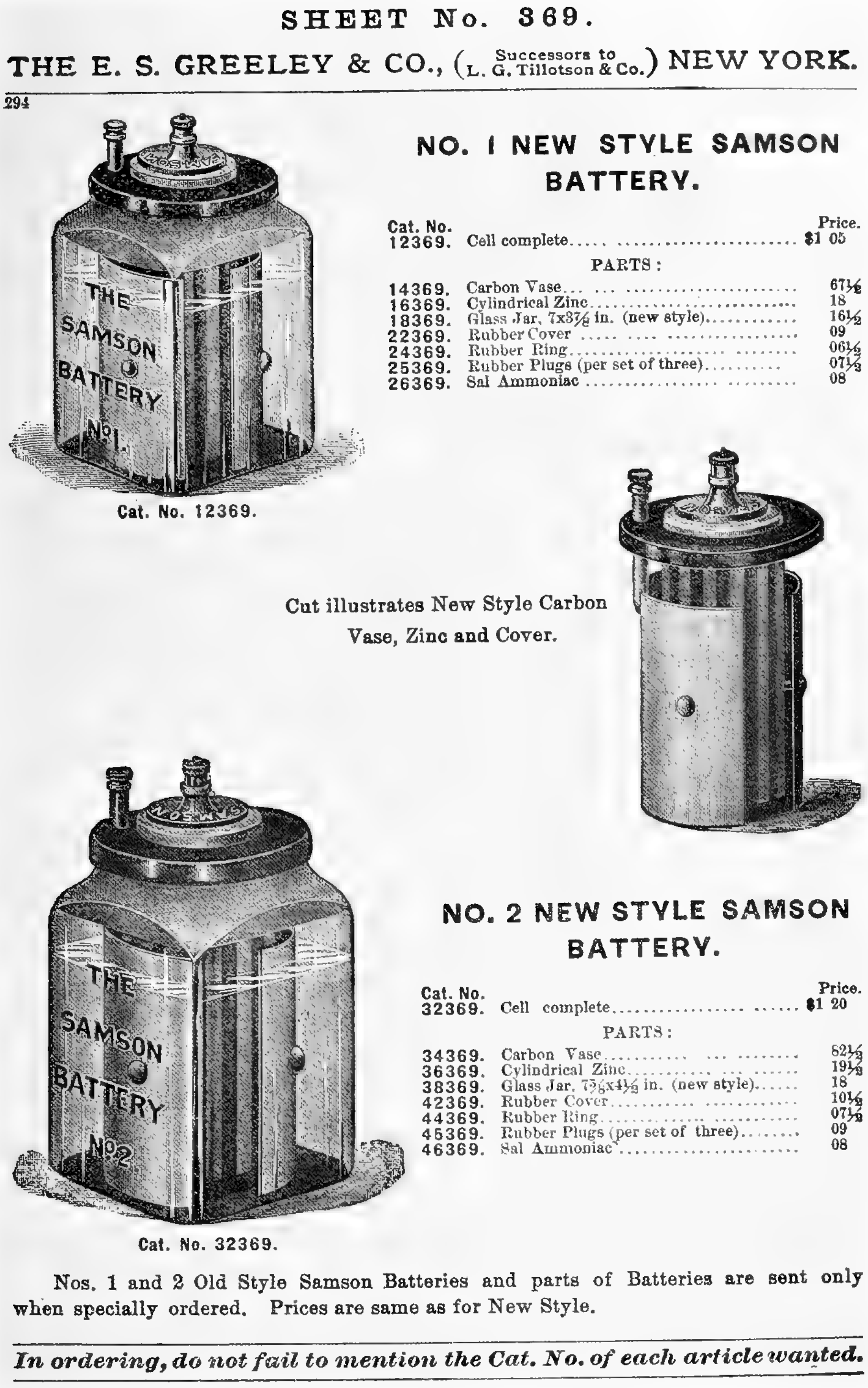
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Figure 35.—This page from an 1892 catalog shows the American version of the Leclanché cell.

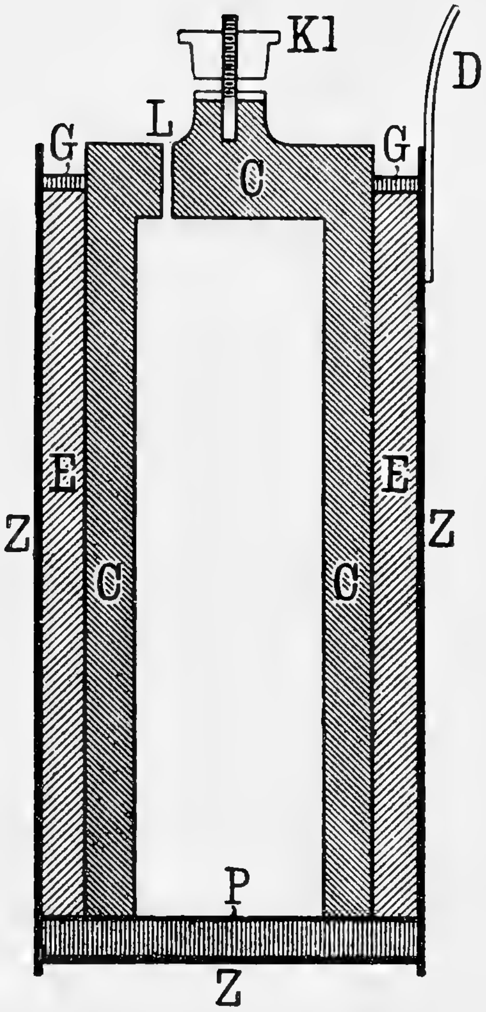

Figure 36.—Gassner's dry cell, 1888. From T. Karass, *Geschichte der Telegraphie*, Braunschweig, 1909, p. 84.

Once cells that produced a lasting current had been invented, the first commercial applications of electricity began to take place.[51] In 1839 M. H. Jacobi introduced electrotyping as a means of accurately reproducing casts and engravings in metal.[52] A short time later, T. Spender and J. Wilson [53] applied for a patent on a similar process in England.

Essentially the same process of electrolysis used in electrotyping was used in electroplating, which appeared commercially at this time. However, it was quite difficult to discover the proper chemical and electrical conditions for electroplating. Auguste de la Rive devised a process to electroplate gold on silver and steel.[54] It has been reported [55] that Jacobi used his electrotyping technique to gild the iron dome of the Cathedral of St. Isaac in St. Petersburg. The Elkington firm in Manchester had started electroplating with zinc as early as 1838. Two years later John Wright of Manchester invented the cyanide process of gold and silver plating and sold it to the pioneering Elkington firm.[56] (This firm also was the first to make commercial use of a generator—for electroplating. The Elkington techniques were introdued into the United States through the Scoville firm [57] in Waterbury, Connecticut.) These new processes of electrotyping and electroplating soon replaced reproduction by stereotype and silver plating by heating silver in intimate contact with copper.

Besides the chemical effects of the electric current, other effects were noticed. One of these was the mechanical effect produced by the galvanic current

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[51] The process of electroplating shares with the electromagnetic telegraph the distinction of having beeen among the first commercially successful applications of the electric current.

[52] M. H. Jacobi, "On the Method of Producing Copies of Engraved Copper-Plates by Voltaic Action; on the Supply of Mixed Gases for Drummond's Light, by Electrolysis; on the Application of Electro-Magnetism as a Motive Power in Navigation, and on Electro-Magnetic Currents," *Philosophical Magazine*, 1839, vol. 15, pp. 161–165.

[53] "A Patent Is Granted to Mr. Spencer and Mr. Wilson, Both of Liverpool, for Certain Improvements in the Process of Engraving on Metals, by Means of Voltaic Electricity," Sturgeon's *Annals of Electricity*, 1841, vol. 7, pp. 380–381.

[54] Auguste de la Rive to Dominique Arago, April 2, 1840, "Sur Un Procédé électro-chimique ayant pour l'objet le dorage de l'argent et du laiton," Académie des Sciences, Paris, *Comptes rendus*, 1840, vol. 10, pp. 578–582; "On the Progress Effected in the Process of Gilding by the Electro-Chemical Method," Stürgeon's *Annals of Electricity*, 1842, vol. 8, pp. 216–219.

[55] Edward H. Knight, *Knight's American Mechanical Dictionary*, 1882, vol. 1, p. 790.

[56] Charles V. Walker, "An Account of a Method of Electro-Gilding and Electro-Plating at the Expense of a Gold or a Silver Anode," *Philosophical Magazine*, 1841, vol. 19, p. 328. Jean B. Dumas, "Rapport sur les nouveaux procédés introduits dans l'art du doreur par MM. Elkington et De Ruolz," Académie des Sciences, Paris, *Comptes rendus*, 1841, vol. 13, pp. 998–1021. George R. Elkington and John De Ruolz, "Report on the New Processes Introduced in the Art of Gilding," Sturgeon's *Annals of Electricity*, 1842, vol. 8, pp. 125–146. *Dictionary of National Biography*, New York, 1921–1922, vol. 6, pp. 658–659 (George R. Elkington). *Journal of the Royal Society of Arts*, December 1, 1865, vol. 14, p. 46 (obituary of George R. Elkington).

[57] P. W. Bishop, "Scoville—The Oldest Brass Company in America." Unpublished manuscript.

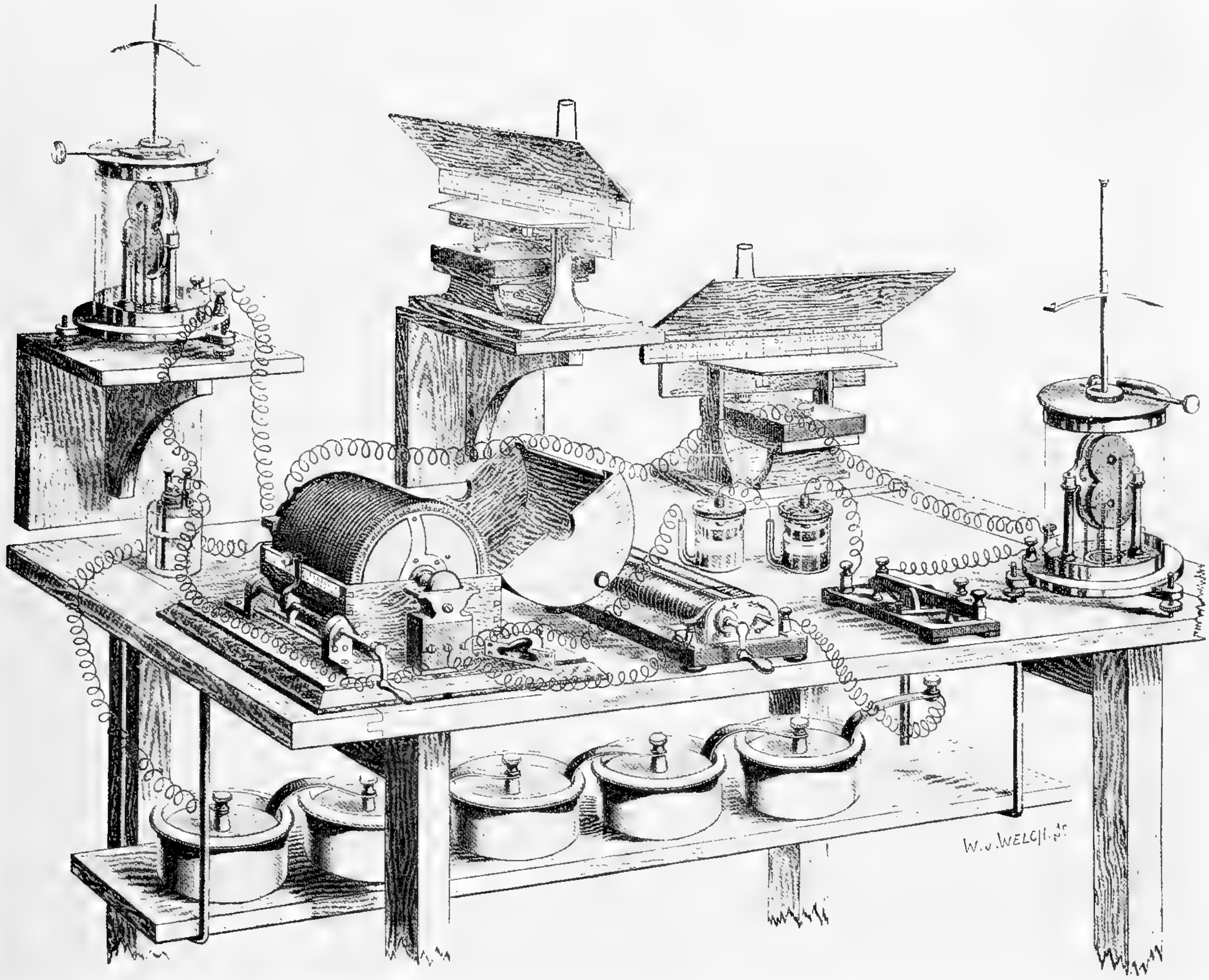

Figure 37.—Calibration of two Clark cells. From *Philosophical Transactions of the Royal Society of London*, 1874, vol. 164, p. 14, fig. 6.

under certain conditions. The possiblilties inherent in such a technique drew the attention of many inventors to the new phenomenon.

The development of steam as a prime mover for factory machinery during the Industrial Revolution and the rapid development of steam locomotives and steamboats during the 30's and 40's of the 19th century made inventors dream of applying the new force of electricity in a similar way to manufacturing and commerce. Before this dream could be realized, however, certain prerequisites had to be fulfilled. A means of applying electrical energy to produce a mechanical force had to be found, a switch had to be devised to make it possible to apply the mechanical force at the right time in the cycle of the motor, and an appropriate recipient for the mechanical force had to be discovered. The invention that enabled man to convert electrical energy into a mechanical force was the electromagnet. The commutator was the switch that determined when the force was applied, and the recipient of the force was the armature. In addition, there had to be devised the most efficient arrangement of electromagnets, commutator, and armature for the production of rotational motion. Actually our modern motor did not develop from the efforts of this period, but such attempts are nonetheless interesting for they reveal the state of electrical technology in the middle of the 19th century.

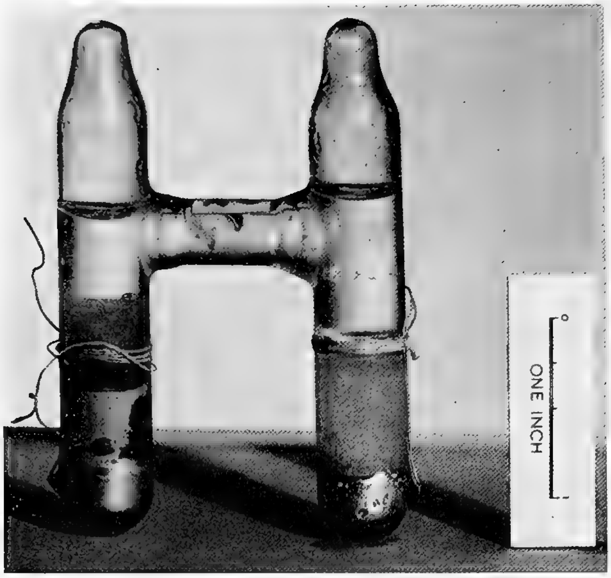

Figure 38.—One of the first Weston cells used by the National Bureau of Standards. (*USNM 316485; Smithsonian photo 46854.*)

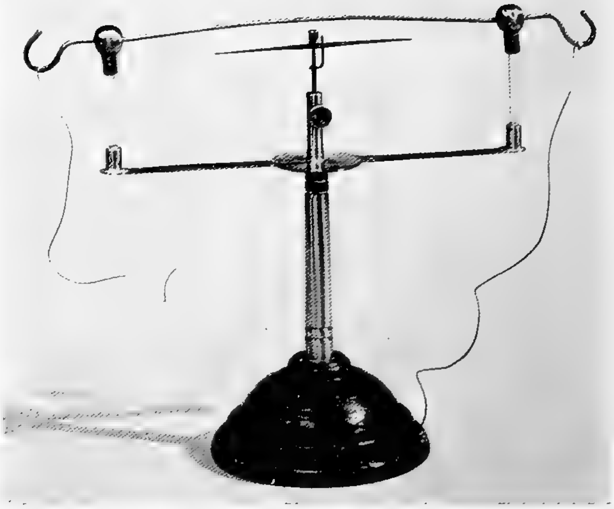

Figure 39.—A model of Oersted's wire experiment. (*USNM 47106–A; Smithsonian photo 31504–A.*)

The Electromagnet

The first step towards the invention of an electromagnet was taken by Hans C. Oersted, a professor of physics at Copenhagen who subscribed to the widely diffused view of the German *Naturphilosoph* that all the forces of nature were somehow related. This belief seemed to Oersted to be borne out especially in the case of electricity and magnetism where the attractions and repulsions followed the same mathematical laws. Other speculators and experimenters had presented what they considered to be proof of a relation between magnetism and electricity, magnetism and light, and electricity and light; but the proof rested on such dubious experiments that most of the prominent scientists of the early 19th century were justifiably skeptical of such an hypothesis. But after many trials Oersted did find a relation between magnetism and electricity when he discovered that a current-carrying conductor, no matter of what material it was made, would cause a magnetic needle in its vicinity to orient itself at right angles to the conductor (fig. 39).

Oersted's brief notice [58] of his discovery was tested within a few weeks by some of the world's leading scientists—by Sir Humphrey Davy [59] at the Royal Institution in London; by Dominique Arago,[60] one of the editors of the *Annales de Chimie et de Physique* at the Académie des Sciences in Paris; by Auguste de la Rive,[61] professor of chemistry at Geneva, Switzerland; by J. S. Schweigger,[62] professor of physics and chemistry at Halle and editor of the *Journal für Chemie und Physik*; and by L. W. Gilbert,[63] professor of physics at the university in Leipzig and editor of the *Annalen der Physik und der physikalischen Chemie*. All of these scientists confirmed Oersted's results.

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[58] Hans Oersted, *Experimenta circa effectum conflictus electrici in acum magneticam*, Hafniae, 1820 (also as an article in many journals such as in *Annales de chimie et de physique*, 1820, vol. 14, pp. 417–425, and "Neuere elektro-magnetische Versuche," Schweigger's *Journal*, 1820, vol. 29, pp. 364–369).

[59] "On the Magnetic Phenomena Produced by Electricity; in a Letter from Sir H. Davy to W. H. Wollaston," *Philosophical Transactions*, 1821, vol. 111, pp. 7–19.

[60] Dominique Arago, "Extrait des séances de l'Académie Royale des Sciences," *Annales de chimie et de physique*, 1820, vol. 15, p. 80.

[61] Auguste de la Rive, "Notice sur quelques expériences électro-magnétiques," *Bibliothèque universelle, sciences et arts*, 1821, vol. 16, pp. 201–203.

[62] J. S. Schweigger, "Zusaetze zu Oersted's elektro-magnetische Versuchen," Schweigger's *Journal*, 1821, vol. 31, pp. 1–6.

[63] Ludwig Gilbert, "Untersuchungen ueber die Einwirkung des geschlossenen galvanisch-elektrischen Kreises auf die Magnetnadel," *Annalen der Physik*, 1820, vol. 66, pp. 331–391.

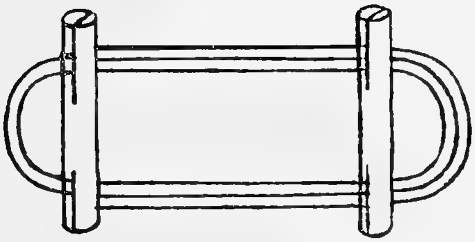

Figure 40.—Schweigger's multiplier. From Schweigger's *Journal für Chemie und Physik*, 1821, vol. 31, pl. 1 (after p. 114).

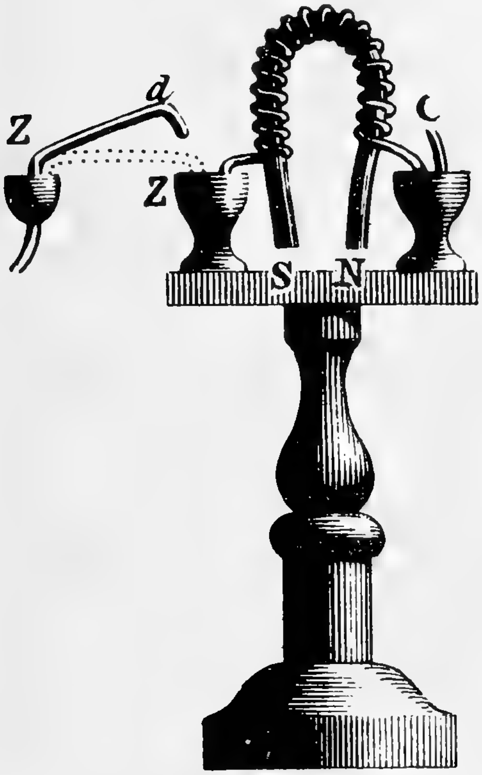

Figure 41.—Sturgeon's first electromagnet. From *Transactions of the Society for the Encouragement of the Arts, Manufactures and Commerce*, 1824, vol. 43, pl. 3.

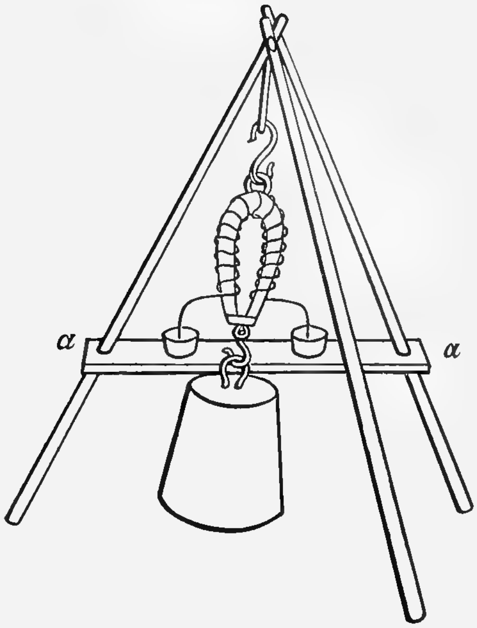

Figure 42.—Sturgeon's later electromagnet. From *Philosophical Magazine*, 1832, vol. 11, p. 201.

In the early portion of his studies of the Oersted effect—which led to the foundation of the science of electrodynamics [64]—André-Marie Ampère pointed out that the combination of a wire and a magnetic needle was an indicator of an electric current and was in contrast to the (electrostatic) electrometer that detected an electrical tension or voltage. Although it was not the first device so called, Ampère proposed that this new combination of a wire and a magnetic needle be called a galvanometer.[65] Independently of Ampère and of one another, Schweigger and Poggendorff, repeating Oersted's experiments, found they could increase the effect of the current on the needle by rolling the wire into a coil and placing the needle inside. Schweigger called his coil a "Verstaerker" or multiplier (fig. 40),[66] while Poggendorff named his a "Condensator" or condenser.[67]

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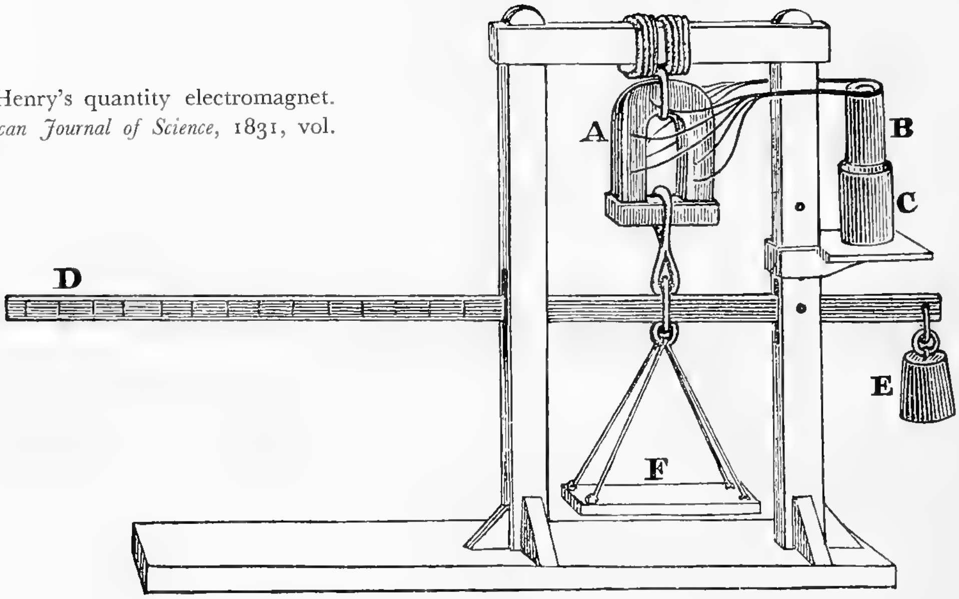
[64] A. M. Ampère, *Théorie des phénomènes électro-dynamiques, uniquement déduite de l'expérience*, Paris, 1826.

[65] *Journal de Paris*, September 18, 1800, vol. 8, no. 368. A. M. Ampère, "De l'action mutuelle de deux courants électriques," *Annales de chimie et de physique*, 1820, vol. 15, pp. 59–76.

[66] J. S. Schweigger, "Zusaetze zu Oersted's elektro-magnetische Versuchen," *Allgemeine Literatur-Zeitung*, 1820, no. 296, cols. 622–624; "Noch einige Worte über diese neuen elektromagnetischen Phänomene," Schweigger's *Journal*, 1821, vol. 31, pp. 35–41.

[67] J. C. Poggendorff, "Account of the New Galvano-Magnetic Condenser," *Edinburgh Philosophical Journal*, 1821, vol. 5, pp. 112–113.

Figure 43.—Henry's quantity electromagnet. From *American Journal of Science*, 1831, vol. 19, p. 408.



That an electric current not only will cause a magnet to move but can create a magnet was the discovery of Arago,[68] who found that a current-carrying conductor will attract iron filings, and that if wire is wound upon a glass tube, and a needle placed inside the tube, the needle will become a magnet when current is passed through the wire. Similar experiments performed by Arago together with Ampère led to the latter's circulating current theory of magnetism.[69] Instead of using a steel core in the form of a bar or cylinder, an English, self-taught physics teacher named William Sturgeon [70] used a horse-shoe-shaped soft iron core and obtained a much more concentrated magnetic field (fig. 41). In 1825 the *Society for the Encouragement of Arts, Manufacture, and Commerce* awarded Sturgeon a medal and a financial prize for this improvement on the electromagnet. By winding a bare wire on a varnished core so that the current passing through the wire would not short out, Sturgeon succeeded in producing an electromagnet that would support a weight of nine pounds when excited by a battery with 130 square inches of zinc (fig. 42). G. Moll [71] of the university at Utrecht, made a still larger electromagnet, weighing 26 pounds, that lifted 154 pounds when excited by a battery with 11 square feet of zinc.

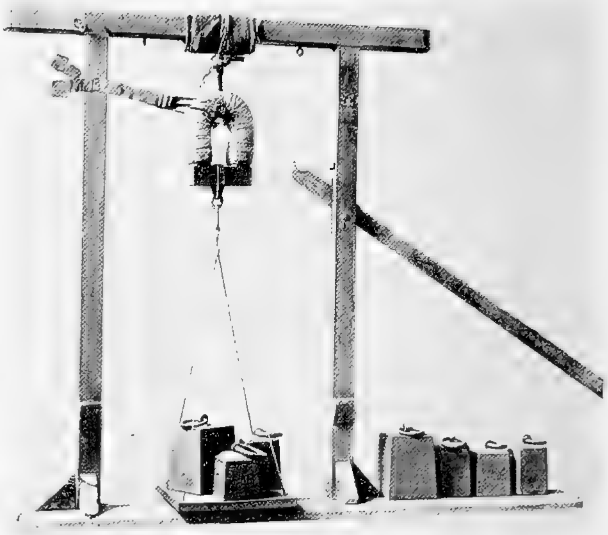


Figure 44.—Henry's "Yale" electromagnet. (*USNM 181343; Smithsonian photo 13346.*)

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[68] Dominique Arago, "Expériences relatives à l'aimantation du fer et de l'acier par l'action du courant voltaïque," *Annales de chimie et de physique*, 1820, vol. 15, pp. 93–102.

[69] A. M. Ampère, "Suite du mémoire sur l'action mutuelle entre deux courants électriques, entre un courant électrique et un aiman ou le globe terrestre, et entre deux aimans," *Annales de chimie et de physique*, 1820, vol. 15, pp. 170–218.

[70] "Papers in Chemistry, No. 3: Improved Electro-Magnetic Apparatus," *Transactions of the Society for the Encouragement of Arts, Manufactures, and Commerce*, 1824, vol. 43, pp. 37–52.

[71] Gerard Moll, "Electromagnetic Experiments," *American Journal of Science*, 1830, vol. 19, pp. 329–337.

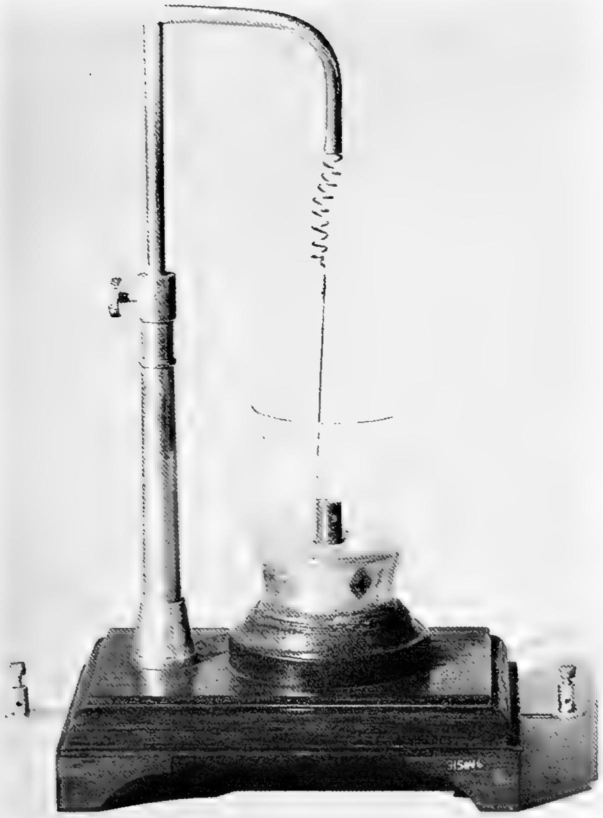

Figure 45.—A model of Faraday's circulating wire experiment. (*USNM 315046; Smithsonian photo 47048–C.*)

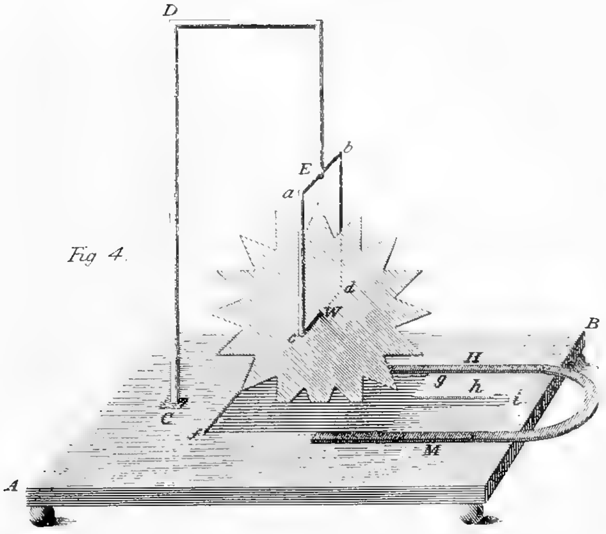

Figure 46.—Barlow's wheel. From *Philosophical Magazine,* 1822, vol. 59, pl. 4, fig. 4.

There were some experimenters in the United States, like James Dana and Rubens Peale, who were also exhibiting electromagnets about this time. A more serious investigator was Joseph Henry, then an instructor at Albany [New York] Academy but who was to become the first Secretary of the Smithsonian Institution. He was one of the first to try to obtain the optimum electromagnet from a given battery. Like Poggendorff,[72] Henry found that the pull of an electromagnet could be increased by adding more turns of wire but only up to a certain number of turns. After that number was reached, in order to increase the force, either the additional turns had to be connected in parallel with the turns already on the coil or a battery with more pairs of plates had to be utilized. These considerations led Henry to distinguish the kind of battery to which each of two kinds of electromagnets responded best: a quantity electromagnet of coils of wire in parallel that responded best to a quantity battery like Hare's calorimotor where the area of the plates is large, and an intensity electromagnet that responded best to an intensity battery like the Cruickshank trough where the number of plates is large. A quantity electromagnet and battery were the best to use for maximum lifting power; while to operate an electromagnet at the end of a long line of wire, an intensity battery at one end and an intensity electromagnet at the other were necessary. On the basis of such considerations, Henry constructed a quantity electromagnet (fig. 43) with a core weighing 21 pounds that used a cell with 72 square inches of zinc to lift 750 pounds.[73] When Professor Silliman of Yale heard of this feat, he requested Henry to make an even larger magnet, and in 1831 Henry constructed a magnet (fig. 44) weighing 59 pounds that lifted 2,000 pounds with a cell using 5

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[72] J. C. Poggendorff, "Physisch-chemische Untersuchungen zur nähern Kenntnis des Magnetismus der voltaischen Säule," Oken's *Isis,* 1821, vol. 1, cols. 687–710.

[73] Joseph Henry, "On the Application of the Principle of the Galvanic Multiplier to Electro-Magnetic Apparatus, and also to the Development of Great Magnetic Power in Soft Iron, with a Small Galvanic Element," *American Journal of Science,* 1831, vol. 19, pp. 400–408.

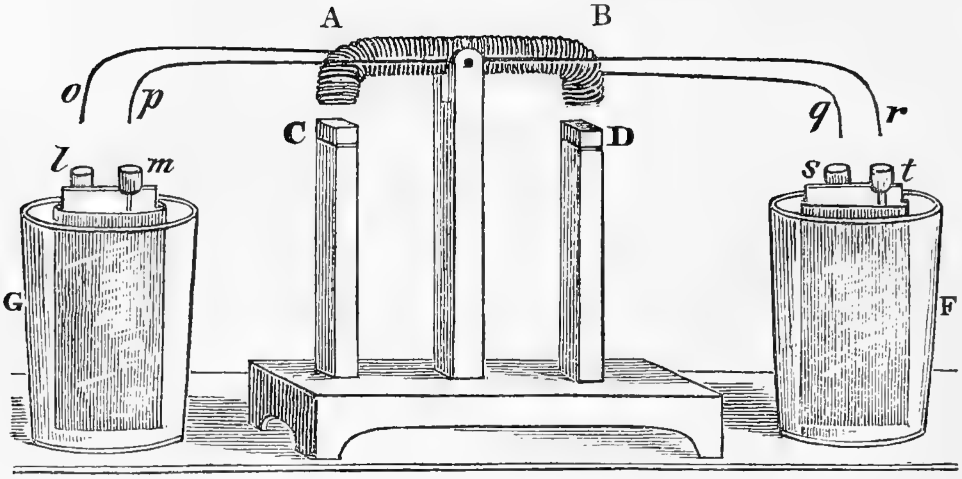

Figure 47.—Henry's electromagnetic motor. From *American Journal of Science*, 1831, vol. 20, p. 342.

square feet of zinc.[74] Two years later at Princeton Henry devised an electromagnet that held the astonishing weight of 3,600 pounds with a battery of 132 square inches of zinc that occupied only one cubic foot.[75]

In 1835 Professor Jacobi, apparently independent of Henry, began a more complete and systematic investigation of the electromagnet.[76] He completed this study in 1844.[77] Henry's distinction between quantity and intensity magnets was expressed again by Jacobi when he asserted that the greatest magnetic force was produced when the resistance of the coil equaled that of the voltaic battery. By the time of Jacobi's experimentation, several electric motors had been constructed, and some of his results were summarized in an article prescribing the proper design of a motor for a boat.[78] But we must turn back a little to examine some of the steps that led to the development of the motors of the 1840's.

ELECTRIC MOTORS

Once it was clear to Michael Faraday at the Royal Institution in London that a current-carrying conductor exerted a force on a magnetic needle, he sought some means of changing this static deflection into continuous rotation.[79] He finally succeeded in producing the circulation of a wire about a magnet and the circulation of a magnet about a wire (fig. 45). Peter Barlow[80] added some other devices to the ones Faraday invented (fig. 46), but both Faraday's and Barlow's apparatus were closer to "philosophical toys" than the machine that Joseph Henry created in 1831,[81] which is illustrated in figure 47.

Henry's apparatus was the first clear-cut instance of a motor capable of further mechanical development.

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[74] Joseph Henry and Dr. Ten Eyck, "An Account of a Large Electro-Magnet, Made for the Laboratory of Yale College," *American Journal of Science*, 1831, vol. 20, pp. 201–203.

[75] "Deposition of Joseph Henry, in the Case of Morse *vs.* O'Reilly, taken at Boston, September, 1849," reprinted in *Annual Report of the . . . Smithsonian Institution . . . for the Year 1857*, 1858, pp. 109–110.

[76] M. H. Jacobi, "On the Application of Electro-Magnetism to the Moving of Machines," Sturgeon's *Annals of Electricity*, 1837, vol. 1, pp. 408–415, 419–444.

[77] M. H. Jacobi and E. Lenz, "Ueber die Anziehung der Elektromagnete," *Annalen der Physik*, 1839, vol. 47, pp. 401–418; "Ueber die Gesetze der Elektromagnete," *Annalen der Physik*, 1839, vol. 47, pp. 225–270; 1844, vol. 61, pp. 254–280, 448–466, and vol. 62, pp. 544–548.

[78] M. H. Jacobi, "Ueber die Principien der elektromagnetischen Maschinen," *Annalen der Physik*, 1840, vol. 51, pp. 358–372; "On the Principles of Electro-Magnetical Machines," Sturgeon's *Annals of Electricity*, 1841, vol. 6, pp. 152–159.

[79] Michael Faraday, "On Some New Electro-Magnetical Motions, and on the Theory of Magnetism," *Quarterly Journal of Science, Literature and Arts*, 1822, vol. 12, pp. 74–96.

[80] Peter Barlow, "A Curious Electro-Magnetic Experiment,' *Philosophical Magazine*, 1822, vol. 59, pp. 241–242.

[81] Joseph Henry, "On a Reciprocating Motion Produced by Magnetic Attraction and Repulsion," *American Journal of Science*, 1831, vol. 20, pp. 340–343.

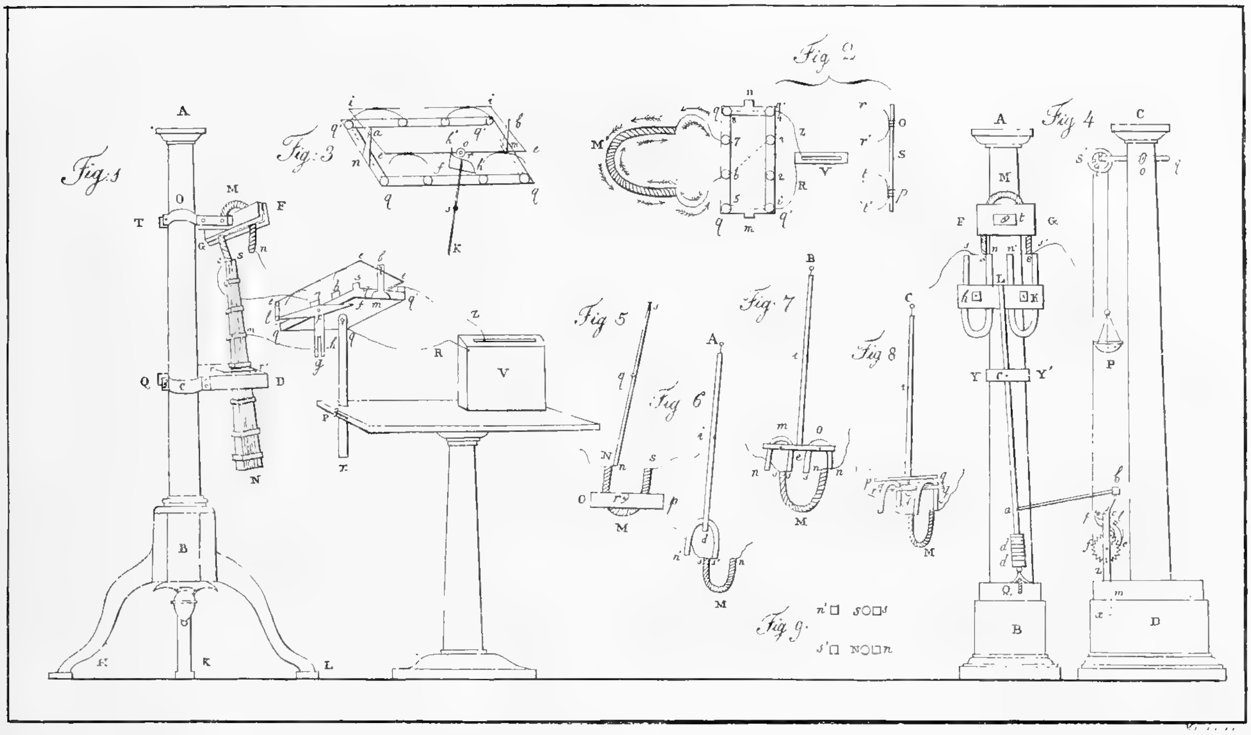

Figure 48.—Dal Negro's electromagnetic machine. From *Annali delle Scienze de Regno Lombardo-Veneto*, March 1834, pl. 4.

It had the essentials of a modern DC motor: a magnet to provide the field, an electromagnet as armature, and a commutator to apply the mechanical forces at the right time. The reciprocating motion of an armature, see-sawing up and down, made and broke contact during the motor's cycle so that the electromagnet pulled on the part of the armature farthest away. Salvatore dal Negro [82] of the university at Padua reported in 1834 on an invention that he had worked out in 1831 of a permanent magnet pendulum kept in oscillation by an electromagnet that changed its polarity by a commutator switch (fig. 48). He added a linkage device so that he could raise a weight with it and found it lifted 60 grams, 5 centimeters in one second. A similar pendulum-instrument was made in 1834 by J. D. Botto [83] in Turin.

Probably the first man to produce the rotary motion of an electromagnet was an English experimenter, Rev. William Ritchie,[84] in 1833. At the end of an article on the attractive force of an electromagnet, he described how an electromagnet could be made to spin and how he was able to set the magnet in sufficiently rapid rotation to raise several ounces over a pulley (fig. 49). About the same time, Dr. T. Edmundson of Baltimore, Maryland, devised a kind of magnetic paddlewheel motor [85] (fig. 50).

During the period of the 1820's and early 1830's, the most successful experimenters with electromagnetism—men like Faraday, Barlow, Sturgeon, Henry, and Ritchie—used chemical cells like Hare's calorimotor. The calorimotor was one of the best cells available, but even so it was bulky in volume and the current it supplied rapidly decreased because of

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[82] Salvatore dal Negro, "Nuova Macchina élettro-magnetica immaginata dall'Abate Salvatore dal Negro," *Annali delle scienze de regno Lombardo-Veneto,* March 1834, pp. 67–80.

[83] J. D. Botto, "Note sur l'application de l'électro-magnétism à la mécanique," *Bibliothèque universelle, sciences et arts,* 1834, vol. 56, pp. 312–316.

[84] W. Ritchie, "Experimental Researches in Electro-Magnetism and Magneto-Electricity," *Philosophical Transactions,* 1833, vol. 123, pp. 313–321.

[85] T. Edmondson, "The Rotating Armatures," *American Journal of Science,* 1834, vol. 26, pp. 205–206.

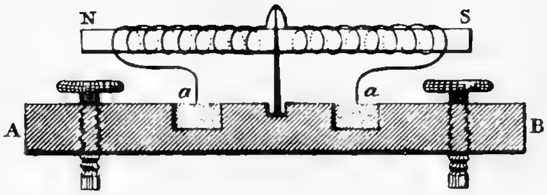

Figure 49.—Ritchie's motor. From *Philosophical Transactions of the Royal Society of London*, 1833, vol. 123, p. 316, pl. 7.

polarization and secondary action, as was true of all its predecessors.

Beginning in the middle 1830's chemical cells were being invented that avoided the polarization and local action of earlier cells. These new cells were good sources of current, and they could produce this current over a longer period of time than could the earlier cells. In addition scientists understood better how to build a strong electromagnet, and how to turn its force on and off by a commutator. It was no accident that electric motors began to seem practical to inventors in the 1830's, for the main elements of a motor were present; it was not long before inventors began to assemble these elements into a device that could be used to drive machinery.

In 1836 William Sturgeon[86] asserted that he had constructed an electric motor in the fall of 1832 (fig. 51), had demonstrated it in March 1833, and had later used it to run models of machinery. Francis Watkins[87] made electric motors (fig. 52) in 1835 that could also be used to drive mechanical models.

In May 1834 M. H. Jacobi[88] built an electric motor (fig. 53) that could lift 10 to 12 pounds at a speed of one foot per second when tested by a Prony brake. Further details on this motor, showing how much zinc was needed to produce a given amount of mechanical work, appeared the following year.[89] Jacobi claimed that a half-pound of zinc would deliver the "demi-force d'un homme" for 8 hours.

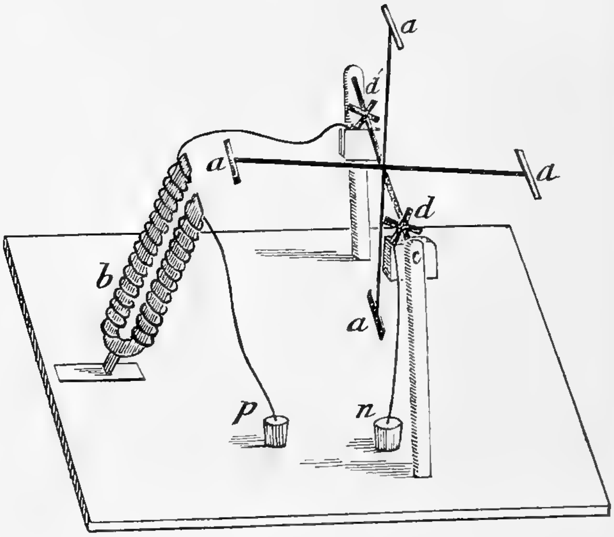

Figure 50.—Edmondson's motor. From *American Journal of Science*, 1834, vol. 26, p. 205.

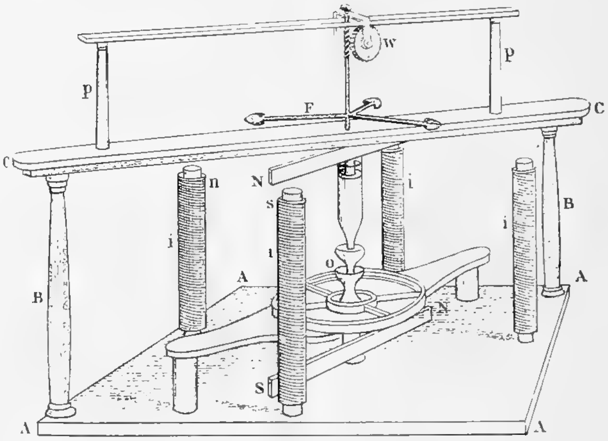

Figure 51.—Sturgeon's motor. From Sturgeon's *Annals of Electricity*, 1837, vol. 1, pl. 2, fig. 17.

In a petition in May 1837 to the Russian czar, Jacobi expressed his high hopes for a well-supplied workshop and 8,000 rubles for 8 years in order to "cover the Neva rather than the Thames or Tiber with magnetic boats."[90] By 1838 Jacobi was able

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[86] William Sturgeon, "Description of an Electro-Magnetic Engine for Turning Machinery," Sturgeon's *Annals of Electricity*, 1836, vol. 1, pp. 75–78.

[87] Francis Watkins, "On Magneto-Electric Induction," *Philosophical Magazine*, 1835, vol. 7, pp. 107–113; "On Electro-Magnetic Motive Machines," *Philosophical Magazine*, ser. 3, 1838, vol. 12, pp. 190–196.

[88] M. H. Jacobi in *L'Institut*, 1834, vol. 2, pp. 394–395.

[89] Jacobi, *op. cit.* (footnote 76).

[90] D. V. Efremov, *The Electromotor in its Historical Development*, Moscow and Leningrad, 1936, pp. 230–247. (In Russian.)

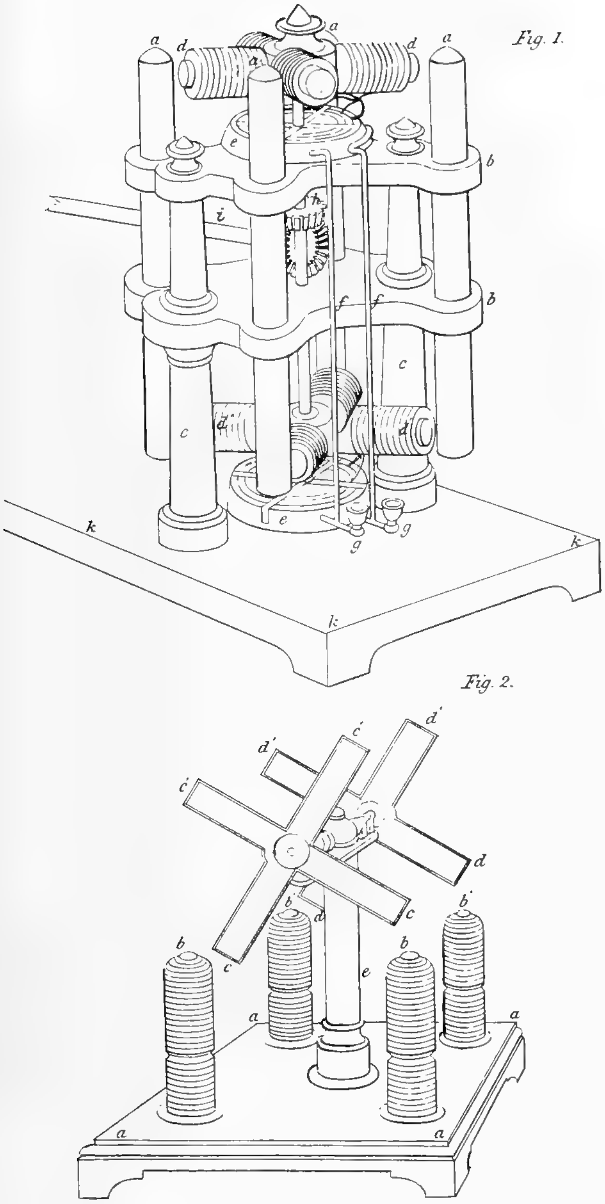

Figure 52.—Watkins' motors. From *Philosophical Magazine*, 1838, vol. 12, pl. 4.

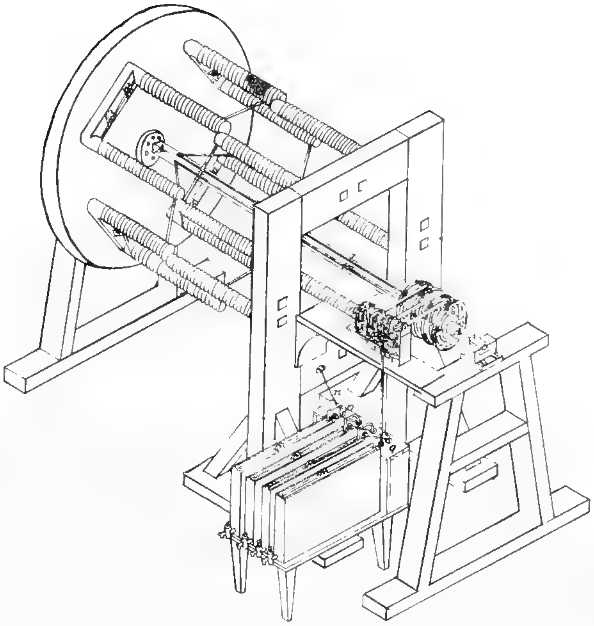

Figure 53.—Jacobi's motor. From Sturgeon's *Annals of Electricity*, 1837, vol. 1, pl. 13.

to use his motor to drive a boat 28 feet long, 7½ feet wide and drawing 2¾ feet of water.[91] Carrying a dozen or so officials of the Russian government, this boat moved at the speed of 1½ miles an hour on the Neva river. The following year, using the same motor, Jacobi found he could double the speed by using 64 Grove cells with the same electrode area. One suspects the fumes from the 64 cells probably contributed as much to the dropping of the project as did the breakdowns of the motor.

The first inventor to build an electric motor able to perform useful work was probably Thomas Davenport, a blacksmith of Brandon, Vermont.[92] In 1833 Davenport was so fascinated by the operation of one of Henry's electromagnets that he bought one. By July 1834 he had worked out a motor with a 7-inch flywheel that rotated at a speed of 30 rpm. Using a shunt-wound motor for drive, Davenport built a motor on rails that is usually called his miniature "train" (fig. 54). He had applied for a patent on his electric motor in 1835, but the fire at the Patent Office in Washington destroyed his application

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[91] Jacobi, *op. cit.* (footnote 52).

[92] Franklin L. Pope, "The Inventors of the Electric Motor," *Electrical Engineer*, 1891, vol. 11, pp. 1–5, 33–39, 65–71, 93–98, 125–130; Walter R. Davenport, *Biography of Thomas Davenport*, Montpelier, Vermont, 1929; Mary Somerville, *Electromagnetism—History of Davenport's Invention of the Application of Electromagnetism to Machinery*, New York, 1837.

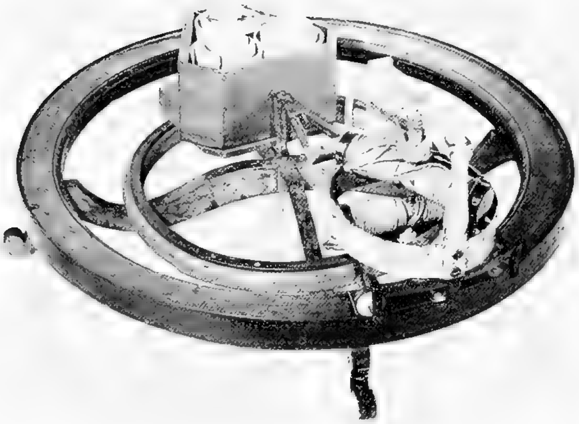

Figure 54.—Davenport's model of an electric "train." The circular track is 4 feet in diameter. (*USNM 181825; Smithsonian photo 38403.*)

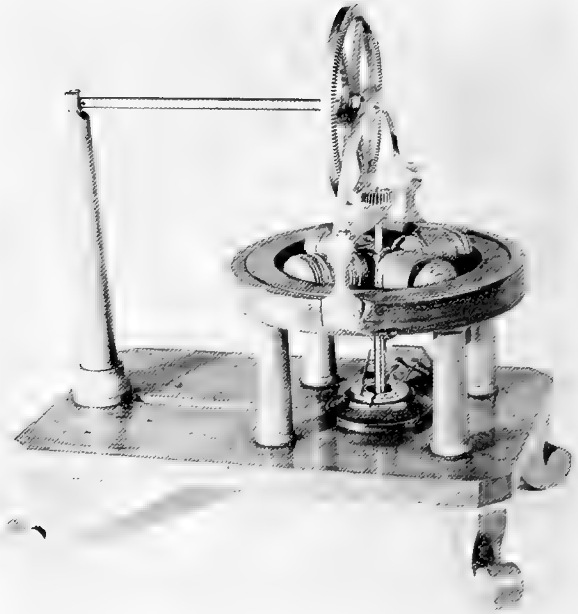

Figure 55.—Patent Office model of Davenport's electric motor. (*USNM 252644; Smithsonian photo 44978.*)

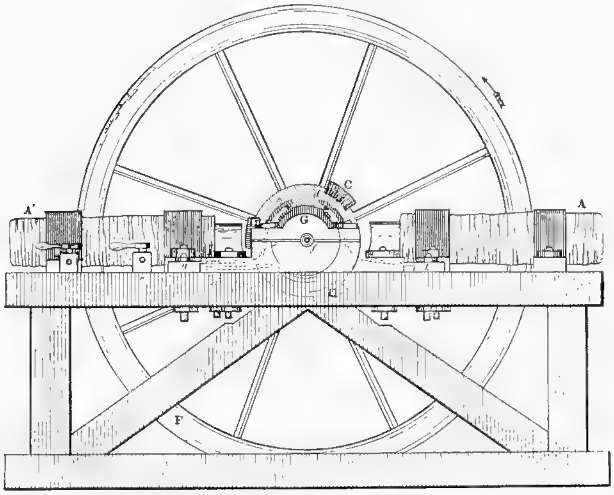

Figure 56.—Davidson's motor. From *Electrical World*, 1890, vol. 16, p. 277, fig. 2.

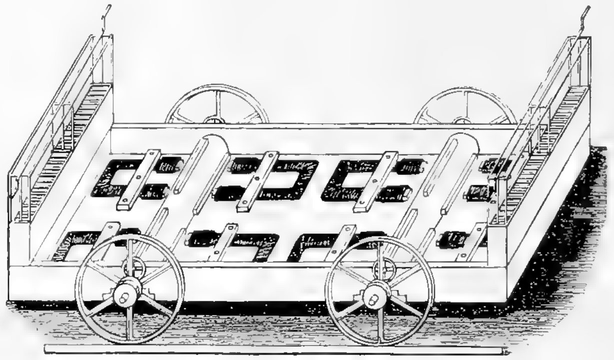

Figure 57.—Davidson's electric locomotive. From T. du Moncel, *Electricity as a Motive Power*, London, 1883, fig. 32.

and he had to apply again in February 1837[93] (fig. 55). By August 1837 he had developed a motor with a 6-pound rotor, about half a foot across, that rotated at a speed of 1,000 rpm and that could raise a 200-pound weight at a speed of 1 foot per minute when driven by three cells. Later in the year, he used this new machine to run a drill and turn a piece of hard wood 3 inches in diameter on his lathe.[94] In an exhibition in

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[93] Thomas Davenport, "Specification of a Patent for the Application of Electro Magnetism to the Propelling of Machinery," *Journal of the Franklin Institute*, 1837, vol. 20, pp. 340–343. U.S. Patent 132, February 25, 1837.

[94] "Notice of the Electro-Magnetic Machine of Mr. Thomas Davenport of Brandon, Near Rutland, Vermont," *American Journal of Science*, 1837, vol. 32, appendix, pp. 1–8; also *Mechanics' Magazine*, London, 1837, vol. 27, pp. 159, 204–207, 404–405, and letter from Thomas Davenport to editor, *American Journal of Science*, 1838, vol. 33, appendix, pp. 1–2.

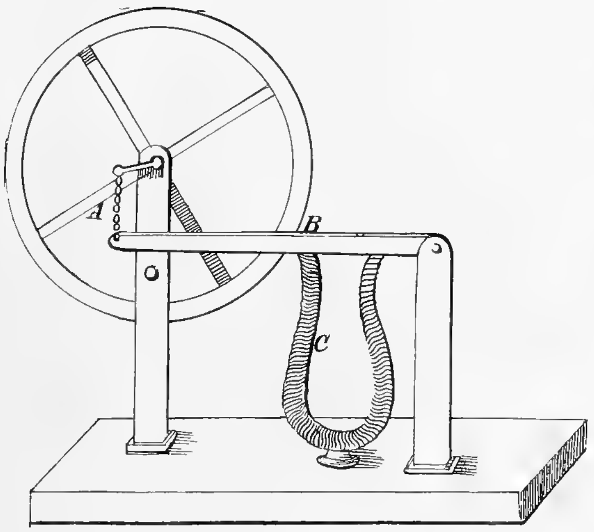

Figure 58.—Clarke's motor. From Sturgeon's *Annals of Electricity*, 1840, vol. 5, pl. 1, fig. 3.

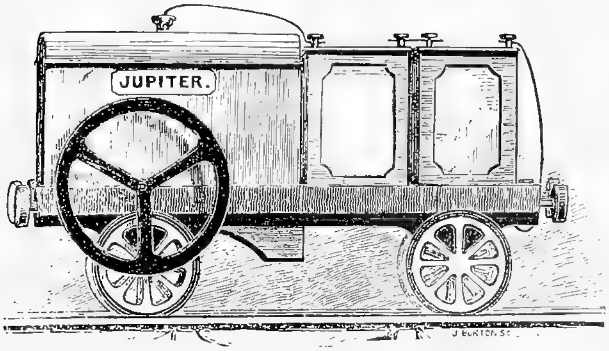

Figure 59.—Clarke's electric locomotive. From Sturgeon's *Annals of Electricity*, 1840, vol. 5, p. 304.

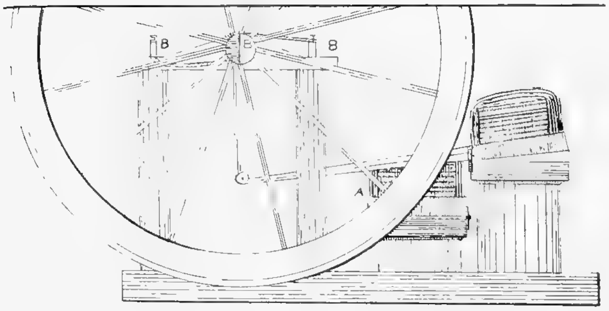

Figure 60.—Wright's motor. From Sturgeon's *Annals of Electricity*, 1840, vol. 5, pl. 3, fig. 4.

London in August 1838, one of Davenport's motors drove a small electric train of several carriages with a total weight of 70 to 80 pounds at a speed of 3 miles per hour.[95] Davenport tried to use his rotating motor to drive a Napier printing press that printed his paper "The Electro-Magnet," but the press required an engine from 1 to 2 horsepower, and he did not succeed in building such a motor until 1840.[96] Success came to Davenport with his development of a reciprocating engine based on a "sucking coil" that he had begun working on in 1838. Davenport built over 100 motors in his lifetime, but lack of financial backing and his inability to obtain an inexpensive source of power defeated him.

By the early 1840's there were a number of inventors of electric motors. In 1839 Robert Davidson of Edinburgh constructed an electric motor that had enough power to turn articles on a lathe or to drive a small carriage (fig. 56). Three years later, Davidson's motor could drive a carriage weighing about 6 tons for a mile and a half at a speed of 4 miles per hour.[97] A drawing of this 1842 motor is shown in figure 57. In 1840 Uriah Clarke[98] devised a reciprocating engine (fig. 58) and then applied it to a 100-pound miniature railway (fig. 59). Thomas Wright[99] reported on a reciprocating engine (fig. 60) that Clarke promptly criticized as impractical. William Taylor patented an electric motor[100] (fig. 61) in 1840. James Joule[101] worked on several different models of electric motors,

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[95] *Mechanics' Magazine*, London, 1838, vol. 28, pp. 321–323; vol. 29, pp. 95–96, 115, 166–168, 170–172.

[96] *Ibid.*, 1840, vol. 32, pp. 407–408.

[97] *Ibid.*, 1840, vol. 33, p. 92; "Electro-Magnetic Locomotive Carriage," Sturgeon's *Annals of Electricity*, 1842, vol. 9, 234–235; "The Earliest Electrical Railway," *Electrical World*, 1890, vol. 16, pp. 276–277.

[98] Uriah Clarke, "Description of an Electro-Magnetic Engine," Sturgeon's *Annals of Electricity*, 1840, vol. 5, pp. 33–34; "Description of an Electro-Magnetic Locomotive Carriage," Sturgeon's *Annals of Electricity*, 1840, vol. 5, pp. 304–305.

[99] Thomas Wright, "On a New Electro-Magnetic Engine," Sturgeon's *Annals of Electricity*, 1840, vol. 5, pp. 108–110.

[100] British Patent 8255, November 2, 1839.

[101] James Joule, "Description of an Electro-Magnetic Engine," Sturgeon's *Annals of Electricity*, 1838, vol. 2, pp. 122–123; 1839, vol. 3, pp. 437–439; 1840, vol. 4, pp. 203–205.

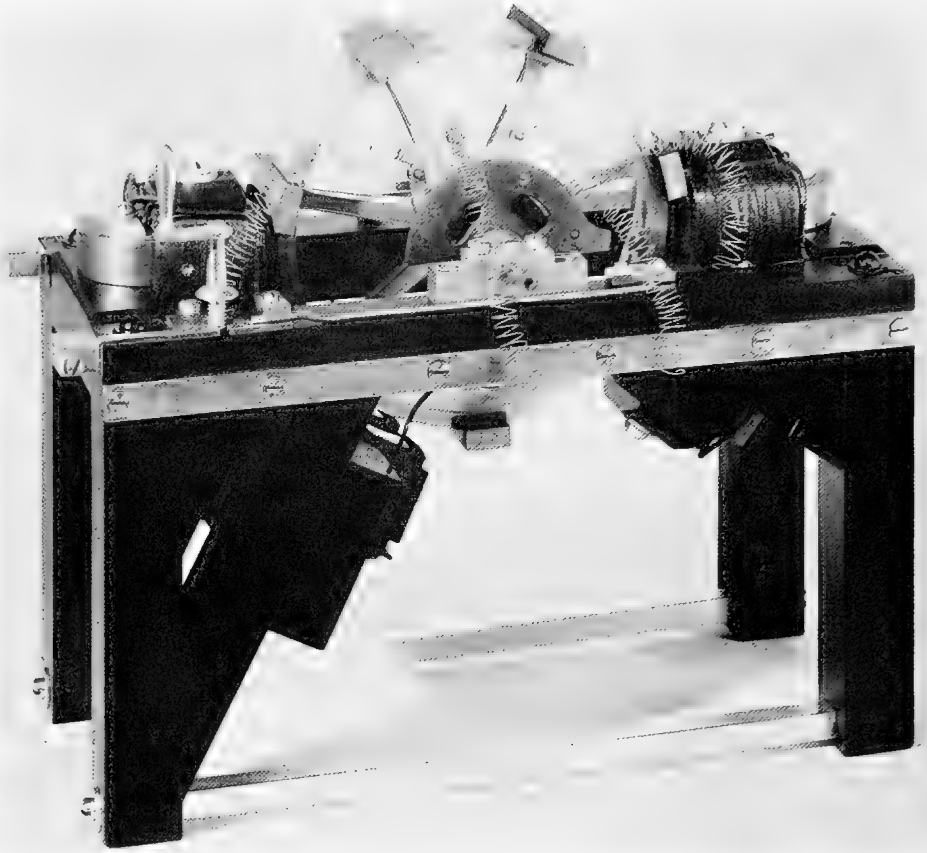

Figure 61.—Taylor's motor. (*USNM 181992; Smithsonian photo 47048.*)

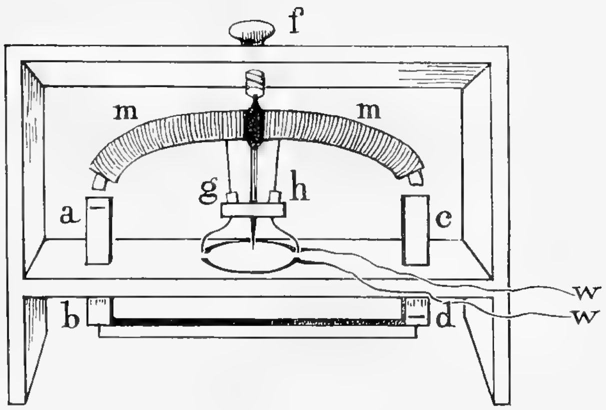

Figure 62.—Joule's rotating motor. From Sturgeon's *Annals of Electricity*, 1839, vol. 3, pl. 13, fig. 1.

including the one shown in figure 62. He devised another kind of motor (fig. 63) in 1842. In the same year, P. Elias, of Haarlem, invented a motor with a ring-type armature [102] (fig. 64).

There were other inventors of electric motors in the the United States. G. Q. Colton,[103] a traveling dentist fresh out of medical college, while demonstrating some wonders of science like laughing gas and the Morse telegraph, made an electric motor that he added to his show. In 1847 Colton placed a reciprocating motor, 14 inches long by 5 inches wide, on a track, and sent power from four Grove cells through the track. This invention (fig. 65) was widely exhib-

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[102] *La Lumière électrique*, 1882, vol. 7, pp. 13–14.

[103] *Scientific American*, September 25, 1847, vol. 3, p. 4. T. C. Martin, "The Electric Railway Work of Dr. Colton in 1847—The First Use of Track as Circuit," *Electrical Engineer*, 1893, vol. 16, pp. 49–51.

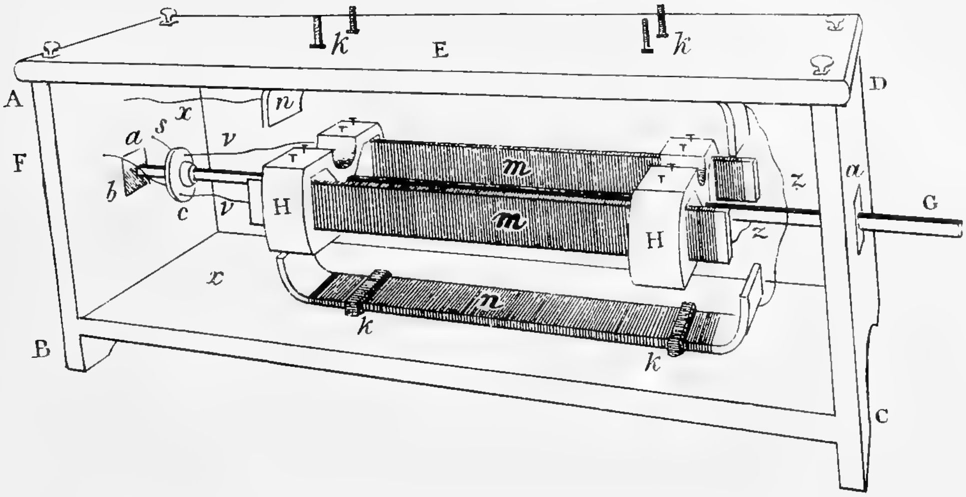

Figure 63.—Joule's motor of 1842. From Sturgeon's *Annals of Electricity,* 1840, vol. 4, pl. 5, fig. 3.

ited and reported throughout the northern and western United States. In 1850 Thomas Hall, one of the assistants to Daniel Davis, a Boston instrument-maker, demonstrated a miniature electric railway in Boston. T. C. Avery patented an electric motor[104] in 1851.

One of the most prolific of these early American inventors was Charles G. Page,[105] many of whose inventions (figs. 66, 67) later appeared in the popular catalogs of Daniel Davis. Page began his work on electric motors in 1837, and by the following year had one that could be used by Davis to power a drill.[106] Shortly thereafter Page moved to Washington, D.C., where he became a Patent Office examiner. After obtaining a $20,000 appropriation from the Government in 1849 he was able to build two motors that were definitely out of the class of "philosophical toys." By the following year his reciprocating motor (fig. 68) could deliver one horsepower, and a short time later he was able to quadruple its output. He estimated the cost of driving the lathe and saw of his shop with this 4-horsepower engine as 20 cents per horsepower-day.[107] In 1851 two of Page's motors drove a 10-ton locomotive at a speed of 10 miles per

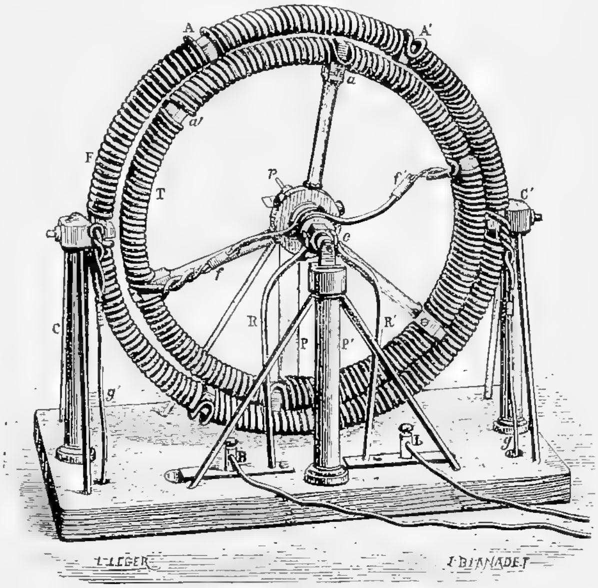

Figure 64.—Elias' ring armature motor. From *La Lumière électrique,* 1882, vol. 7, p. 14, fig. 13.

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[104] U.S. Patent 7950, February 25, 1851. The Patent Office model is in the Smithsonian Institution (USNM 308563).

[105] "Charles Grafton Page," *American Journal of Science,* 1869, vol. 48, pp. 1–17.

[106] Charles G. Page, "Experiments in Electro-Magnetism," *American Journal of Science,* 1838, vol. 33, pp. 118–120; "Electro-Magnetic Apparatus and Experiments," *American Journal of Science,* 1838, vol. 33, pp. 190–192; "Magneto-Electric and Electro-Magnetic Apparatus and Experiments," *American Journal of Science,* 1839, vol. 35, pp. 252–268.

[107] Charles G. Page, "On Electro-Magnetism as a Moving Power," *American Journal of Science,* 1850, vol. 10, pp. 343–349, 473–476.

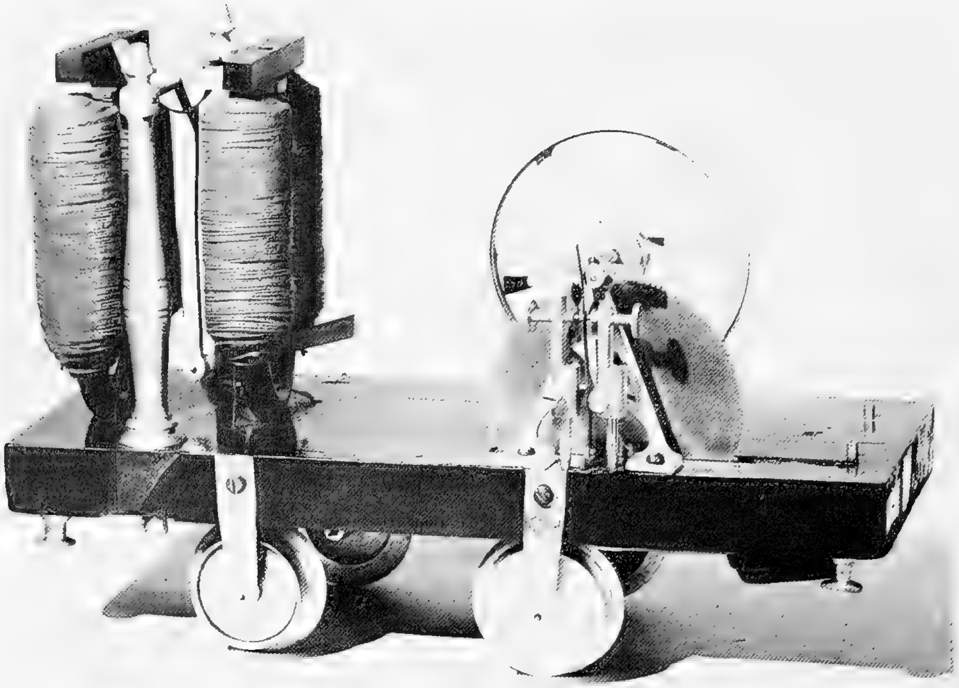

Figure 65.—Colton's electric locomotive. (*USNM 181577; Smithsonian photo 47048–B.*)

hour. A few months later, his motors had reached an estimated 8 to 20 horsepower, and on a 39-minute trip from Washington to Bladensburg had driven a locomotive at a top speed of 19 miles per hour.[108] However, the trip was so rough the diaphragms of the 50 Grove cells—required for each motor—and the insulation in the motors broke down. Page's funds were exhausted by then, and he made no further experiments.

Another of these successful early inventors was Moses G. Farmer of Dover, New Hampshire. Farmer devised an electric motor in 1846 that in its first public exhibition in July 1847 drove an electric train (fig. 70) of two cars on an 18-inch-gauge track.[109] Farmer had other exhibitions in New England later in the year; but his exhibitions were not financially successful, so he turned to the field of telegraphy.

By midcentury the general public was becoming increasingly aware of the possibilities of electrical power. Part of the increase in public attention resulted from the awarding of prizes for the invention and use of electric motors. Beginning in 1844 the French instrument-maker G. Froment constructed many motors (such as the one shown in fig. 69). Napoleon III awarded him the Volta prize in 1857 for having a shop completely run by electric motors.[110] Søren Hjorth, of Denmark, developed a motor (fig. 71) that was shown at the Great Exhibition of 1851 in London, where it won considerable attention as well as a prize.

By this time two basic forms of the electric motor had been developed. One of the basic forms was a reciprocating engine, where an armature was pulled into a solenoid, as in Page's motor, or an armature hinged at one end was pulled down by an electromagnet, as in Clarke's motor. Linkages changed the linear motion to a rotary one. The other basic form

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[108] Walter K. Johnson, "Report on Professor Page's Electro-Magnetic Locomotive," *American Journal of Science*, 1851, vol. 11, pp. 473–476; "Professor Page's Electric Engine," *Scientific American*, 1854, vol. 9, p. 394. Page patented his electric motor (U.S. Patent 10480) on January 31, 1854.

[109] *Electricity and Electrical Engineering*, 1893, vol. 4, p. 279.

[110] *Cosmos*, May 8, 1857, vol. 10, pp. 495–497; *Les Mondes*, May 7, 1863, vol. 1, pp. 337–338.

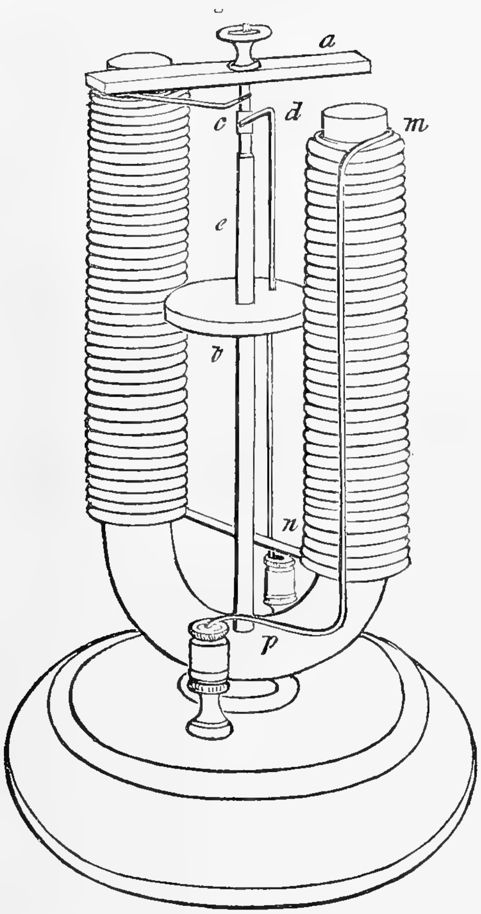

Figure 66.—Page's rotating motor. From *American Journal of Science,* 1838, vol. 35, p. 262.

was a paddle wheel, where an armature was kept in constant motion by a commutator switching on a field to tease the armature ahead at the right time. The engines of Ritchie, Jacobi, Davenport, Davidson, and Froment were of this second form. After mid-century there was a further proliferation of electric motors, but no new basic types were introduced until the advent of AC power.

In spite of the sanguine hopes of many of the early inventors, most scientists and engineers could not see any advantage in the use of electric power over that of steam. The greatest difficulty in the use of electricity lay in the relatively high cost of production of electrical power in comparison with that of steam. Instead of consuming coal in a chemical reaction that produced heat and the expansion of water, one dissolved a metal in an acid in a chemical reaction

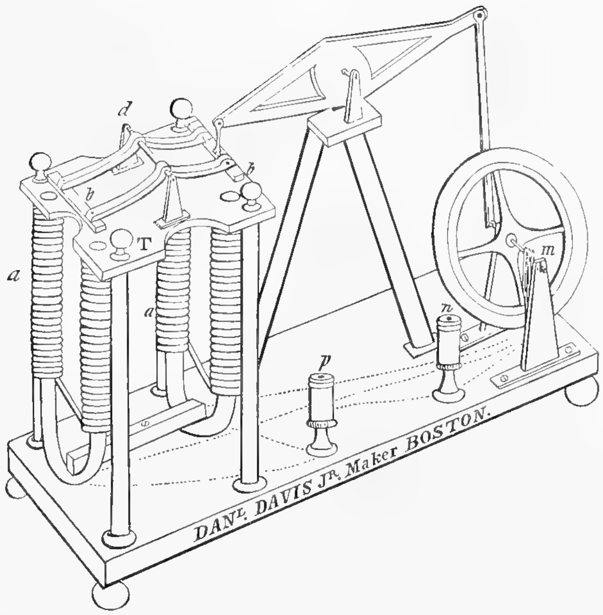

Figure 67.—Page's reciprocating motor. From *American Journal of Science,* 1838, vol. 35, p. 264.

that produced an electrical current. Metals and acids were much more expensive than coal and water.

A few engineers and scientists calculated just how much more expensive it was to produce an electrical current than it was to produce steam. In 1846 Scoresby and Joule[111] estimated that an electric motor could raise 80 pounds a distance of 1 foot for each grain of zinc consumed, while the best Cornish steam engine would raise 143 pounds the same distance for each grain of coal that was burned. Page had estimated the cost of his 1850 motor as greater than that of the cheaper steam engines but less than that of the highest priced ones.[112] Robert Hunt made an even more adverse estimate than Scoresby and Joule had made when he calculated in 1850 that electrical power was 25 times more expensive than steam power.[113] Obviously the electric motor could not

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[111] William Scoresby and James Joule, "Experiments and Observations on the Mechanical Powers of Electro-Magnetism, Steam and Horses," *Philosophical Magazine,* 1846, vol. 28, pp. 448–455; also *Philosophical Magazine,* 1850, vol. 36, pp. 550–552.

[112] Charles Page, *op. cit.* (footnote 107).

[113] Robert Hunt, "On the Application of Electro-Magnetism as a Motive Power," *Journal of the Franklin Institute,* 1850, vol. 20, pp. 334–336.

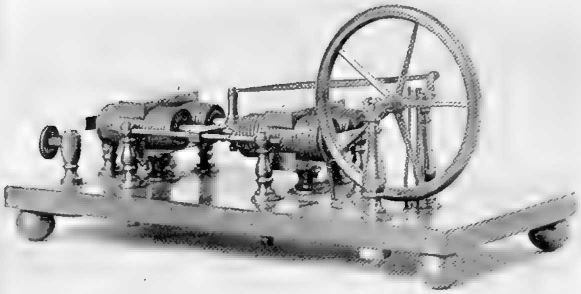


Figure 68.—Patent Office model of Page's reciprocating motor. (*USNM 252672; Smithsonian photo 29677.*)

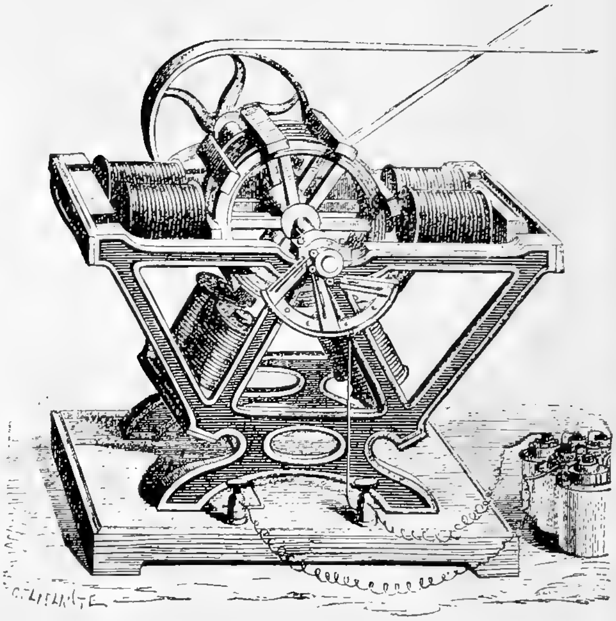


Figure 69.—One of Froment's motors. From T. du Moncel, *Electricity as a Motive Power*, London, 1883, fig. 35.

compete with steam until some cheaper means of producing electrical current could be found.

Another very important deterrent to the use of electrical power was the problem of distributing electrical current. Although by midcentury one could signal over long distances, power could be transmitted efficiently only within an area the size of a large room. Until some better means of distributing electricity was found, inventors had to use very bulky containers full of corrosive liquids directly at the place where the power was consumed.

The problems of the production and distribution of power were not solved until after the invention of the dynamo and the transformer. Moreover, on the eve of the last two decades of the 19th century—decades that were to see the explosive development of electrical technology—Théodose du Moncel was expressing the opinion of most scientists and engineers when he warned against the "pompous announcements of certain constructors and certain journals"

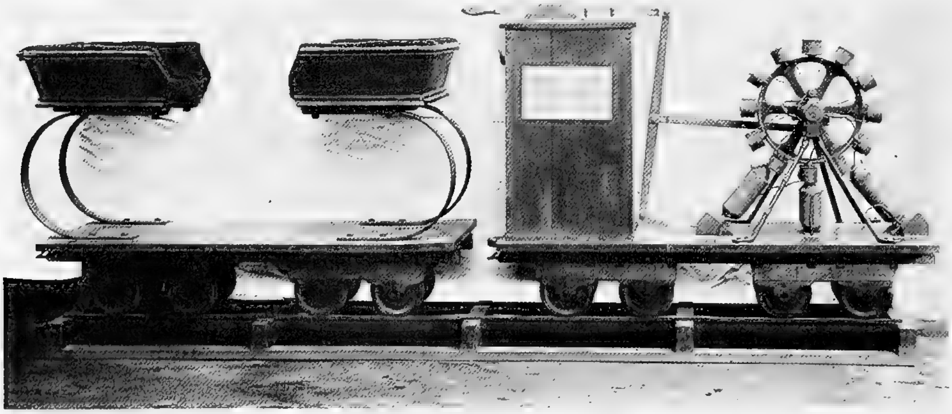
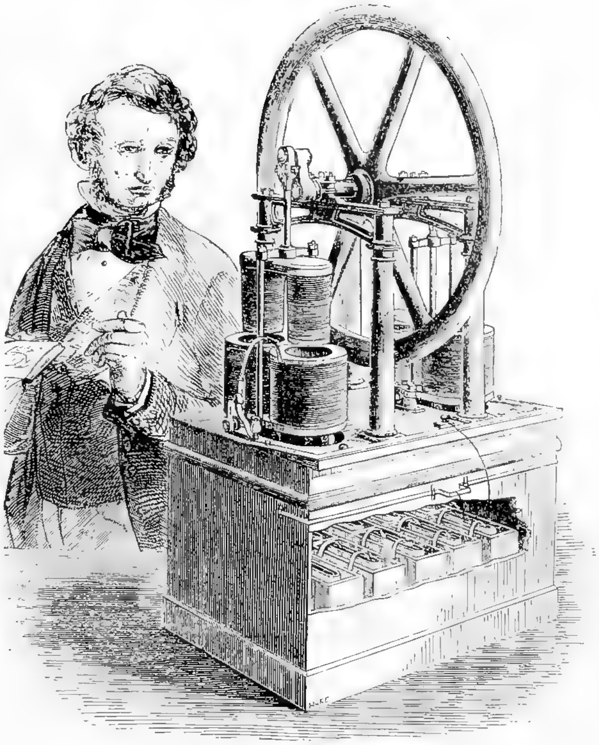


Figure 70.—Reproduction model of Farmer's electric train. The locomotive is about 4 feet in length. (*USNM 181348; Smithsonian photo 14588.*)

Figure 71.—Hjorth's motor. From *Illustrated London News,* May 12, 1849, vol. 14, p. 309.



and asserted that "what is certain until the present time, is that no electric motor has reached one horsepower in magnitude." [114] However, Du Moncel was not pessimistic, for he saw in the dynamo that had recently been invented a device that might be converted into a commercially successful motor. How this development occurred will be discussed in a subsequent article of this series.

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[114] Théodose du Moncel, *Exposé des applications de l'électricité* ed. 3, Paris, 1878, vol. 5, p. 343.

THE DEVELOPMENT OF ELECTRICAL TECHNOLOGY IN THE 19th CENTURY:

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2. The Telegraph and the Telephone

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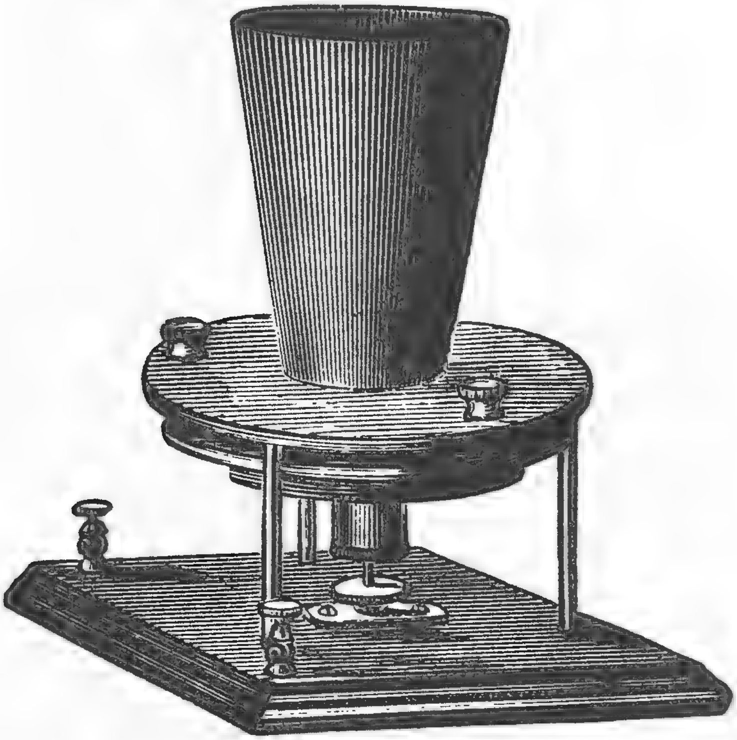

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Paper 29

The Development of Electrical Technology in the 19th Century:

2. The Telegraph and the Telephone

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THE DEVELOPMENT OF ELECTRICAL TECHNOLOGY IN THE 19th CENTURY:

2. The Telegraph and the Telephone

by W. James King

The first attempt to use electric current to transmit information was made by a Bavarian professor, Samuel T. Soemmerring, during the Napoleonic wars. Soemmerring's invention and many other electrical transducers for communications were at first considered to be curious "philosophical toys" that could never be applied in commerce; however, they were intermediate steps in the creation of an electrical technology. Their many successors, discussed in this article, played an ever stronger role in regional growth and economic expansion.

Among the instruments described and illustrated in this paper are those devised by Joseph Henry, Samuel Morse, Thomas Edison, Alexander Graham Bell, and many lesser-known figures. A number of the 19th-century inventions described are in the collections of the Smithsonian Institution.

THE AUTHOR: *W. James King—formerly curator of electricity, United States National Museum, Smithsonian Institution—is associated with the American Institute of Physics.*

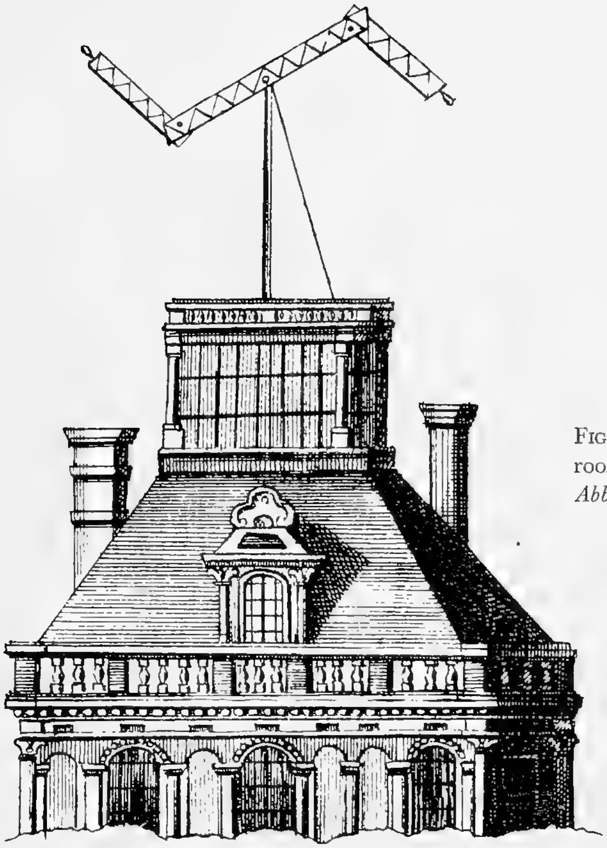

Figure 1.—Chappe telegraph mounted on the roof of the Louvre. From *Beschreibung und Abbildung des Telegraphen*, Leipzig, 1795, pl. 1.

The 19th century began with the tumult and ferment of the French Revolution and Napoleonic wars which broke many of the political and social barriers that had divided Europe. Through these broken barriers stretched the communication lines of the revolutionary armies, in particular a semaphore telegraph system (figs. 1–5) invented by Claude Chappe in 1792.[1] Messages were sent in the Chappe system by using the various positions of the crossarms on a pole to symbolize numbers. Sets of such numbers could be looked up in a dictionary that correlated each set with a French word. Later the Emperor used this telegraph to administer his conquests. In good weather each symbol of a message was carried through the 14 stations between Paris and the Rhine in about 6 minutes. It took about a quarter of an hour for a message to go from the Rhine to Berlin.[2] Napoleon wanted mobile telegraph units to assist in his invasion of Russia but this project was never carried out. At various times during the first part of the 19th century, optical, pneumatic, hydraulic, and electrical telegraphs were both suggested and invented to compete with this semaphore telegraph; but it was not until mid-century that the semaphore telegraph was finally replaced by the electromagnetic telegraph.

The first attempt to use electric current to transmit information resulted directly from the use of the Chappe telegraph. Bavaria was allied with France

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[1] Anonymous, *Beschreibung und Abbildung des Telegraphen, oder der neuerfundenen Fernschreibemaschine in Paris*, Leipzig, 1795; Grethe, "Der erste Chappe'sche Telegraph in Paris, *Archiv für Post und Telegraphie*, 1895, vol. 23, pp. 650–654; Ignace U. J. Chappe, *Histoire de la télégraphie*, Paris, 1824, 2 vols.; Abbé F. N. M. Moigno, *Traité de télégraphie électrique*, Paris, 1849, pp. 252–258.

[2] Franz Schnabel, *Deutsche Geschichte im Neunzehnten Jahrhundert*, Freiburg, 1929–1937 (4 vols.), vol. 3, pp. 391–392.

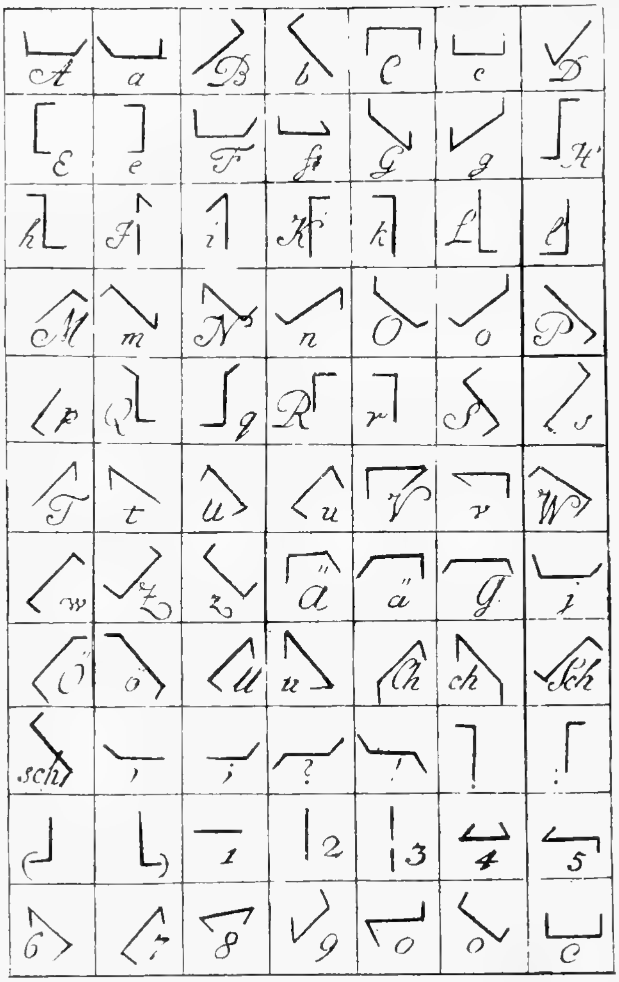

Figure 2.—Alphabet of the Chappe telegraph. From *Beschreibung und Abbildung des Telegraphen*, Leipzig, 1795, pl. 3.

in the first decade of the 19th century; and when Austria invaded Bavaria this maneuver was reported to Napoleon in Spain with such speed that he was able to meet the invaders on the battlefield in four days. Such rapid transmission of information led the Bavarian king to desire a similar telegraph system; and so the prime minister of Bavaria asked the president of the Bavarian Academy of Sciences, Prof. Samuel T. Soemmerring, a well known anatomist, to transmit this request to the academy. A month later, in August 1809, Soemmerring himself acted on this request by demonstrating a new kind of telegraph (figs. 6, 7) to the academy.[3]

This first galvanic telegraph was based upon the relatively recent discovery of the electrolysis of water. By using 35 wires attached to 35 gold electrodes placed in the bottom of a tank of water with glass walls, Soemmerring could indicate any two letters of the German alphabet (or any numeral) by connecting the appropriate electrodes to a voltaic pile. An effervescence at the two electrodes revealed the proper pair, with the first symbol in the sequence indicated by a greater amount of gas forming at the negative electrode than at the positive electrode. By using such a detector of the galvanic current, Soemmerring found that he could transmit signals through 2,000 feet of wire. A call alarm was added to the Soemmerring telegraph in 1810, and the following year this apparatus was operated over a line 4,000 feet long. By then the inventor had reduced the number of wires in the cable by eliminating the numerals; but he added a sign for "repeat" and one for a period, which made 27 wires in all. Later, in 1812, Soemmerring transmitted signals through 10,000 feet of wire wound on reels.

Soemmerring sent models of his electrolytic telegraph to Paris, Vienna, Geneva, and St. Petersburg. The telegraph was presented to the Institut de France and a committee was formed there to report on it, but the equipment was returned to its inventor in a few years without any formal action having been taken. The Soemmerring telegraph may have been demonstrated to Napoleon during the time it was in Paris; at least Napoleon is reported to have rejected it with the comment, "C'est une idée germanique."[4]

Although Soemmerring's invention was only a "philosophical toy," since no tests were made of it

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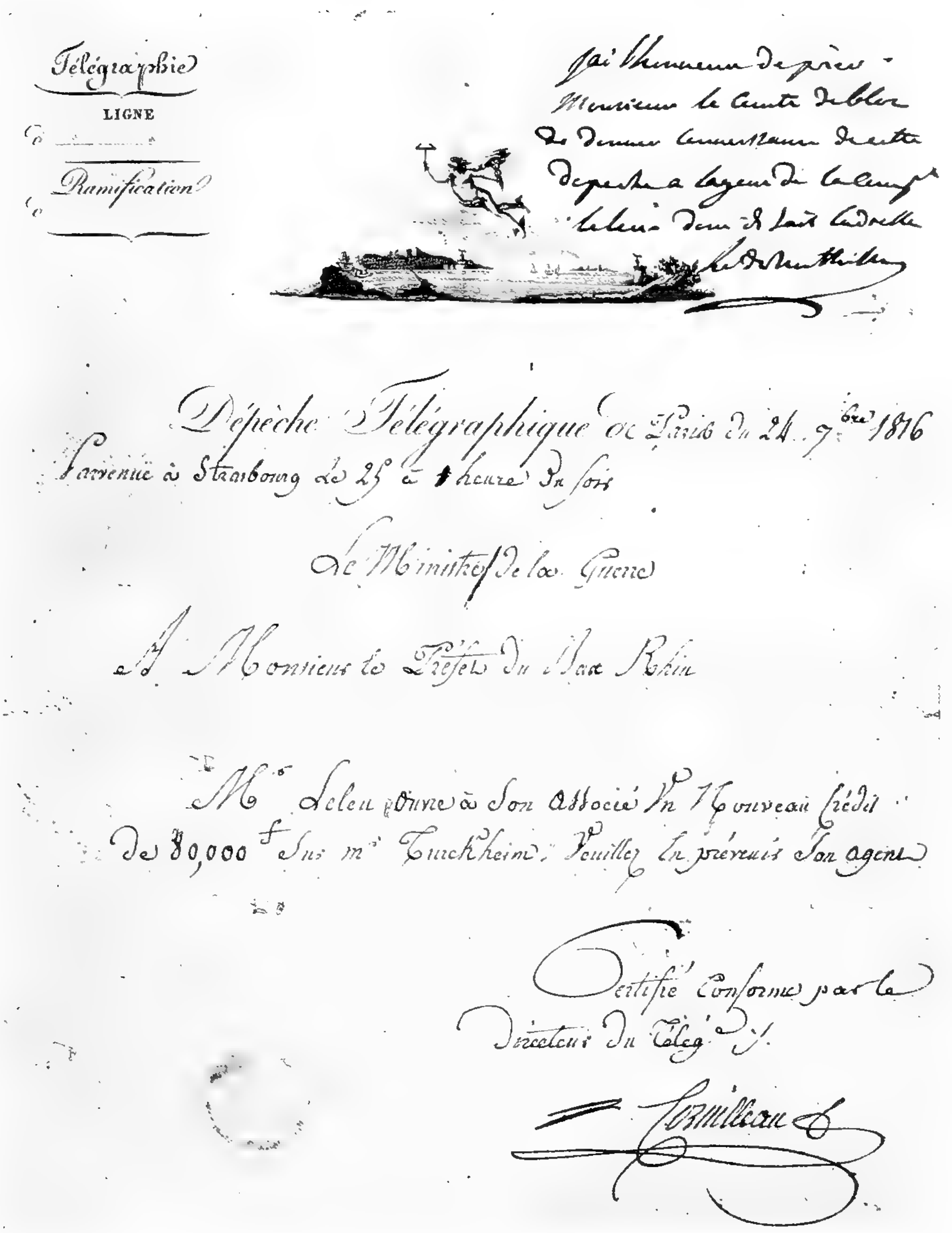
[3] T. S. Soemmerring, "Ueber einen elektrischen Telegraphen," *Die königlichen Akademie der Wissenschaften zu München, Denkschriften,* 1810, vol. 2, pp. xxvii, 401–414; J. S. Schweigger, "Über Sömmerring's elektrischen Telegraphen, I: Darstellung der Sache mit den Worten ihres Erfinders," *Journal für Chemie und Physik* (hereinafter cited as Schweigger's *Journal*), 1811, vol. 2, pp. 217–231; "Bemerkungen über Herrn Prem. Lieut. C. J. A. Prätorius Aufsatz: Über die Unstatthaftigkeit der elektrischen Telegraphen für weite Fernen," *Annalen der Physik,* 1811, vol. 39, pp. 478–482; W. Soemmerring, "Historische Notizen über Samuel Thomas von Soemmerring's Erfindung des ersten galvanisch-elektrischen Telegraphen," *Physikalische Verein zu Frankfurt am Main, Jahresbericht,* 1857–1858, pp. 23–36; J. Hamel, "Die Entstehung der galvanischen und elektromagnetischen Telegraphie, "*L'Académie impériale des sciences de St. Pétersbourg, Bulletin,* 1860, vol. 2, cols. 97–136, 298–303.

[4] Schnabel, *op. cit.* (footnote 2), p. 168.



Télégraphie

LIGNE

de

Ramification

de

J'ai l'honneur de prier
Monsieur le Comte de [illegible]
de donner connaissance de cette
dépêche à l'agent de la Comp^e
[illegible]

Dépêche Télégraphique de Paris du 24. 7^bre 1816
Parvenue à Strasbourg le 25 à ~~4~~ heure du soir

Le Ministre de la Guerre

A Monsieur le Préfet du Bas Rhin

M^r Lelen donne à son associé un nouveau crédit de 80,000 f sur M^r Turckheim. Veuillez en prévenir son agent.

Certifié Conforme par le
Directeur du Télég.^ph

FIGURE 3.—Money order sent by semaphore telegraph in 1816. Note the telegraph Mercury is carrying. Photo courtesy of the Burndy Library.

over actual land lines, still it was the first galvanic telegraph that was worked out, and it stimulated development of other electrical telegraphs both directly and indirectly. Thus in 1816 J. R. Coxe [5] suggested another electrochemical telegraph.

André Marie Ampère [6] was the first of many to see in Hans Oersted's discovery of a relationship between galvanism and magnetism a means of signaling at a distance. However, Ampère did not immediately

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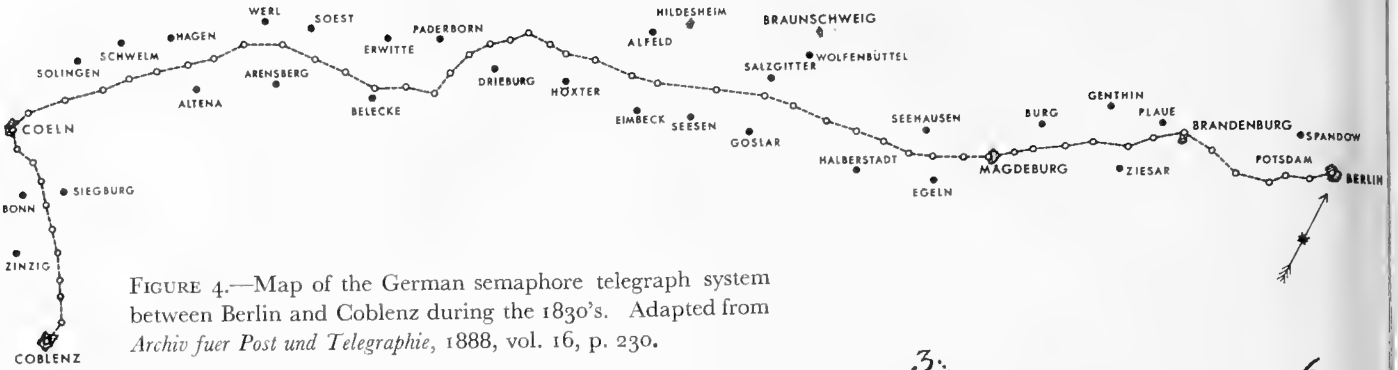
[5] J. R. Coxe, "Use of Galvanism as a Telegraph," *Annals of Philosophy*, 1816, vol. 7, pp. 162–163.

[6] A. M. Ampère, "Mémoire . . . sur les effets des courans électriques," *Annales de chimie et de physique*, 1820, vol. 15, pp. 59–76, 170–218.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ALTENA
DRIEBURG
HÖXTER
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EIMBECK
SEESEN
GOSLAR
GENTHIN
BURG
PLAUE
SEEHAUSEN
BRANDENBURG
SPANDOW
HALBERSTADT
MAGDEBURG
ZIESAR
POTSDAM
BERLIN
EGELN
SIEGBURG
BONN
ZINZIG
COBLENZ

FIGURE 4.—Map of the German semaphore telegraph system between Berlin and Coblenz during the 1830's. Adapted from *Archiv fuer Post und Telegraphie*, 1888, vol. 16, p. 230.

recognize the theoretical basis for such a transmission; that is, that the current in a simple closed circuit has the same value at every point in the circuit. Ampère originally believed that each conductor in a circuit—each of the loops of wire in a coil, for example—required its own chemical cell. Pierre Simon Laplace pointed out to Ampère that the Oersted effect could be produced everywhere in a long conductor, which fact argued for the hypothesis that the galvanic current was everywhere the same. Accordingly, a magnetic needle would be able to indicate the presence of a current when a battery was connected to a wire through which the current was passed, no matter how long the wire or how far away the needle. By using a pair of wires and a magnetic needle for each letter of the alphabet, Ampère suggested that one could communicate at a distance by opening and closing the circuit proper to each letter, for the motion of the needle would indicate the appropriate symbol.

William Alexander[7] demonstrated at an exhibit in Edinburgh in 1837 how such an Amperian needle telegraph might be set up (fig. 8). The distance covered by this exhibit was only 5 feet, but the exhibit showed how 30 wires and a copper rod, which was used for the common return, could indicate all the letters of the alphabet and some of the punctuation marks. When the battery was connected to a certain wire, the closing of the circuit caused the magnetic needle associated with that wire to move and to uncover the corresponding letter of the alphabet on a panel. The combinations obtained by closing the circuits in proper order resulted in the transmissions of combinations of the letters that formed a word.

It would appear that Ampère's suggestion of an electromagnetic telegraph should have led directly to its invention, but, instead, only the first step toward

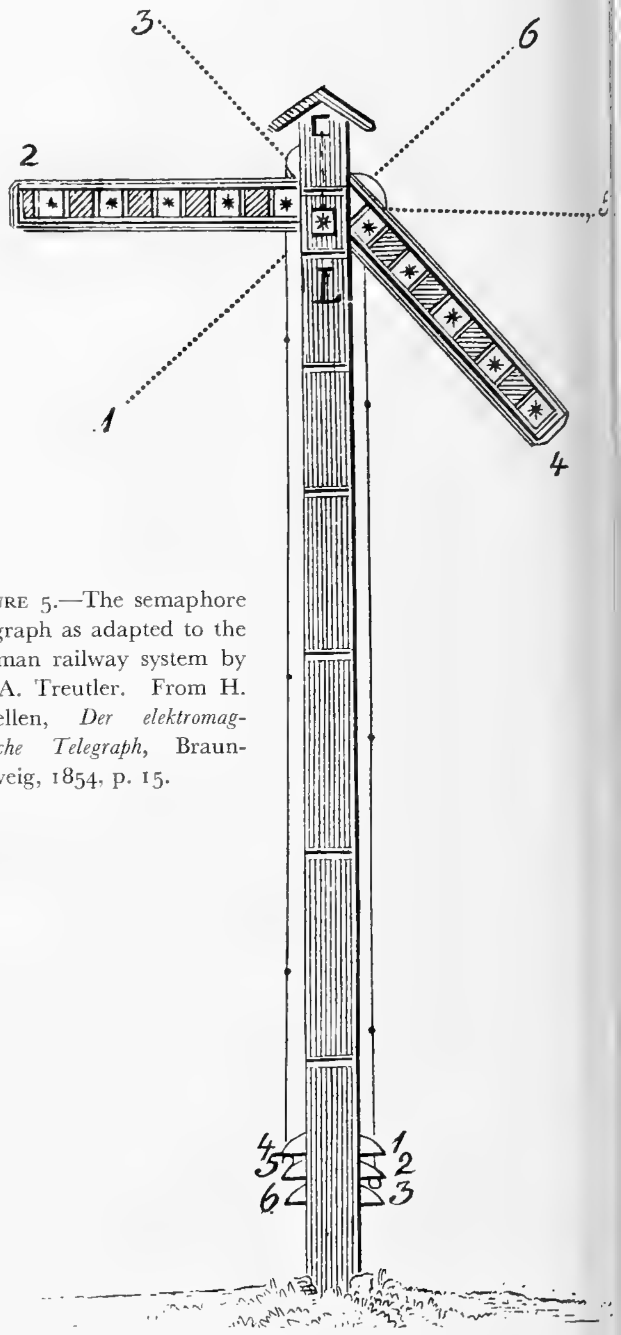
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FIGURE 5.—The semaphore telegraph as adapted to the German railway system by G. A. Treutler. From H. Schellen, *Der elektromagnetische Telegraph*, Braunschweig, 1854, p. 15.

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[7] "Alexander's Electric Telegraph," *Mechanics' Magazine*, London, November 25, 1837, vol. 28, pp. 122–123; J. J. Fahie, *A History of Electric Telegraphy to the Year 1837*, London, 1884, pp. 448–468.

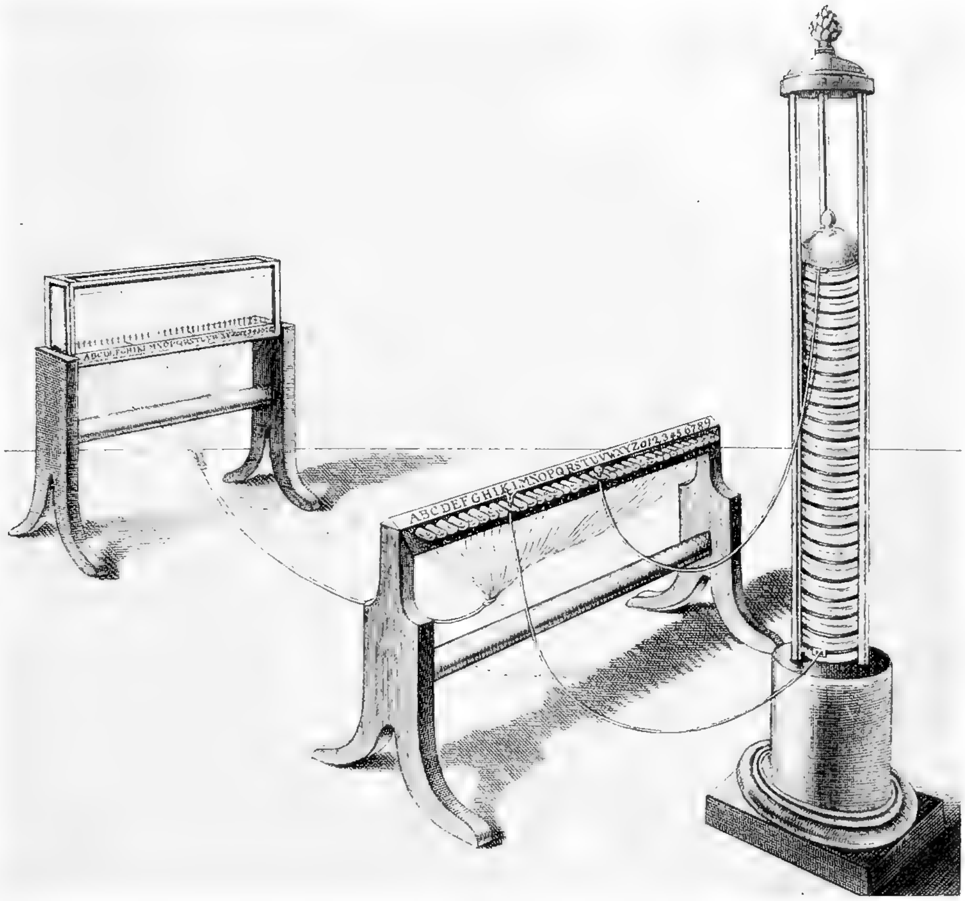

Figure 6.—Soemmerring's electrochemical telegraph of 1809, general view. From *Die königliche Akademie der Wissenschaften zu München, Denkschriften*, 1809–1810, vol. 2, pl. 5.

the realization of such a device had been taken. This first step was the easiest and the one that only a successful inventor could get beyond. Two problems involved in signaling by means of an electric current had to be overcome in order to produce a workable electromagnetic telegraph.

The work of Soemmerring and Ampère had provided inventors with two distinct means of detecting a signal by means of electricity. It was no difficult task to transmit a signal within the confines of a room, but it was impossible to produce an effect across a distance of several miles if just an arbitrary combination of coils and batteries was used. Moreover, the telegraphs of Soemmerring and Alexander used 20 to 30 wires. If the messages were to be exchanged between cities miles apart, there was the very considerable economic problem of installation and maintenance of the circuits as well as the technical problem of providing appropriate material for the wire and the proper insulation. Yet these problems of signaling at a distance and of reducing the great number of wires required for transmitting signals had to be solved if any commercial application of the telegraph was to be made.

Because of the imperfect state of electrical theory, it was usually a little time after the invention of a signaling device before its inventor appreciated that these problems of distance and economy existed. Eventually it was learned that the proper combination of batteries and magnets (impedance matching) solved the problem of transmitting signals over long distances. It was also learned that the great number of lines required could be reduced by the use of a binary code, which was based on the two conditions

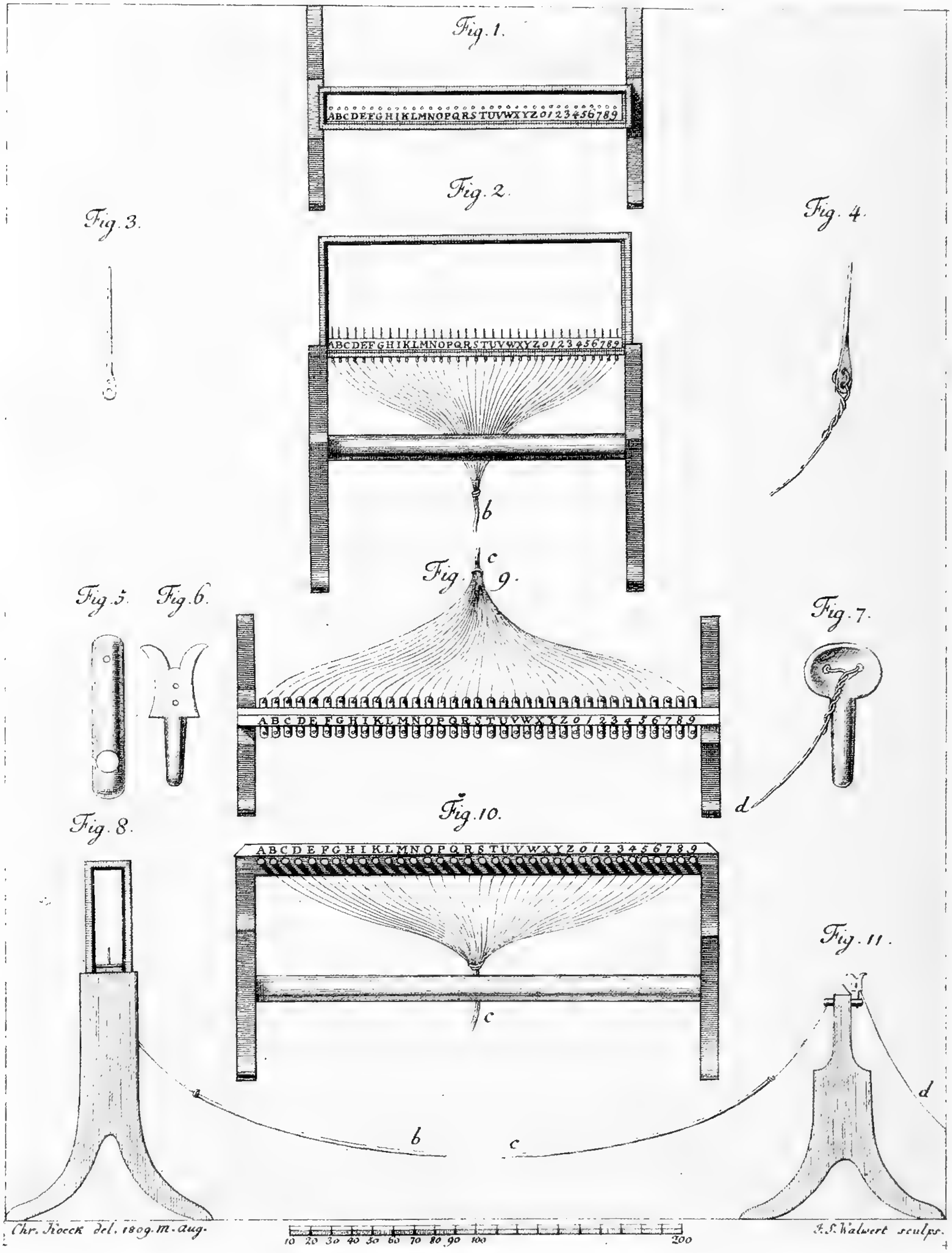
Fig. 1.
ABCDEFGHIKLMNOPQRSTUVWXYZ0123456789
Fig. 2.
ABCDEFGHIKLMNOPQRSTUVWXYZ0123456789
Fig. 3.
Fig. 4.
b
c
Fig. 9.
Fig. 5.
Fig. 6.
ABCDEFGHIKLMNOPQRSTUVWXYZ0123456789
Fig. 7.
d
Fig. 8.
Fig. 10.
ABCDEFGHIKLMNOPQRSTUVWXYZ0123456789
c
Fig. 11.
d
b
c
Chr. Koeck del. 1809. m. aug.
10 20 30 40 50 60 70 80 90 100 200
J. S. Walwert sculps.

Figure 7.—Soemmerring's electrochemical telegraph of 1809, showing details of construction. From *Die königliche Akademie der Wissenschaften zu München, Denkschriften*, 1809–1810, vol. 2, pl. 5.

of a circuit—in one code either all of the current flowed or none of it flowed; in another code the current could flow either in one direction or the other.

As a result of certain experiments, it was at first argued that a galvanic current could not be transmitted to a point at any great distance. Thus, in 1825 Peter Barlow[8] attacked Ampère's proposal for a telegraph on the basis of the slight effects produced in what Barlow considered very long circuits. Barlow found that he could detect little Oersted effect at the maximum distance of his circuits, which was 200 feet. Barlow's conclusion was that the effect diminished approximately as the square root of the distance along the wire from the battery. From this hypotheses Barlow decided that an electric telegraph based on the Oersted effect was not only impractical but was theoretically impossible.

In spite of Barlow's animadversions, some inventors tried to devise apparatus for a needle telegraph. In 1830 William Ritchie[9] described an astatic needle galvanometer that could be used as a receiver in such a system. Ritchie agreed with the conclusions of Barlow as to how the current varied along the line but argued that this variation could be overcome by modifying the battery: the longer the telegraph line, the more pairs of plates were necessary to signal over the line. With a needle galvanometer and a larger battery than Barlow's, Ritchie found that he could signal over a distance of several hundred feet. Ohm too stated in 1832 that one needed only to increase the number of plates in the battery and the thickness of the wire in order to produce an effect over a distance.[10]

A more thorough solution to the problem of transmitting electromagnetic signals to a distant point was announced by Joseph Henry.[11] In 1830 Henry demonstrated that an electromagnet could be operated through a thousand feet of wire if an intensity battery, of many pairs of plates, were connected to one end of the line and an intensity electromagnet, of many turns of wire, to the other end. In 1831 and 1832 he showed his classes at the Albany Academy that by having the electromagnet operate a clapper and strike a bell he could transmit signals through a mile of wire (fig. 9). Sometime in 1836 or 1837 Henry added a relay to a similar long line that had been set up for his classes at Princeton in 1835. An intensity electromagnet actuated by a distant intensity battery closed the local circuit of a powerful quantity electromagnet and a quantity battery. Although Henry realized at an early date that he had all the components of a complete electromagnetic signaling system, he did not attempt to make an invention of them.

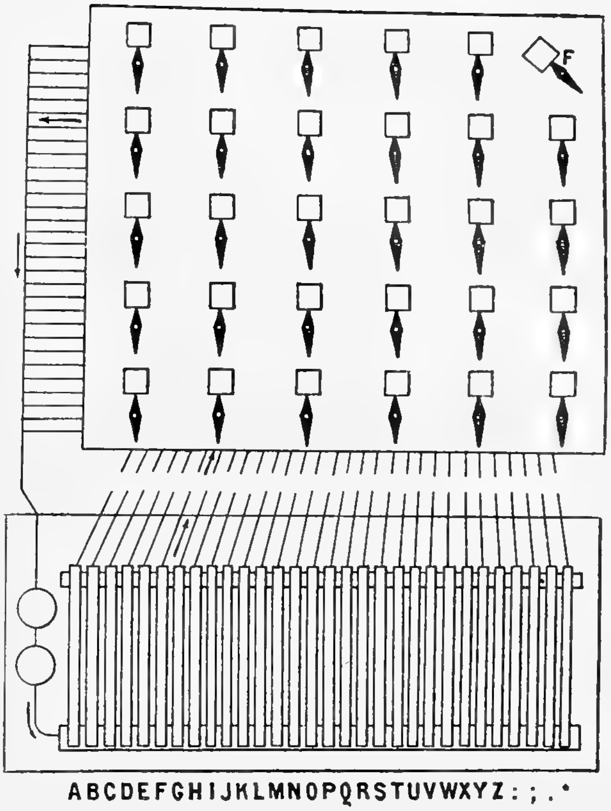

Figure 8.—Alexander's telegraph in which a moving magnetic needle would uncover a letter. From *La Lumière électrique*, 1883, vol. 8, p. 333.

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[8] Peter Barlow, "On the Laws of Electro-Magnetic Action . . . ," *Edinburgh Philosophical Journal*, 1825, vol. 12, pp. 105–114.

[9] *Philosophical Magazine*, 1830, vol. 7, p. 212.

[10] G. T. Fechner, ed., *Repertorium der experimental Physik*, 1832, vol. 1, pp. 402–403.

[11] Joseph Henry, "On the Application of the Principle of the Galvanic Multiplier to Electro-Magnetic Apparatus, and also to the Development of Great Magnetic Power in Soft Iron, with a Small Galvanic Element," *American Journal of Science*, 1831, vol. 19, pp. 400–408; "Proceedings of the Board of Regents of the Smithsonian Institution," *Annual Report of the . . . Smithsonian Institution . . . for the Year 1857*, 1858, pp. 85–117; William B. Taylor, "Henry and the Telegraph," *Annual Report of the . . . Smithsonian Institution . . . for the Year 1878*, 1879, pp. 262–360; Thomas Coulson, *Joseph Henry, His Life and Work*, Princeton, 1950.

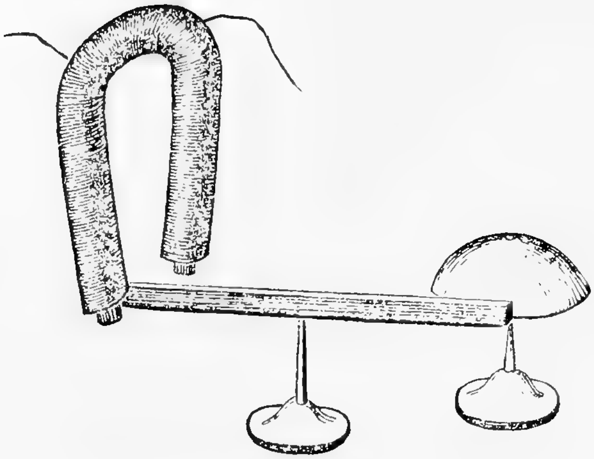

Figure 9.—Henry's "telegraph" signal of 1831–1832. From *Annual Report of the Smithsonian Institution . . . for the Year Ending June 30, 1857*, 1858, p. 105, fig. 7.

During the 1830's a number of inventors recognized the possibility that a binary code might reduce the number of wires necessary to transmit electrical telegraphs. Much earlier Schweigger[12] had suggested that modifying Soemmerring's system by the use of a binary code could eliminate many of the wires required in the Soemmerring device, but the first to attempt to put a binary code into practice in an electromagnetic signaling system were two German physicists—Carl F. Gauss and his assistant, Wilhelm Weber.[13] Gauss and Weber also understood how to transmit signals over distances of a mile or so.

It was while Gauss was studying the magnetism of the earth that he found that some of the equipment employed in his research could also be used for a telegraph. Gauss had shown an interest in telegraphs before this; he was one of the many visitors who, during the 1810's, had stopped in Munich to see Soemmerring's apparatus, and in the early 1820's he had invented a heliograph, or optical telegraph, that used a binary code.

Gauss had begun his observations on the earth's magnetism with equipment that he set up in the Göttingen astronomical observatory in 1832. Early in 1833 Gauss and Weber converted one of their instruments into a needle galvanometer so that they could test the validity of Ohm's work on circuits. A bar magnet weighing about a pound constituted the needle; the coil consisted of 300 feet of wire; a chemical battery supplied the power; and a commutator could reverse the current in the coil and make the needle swing to the right or left. Weber set up a double copper line that ran between the astronomical observatory and the laboratory of the University of Göttingen—a distance of 8,000 feet. Gauss and Weber soon found that their circuit could be used for other purposes as well as for testing Ohm's theories.[14] At first it was used to synchronize the clocks between the two buildings, but by Easter 1833 it was part of a communications system that was occasionally used for sending words and even phrases. For an illustration of a later telegraph by Gauss and Weber, see figure 10.

In the meantime funds had been obtained by the University of Göttingen for a magnetic observatory, which was in operation by 1834. The same line was extended several hundred feet from the astronomical observatory to the magnetic observatory, and a galvanometer with a 4-pound needle and a coil of 1,100 feet of wire were placed in the new building. By the following year that galvanometer had been moved to the laboratory and a new one set up in the astronomical observatory. The needle for the new galvanometer was 1.2 meters long and weighed about 25 pounds. It was hung by a bifilar suspension in order to increase the speed of its response, and the needle was moved inside a multiplier of 2,700 feet of fine wire. The chemical battery, which produced a gradually decreasing current, was replaced by a coil that could induce an electric current whenever it was

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[12] J. S. Schweigger, "Über Sömmerring's elektrischen Telegraphen, III: Nachschreiben des Herausgeber's," Schweigger's *Journal*, 1811, vol. 2, pp. 238–247.

[13] C. F. Gauss, *Werke*, Berlin, 1929, vol. 11, Abt. 2, Abh. 2, *passim;* Ernst Feyerabend, *Der Telegraph von Gauss und Weber im Werden der elektrischen Telegraphie*, Berlin, 1933. It should be noted that in describing the Gauss and Weber telegraph, this work uses units of the local German foot.

[14] *Göttingische gelehrte Anzeigen*, December 27, 1832, vol. 2, pp. 2049–2058; *Göttingische gelehrte Anzeigen*, August 9, 1834, vol. 2, pp. 1265–1274; also reported in *Dinglers polytechnisches Journal*, 1835, vol. 55, pp. 392–394, and *Annalen der Physik und Chemie*, 1834, vol. 32, pp. 562–569; letter of November 8, 1833, quoted in F. Danneman, *Die Naturwissenschaften in ihrer Entwicklung und in ihrem Zusammenhange*, Leipzig, 1922, vol. 4, pp. 398–399; letter of November 20, 1833, quoted in E. Feyerabend, *op. cit.* (footnote 13), pp. 43–46; *Göttingische gelehrte Anzeigen*, March 7, 1835, vol. 1, pp. 345–357; "Erdmagnetismus and Magnetometer," *Jahrbuch für 1836* (H. C. Schumacher, ed.), 1836, pp. 38–39.

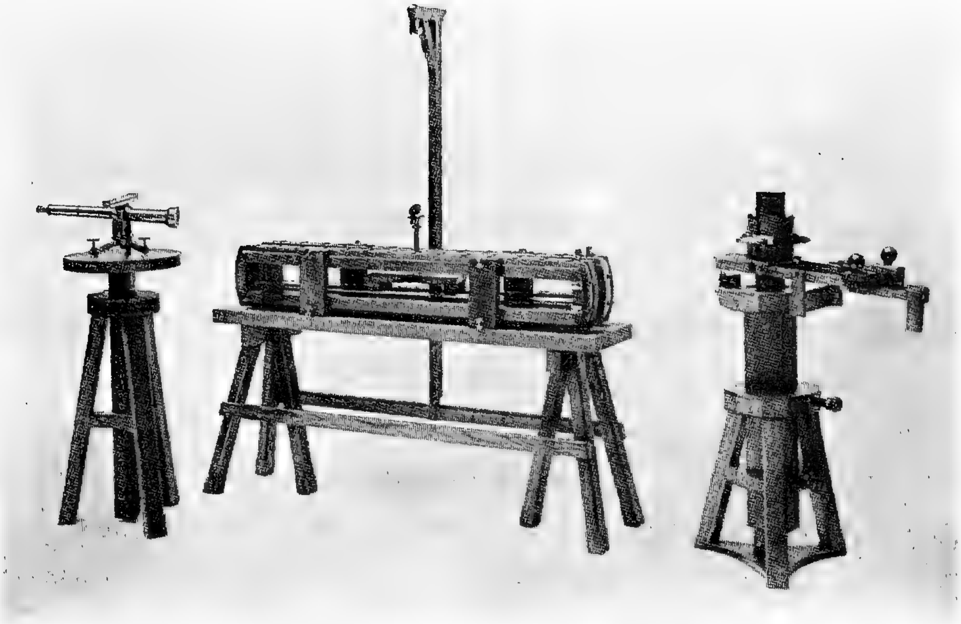

Figure 10.—Gauss and Weber's telegraph of 1836. From E. Feyerabend, *Der Telegraph von Gauss und Weber . . .*; Berlin, 1933, p. 41.

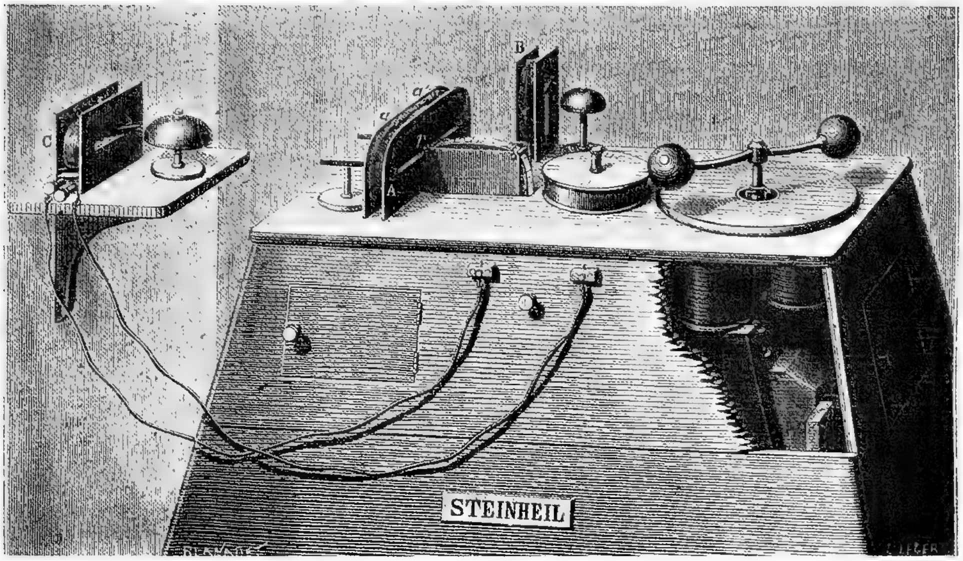

Figure 11.—Oblique view of Steinheil's telegraph. From A. Guerout, "L'Histoire de la télégraphie électrique," *La Lumière électrique*, 1833, vol. 8, p. 361.

moved along a pair of bar magnets (see fig. 10). A year later Weber improved the moving coil mechanically and combined the commutator with it. He also added an alarm.

Various combinations of left and right swings of the needle up to four in number indicated the various letters of the alphabet. Successive letters were indicated by short pauses of the needle, and successive words by longer pauses. The speed of transmission was quite slow—only about seven letters per minute could be sent, although initially only two letters per minute could be sent.

In 1835 officials of the Leipzig-Dresden railway who saw the apparatus were so favorably impressed by it that they considered installation of such a telegraph to control railway traffic. However, in spite of Gauss' suggestion that possibly the tracks could be used as part of the telegraph circuit, they finally decided that the project would be too expensive. The Gauss-Weber telegraph continued in operation at the University of Göttingen until 1838, when Weber was forced to leave the university because of political difficulties and Gauss turned his attention to other researches.

In 1835, at the express invitation of Gauss, Prof. Karl A. Steinheil of the Bavarian Academy of Sciences began working on a simplified and more practical version of Gauss and Weber's needle telegraph. After making a number of changes, Steinheil completed his apparatus (figs. 11–13) by 1836. The moving coil inductor was replaced by a large magneto based on Clarke's generator. The moving needle in the multiplier could be used in one of the following ways: to strike against one of a pair of bells, each of a different tone, or to ink dots on a recording tape. The various combinations of tones, or dots, indicated acoustically, in the case of the bells, or graphically, in the case of the dots, the various letters of the alphabet.[15]

The Steinheil telegraph was used successfully over a long circuit. By July 1837 Steinheil had set up three telegraph lines from the laboratory in the academy in Munich—one that extended 0.9 km. to his home, one that extended 0.1 km. to the shop of the academy, and one that extended 5 km. to the astronomical observatory. Each of these stations was connected to the laboratory by a pair of copper or iron wires strung on poles or buildings. A simple switching device at the central telegraph station in the laboratory enabled Steinheil to connect any combination of the four stations together. With this system he was able to send about six words per minute.

In 1838 the Bavarian government became interested in Steinheil's telegraph system, and a 5-mile line along the Nürnberg-Fürth railroad was proposed. Steinheil tried to implement Gauss' suggestion of using the railroad tracks in order to save some of the expenses, but the difficulty in insulating the tracks caused the plan to be abandoned. However, Steinheil's experiences showed him in June 1838 how he could use the earth as one half of the telegraph line. The ground return thus obtained reduced the installation and maintenance cost of the telegraph line considerably. Steinheil's telegraph system worked so well on the Nürnberg-Fürth railroad that the Bavarian government decided to try a line with a ground return along a portion of the Munich-Augsburg railroad. However, the expense of installing the single line was still too great, and the authorities decided against the application of Steinheil's telegraph.

Even before Gauss inspected Soemmerring's telegraph, it had been seen by Baron Pavel L. Schilling,[16] a member of the Russian embassy staff at Munich. Schilling became a close friend of Soemmerring, and it was Schilling who carried Soemmerring's telegraph to St. Petersburg and a friend of Schilling who took another model to Vienna to demonstrate it to Emperor Francis I. Schilling later worked out a needle telegraph system, but it is difficult to determine when this occurred, what were the construction details of his first instruments, and how his code functioned. J. Hamel, who knew Schilling personally, reported that Czar Alexander, who died in 1825, had followed Schilling's efforts to develop an electrical telegraph.

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[15] Karl Steinheil, "Ueber Steinheil's electro-magnetischen Telegraphen mit betreffenden historischen Notizen," *Dinglers polytechnisches Journal*, 1838, vol. 67, pp. 388–391; "Notice sur le télégraphe galvanique de M. Steinheil," *Comptes rendus*, 1838, vol. 7, pp. 590–593; "Beschreibung des galvano-magnetischen Telegraphen zwischen München und Bogenhausen, errichtet im Jahre 1837," *Dinglers polytechnisches Journal*, 1838, vol. 70, pp. 292–302; "Zum Andenken Steinheils," *Archiv für Post und Telegraphie*, 1888, vol. 16, pp. 402–405.

[16] Oken's *Isis*, 1836, vol. 29, col. 727; G. W. Muncke, article "Telegraph," *Gehler's physikalisches Woerterbuch*, Leipzig, 1838, vol. 9, pp. 100–126; J. Hamel, "Ueber die Erfindung des elektromagnetischen Telegraphen durch Baron Schilling von Canstatt und die Ueberführung des neuen Apparates nach England und Amerika," *Gesellschaft deutscher Naturforscher und Aerzte, Berichte*, 1857, vol. 33, pp. 60–65; Hamel, *op. cit.* (footnote 3); Auguste Guerout, "L'Historique de la télégraphie électrique," *La Lumière électrique*, 1883, vol. 8, pp. 332–339; Feyerabend, *op. cit.* (footnote 13), pp. 17–22.

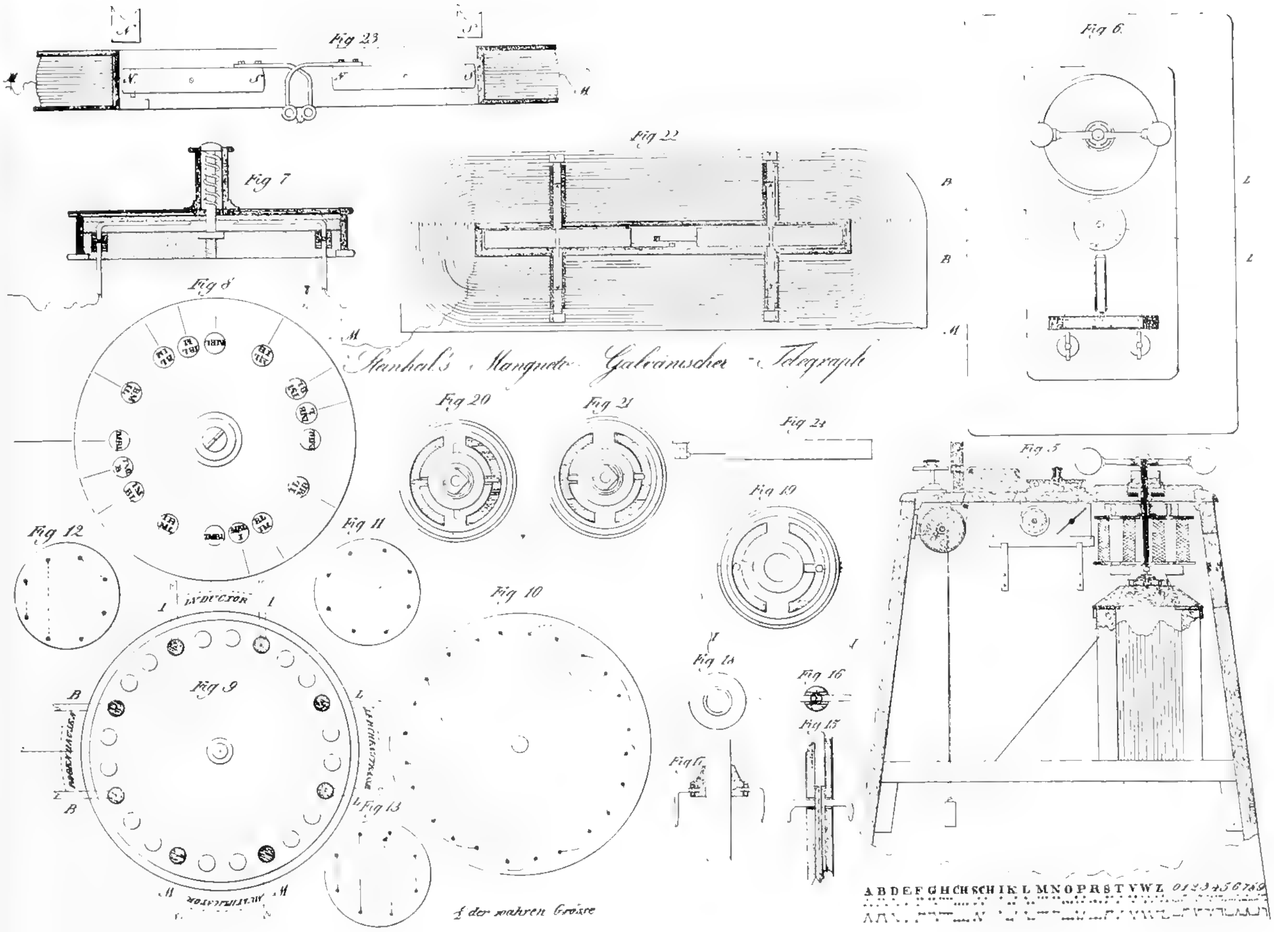
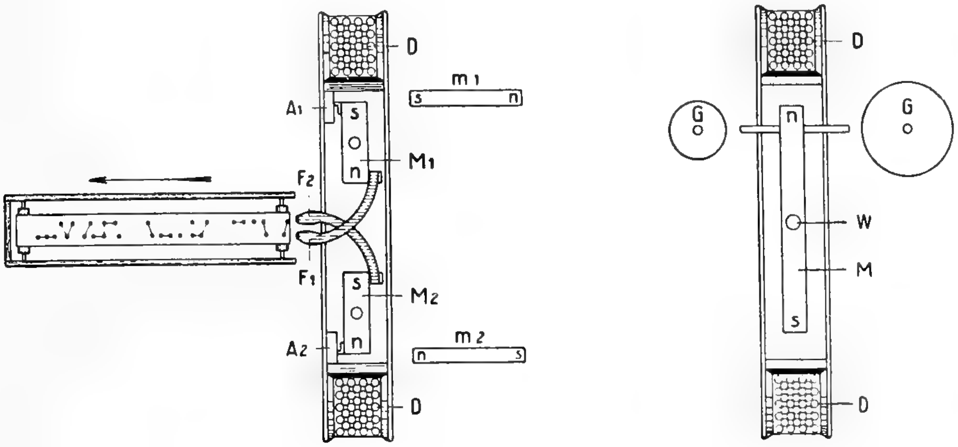


Fig 23
Fig 6.
Fig 22
Fig 7
Fig 8
Steinheil's Magnet-Galvanischer Telegraph
Fig 20
Fig 21
Fig 24
Fig 5
Fig 19
Fig 12
Fig 11
Fig 10
INDUCTOR
Fig 9
Fig 13
Fig 14
Fig 16
Fig 15
Fig 17
¼ der wahren Grösse
A B D E F G H CH SCH I K L M N O P R S T V W Z 0 1 2 3 4 5 6 7 8 9

FIGURE 12.—Details of Steinheil's telegraph. From *Dinglers polytechnisches Journal*, 1838, vol. 70, pl. 4.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G
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W
M
s
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FIGURE 13.—Steinheil's two receivers: one to ink combinations of signs on a moving paper tape and one to produce two different bell sounds. From E. Feyerabend, *Der Telegraph von Gauss und Weber . . .*; Berlin, 1933, p. 63.

However, this remark could very well have referred to a variant of Soemmerring's instrument although Hamel implied that he was speaking of a needle telegraph. Baron Alexander von Humboldt remarked that in 1832 Schilling had shown an electrical telegraph (fig. 14) to Czar Nicholas I in Berlin.

The first contemporary description that we have of Schilling's instruments is a report of a 5-needle, 6-wire telegraph that he successfully exhibited at a scientific meeting in Bonn in 1835. This apparatus was a simple one consisting of five needle galvanometers. The suspension of each needle had a paper disk marked with a horizontal stripe on one side and a vertical stripe on the other. The bottom end of the suspension rested in a tiny bowl of mercury to damp the oscillations of the magnetic needle under the influence of the current. Schilling also provided an alarm for his telegraph. The code he used seems to have been a binary one—an idea that may have resulted from his visit to Gauss in 1833. A demonstration that Schilling made in Vienna in 1836 induced two local scientists to try to set up a telegraphic line along the streets that could be used with Schilling's instruments. Another demonstration that Schilling made to the Russian government in 1837 led to plans that were prevented by his death in the same year—the Russian government planned to lay an 8-mile submarine cable in an arm of the Bay of Finland near St. Petersburg to connect the fortress of Kronstadt with Peterhof.

The display of the Russian government at the Paris electrical exhibition of 1881 included an apparatus that was said to have been successfully demonstrated previously by Schilling. The transmitter of this apparatus was a 16-key, piano-type keyboard connected by eight wires to a receiver consisting of six needle galvanometers, plus another galvanometer that was used for a call alarm (fig. 15).

The Russian government asked M. H. Jacobi to continue Schilling's work in electrical telegraphy upon the latter's death, but Jacobi abandoned Schilling's needle telegraph in favor of another approach.[17] Jacobi sought also to reduce the many wires that had been necessary in Schilling's instrument by using a simpler binary code. Functionally, Jacobi's first instrument (fig. 16), completed in 1839, was similar to Morse's 1837 instrument. An electromagnet at the receiving station of the Jacobi telegraph was actuated by a key, at a distant point, that closed a circuit. The resulting up-and-down motion of the armature was recorded as a wavy line on a moving plate. This instrument was used in 1839 on an experimental underground line in St. Petersburg that ran from the Winter Palace across the square to the General Staff Building. In 1843 the line was extended from the Winter Palace to Tsarskoe Selo, some 15 miles away.

After experimenting with various electrophysiological telegraphs in the early 1840's, Jacobi invented a dial telegraph in January 1845 that was similar to an instrument that Wheatstone had patented five years earlier; both instruments used pulses of current to actuate a step-by-step mechanism. After the apparatus was successfully tested in 1845 during Russian military maneuvers, it replaced the telegraph instrument that had been used earlier on the lines between St. Petersburg and Tsarskoe Selo. Another dial telegraph operated between St. Petersburg and Peterhof. While working with these lines, Jacobi discovered that they acted as condensers and tended to distort the signal transmitted along them. He found that this distortion was more noticeable with underground lines than with overhead lines.

Jacobi's work in telegraphy must be considered as being of an experimental nature, however, for it was not until 1853, after Siemens and Halske introduced their system, that a semaphore telegraph line between St. Petersburg and Kronstadt was replaced by an electrical one.

Efforts were also made in England to work out a needle telegraph using a binary code system. In March 1836 William F. Cooke, the son of an English anatomist, attended a lecture at the University of Heidelberg where he saw Prof. G. W. Muncke demonstrate an electrical telegraph[18] (fig. 17). Muncke, the chairman of the meeting at Bonn at which Schilling had exhibited his apparatus, had become so interested in Schilling's device that he had sought and obtained permission to have a 3-needle model of this telegraph made. Cooke copied Muncke's model,

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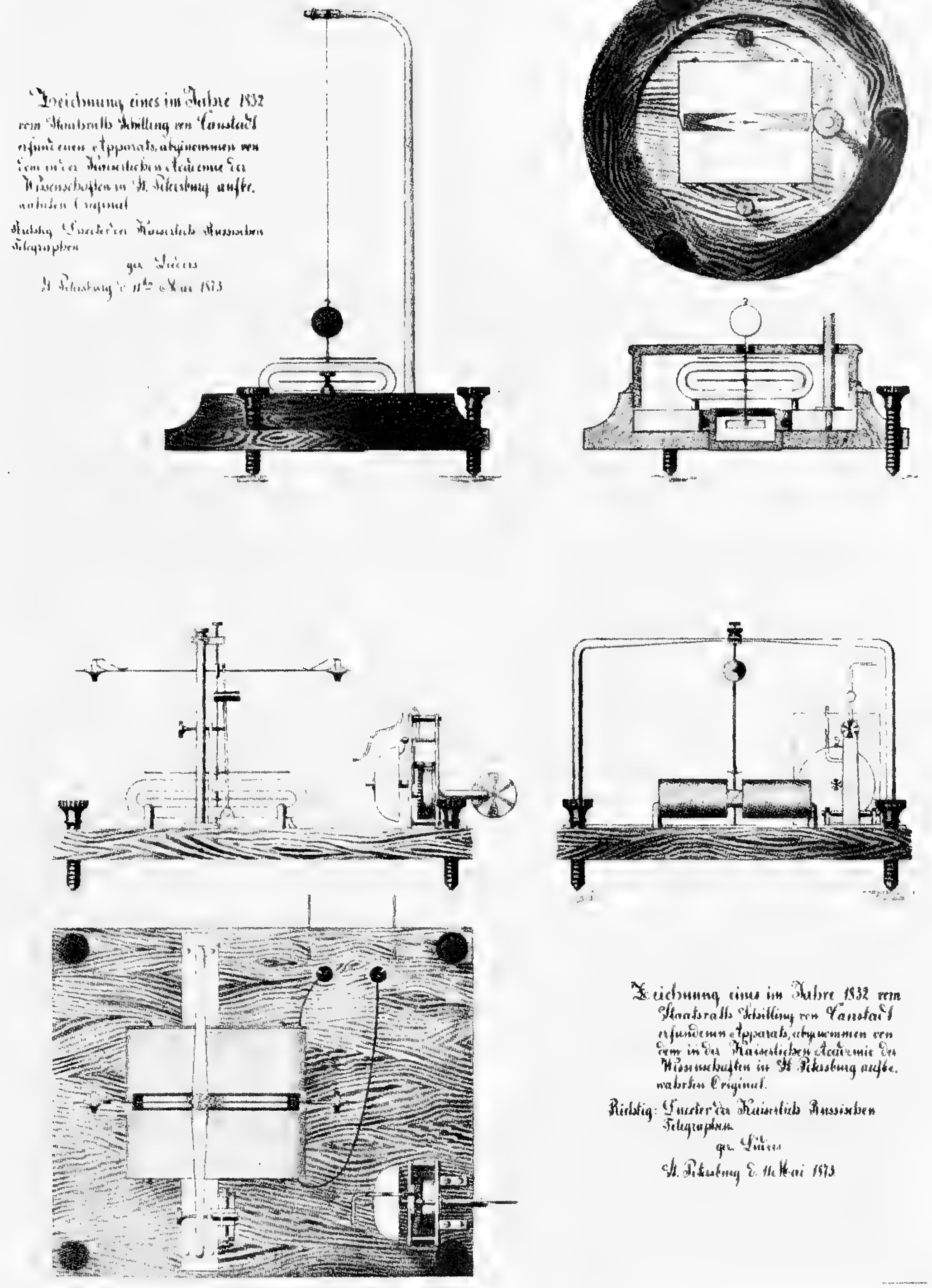
[17] M. I. Radovskii, *Boris Semenovich Iakobi*, Leningrad and Moscow, 1953; Akademia Nauk SSSR, Komissiia po istorii fiziko-matematischeskikh nauk, *Boris Semenovich Iakobi: Bibliograficheskii ukazatel*, compiled by M. G. Novlianskaia under the editorship of K. I. Shafranovskovo. Moscow and Leningrad, 1953.

[18] W. F. Cooke, *The Electric Telegraph: Was It Invented by Professor Wheatstone?*, London, 1857, 2 vols.; Latimer Clark, "Sir William Fothergill Cooke," *Journal of the Society of Telegraph Engineers*, 1879, vol. 8, pp. 361–397.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Richtig: Director der Kaiserlich Russischen
Telegraphen
gez. Lüders
St. Petersburg d. 11ten Mai 1873
Zeichnung eines im Jahre 1832 vom
Staatsraths Schilling von Canstadt
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dem in der Kaiserlichen Academie der
Wissenschaften in St. Petersburg aufbe-
wahrten Original.
Richtig: Director der Kaiserlich Russischen
Telegraphen
gez. Lüders
St. Petersburg d. 11. Mai 1873

FIGURE 14.—Schilling's basic elements for his 1832 telegraph (needle galvanometer and call alarm). From E. Feyerabend, *Der Telegraph von Gauss und Weber . . .*; Berlin, 1933, p. 21.

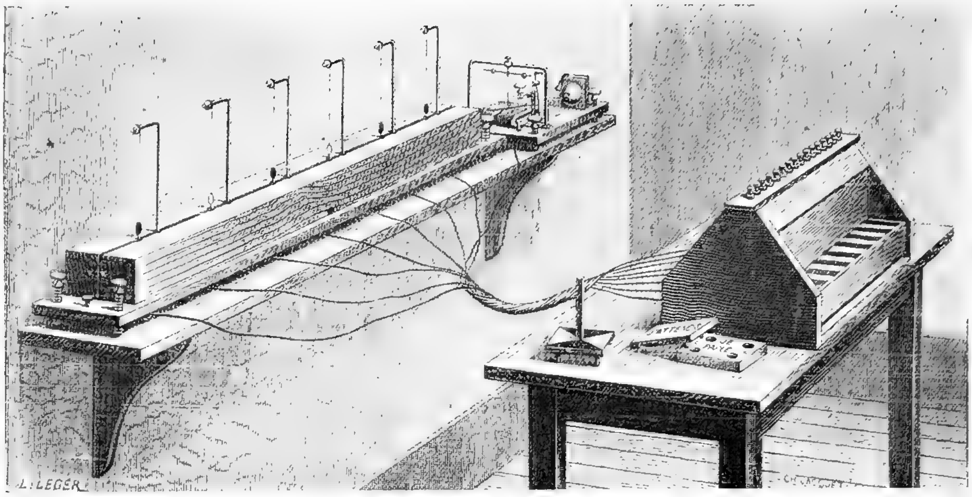

FIGURE 15.—Schilling's 6-needle telegraph and alarm as exhibited at the Paris International Electrical Exhibition of 1881. From *La Lumière électrique*, 1883, vol. 8, p. 337.

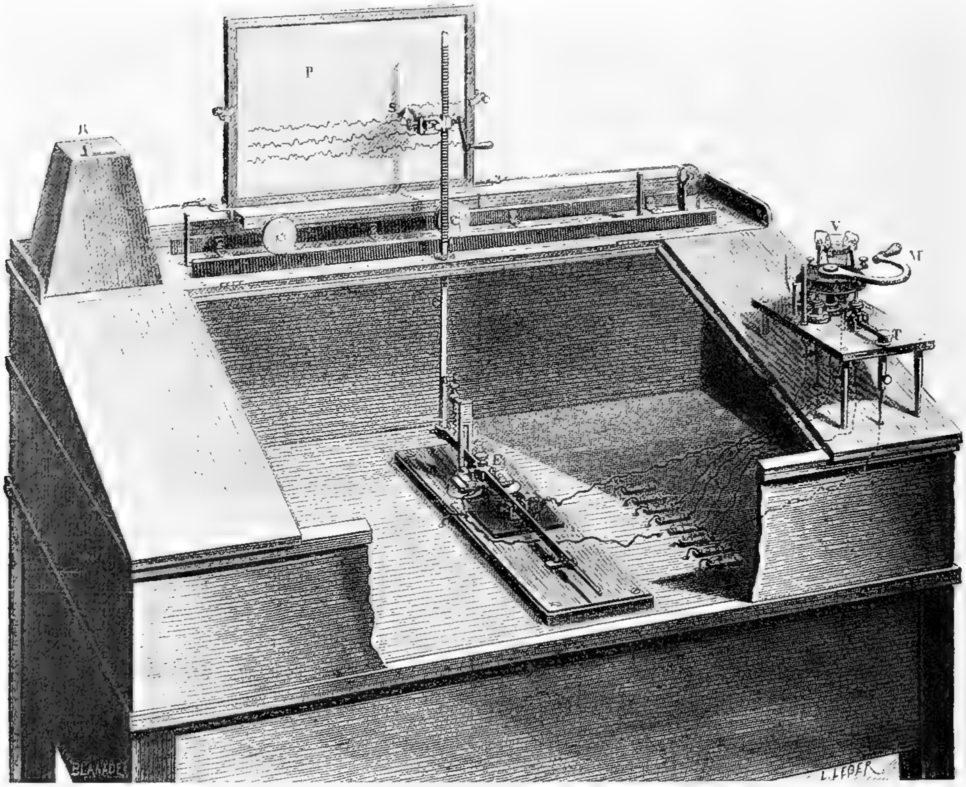

FIGURE 16.—Jacobi's recording telegraph of 1839 as shown at the Paris International Electrical Exhibition of 1881. From *La Lumière électrique*, 1883, vol. 8, p. 425.

believing it to be a reproduction of Gauss' telegraph, and returned to England in April with the intention of transforming his model from a piece of lecture demonstration apparatus into a commercial instrument.

After spending the summer of 1836 working on the needle telegraph, as well as on an unsuccessful synchronous telegraph discussed below, Cooke interested the Liverpool and Manchester railroad in trying his needle telegraph for communications through a railroad tunnel at Liverpool. However, Cooke soon discovered that his instrument, while it would work in the space of a laboratory, would not work over a mile-long line.

Since Cooke was neither a professional scientist nor an instrument-maker, he sought technical assistance from several prominent men, including Michael Faraday. Finally, in February 1837, he met Charles Wheatstone,[19] who was professor of experimental physics at King's College, London. Several years previous to the time Cooke met him, Wheatstone, with the ultimate intention of devising an electrical telegraph, had been investigating the distant transmission of electrical forces. In 1834 Wheatstone had been successful in sending signals through a reel of wire several miles long and was convinced that this newly discovered physical force was capable of being used for communication. In June 1836 Wheatstone had proposed a needle telegraph, the essential part of which used what he called a "permutating keyboard" that could send 30 different signals over six wires. However, Wheatstone had run into the same difficulty as Cooke had—that of transmitting signals over a long line—and the two men decided to tackle their problems together. Wheatstone and Cooke added to their system a sensitive relay that needed to move only 1/20 inch in order to actuate an alarm, but the main problem of transmitting signals to a distance remained unsolved.

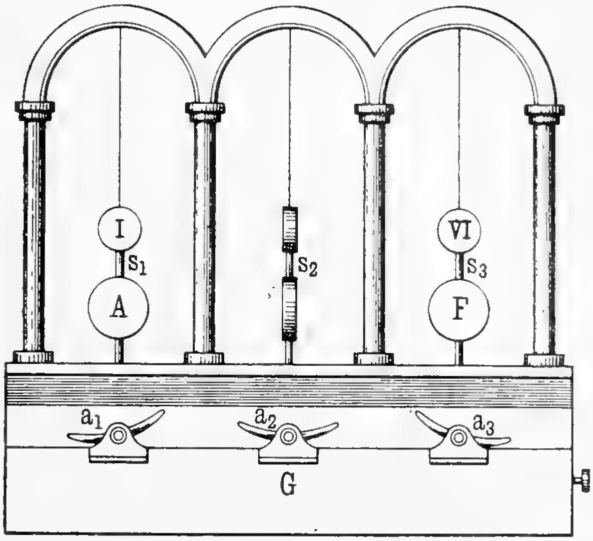

FIGURE 17.—Muncke's 3-needle copy of Schilling's telegraph. From T. Karass, *Geschichte der Telegraphie*, Braunschweig, 1909, p. 136.

During a trip to Europe in 1837 Joseph Henry had visited a number of laboratories, that of Wheatstone, among others. Among the topics Henry discussed during a visit to Wheatstone's laboratory were the different properties of quantity and intensity electromagnets, and of how an intensity electromagnet and battery on a very long circuit had been used at Princeton to actuate a quantity electromagnet and battery on a local circuit. Possibly as a result of such a discussion, within a few weeks following Henry's visit to their laboratory Wheatstone and Cooke solved their difficulties in the transmission of telegraph signals over long distances. In May 1837 they applied for a patent on their 5-needle invention, which included a call alarm based on a relay and local circuit (figs. 18, 19, 22). This British patent (7390) was obtained on June 12, 1837. The transmitter of the Wheatstone-Cooke telegraph [20] was a set of five tapper keys that acted as switches. The various keys could indicate the various letters by moving different combinations of needles to left and right positions.

Wheatstone and Cooke's instruments were tested with some success in July 1837 on a 1.4-mile line that ran along the London and Birmingham railway between Euston Square and Camden Town. The 5-wire line was mounted on blocks of wood, and the whole was covered with tar and buried in the ground along the railroad tracks. However, mechanical difficulties, the expense of installation, and the problem of proper insulation prevented further application of this method for a time.

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[19] *Proceedings of the Royal Society of London*, 1876, vol. 24, pp. xvi–xxvii (obituary); *Minutes of Proceedings of the Institution of Civil Engineers*, 1876, vol. 47, pp. 283–297 (obituary); *Magazine of Popular Science and Journal of the Useful Arts*, 1837, vol. 3, p. 110.

[20] "Wheatstone and Cooke's Electric Telegraph," *Mechanics' Magazine*, London, August 1, 1840, vol. 33, pp. 161–170; W. H. Preece, "Communication," *Journal of the Institution of Electrical Engineers*, 1897, vol. 26, pp. 633–635.

On April 18, 1838, Cooke secured British patent 7614 for a much simpler form of the needle telegraph than the one he had patented with Wheatstone the preceding year. This telegraph (figs. 20, 22) was a 5-wire system that still used the five keys to transmit the signal combinations but it required only two needles to indicate the letters of the alphabet. The speed of transmission was about 30 letters per minute. This telegraph was first used on a 13-mile line that was set up in May 1838 in order to control traffic on that part of the Great Western railway that ran from a borough of London (Paddington Station) to West Drayton. The transmission lines were initially placed in iron tubes 6 inches from the ground, but these lines proved to be unsatisfactory, and the inventors soon decided to use bare wire supported by insulators on telegraph poles.[21]

In 1842 the telegraph line of the Great Western railway was extended five more miles so that it ran past West Drayton to Slough. Other lines were soon put up, and by 1844 the Yarmouth and Norwich railway was dispatching trains by telegraph; London was in telegraphic communication with Dover by 1846 and with Edinburgh by 1848.

Wheatstone and Cooke devised, in 1845, a single-needle, 2-wire system (figs. 21, 22) over which the average skilled operator could transmit about 25 words per minute (British patent 10655, May 6, 1845). Either two tapper keys or a single drop handle was used to make the signal combinations. This telegraph was popular in England until about 1900 and was used for railway lines or telegraph offices where the traffic was heavy but not enough to warrant mechanization.

The publicity attendant on the capture of a murderer through a telegraph message [22] in 1845 attracted the attention of the public to the new invention, and it rapidly changed from a curious novelty to a necessary means of communication. By the following year the British government was seriously considering a

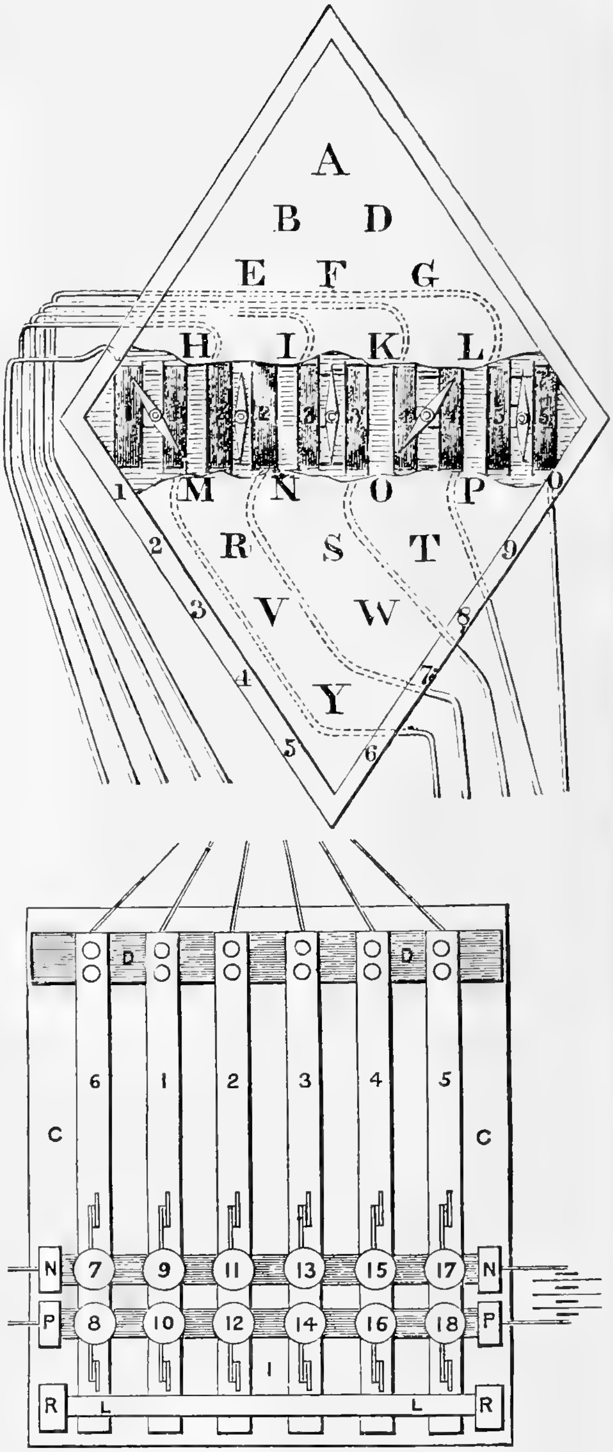

FIGURE 18.—Wheatstone and Cooke's 5-needle telegraph receiver (*top*) and transmitter of 1837. Two keys on the transmitter had to be depressed to select a given letter. From R. Sabine, *The History and Progress of the Electric Telegraph*, London, 1872, pp. 44–45.

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[21] "Wheatstone's Electric Telegraph," *Mechanics' Magazine*, London, August 11, 1838, vol. 29, p. 320; "Galvanic Telegraph," *Mechanics' Magazine*, London, October 20, 1838, vol. 30, p. 48; "The Galvanic Telegraph at the Great Western Railway," *Mechanics' Magazine*, London, September 7, 1839, vol. 31, p. 432; Francis Whishaw, "The Electric Telegraph—Mr. Cooke's Improved System as Applied to the Great Western Railway," *Mechanics' Magazine*, London, June 3, 1843, vol. 38, pp. 467–469.

[22] *Illustrated London News*, November 28, 1846, p. 339

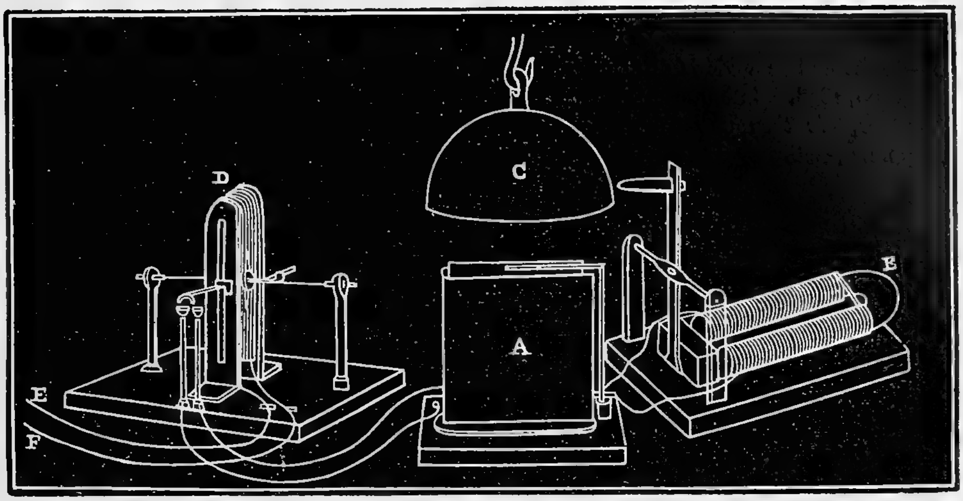

FIGURE 19.—Wheatstone and Cooke's local circuit (including relay and call alarm) for their 1837 telegraph. From G. B. Prescott, *History, Theory, and Practice of the Electric Telegraph*, Boston, 1860, p. 414.

proposal to connect all government buildings in England by a network of telegraph lines. The telegraph system between London and Slough was the first one in England to be opened to public service. The effectiveness of communicating by telegraph was proved during the troubled times of 1848 and during the Crimean War. In the 1850's telegraph lines spread rapidly throughout the continent and Great Britain, and by April 1855 London could communicate directly with Sebastopol.

Wheatstone and Cooke also invented another kind of telegraph instrument, known as the dial telegraph. The first version of this system, worked out by Cooke in 1836, was based upon two synchronous mechanical clocks, the one at the transmitting station indicating the same letter as the one at the receiving station. The transmitting station closed the circuit and permitted the lettered dial on both clocks to turn until the letter desired was indicated at the transmitter; whereupon the circuit was opened and the clocks stopped. Since the clocks were synchronized, the receiving one would stop at the same letter as the transmitting one. The transmitting station would then perform the same operations for the next letter and so on.

This synchronous system was difficult to reduce to practice, so Wheatstone and Cooke patented another version of a dial telegraph on January 21, 1840 (British patent 8345). In this case the dial at the receiver was driven by the transmitting dial instead of being controlled in its motion at the receiving station. Moving an indicator over the dial at the transmitting station sent a number of pulses down the line according to the number of letters passed over. These pulses released an escapement, allowing a weight-driven pointer to turn until the desired letter was indicated. This system was called the "step-by-step" dial telegraph (figs. 23, 24). The speech by Queen Victoria that opened Parliament in 1845 was sent at a rate of five words per minute by this system.[23] In 1858 Wheatstone modified the dial telegraph by using a magneto to provide the pulses (British patent 1241, August 2, 1858). This form of the dial instrument was quite popular with the British for the remainder of the 19th century. The ABC instrument (fig. 25), as Wheatstone's dial telegraph usually was called, had an average speed of about five words per minute; it was used to connect small towns where traffic was light and that were on circuits of not more than four stations. As late as 1920 there were more than 1,000 ABC units still in use. Apparently, the reason for the survival was the simplicity of operation.

Edward Davy, an English competitor of Wheatstone and Cooke, came very close to creating a practical

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[23] "The London and Portsmouth Electric Telegraph," *Mechanics' Magazine*, London, February 8, 1845, vol. 42, p. 96.

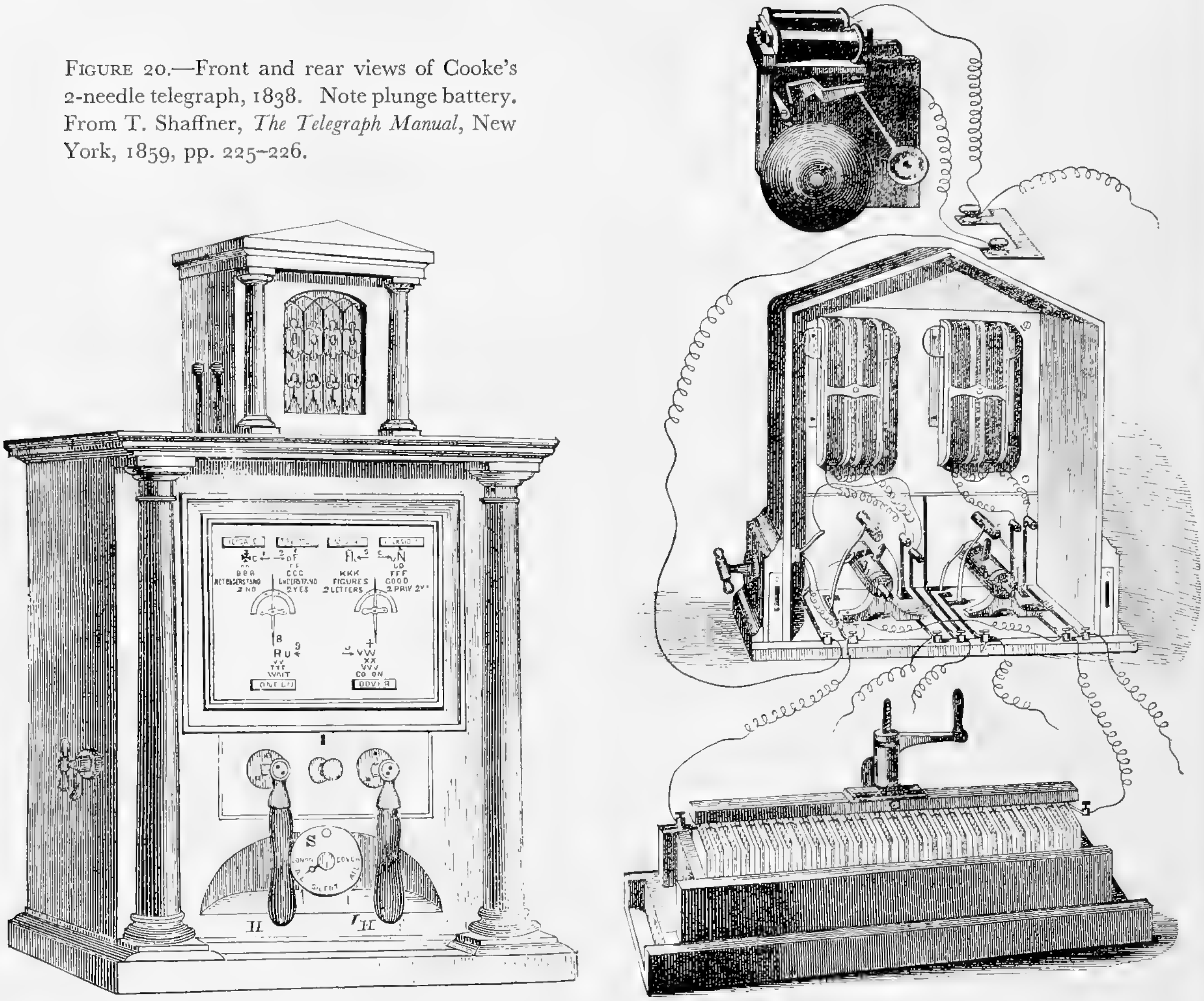

Figure 20.—Front and rear views of Cooke's 2-needle telegraph, 1838. Note plunge battery. From T. Shaffner, *The Telegraph Manual*, New York, 1859, pp. 225–226.

telegraph system.[24] Davy's first telegraph (1836) was a very crude electrostatic device with 26 wires—one for each letter of the alphabet. However, this inventor's experimentation developed rapidly and had progressed so far by the beginning of 1837 that he was making successful tests on a needle telegraph through a mile of wire in Regent's Park. Later in that year Davy filed a caveat for an 8-wire needle telegraph that included a relay. A working model of this was shown in December 1837 at the Belgrave Institute in London. This device had a keyboard of 12 keys that actuated screens that uncovered the appropriate letters.

In 1838 Edward Davy patented an instrument that required two wires and a common return to actuate a combination needle and electrochemical telegraph (British patent 7719, July 4, 1838). The needles served as relays to close a local circuit, and a chemical decomposition was thus produced on a treated fabric; combinations of marks and spaces indicated the desired letter. In spite of much ingenuity and a considerable understanding of the electrical problems involved, Davy never created an invention that was brought to commercial application. Personal matters forced him to leave England in 1839, just at the time when the major problems of his telegraph had been worked out and when it might have been possible for him to make a commercial success of his invention.

Alexander Bain of Edinburgh was more successful than Davy as a competitor of Wheatstone and Cooke.

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[24] J. J. Fahie, *History of Electric Telegraph to the Year 1837*, London, 1884, pp. 349–447, 516–529.

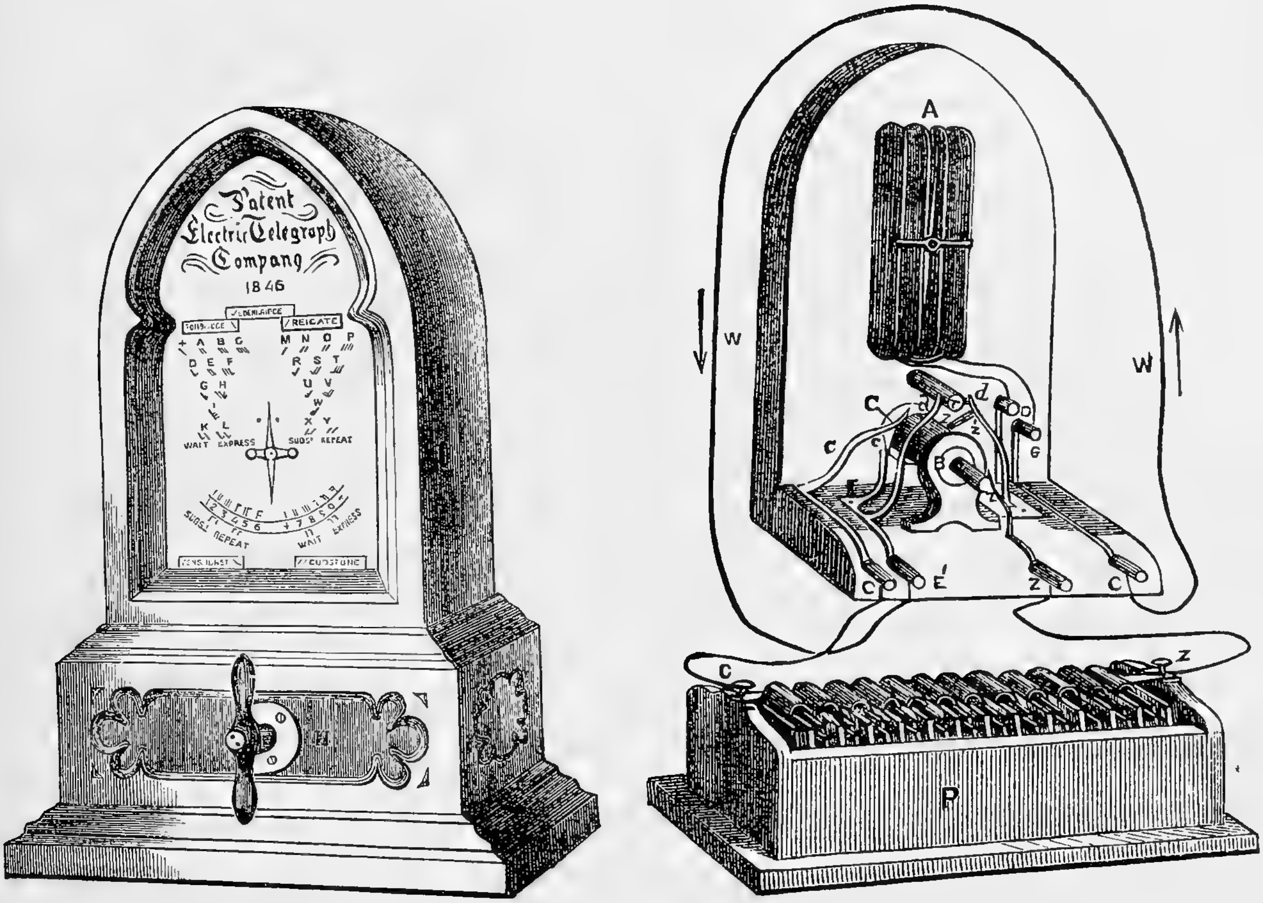

FIGURE 21.—Front and rear views of Wheatstone and Cooke's single-needle telegraph, 1845. Note trough battery. From T. Shaffner, *The Telegraph Manual*, New York, 1859, pp. 222, 225.

Like Davy, Bain also revived the idea of an electrochemical telegraph.[25] Bain originally used an ordinary Morse key to open and close the circuit at the transmitting end of the line. Chemically treated paper at the receiving end of the line recorded the action of the transmitter as dots and dashes. However, Bain's first application for a patent was not granted because of conflict with the Morse system. Bain then replaced the Morse key by an automatic one using punched paper. One machine prepared a paper tape by punching broad dots in two parallel rows in it, the various combinations of dots representing different letters. This tape was then passed between two styli and a metal roller, thereby opening and closing a circuit. The signals thus produced were recorded electrochemically at the receiving end as two similar rows of marks on another paper tape (fig. 26). The Bain system was widely used for a time, for it was capable of high-speed transmission. In 1850 it was used on a 187-mile line from London to Liverpool via Manchester. There were also about 1,200 miles of telegraph lines using this system in the United States in the same period (see fig. 27). However, defects in the crude machinery used in this system and interference on its lines produced spurious signals, and these faults eventually led to the replacement of the Bain telegraph by more efficient automatic signaling devices.

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[25] Alexander Bain, British patent 11480 (December 12, 1846); "Mr. Bain's New System of Electro-Telegraphic Communication," *Mechanics' Magazine*, London, June 19, 1847, vol. 46, pp. 590–592.

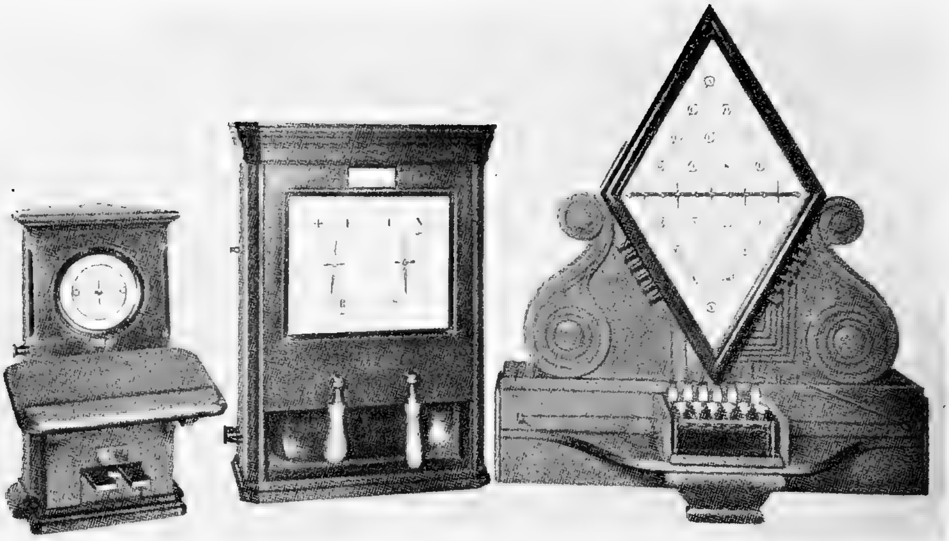

FIGURE 22.—Wheatstone and Cooke's single-needle, double-needle, and 5-needle telegraphs (left to right). From E. Feyerabend, *Der Telegraph von Gauss und Weber*, Berlin, 1933. p. 75.

Mechanization of the process of telegraphy brought about the instrument that eventually came to dominate those English telegraph lines where traffic was heavy. In the dial and the needle telegraph systems the speed of transmission depended on the rapidity with which the transmitter could be worked manually; further progress was made by replacing the manual key with Bain's paper tape. With Wheatstone's "automatic fast speed printing instrument" (fig. 28) of 1858 (British patent 1239, June 2, 1858), the operator first used a manual perforator to punch holes in a stiff paper tape which was then sent through a transmitter that was operated by this tape. The receiver recorded the message produced by this transmitter directly in the form of dots and dashes. Later the Wheatstone receiver produced punched tape similar to that used in the transmitter, and this tape was used to operate a printing machine. Depending upon the circuit, from 50 to 150 words per minute could be sent by this method, which was used in most English telegraph systems carrying heavy traffic during the 19th century.

Across the ocean in the New World, inventors were also seeking to apply electricity to communication devices. The first inventor actually to devise and set up an electric telegraph in the United States was Harrison G. Dyar.[26] Sometime between 1826 and 1828 Dyar worked out an electrochemical system whereby messages were recorded by sparks passing through treated paper and discoloring it. The dot and dash pattern formed by the discolorations indicated the message. Dyar's telegraph was tried out near a race track on Long Island by setting up poles with insulators to carry the wire that formed half the circuit and using the earth as a ground return for the other half. However, an unscrupulous partner, seeking a greater share in the expected gains, forced Dyar to drop his invention.

It was thus left to another American, Samuel F. B. Morse, an inventor-painter, to patent a practical electromagnetic system of telegraphy.[27] Instead of basing the receiving instrument upon the torsion of a needle in a galvanometer coil or upon electrolysis, Morse based his telegraph on the direct pull of an

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[26] Alfred Munroe, *Concord and the Telegraph*, Concord Antiquarian Society, Concord, Massachusetts, n.d. (around 1902).

[27] Alfred Vail, *The American Electro-Magnetic Telegraph: With the Reports of Congress, and a Description of all Telegraphs Known, Employing Electricity or Galvanism*, Philadelphia, 1845; *United States Reports*, 1835, vol. 56, pp. 62–137; Samuel I. Prime, *Life of Samuel F. B. Morse, LL.D., Inventor of the Electro-Magnetic Recording Telegraph*, New York, 1875; Edward L. Morse, ed., *Samuel F. B. Morse—His Letters and Journals*, New York, 1914, 2 vols.; Carleton Mabee, *The American Leonardo: A Life of Samuel F. B. Morse*, New York, 1943.

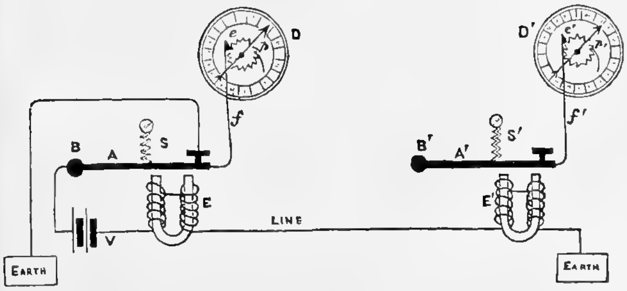

FIGURE 23.—Principle of Wheatstone and Cooke's "step-by-step" dial telegraph. From R. Sabine, *History and Progress of the Electric Telegraph*, London, 1872, p. 177.

electromagnet. The relative simplicity and ruggedness of the Morse system made it the most successful one in 19th-century America and, indeed, in the greater portion of the world outside the British Empire.

Morse apparently started thinking about an electrical telegraph upon his return from France in 1832, as the result of some conversations on board ship. A copy of Morse's notebook dealing with the subject of these conversations is preserved in the Museum of History and Technology of the Smithsonian Institution. The copy includes a sketch of what appears to be an electrochemical receiver similar to Dyar's and another sketch in which an electromagnet actuates an armature to move a style against a roll of paper (fig. 29). However, Morse's ignorance of electricity and his need to make a living prevented him from building a working model of his telegraph for several years.

In November 1835 Morse obtained a position at New York University as professor of arts and design. Since his duties there left him some free time, he began to reduce his ideas on telegraphy to practice. By the end of that year he had worked out a transmitter and an electromagnetic receiver. This device was literally a telegraph—an instrument for writing at a distance. Type was set up in a port rule or composing stick (fig. 30, top), which was then cranked through a device that opened and closed the circuit according to the hills and valleys on the type. At the other end of the line, this opening and closing of the circuit caused a wooden pendulum, suspended on an old canvas-stretcher, to swing back and forth, and, in so doing, to make zig-zag marks on paper tape (fig. 30, bottom). However, further progress was halted by the usual problem of telegraph inventors—

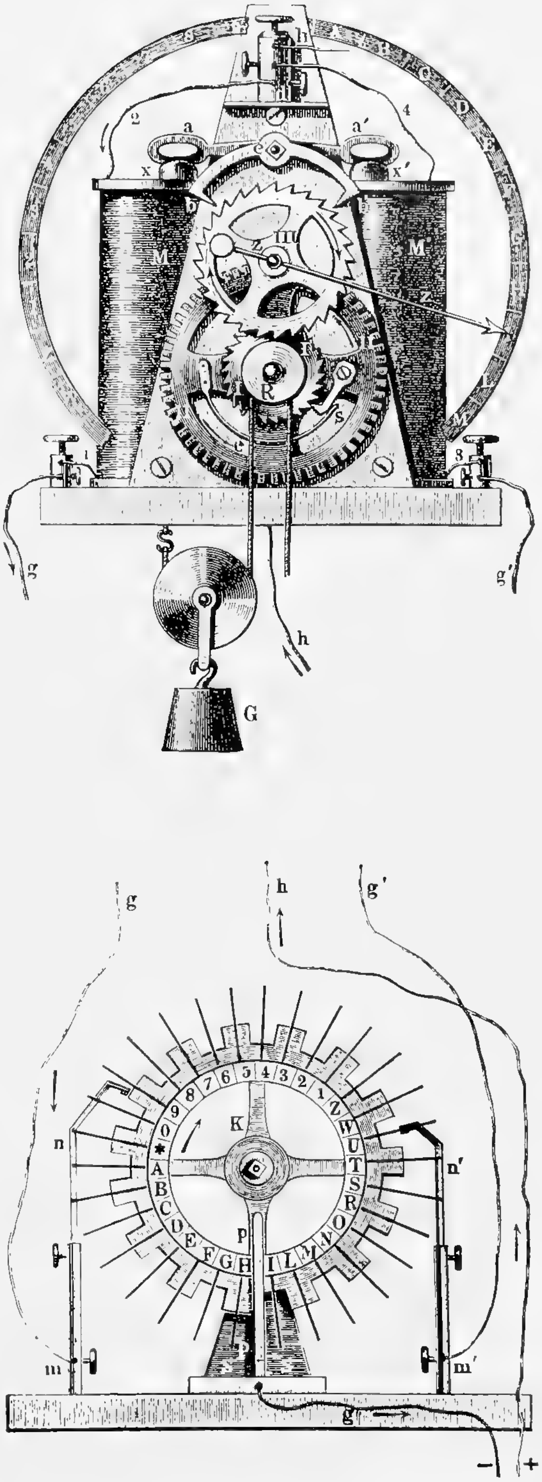

FIGURE 24.—Wheatstone and Cooke's "step-by-step" receiver (*top*) and transmitter of 1840. From E. Feyerabend, *Der Telegraph von Gauss und Weber*, Berlin, 1933, p. 78.

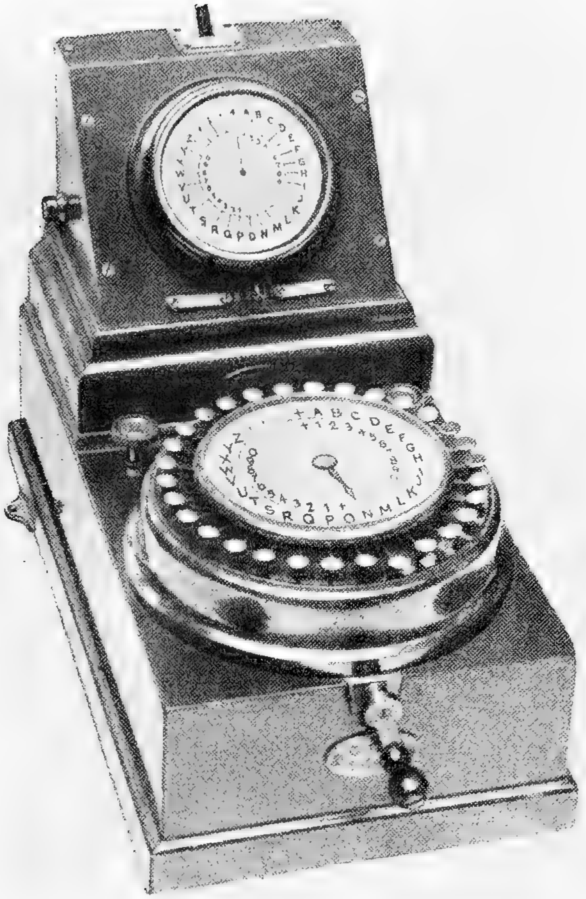

Figure 25.—Wheatstone's ABC telegraph, an instrument made in 1876 and based upon the patent of 1860. From E. Feyerabend, *Der Telegraph von Gauss und Weber*, Berlin, 1933, p. 79.

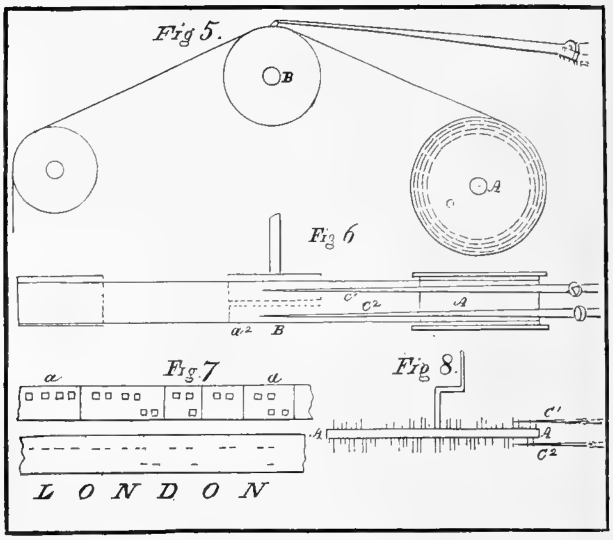

Figure 26.—Bain's electrochemical telegraph as used with punched paper tape. From L. Turnbull, *The Electro-Magnetic Telegraph*, Philadelphia, 1853, p. 38.

that of making the register work not only in the laboratory but over a distance. When Morse showed his instrument to his colleague, Leonard Gale, professor of chemistry at New York University in January 1836, it would not work through 40 feet of wire.

In a letter dated March 10, 1837, Levi Woodbury, Secretary of the Treasury, requested that proposals for a telegraph be submitted to the U.S. Government. Secretary Woodbury was of course thinking of the semaphore telegraph. When Morse heard of this letter, it stimulated him to do more intensive work on his own invention for fear of losing the Federal priority to others.

Sometime during the same spring, Morse confided to Gale that if he could work his telegraph through 10 miles of wire, he could work it around the world. For Morse had conceived that a relay (fig. 31) could

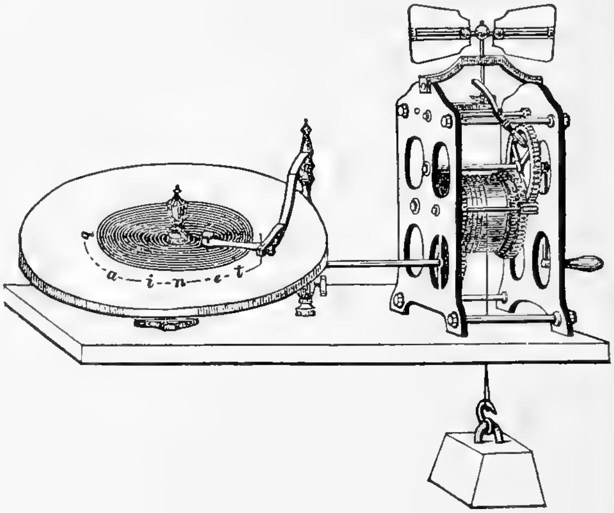

Figure 27.—American form of Bain's electrochemical receiver. From G. B. Prescott, *History, Theory, and Practice of the Electric Telegraph*, Boston, 1860, p. 129.

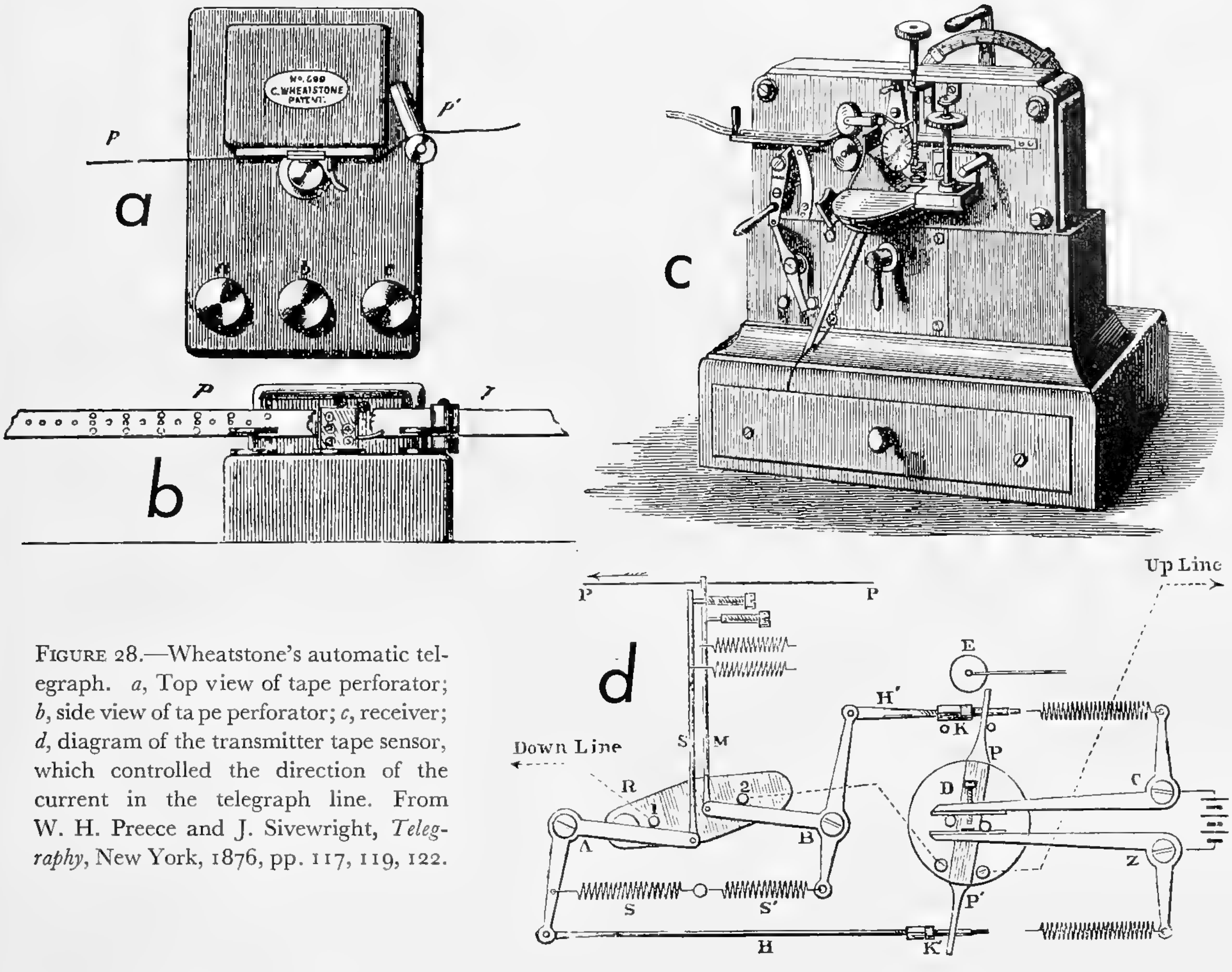

FIGURE 28.—Wheatstone's automatic telegraph. *a*, Top view of tape perforator; *b*, side view of tape perforator; *c*, receiver; *d*, diagram of the transmitter tape sensor, which controlled the direction of the current in the telegraph line. From W. H. Preece and J. Sivewright, *Telegraphy*, New York, 1876, pp. 117, 119, 122.

repeat the signal from one 10-mile circuit to the next. He was fortunate in his choice of a confidant, for Gale was familiar with Henry's work on electromagnets and spent the summer and fall of 1837 modifying Morse's electromagnet and battery so that they corresponded with Henry's devices. By September 2, 1837, Gale could signal through 1,700 feet of wire; by September 27, through one-half mile of wire; by October 24, through 3½ miles of wire; and by November 13, through the desired 10 miles of wire.

A chance visit to Morse on September 2, 1837, by a young man named Alfred Vail [28] made it possible for Morse to submit a proposal for a telegraph to the Government. Vail was fascinated by Morse's instrument and by Morse's idea for a relay to be used in conjunction with it. On September 23, Vail agreed to construct at his own expense a telegraph based upon Morse's design that was to be ready on January 1, 1838. For bearing the cost of patenting the invention, Vail obtained a share in it, thereby joining Gale who also had an interest in it. On September 27, 1837, Morse wrote to the Secretary of the Treasury explaining the advantages of his new means of telegraphy, and the following day applied for a caveat that was granted on October 3, 1837.

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[28] Franklin L. Pope, "The American Inventors of the Telegraph. With Special References to the Services of Alfred Vail," *The Century Illustrated Monthly Magazine*, April 1888, vol. 13, pp. 924–944; "Invention of the Electro-Magnetic Telegraph," *Electrical World*, 1895, vol. 26, pp. 71–73, 105–108, 129–132, 153–156, 181–185. (Articles and letters written by the sons of Morse and Vail also appear in this volume of *Electrical World*. Each comments on the relative contribution of his father to the invention of the telegraph.)

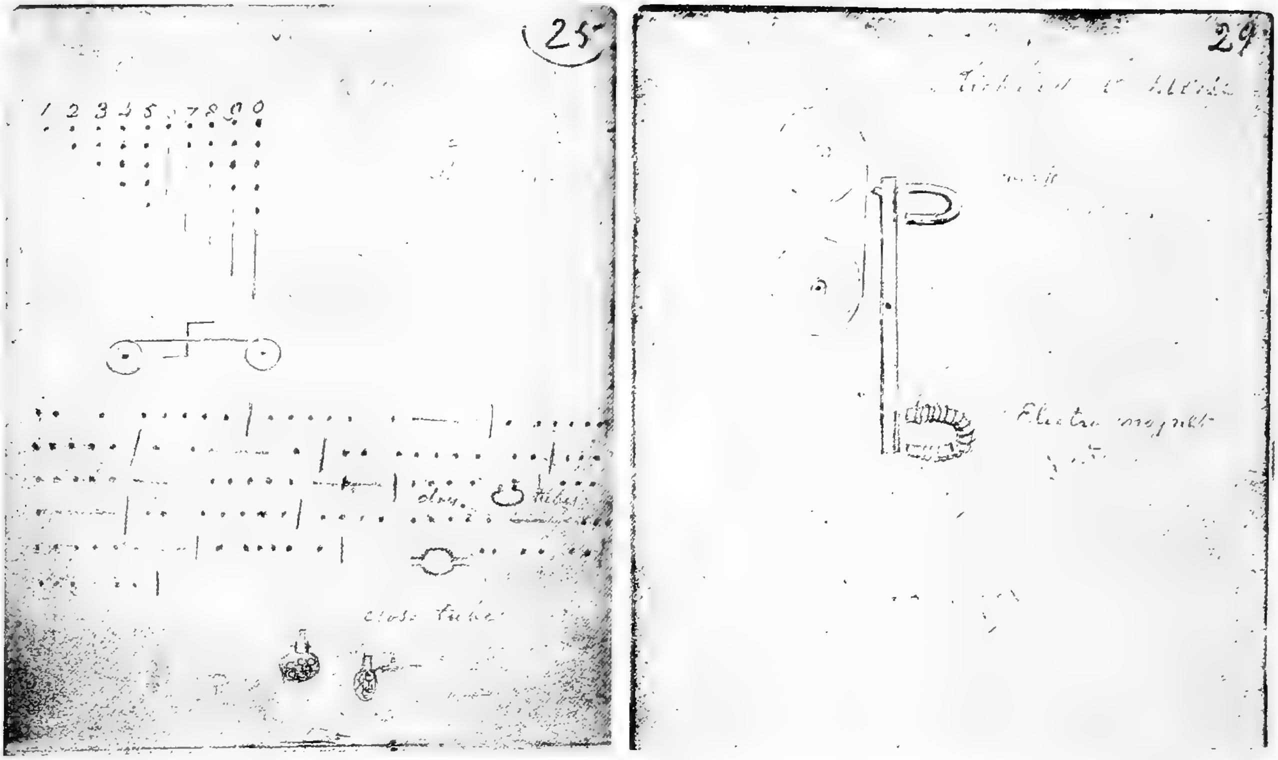

Figure 29.—Sketches on faded pages of Morse's notebook of 1832. At left, page with drawing of an electrochemical or electrostatic telegraph with combinations of signs; at right, drawing of an electromagnetic telegraph. From F. O. J. Smith's copy of Morse's notebook in the Smithsonian Institution. (*Smithsonian photos 17479, 44590–C.*)

For the remainder of 1837 Vail worked on the Morse invention at Morristown, New Jersey, where his father owned and ran the Speedwell Iron Plant, while Morse worked out a dictionary for the machine whereby numbers indicated words, as in the semaphore telegraph.

On January 6, 1838, the three partners had an instrument that could operate through 3 miles of wire. It differed somewhat from the register of the previous year in that the motion of the armature was now vertical instead of horizontal and resulted in dots and dashes on the tape instead of zig-zag marks. (It is difficult to determine the relative share of Morse and of Vail in these transformations since the partners agreed to ascribe all changes to Morse.) These dots and dashes formed the elements of an alphabetic binary code and were the ancestor of our present-day Morse code. On January 11, 1838, the partners made a public demonstration of their apparatus in Morristown using Morse's dictionary. Other demonstrations were made at New York University on January 24 and at The Franklin Institute on February 8. On February 20 the instrument was demonstrated to the Committee of Commerce of the U.S. House of Representatives. There the chairman of the committee, F. O. J. Smith, made a favorable report on the Morse invention.

Morse and F. O. J. Smith (who soon became another partner) spent the rest of 1838 and the beginning of 1839 in Europe in an attempt to obtain patents and financial backing abroad. Sometime during this period Vail sent Morse a new form of transmitter that was operated manually instead of being automatic. This was the "key" that has since become familiar to all. Although Morse made several successful demonstrations in Europe he did not find any backers, and legal difficulties prevented his obtaining any overseas patents.

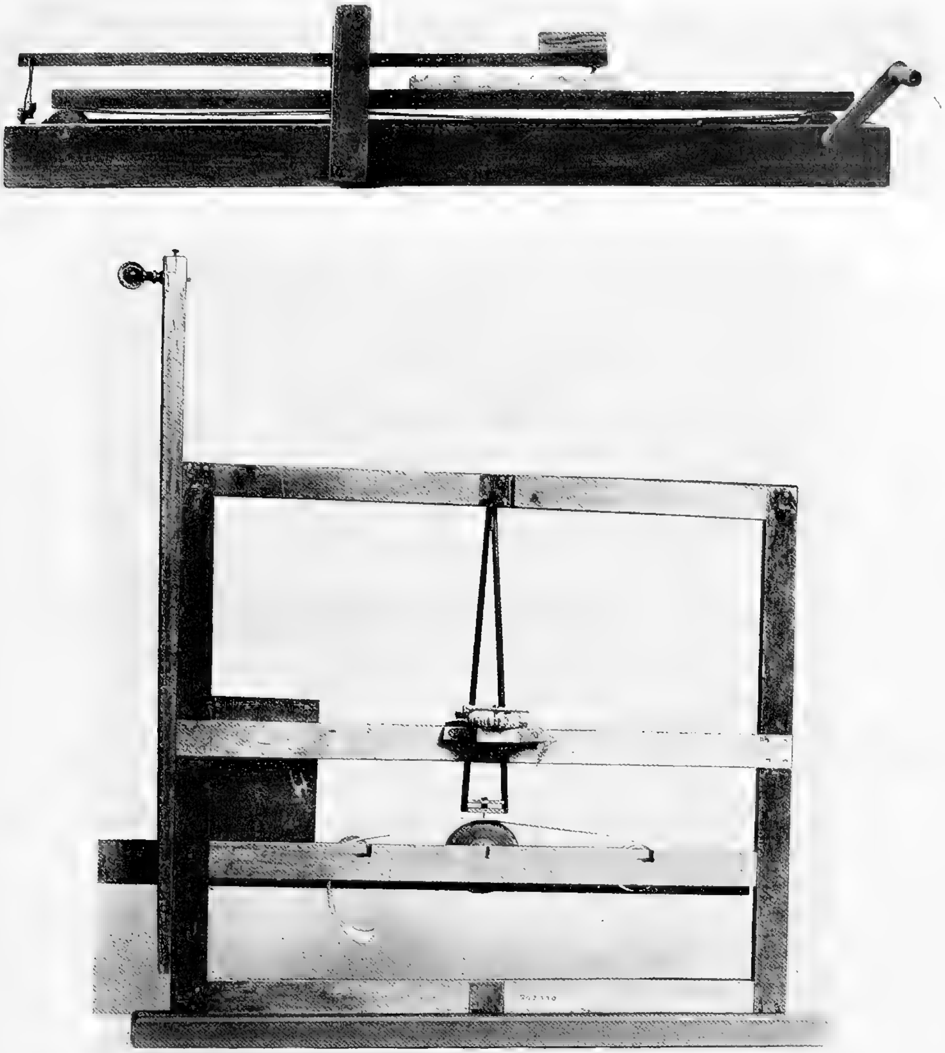

FIGURE 30.—Morse's canvas-stretcher receiver (*top*) and port-rule transmitter of 1837. It is difficult to fix the date of actual construction of this apparatus. Morse gave it to Western Union at some time prior to his death in 1872, and Western Union gave it to the Smithsonian Institution in 1896. (*USNM 181250, Smithsonian photos 13366 and 14593–A.*)

After returning to the United States, Morse asked that his patent be issued, which it finally was on June 20, 1840, as U.S. patent 1647 (reissued in 1846 and 1848). However, in spite of the earlier favorable report by a committee of Congress, Morse was unable to obtain funds from the Government until March 3, 1843. The partners decided to use the $30,000 appropriated by Congress to set up a line along the 40 miles of the Baltimore and Ohio Railroad running between Baltimore and Washington. After an unsuccessful attempt to lay a subterranean line, they had the line placed on glass insulators on poles. The first message was sent on May 24, 1844, at a speed of about 30 letters per minute. (For the instrument used in these trials and for later devices of Morse and Vail, see figures 32–35.)

While Morse obtained a certain amount of publicity in Congress when he sent reports to Washington on the Whig and Democratic presidential nominating conventions in Baltimore, the lines in general

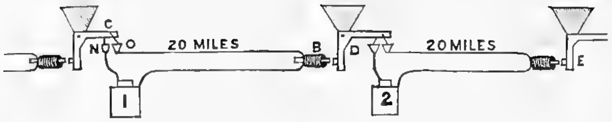

FIGURE 31.—Morse's relay plan of 1837. From J. Reid, *The Telegraph in America*, New York, 1879, p. 80.

carried practically no traffic. Little revenue from Morse's telegraph had come in by the end of the year; and when Morse offered to sell his invention to the Government, the offer was rejected.

In May 1845, Morse and his associates formed a private company, the Magnetic Telegraph Company, in order to exploit their invention. They immediately set about expanding their telegraph facilities and by June 1846 they could exchange messages between Washington and New York. The declaration of war between Mexico and the United States one month previous to this accomplishment gave additional impetus to the further expansion of the telegraph, and, from that time on, use of the telegraph grew rapidly in the United States.[29] Telegraph lines reached St. Louis by December 1847, and New Orleans by the following July.

The initial successes of the Magnetic Telegraph Company led to the establishment of a number of rival organizations. Some of these companies were formed for purely speculative purposes and many of these did not last, but a few survived by consolidating among themselves. Others were organized for the purpose of gathering and reporting news, and one of these companies was the New York Associated Press, formed in 1848 by several New York newspapers to provide a reliable source for domestic news. Unlike the British, the American railroad companies did not realize the value of this new invention for the dispatching of trains and for the coordination of train movements until the early 1850's. These two inventions, the railroad and the telegraph, worked together in the opening of the American West. A particularly energetic organization in this expansion was the Western Union Telegraph Company, which was formed in 1856 under the direction of Hiram Sibley who merged a number of existing facilities. By 1861 the telegraph system had reached California.

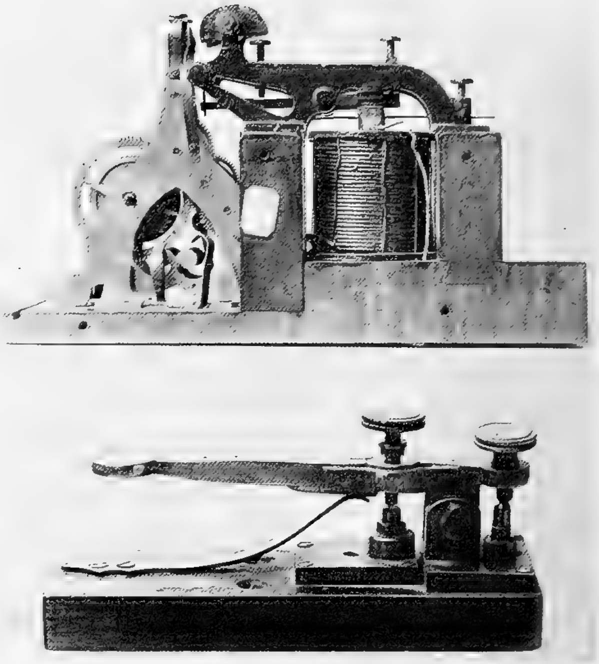

FIGURE 32.—The Morse-Vail telegraph. *Top*, original register used in the Baltimore-Washington trials of 1844, now at Cornell University, Ithaca, New York. (Smithsonian photo 29651.) *Bottom*, original telegraph key used in the mid-1840's, perhaps at the same time as the Washington-Baltimore trials. Alfred Vail's signature is impressed into the wooden base of both instruments. (*USNM 181411; Smithsonian photo 27979.*)

By the end of the 1840's, other telegraph systems in the United States were in competition with Morse's system, for his invention had finally proven to be a profitable one. One of these later systems was an improvement that Bain had worked out on his electrochemical telegraph (U.S. patent 6328, April 17, 1849). A more important competitor of the Morse system was the letter-printing telegraph. Vail had made detailed sketches of a printing telegraph as early as 1837 but had never patented it. In April 1846 Royal E. House of Vermont invented a printing telegraph whose transmitter (fig. 36) had a set of keys like those on a piano (U.S. patents 4464, 9505). There was one key for each letter of the alphabet. Each key produced a certain number of electrical impulses. At the receiving station these impulses advanced a type wheel until finally the letter that had been signaled by the transmitter was reached and was

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[29] James Reid, *The Telegraph in America*, New York, 1879; Robert L. Thompson, *Wiring a Continent: The History of the Telegraph Industry in the United States, 1832–1866*, Princeton, 1947.

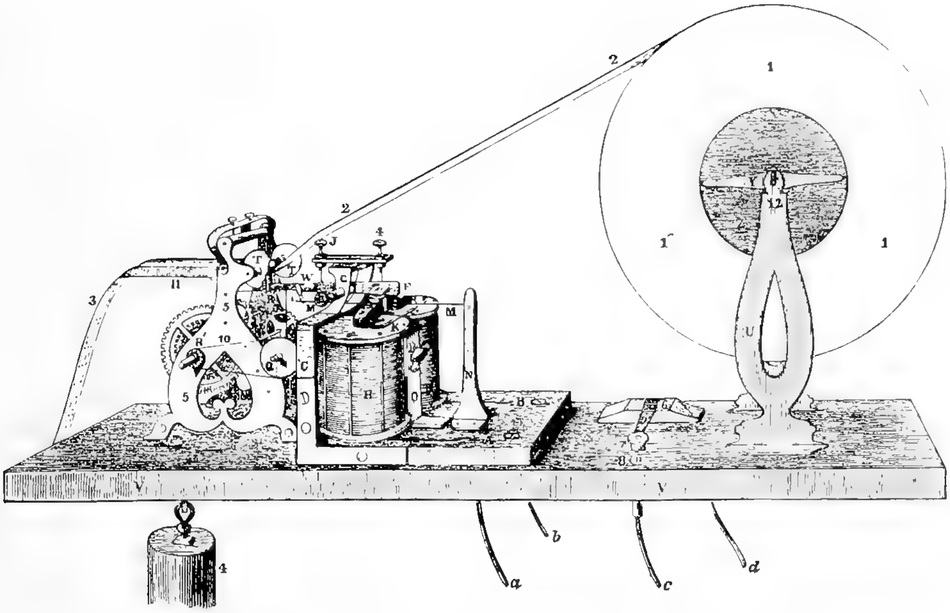

FIGURE 33.—Morse-Vail 1845 telegraph. From A. Vail, *The American Electro Magnetic Telegraph*, Philadelphia, 1845, p. 19.

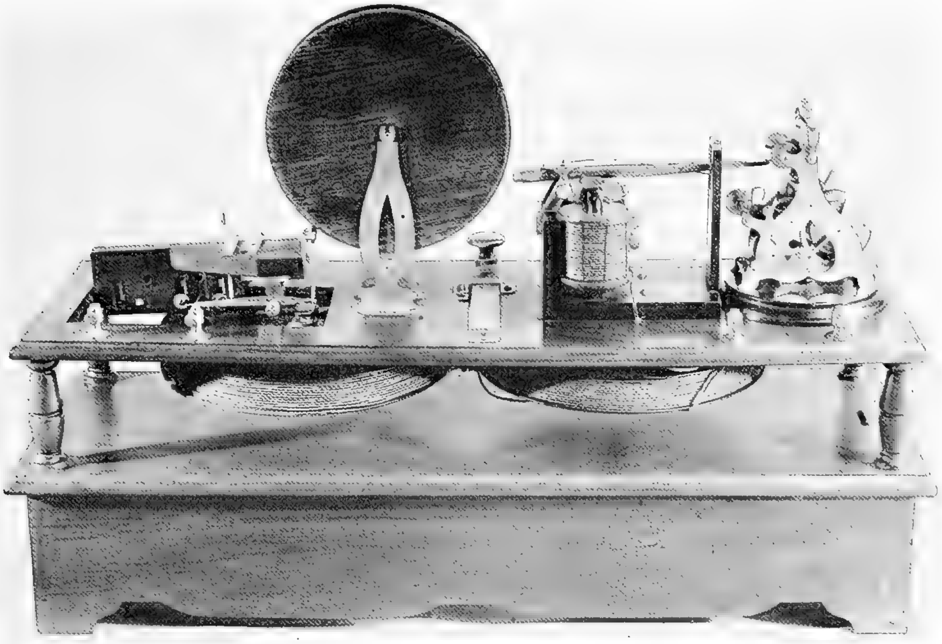

FIGURE 34.—Morse system relay, key, and register of about 1846 (reproduction made about 30 years later). (*USNM 180037; Smithsonian photo 45668.*)

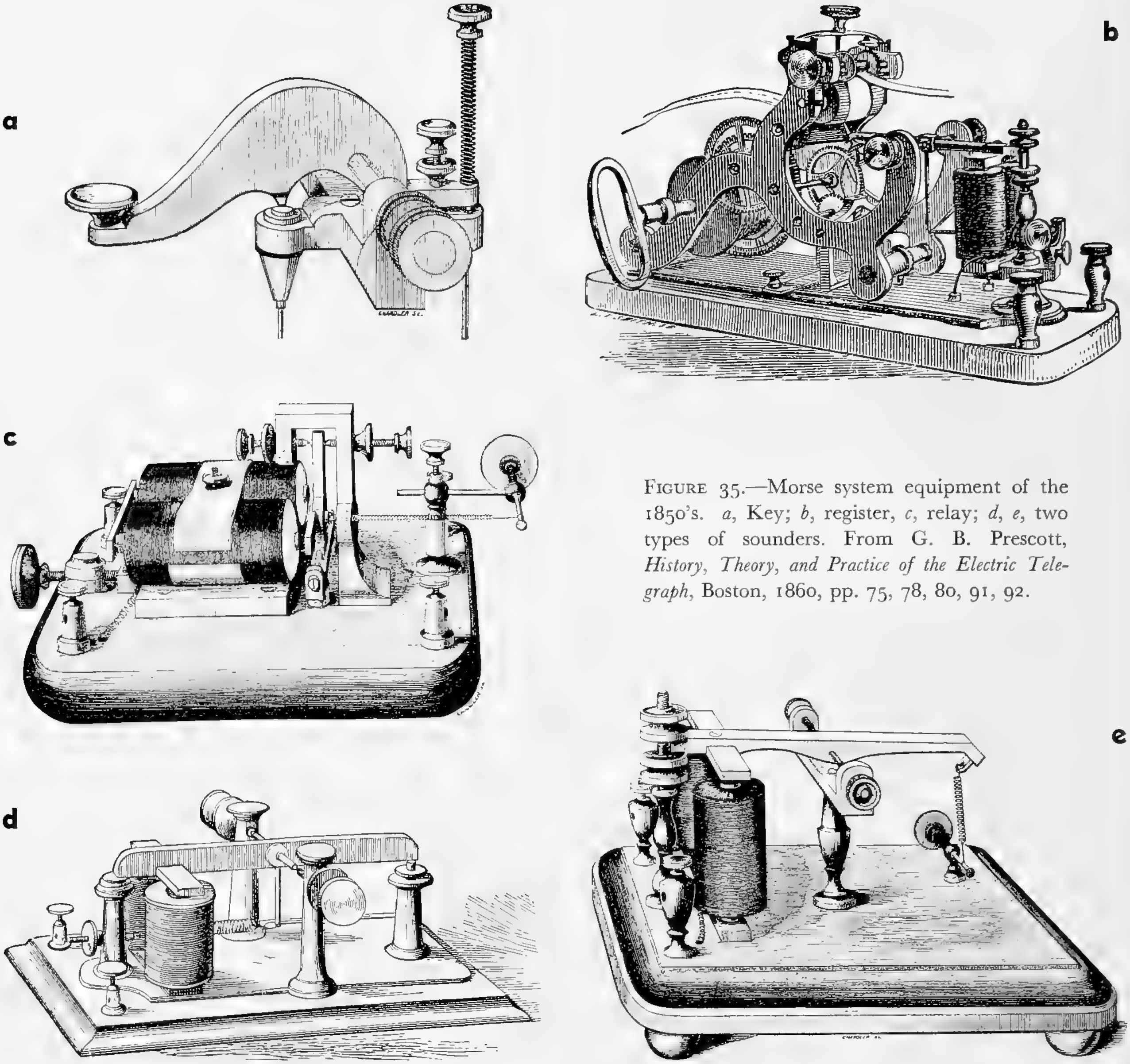

FIGURE 35.—Morse system equipment of the 1850's. *a*, Key; *b*, register, *c*, relay; *d*, *e*, two types of sounders. From G. B. Prescott, *History, Theory, and Practice of the Electric Telegraph*, Boston, 1860, pp. 75, 78, 80, 91, 92.

stamped on a paper tape. In the meantime the tape had been advanced to receive the next letter. The House machine was used extensively on short lines until it was replaced by a better system invented in 1856 by David Hughes, a professor of music in Kentucky.

Hughes' instrument (fig. 37) was based on synchronous movements of corresponding parts at transmitter and receiver. These movements were kept in synchrony by setting a vibrating spring so that it produced a musical note of a certain pitch. The House machine could not be used over very long lines, but it could send from 10 to 20 words per minute, while the speed attained by the Hughes machine was somewhat lower. However, the Hughes telegraph could be used over longer lines than could the House device, and, in its later modifications (fig. 38), the Hughes system was used on the continent of Europe as a printing telegraph until the turn of the century. The Wheatstone automatic telegraph was used for the same purpose in England.

Several years after the invention of the Hughes

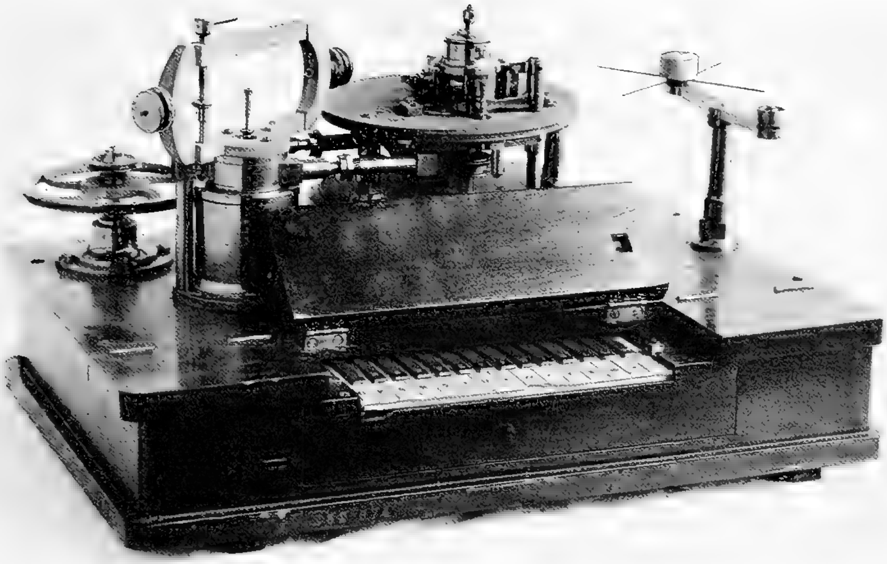

FIGURE 36.—Patent Office model of House's printing telegraph, U.S. patent 9505 (December 28, 1852). (*USNM 252674; Smithsonian photo 30396.*)

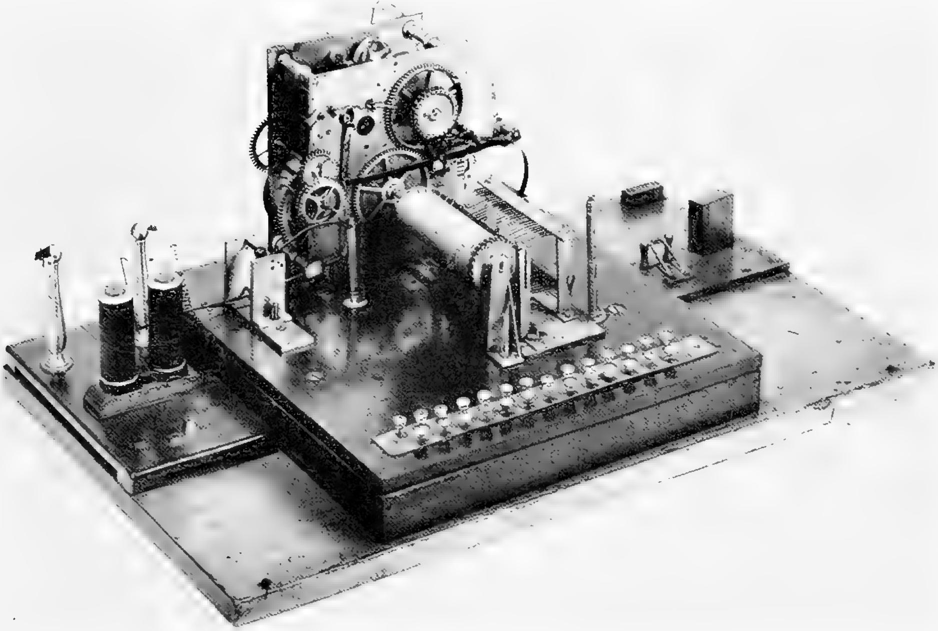

FIGURE 37.—Patent Office model of Hughes' printing telegraph, U.S. patent 14917 (May 20, 1856). (*USNM 252675, Smithsonian photo 46777–G.*)

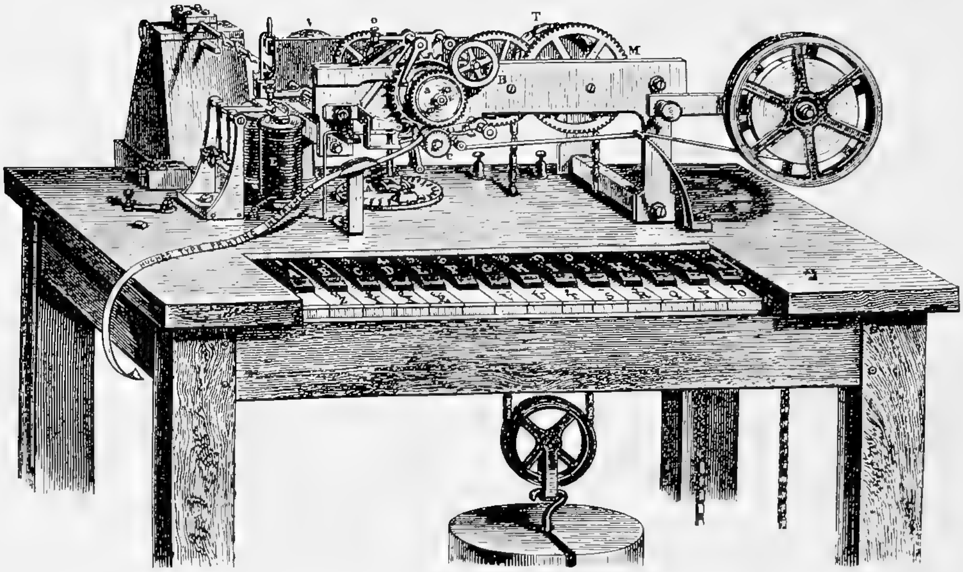

FIGURE 38.—European Hughes printing telegraph. From W. H. Preece and J. Sivewright, *Telegraphy*, New York, 1876, p. 89.

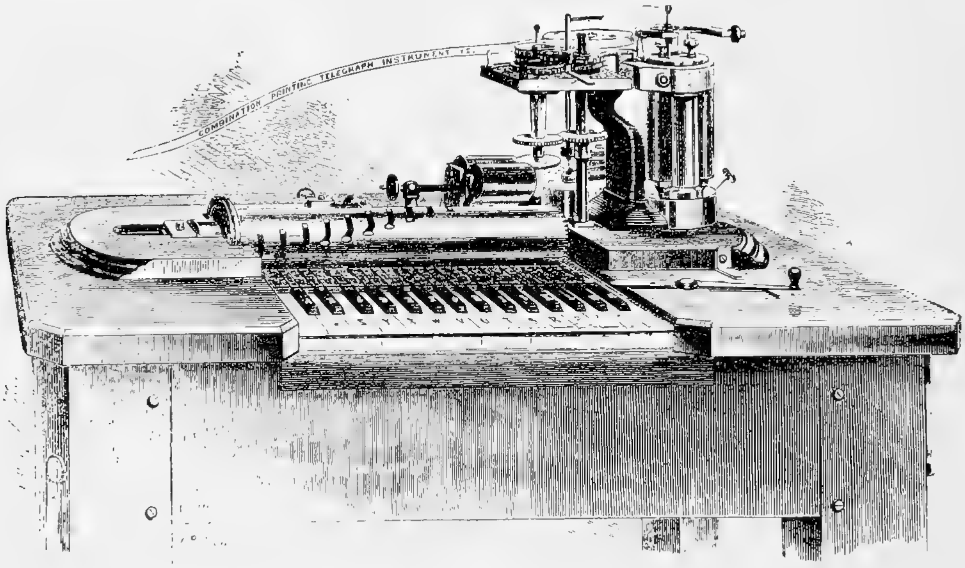
COMBINATION PRINTING TELEGRAPH INSTRUMENT

FIGURE 39.—Phelps' combination printing telegraph, U.S. patent 26003 (November 1, 1859). From G. B. Prescott, *History, Theory, and Practice of the Electric Telegraph,* Boston, 1860, frontispiece.

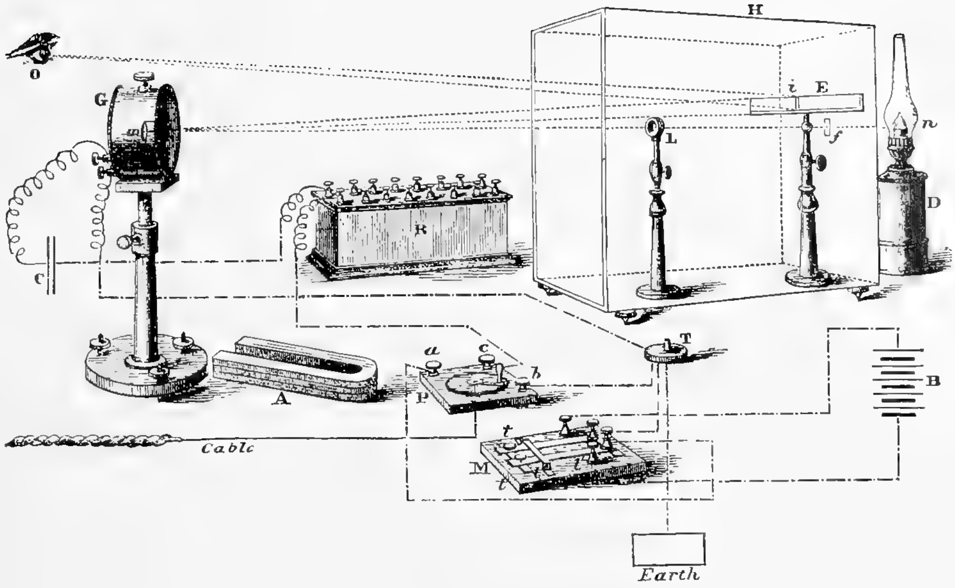

Figure 40.—Thomson's "speaking galvanometer" and transmitting key as used in marine cable telegraphy. From W. H. Preece and J. Sivewright, *Telegraphy*, New York, 1876, p.138.

machine, George M. Phelps[30] of Troy, New York, combined certain features of the House and the Hughes machines to produce the Phelps "combination telegraph" (fig. 39) that could initially send about 30 words per minute and that was constantly improved until it could send up to 60 words per minute. This combination machine, patented in 1859, had considerable success where traffic was sufficiently heavy to warrant the use of a rather complicated and expensive machine.

In addition to expanding the telegraph across continents, engineers and investors sought to join telegraph networks that ended at a coastline. In the 1840's numerous attempts were made to lay a cable under water, but this goal was not attained until gutta-percha was applied as underwater insulation.[31] C. V. Walker laid a successful gutta-percha cable along two miles of the English Channel in January 1849, and later the same year a similar cable was successfully laid under the Connecticut River, at Middletown. The brothers Jacob and John Brett laid a gutta-percha cable between Dover and Calais in 1850, but it remained in operation less than a day. Then the brothers manufactured another cable and placed armor over the gutta-percha. This cable was laid in 1851 and remained in operation for a decade. The success of this cable led to more submarine cables: England was joined with Holland and Ireland in 1853 and with India in 1864; among other cables laid in North America was the one joining Nova Scotia and Newfoundland in 1856.

One of the men involved in the laying of the Newfoundland cable was the retired businessman, Cyrus Field,[32] who saw that the cable across the Gulf of St. Lawrence might be the first step in the laying of a cable across the Atlantic. Several years before the Newfoundland cable was laid, a hydrographer had pointed out the existence of a submarine plateau between Ireland and Newfoundland. This plateau promised a natural advantage for laying an Atlantic cable. In 1856 Field enlisted Charles Bright and John Brett to join him in organizing the Atlantic Telegraph Company for the purpose of undertaking to lay a cable between Newfoundland and Ireland. By 1857 some 2,500 miles of armored gutta-percha cable had been manufactured, and the cable-laying ship started from Ireland at the end of the summer. However, the cable broke about 330 miles away from the starting point, and the project had to be postponed to the following year. It was not until the second attempt in 1858 that the cable was successfully laid; signals were sent through it for a few weeks, but then it failed.

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[30] George Phelps, U.S. patent 26003 (November 1, 1859); George B. Prescott, *History, Theory, and Practice of the Electric Telegraph*, Boston, 1860, pp. 144–155; *Electricity and the Electric Telegraph*, New York, 1888, 2 vols., vol. 2, pp. 642–647.

[31] C. Willoughby Smith, *The Rise and Extension of Submarine Telegraphy*, London, 1891; Charles Bright, *Submarine Telegraphs: Their History, Construction and Working*, London, 1898; G. R. M. Garatt, *One Hundred Years of Submarine Cables*, London, 1950.

[32] Charles F. Briggs and Augustus Maverick, *The Story of the Telegraph and a History of the Great Atlantic Cable*, New York, 1858; *Report of the Joint Committee Appointed by the Lords . . . of the Privy Council . . . and the Atlantic Telegraph Company to Inquire into the Construction of Submarine Telegraph Cables*, London, 1861; Henry M. Field, *The Story of the Atlantic Telegraph*, New York, 1892.

In addition to the considerable mechanical problem of contriving a submarine cable for the Atlantic Ocean and of successfully laying it along the bottom, there was also the electrical problem of the invention of a new kind of telegraph receiver. Obviously none of the commercial instruments of the time were able to work through a line thousands of miles long, and it was impossible to insert relays into the circuit of a line at the floor of the sea. Moreover, even if sensitive receivers were used, the line acted like a huge Leyden jar and smeared out the signal.

The problem of designing a new receiver for the Atlantic cable was solved by Prof. William Thomson—later Lord Kelvin.[33] In 1855 Thomson had published an article on signaling through submarine cables, in which he pointed out some of the problems that would have to be met. After joining the Atlantic Telegraph Company as one of the directors, Thomson turned his attention to finding a practical method of eliminating the difficulties in the detection of oceanic cable signals. The most sensitive detector known at that time was the needle galvanometer [34] as provided with a mirror, and it was upon this instrument that Thomson, in 1858, based a new telegraph receiver with a "speaking" galvanometer (fig. 40) that could be used on shipboard without being influenced by the rolling motion of the sea. C. F. Varley (1862) and C. W. Smith (1866) independently showed how the addition of a condenser to each end of the cable would insulate the cable and sharpen the signal, and thus counterbalance the loss of signal definition resulting from its passage through the cable. Later, in 1867,[35] Thomson patented the siphon recorder, which was able to furnish a permanent record of the message. In this siphon recorder, a mobile coil of wire about one pole of a stationary permanent magnet replaced the magnetic needle and fixed coil used in conventional galvanometers. Thomson's final (1871) form of galvanometer [36] was so sensitive that the current from a chemical cell (made from a silver thimble) could be detected after being sent across the ocean and back again. By the time these improvements in the cable system were worked out, two successful Atlantic cables had been laid.

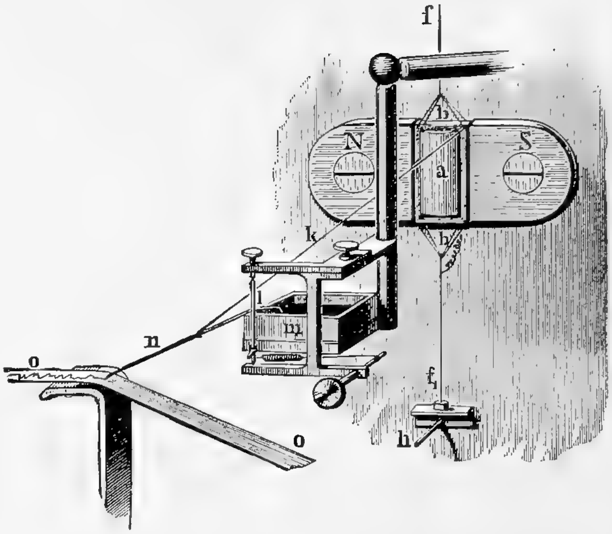

FIGURE 41.—Movement of Thomson's siphon recorder of 1871. From G. B. Prescott, *Electricity and the Electric Telegraph*, New York, 1859, pp. 459, 461.

In spite of the considerable monetary loss resulting from the breakdown of the first Atlantic cable, Cyrus Field did not become discouraged and in 1864 he was able to organize another company, which first attempted to lay a cable in 1865. This cable came within 660 miles of Newfoundland when it broke. By then it was too late in the year to undertake a relaying; however, in the summer of 1866 Field's company was successful. Moreover, the company was able to find and use the cable that had been laid the previous year, so that the net result was two cables under the Atlantic Ocean. These cables remained in use for a

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[33] Silvanus P. Thompson, *Life of William Thomson: Baron Kelvin of Largs*, London, 1910, 2 vols.

[34] William Thomson, British patent 329 (February 20, 1858).

[35] British patent 2147 (July 23, 1867).

[36] British patent 252 (January 31, 1871).

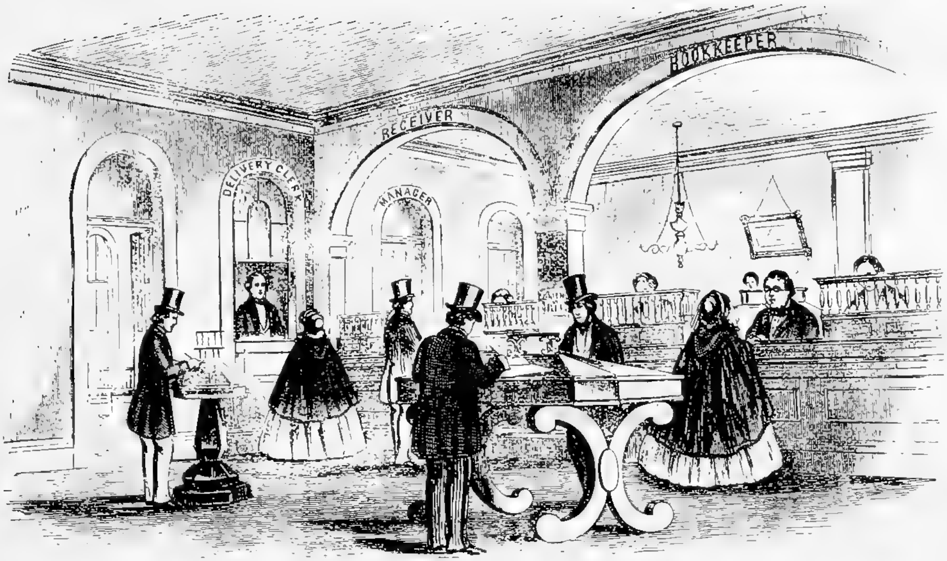
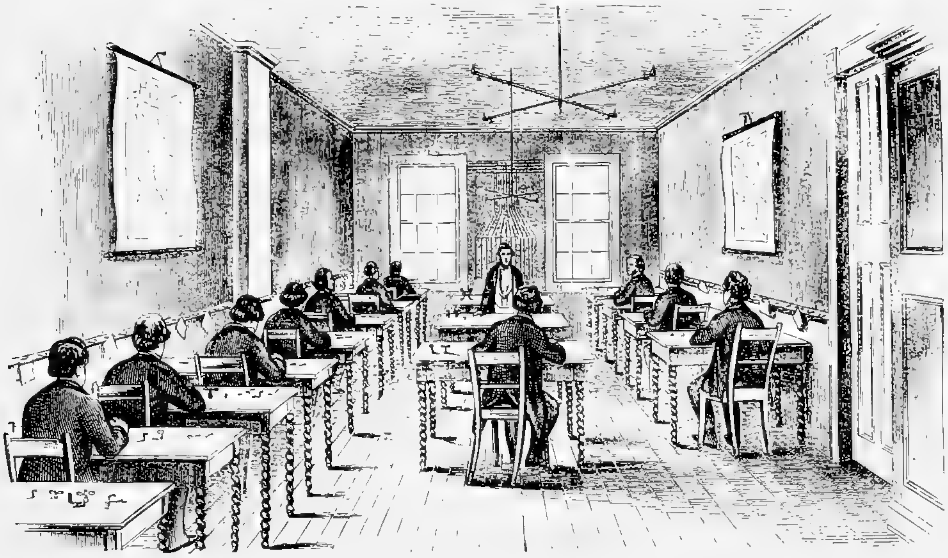


FIGURE 42.—American telegraph office (*top*) and operating room of the mid-19th century. From T. Shaffner, *The Telegraph Manual*, New York, 1859, pp. 459, 461.



decade before they went out of service, and by then others had been laid.

In addition to the submarine cable system, the land telegraphic system was also growing. By 1865 there were 16,000 miles of telegraph lines in Great Britain, 64,000 miles in France, and 28,000 miles in Prussia. In the United States the Civil War had interfered with the normal economic growth of business, but by the end of the war the three largest telegraph companies in the country had 83,000 miles of telegraph lines. (See figs. 42–45.)

In spite of the tens of thousands of miles of telegraph lines in the world, there never were enough to satisfy the ever-growing need for improved communications. Inventors sought to devise various multiple telegraph systems[37] by which a number of messages could be sent over a single line either simultaneously or in rapid succession. A system by which two messages could be sent simultaneously over the same wire was called duplex, and one over which four could be sent at the same time over the same wire (two in each direction) was called quadruplex. A system that could transmit a number of messages in rapid succession was originally called a multiplex system (fig. 46). Since receivers always were more sluggish than transmitters, a multiplex system changed the "dead" intervals of the receiver to an advantage. Various electrical and mechanical techniques were applied to establish a practical multiplex system that could be duplexed or quadruplexed.

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[37] George B. Prescott, *Electricity and the Electric Telegraph*, New York, 1888, 2 vols. pp. 769–918.

The earliest duplex circuit was based upon a bridge circuit in which currents in the transmitting station would divide and then come together again in such a manner as to cancel one another out and not actuate the local receiver. Currents from the other station instead of canceling would add so as to operate the local receiver. Such a bridge circuit could be applied to telegraph systems if the impedance of the telegraph line joining the stations was related in a certain way to the impedance of the stations. The first attempts to work out such a bridge circuit were made in 1853 by Wilhelm Gintl, director of the Austrian State Telegraph, and in 1857 by Carl Frischen, a Hanoverian telegraph inspector. However, the circuits of Gintl and of Frischen and those of certain subsequent inventors tried to match the impedance of the telegraph line with resistances only. Since a real telegraph line has a capacity as well as a resistance, no satisfactory duplex method was devised until both these features were taken into account. Joseph B. Stearns of Boston succeeded in creating a duplex telegraph by adding a capacitance to the circuit in the proper place (fig. 47).

Thomas A. Edison[38] was the first designer of a practical quadruplex system. In 1874 he showed how two duplex circuits could be superimposed by using a reversal of current to signal in one circuit, and an increase and decrease of current away from the reference level to signal in the other circuit. While the message-carrying capacity of telegraph lines was increased by such duplex and quadruplex methods (fig. 48), they reduced the speed of transmission for each station; consequently other methods of multiple telegraphy were sought.

Multiplexing a line was another method by which a single line could be used for transmitting messages between a number of stations. Multiplexing was originally a mechanical method that used a commutator to switch rapidly among several pairs of transmitters and receivers. It is obvious that by this method many messages could be sent over a single line but that they could not be transmitted simultaneously. The multiplex system was first suggested in 1852 by Moses G. Farmer, whose idea was to set up a commutator, similar to that in the distributor of an automobile, at each end of a telegraph line in such a manner that the motion of the brushes in the commutator was synchronized so as to join corresponding stations at each end of the line. However, it was some time after Farmer conceived this idea that it was reduced to practice.

After Patrick B. Delany and Bernhard Meyer had made initial attempts to create a practical multiplex system, between 1872 and 1878 J. M. E. Baudot[39] managed to devise a workable multiplex system. While the Morse system could send up to 25 dispatches per hour and the European Hughes machine could send 60 dispatches per hour, the duplex process enabled them to transmit 45 and 110 dispatches per hour, respectively. The quadruplex process as applied to the Wheatstone automatic telegraph could send 90 dispatches per hour and 160 dispatches per hour if the system was duplexed again. A hundred dispatches per hour could be sent by the Meyer multiplex system, and 160 by the Baudot system and almost double that if duplexed. Use of the Baudot system spread in France in the 1880's, and in the late 1890's it was introduced into England. Further improvements in the Baudot system and its combination with other systems led to the present printing telegraph system.

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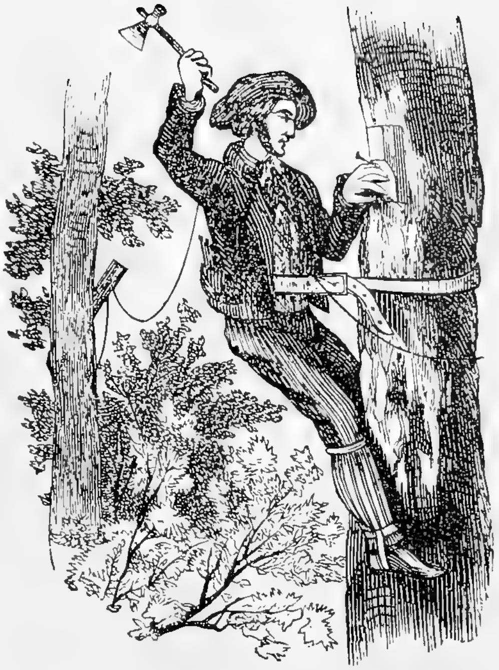
[38] Thomas A. Edison, U.S. patents 207723 and 207724 (September 3, 1878), and 209241 (October 22, 1878); F. L. Dyer and T. C. Martin, *Edison: His Life and Inventions*, New York and London, 1910, 2 vols.; Matthew Josephson, *Edison: A Biography*, New York, 1959.

[39] French patents 103898 (June 17, 1874), 11719 (March 2, 1876), and 146716 (January 6, 1882); Théodose du Moncel, "Systèmes télégraphiques imprimeurs à transmissions multiples," *La Lumière électrique*, 1880, vol. 2, pp. 61–66, 81–84; "J. P.," "Etude sur le système de transmission multiple et le télégraphe imprimeur de M. Baudot," *La Lumière électrique*, 1881, vol. 4, pp. 378–380, vol. 5, pp. 53–57; 1882, vol. 6, pp. 55–60, 79–82, 127–131, 177–184, 198–202; Théodose du Moncel, "Rapport . . . sur le télégraphe multiple de M. Baudot," *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1883, vol. 10, pp. 149–154; A. C. Booth, "The Baudot Telegraph System Duplexed," *Post Office Electrical Engineers' Journal*, 1911, vol. 3, pp. 336–339, and "Progress of the Baudot System," 1914, vol. 6, pp. 324–336.

The high speed of transmission of the Baudot system was largely due to the replacement of the Morse code by an older one, the 5-unit code, which had originally been used in the Gauss-Weber and the Wheatstone-Cooke telegraph systems. In the 5-unit code each signal was formed by the proper combination of five plus or minus currents. The correct combination of currents was created by depressing the appropriate jacks on a keyboard equipped with five keys. There was one keyboard at each transmitting station, and a number of these stations were connected to the commutator. The commutator, as in Farmer's suggestion, connected each keyboard in succession to the line. Usually four keyboards were used; if so, there were four main segments on the commutator, with one segment for each keyboard. Each segment was further subdivided with one subdivision for each key of the keyboard corresponding to that segment. As the brush on the commutator moved over the segments, each key of a given keyboard was connected in succession to the line. An



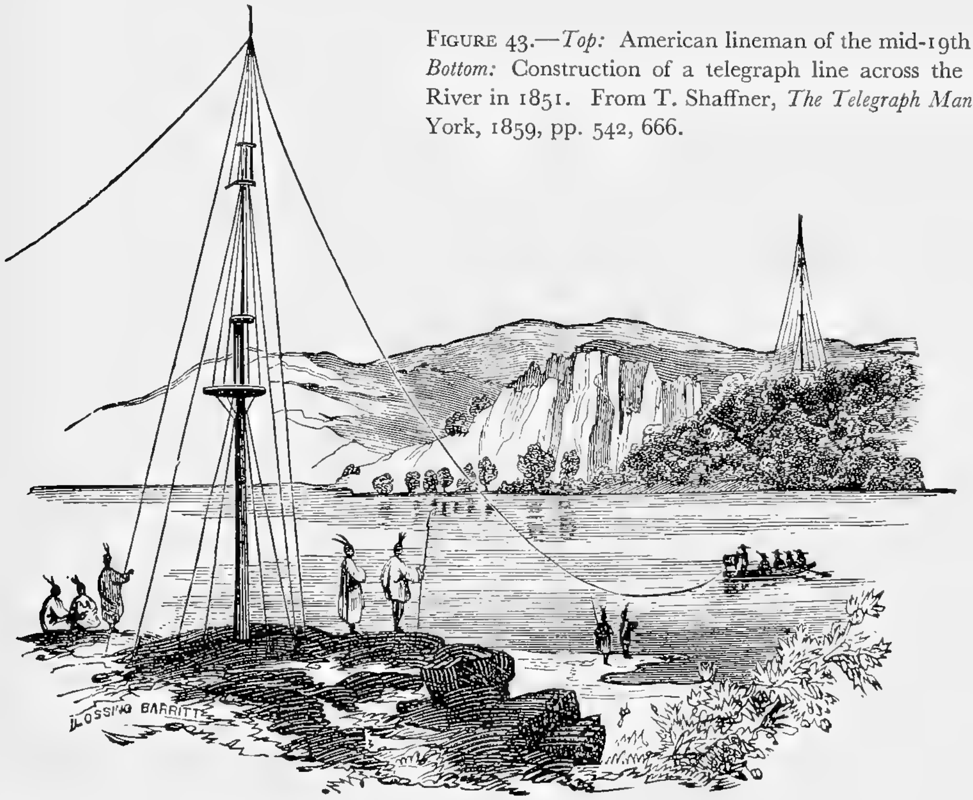


FIGURE 43.—*Top:* American lineman of the mid-19th century. *Bottom:* Construction of a telegraph line across the Missouri River in 1851. From T. Shaffner, *The Telegraph Manual*, New York, 1859, pp. 542, 666.

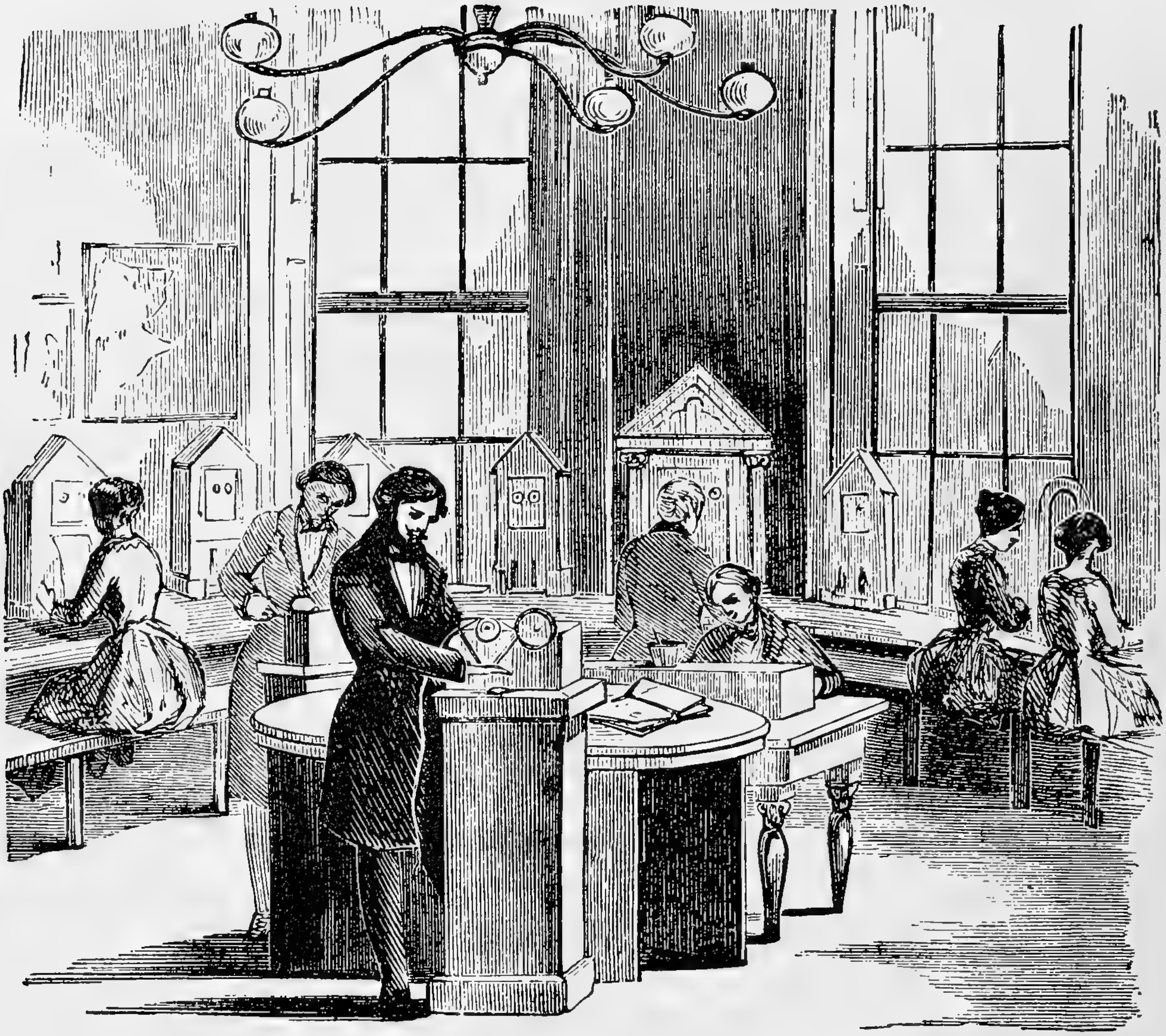
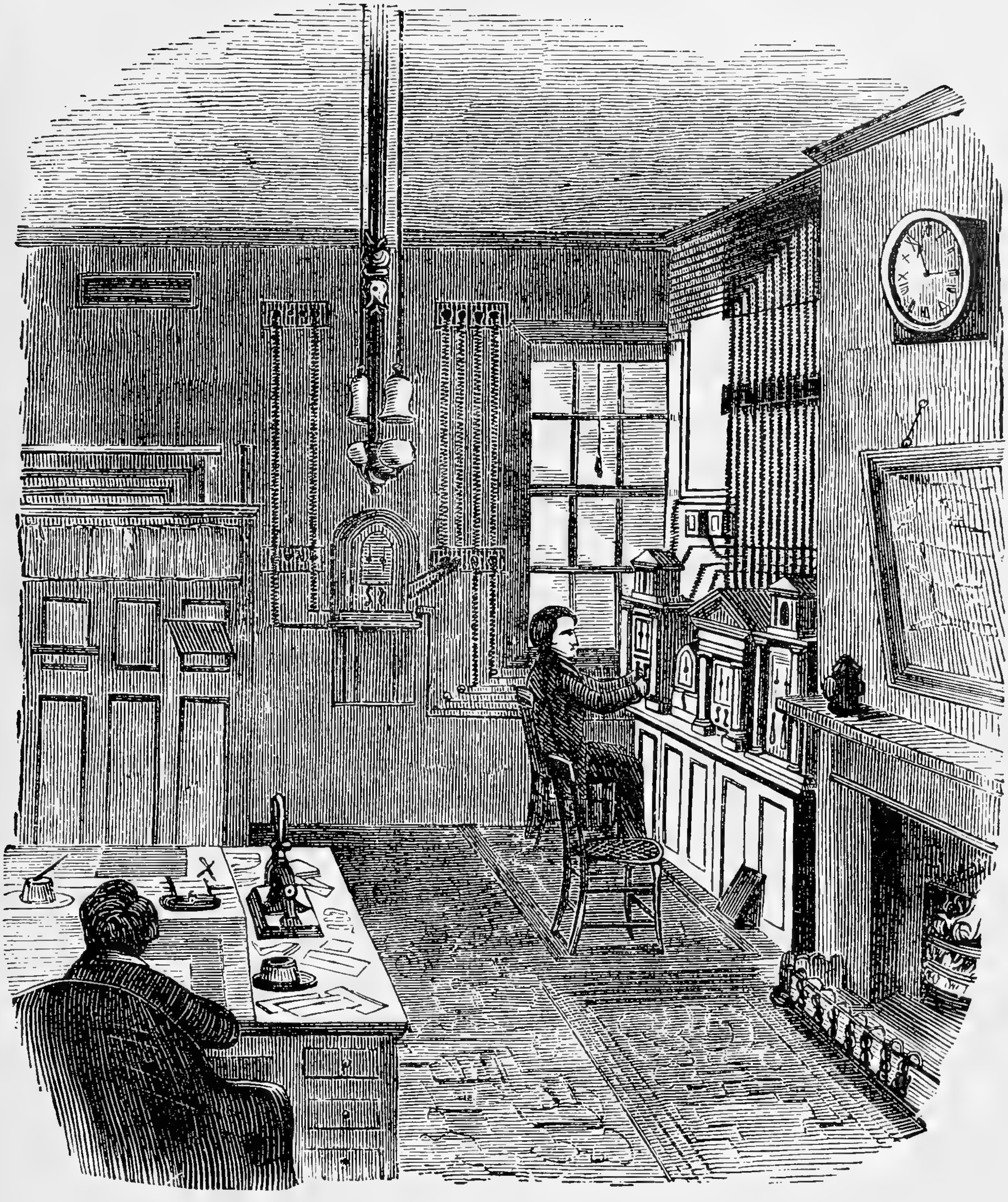


FIGURE 44.—*Above, and on facing page:* English telegraph offices of the mid-19th century. From T. Shaffner, *The Telegraph Manual*, New York, 1859, pp. 233, 235.

identical commutator moving synchronously at the receiving station switched the combinations of signals to four groups of polarized relays, each relay being connected to one of the five subdivisions of the four segments of the receiving commutator. Each group of relays actuated a certain one of the four printers at the end of the line. With this device the operator at each transmitting station could send about 150 letters per minute. (See figs. 49–53.)

Also tried was another method of multiple telegraphy that used different transmitters—each with its own characteristic frequency of alternating current—that sent the different currents simultaneously over the common line. These currents were separated at the receiving end of the telegraph by use of analyzers, each of which was sensitive to only one frequency. This method of communication did not have any commercial success until the 20th century, but such harmonic multiple telegraphy led to another means of electrical communication. After trying to send tones and combinations of tones over a telegraph line, some inventors went on to study the



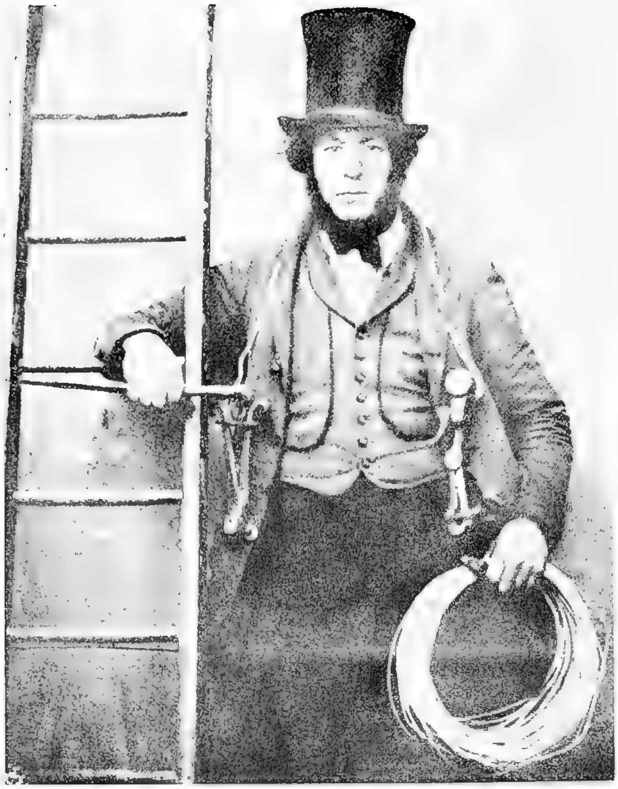


FIGURE 45.—English lineman of the mid-19th century. His hat served both as protection from the elements and as storage space for extra tools. From *Post Office Electrical Engineers Journal*, April 1913, vol. 6, opposite p. 1.

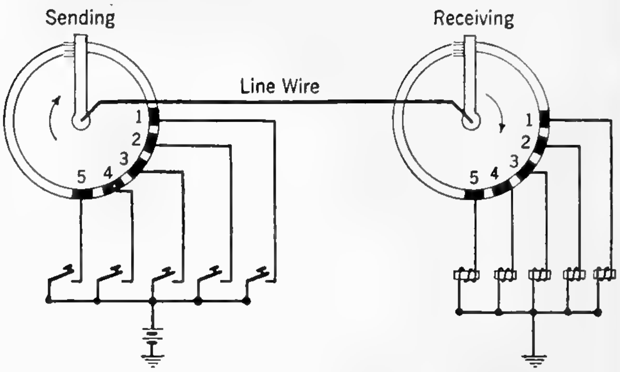


FIGURE 46.—Schematic diagram of a pair of multiplex distributors, by means of which one transmitter-receiver after another is switched to a common line. Reprinted (with permission) from A. Albert, *Electrical Communication*, New York, 1940, p. 230.

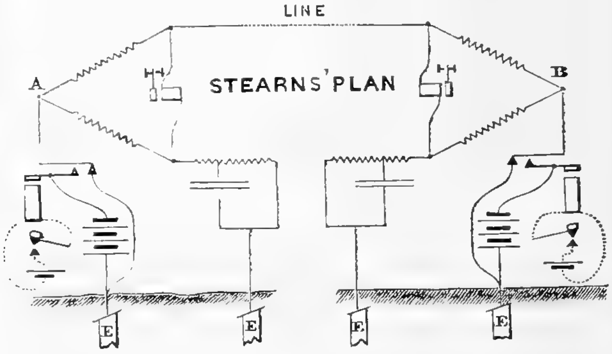


FIGURE 47.—Stearns' duplex circuit, U.S. patent 126847 (May 14, 1872). From W. H. Preece and J. Sivewright, *Telegraphy*, New York, 1876, p. 157.

possibility of transmitting the sounds produced by the human voice by means of an electric telephone.

Although it was in 1854 that Charles Borseul had suggested a telephone for transmitting the human voice by means of electricity, the term "telephone" was not applied to an actual electrical instrument until Philipp Reis devised his instrument in 1860.[40] In 1859, after becoming a teacher of science in a gymnasium near Frankfurt am Main, Reis returned to the studies on sound that he had begun previously. By the following year he had completed his telephone, and he exhibited several forms of it during the next four years. (See figs. 54, 55.) Over 50 articles appeared on the Reis telephone, and reproductions of it produced by several instrument-makers appeared in many physical laboratories of Europe and America. By 1869 the Reis instrument had been publicly demonstrated in the United States.[41]

Reis' instrument was based on the principle that an imperfect or intermittent contact in a circuit can modulate (i.e., control) the current flowing through that circuit. When a diaphragm in the transmitter of the Reis telephone vibrated under the influence of the human voice, a variation occurred in the pressure of a metal point on a metal plate. This variation in pressure modulated the current in the circuit. The receiver of the Reis machine consisted of a knitting needle placed inside an electromagnet which was

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[40] Silvanus P. Thompson, *Philipp Reis: Inventor of the Telephone*, London, 1883.

[41] "The Telephone," *Manufacturer and Builder*, 1869, vol. 1, pp. 129–130.

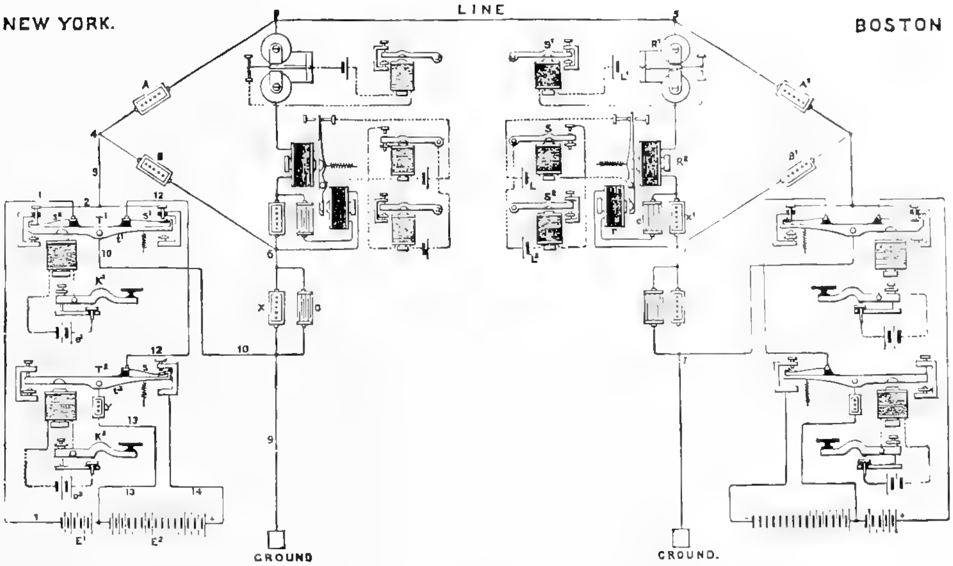
NEW YORK.
LINE
BOSTON
GROUND
GROUND.

FIGURE 48.—Western Union's first practical quadruplex circuit, 1874. From G. B. Prescott, *The Speaking Telephone*, New York, 1878, p. 311.

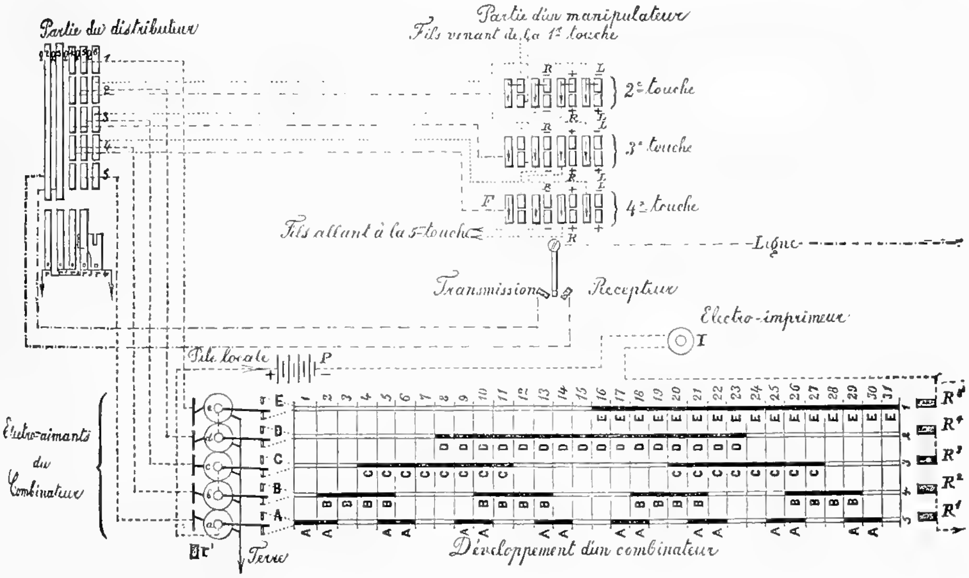
Partie du distributeur
Partie d'un manipulateur
Fils venant de la 1e touche
2e touche
3e touche
4e touche
Fils allant à la 5e touche
Ligne
Transmission
Recepteur
Electro-imprimeur
Pile locale
Electro-aimants du Combinateur
Terre
Développement d'un combinateur

FIGURE 49.—Diagram of the Baudot multiplex system. From *La Lumière électrique*, 1882, vol. 6, p. 60.

mounted on a resonator. The electromagnet made the needle vibrate according to the rate at which the diaphragm in the transmitter vibrated, and the resonant box gave the vibrations a greater intensity. This vibration probably was magnetostriction rather than the vibration of the ordinary telephone diaphragm. If one spoke into the transmitter of a good instrument, the sound heard by pressing the ear against the cover of the receiver was said to be similar to that of a human voice as filtered through a toy trumpet.

It is difficult to determine how well Reis' telephone could reproduce articulate sounds. The American courts involved in the telephone patent trials declared flatly that the instrument could not reproduce speech

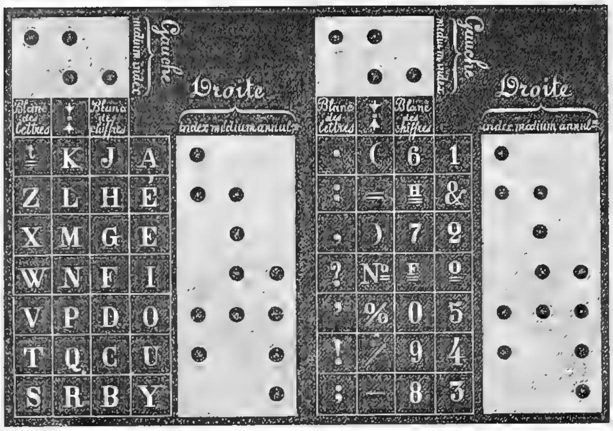

Figure 50.—Baudot's multiplex alphabet. From *La Lumière électrique,* 1880, vol. 2, p. 83.

and could never do so, even with modifications. Some scientists also took this negative position, for it seems to have been a difficult task to get this form of the telephone to reproduce unarticulated sound, let alone speech. But a few scientists, among them Silvanus P. Thompson in Great Britain and E. J. Houston in the United States, asserted that with proper adjustment the Reis instrument could reproduce and transmit human speech. However, this early telephone must be considered as, at best, another of the "philosophical toys" of the 19th century that later, after they had been reduced to practice, became inventions of enormous economic value.

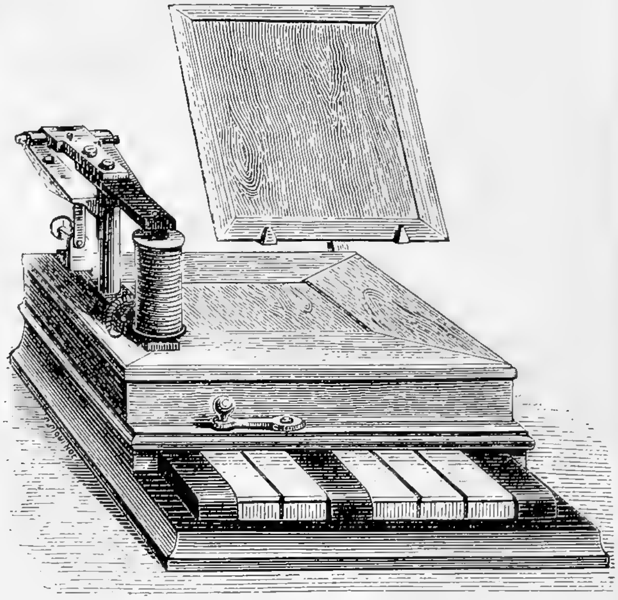

Figure 51.—Baudot's multiplex telegraph transmitter keyboard. The cadence counter on top of the case enabled the operator to transmit at the correct speed. From *La Lumière électrique,* 1882, vol. 6, p. 81.

The line of electro-acoustic experimentation that resulted in the telephone started with the discovery that an electric current could produce those mechanical vibrations that we hear as sound. As early as 1837, Charles Page found that when an electromagnet

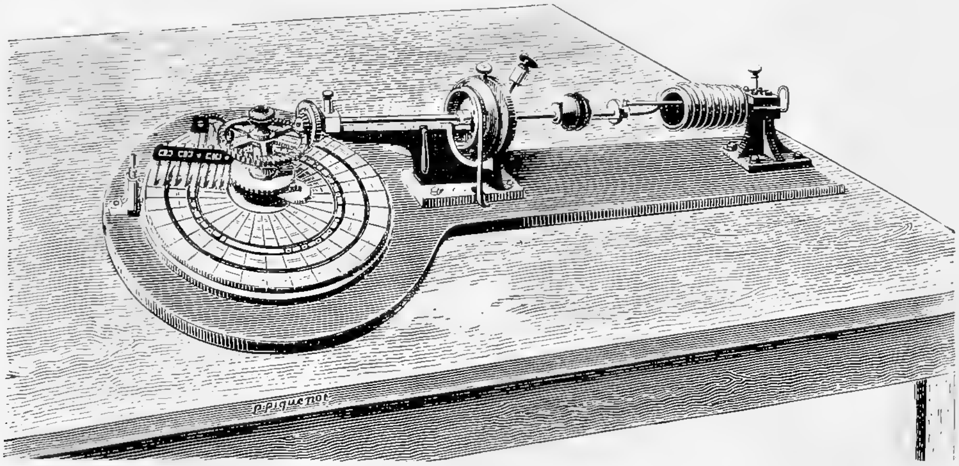

Figure 52.—Baudot's multiplex transmitter distributor commutator. From *La Lumière électrique,* 1882, vol. 6, p. 60.

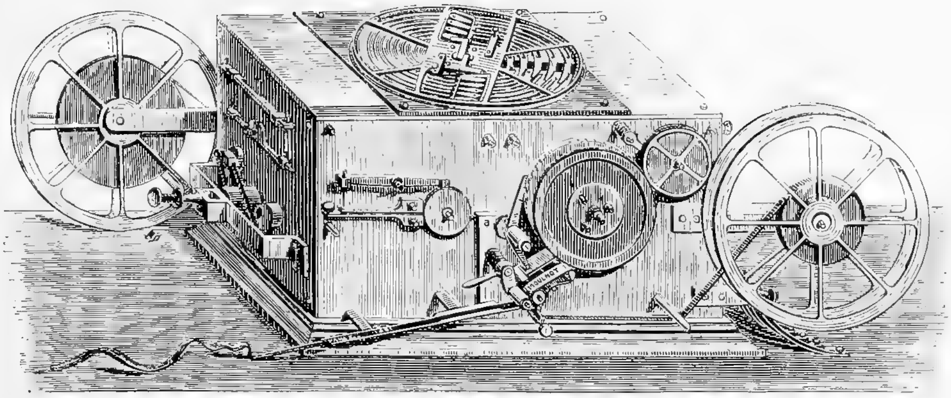

FIGURE 53.—One of the Baudot multiplex receivers, showing the distributor commutator on top of the case. From *La Lumière électrique*, 1882, vol. 6, p. 128.

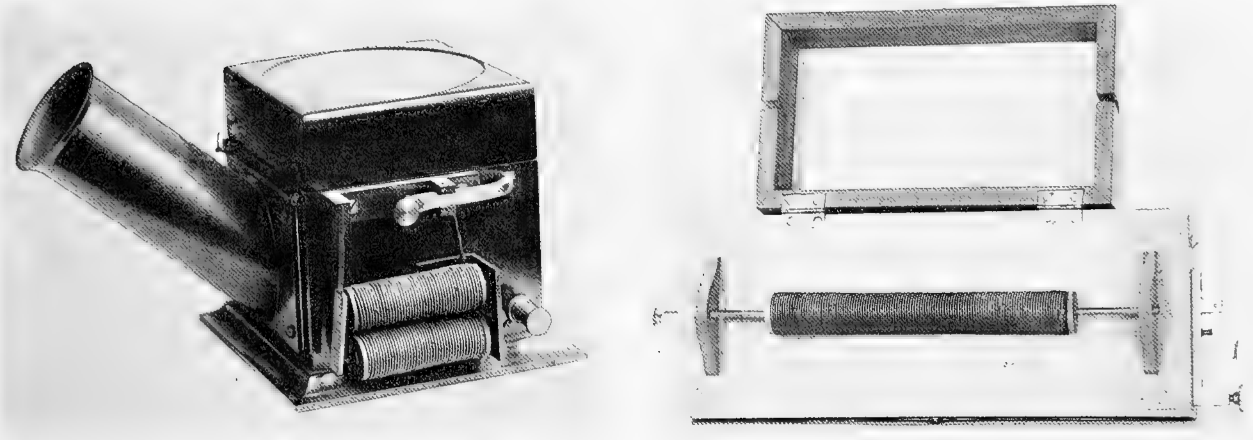

FIGURE 54.—The Reis telephone transmitter (*left*) and receiver that Joseph Henry showed Alexander Graham Bell in 1875. (*USNM 180179; Smithsonian photos 30537, 47876–E.*)

was energized by a current, a sound could be heard in the electromagnet.[42] Helmholtz's classic *Die Lehre der Tonempfindungen*, the first edition of which appeared in 1862, showed how electromagnets could be used to drive tuning forks, how a tuning fork could be used to produce an alternating current of a given frequency, and how only a tuning fork of the right frequency would respond to a given alternating current. But this was not a new discovery, for Abbé Laborde[43] had already suggested in 1860 that a multiple telegraph system might be based upon the proper combination of electrically driven tuning forks.

One of the first inventors of a practical communications system using alternating currents of different frequencies was Elisha Gray,[44] superintendent of the

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[42] Charles Page, "The Production of Galvanic Music," *American Journal of Science*, 1837, vol. 32, pp. 396–397; "Experiments in Electro-Magnetism," *American Journal of Science*, 1838, vol. 33, pp. 118–120.

[43] Abbé Laborde, "Vibrations transmises et réproduites à distance par l'électricité," *Comptes rendus*, 1860, vol. 50, pp. 692–694.

[44] Lloyd W. Taylor, "The Untold Story of the Telephone," *American Physics Teacher*, 1937, vol. 5, pp. 243–251. Many of the instruments that Gray invented for his harmonic multiple telegraph may still be seen in the Museum of History and Technology of the Smithsonian Institution.

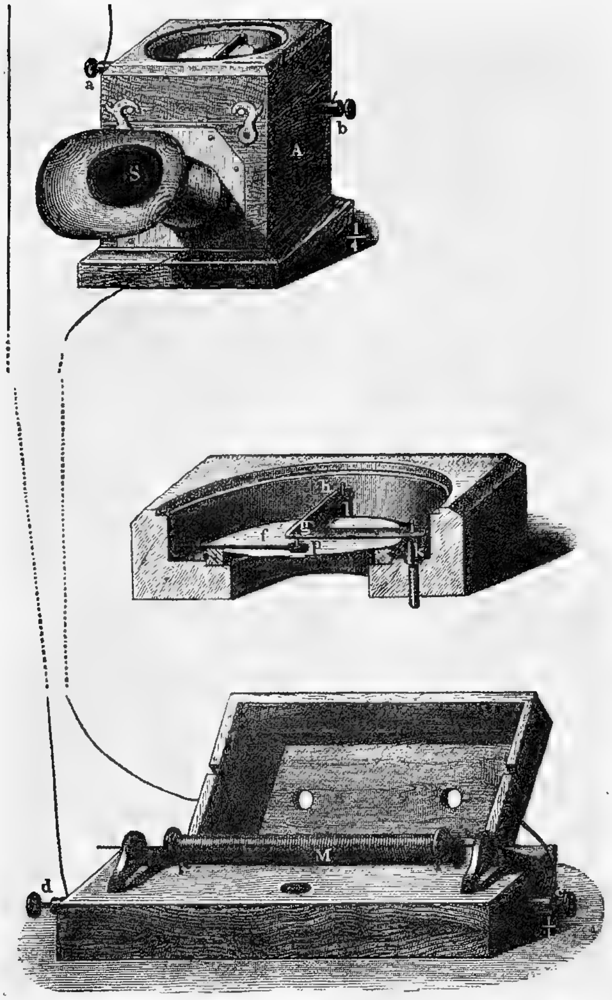

FIGURE 55.—Reis telephone. Transmitter (*top*); detail of diaphragm contact (*middle*); and receiver.

Western Electric Manufacturing Company. Sometime during the winter of 1873–1874, he began to construct instruments that could transform mechanical vibrations into electrical signals and then change the signals back again into vibrations.

The transmitters that Gray used consisted of electromagnets that caused a metal reed to vibrate, thereby interrupting, at a definite rate, the flow of current in the circuit. By May 1874 Gray had constructed a transmitter of eight such vibrators corresponding to the eight notes of a diatonic scale. By July he had an instrument that could produce two such octaves of alternating current.

At the same time that Gray was working on his transmitters, he was also trying various kinds of receivers. He devised two main types. One was based upon the fact that if electricity flows between two solids in rubbing contact, the friction between the two bodies will change with the voltage applied across them. The other type of receiver was based upon the phenomenon already used by Helmholtz and Laborde: the mechanical vibrations produced in the armature of an electromagnet carrying an alternating current correspond to the frequency of the current. Gray found the latter method to be more useful, although the former was not too impractical, for Edison's chalk telephone was subsequently to be based upon it. Gray decided in the spring of 1874 that the receiver should be a circular metal diaphragm—either partially clamped along its edge or entirely clamped around its circumference—driven by an electromagnet. One of his experimental diaphragms finally was a metal washbasin (USNM 214296) and the other a metal cover of a shoe-polish can (visible in fig. 57).

If one struck out a tune on the keyboard of Gray's transmitter, then the receiver at the end of the telegraph line would play the tune. Gray demonstrated his device to officials of the Western Electric Company in New York City in May 1874 and to Joseph Henry at the Smithsonian Institution in the following month. He demonstrated it in London in December of the same year. By January 1875 he had worked out a patentable system for his electric organ[45] (fig. 57).

Gray found he could also apply his experimentation to multiple telegraphy. If there were several stations connected to the same telegraph line, each station with its own transmitting frequency, then signals from the different stations could be detected only if a given receiver was tuned to the appropriate frequency. He applied for a patent on a harmonic multiple telegraph system (fig. 56) on June 28, 1875, and he received the patent on July 20, 1875.[46] He also applied his method of transmitting tones of different frequency to the invention of a printing telegraph.[47]

In 1875, while working on the transmitter for his multiple telegraph system, Gray realized that if a number of tones could be sent at the same time over a

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[45] U.S. patents 165728 (July 20, 1875), transmitter; 166094 (July 27, 1875), receiver; 166095 (July 27, 1875), diaphragm receiver; 166096 (July 27, 1875), transmitter.

[46] U.S. patent 173460.

[47] U.S. patent 179549.

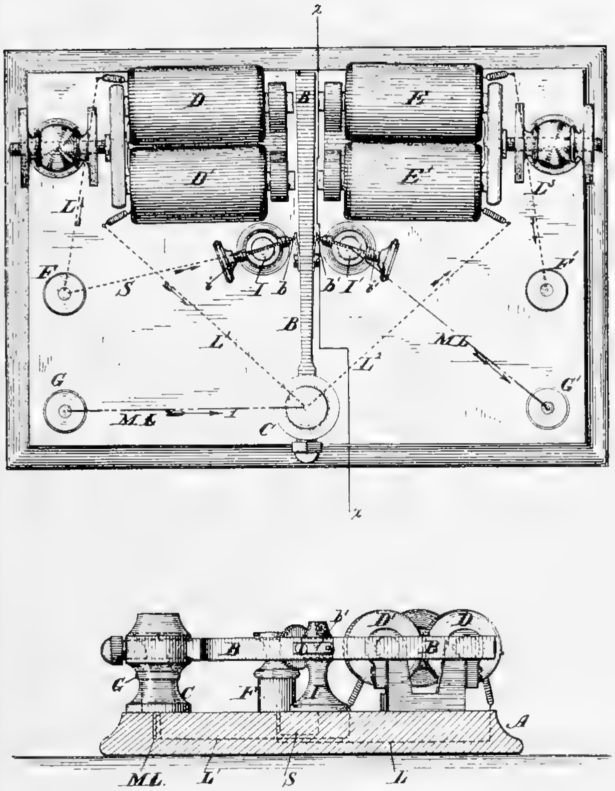
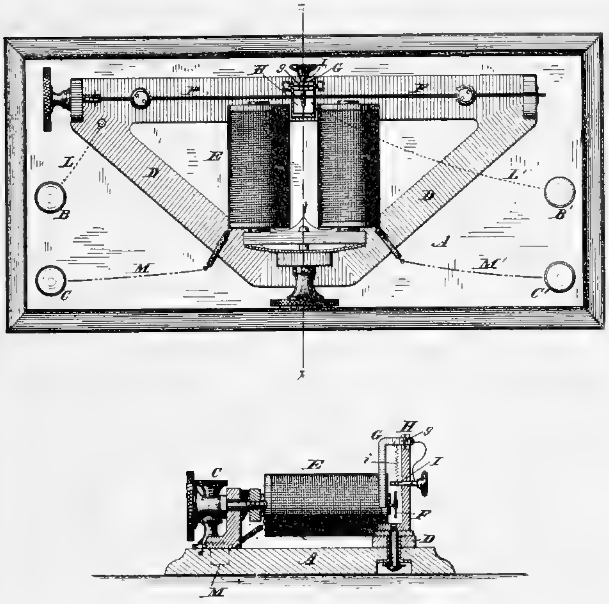


FIGURE 56.—Gray's harmonic multiple telegraph of 1875. *Above*, transmitter; *below*, receiver. By tuning each pair to the same frequency and different pairs to different frequencies, as many telegraph messages as there were pairs could be sent over the same line. From U.S. patents 165728 (July 20, 1875) and 166094 (July 27, 1875).



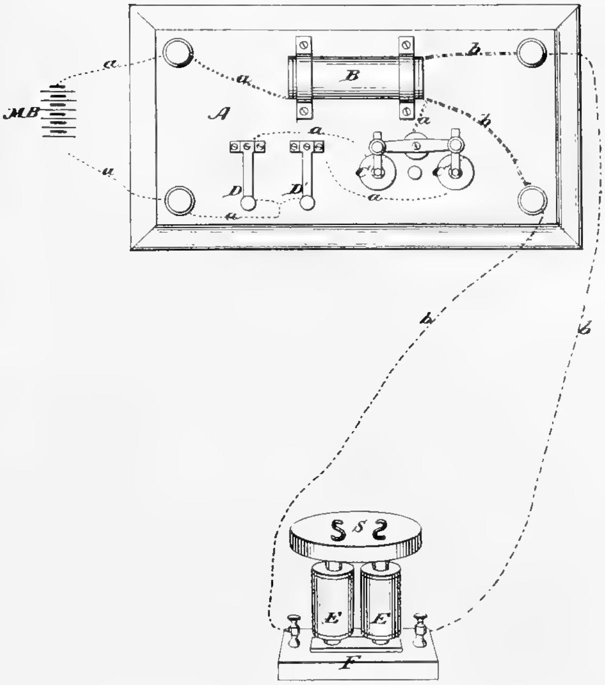


FIGURE 57.—Gray's telegraph for transmitting musical tones, 1875. A single receiver could respond to any frequency over a broad range. From U.S. patent 166095 (July 27, 1875).

telegraph wire, then so could the human voice. At first he tried to devise an instrument capable of separately reproducing each of the most common tones of the human voice. This was necessarily a difficult task because a different unit was contemplated for each of the main parts of human speech. Late in 1875, however, Gray came upon the so-called "lover's telegraph," which consisted of a short cylinder of metal or wood that was open at one end and had a membrane across the other end. The centers of the membranes of two such instruments were connected by a taut wire. When a person spoke into one cylinder, the speech could be heard in the other. This device showed Gray that the vibrating diaphragm receiver he had already invented (fig. 57) should be capable of repeating speech transmitted to it, and that consequently part of his task had already been accomplished. He had only to devise a transmitter, which he did a short time later.

The transmitter that Gray designed was a cylinder, at one end of which was a diaphragm with a light metal wire fastened to the side facing away from the cylinder. The cylinder was placed over a container

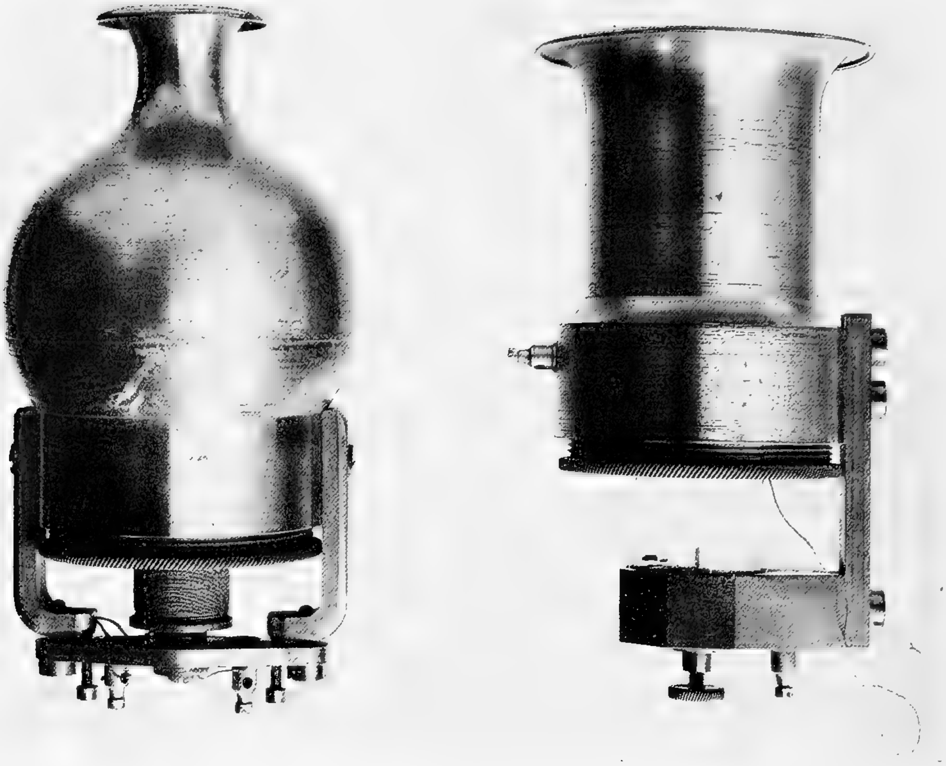


Figure 58.—Reproductions of Gray's telephone transmitter and receiver of 1876. (*USNM 308211, 308212; Smithsonian photo 17204.*)

of acidulated water so that when sound entered the cylinder, its diaphragm vibrated and moved the wire attached to it up and down in the liquid. If the liquid and the wire were made part of an electrical circuit with a battery and a Gray receiver, the varying liquid-wire contact would modulate the current produced by the battery, and the receiver would reproduce this modulation in the form of sound.

In January 1876 Gray went to Washington to patent some further improvements on his harmonic telegraph and while there drew up a caveat for his method of transmitting and reproducing speech (fig. 58). This caveat was filed on February 14, 1876.[48]

Gray did not test one of his liquid transmitters until he attended the Philadelphia Centennial Exposition in July 1876 as one of the judges of the electrical exhibits. He had a transmitter made and demonstrated it to some of his friends who were in attendance at the exposition.

On the same day that Gray applied for a caveat on the transmission of speech, another inventor applied for a patent on an invention having the same purpose. This other invention received U.S. patent 174465, a number which came to represent one of the most valuable patents ever issued. The man who applied for and received this patent was Alexander Graham Bell.

Bell, born in Scotland in 1847, had emigrated to Canada with his parents. He had followed in his family's tradition of studying human speech and acoustics, and before he left Edinburgh in 1870 he had begun the study of Helmholtz's *Die Lehre der Tonempfindungen.* Sometime between 1867 and 1870 further study of the apparatus described in this work—in particular of the tuning forks that were driven by an electromagnet—suggested to him the possibility of a harmonic multiple telegraph. In the fall of 1872, after he had moved from Brantford,

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[48] George B. Prescott, *The Speaking Telephone, Talking Phonograph and Other Novelties,* New York, 1878, pp. 202–205.

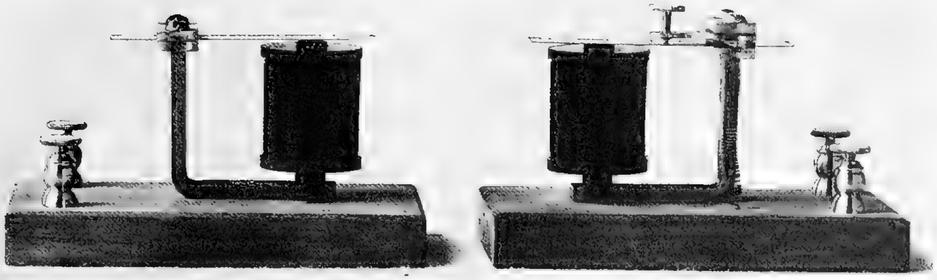

FIGURE 59.—Reproductions of Bell's harmonic multiple telegraph transmitter and receiver. (*USNM 308211, 308212; Smithsonian photo 17204.*)

Ontario, to Boston, Massachusetts, Bell started experimenting with such a telegraph. He first considered using tuning forks to interrupt the circuit at the transmitting end, for a tuning fork could produce a response only in another electrically driven tuning fork of the same frequency. A number of forks of different frequencies could thus be used for multiple telegraphy on a single telegraph line. In November 1873 Bell replaced the tuning forks with steel reeds. However, difficulties in putting his concepts into practice caused Bell to drop his experimentation for a while.

In the meantime, however, Bell did not cease developing his ideas. During the summer of 1874 it occurred to him that if a magnetized reed were vibrated before a coil of wire it would induce a fluctuating current in which the vibrations would correspond exactly to the sound waves causing the current. If this undulatory current could actuate at the end of the line an instrument similar to the one producing the current, such a receiver would produce a response—but only in a receiver tuned to the same frequency as that of the transmitter. If those conditions were met, much of the auxiliary apparatus used in most electromagnetic communication devices to interrupt and power the circuit could be eliminated. Moreover, with such a device there would be an exact reproduction of the sound waves transmitted in the form of an undulatory current rather than by the set of pulses produced by a vibrating reed.

Bell also speculated that if at one end of a line there were a set of magnetized reeds of varying lengths (like the reeds in a harmonica or Aeolian harp) acting as armatures for an electromagnet and a similar instrument at the other end of the line, such a "harp" apparatus (fig. 60) would be capable of transmitting and reproducing complex tones in the same manner that Helmholtz compounded complex sounds with his tuning forks. Indeed, a pair of such instruments might even be capable of transmitting human speech over a telegraph wire.

Further speculation suggested to Bell that his complex "harp" apparatus might be reduced to a single vibrator. Among the acoustical instruments that Professor Charles Cross of the Massachusetts Institute of Technology showed Bell during the winter of 1873–1874 were Koenig's manemetric capsule, Scott's phonautograph, and possibly Reis' telephone. Bell's consideration of these instruments brought to his attention the similarity between the mechanical motions of the diaphragms used in them and the motion of his vibrating reeds. He thought that perhaps, if he attached a magnetized armature to the center of a membrane that vibrated under the influence of a human voice, currents could be induced that might reproduce the human voice in a similar instrument installed at a distance. This first form of Bell's magneto telephone is described in his patent of 1876. However, when Bell first made these speculations, he rejected them as impractical, for he held that not enough current could be induced either in the "harp" instrument or in the membrane instrument to actuate a receiver.

Instead of completing work on his telephone, Bell continued to experiment with his harmonic multiple telegraph, for which he obtained a U.S. patent (161739) on April 6, 1875 (fig. 59). Bell successfully demonstrated his telegraph to Western Union officials in March 1875, showing how two messages could be sent simultaneously over 200 miles of telegraph line. Work on the telephone was still in progress, however.

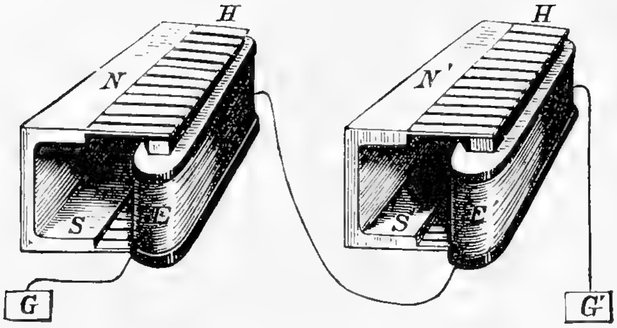

FIGURE 60.—Bell's "harp" apparatus. From G. Prescott, *The Speaking Telephone*, New York, 1878, p. 67.

Bell had visited Joseph Henry at the Smithsonian Institution and discussed with him some of the problems involved in the reproduction of sound. Bell showed Henry how an empty coil might produce audible sound, and Henry demonstrated a Reis telephone to Bell.[49]

Some experiments that Bell performed in June 1875 indicated that his speculations of the previous summer concerning a magneto telephone might be feasible after all. During an attempt to send three messages over his multiple telegraph, Bell found that one magnetized reed could actuate another one without a battery in the circuit. Thereupon Bell instructed his associate, Thomas A. Watson,[50] to make two instruments, and to use in each instrument a magnetized reed attached to a membrane diaphragm. The reed acted as an armature to an electromagnet, and the electromagnet was in turn connected to another similar instrument. But while sounds and changes of pitch were audible in its receiver, this membrane telephone (fig. 61) could not reproduce speech.

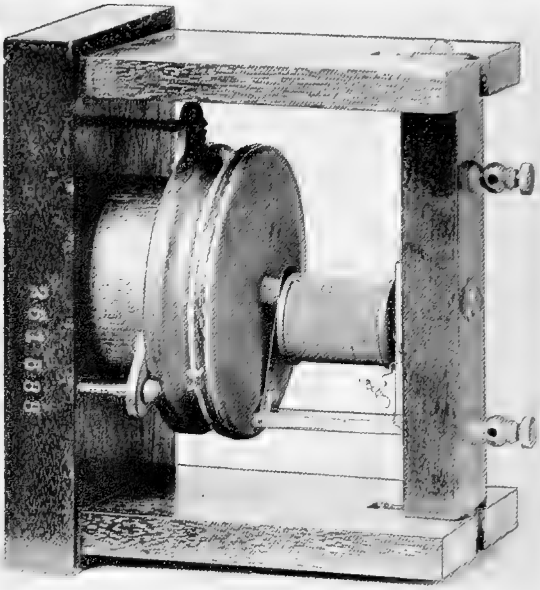

Figure 61.—Reproduction of Bell's diaphragm magneto telephone of 1875. This model was made under Bell's direction to serve as an exhibit in one of the many patent trials in which he was involved. (*USNM 251533; Smithsonian photo 29310.*)

In spite of its failure to transmit articulate speech, Bell drew up patent specifications (fig. 62) for his membrane telephone, and his patent was granted on March 7, 1876. Among his claims, Bell included the basic method of electrical telephony—electrical currents repeating the wave forms of sounds—as well as all instruments for producing these currents and all instruments for reproducing sound from these currents. Bell's claims to the basic method of telephony were so broad that they were attacked by some 600 patent suits, all of which were withstood.

Bell and Watson were unable to reduce their method to practice until a month after Bell had applied for a patent on it, when Bell tried another kind of transmitter. This transmitter was of a type that modulated the current from a battery and was similar to the one described above in the discussion of Gray's caveat. On March 9, 1876, Bell's first model of this instrument transmitted a few sounds that were audible in a membrane receiver, and the next day a better model (fig. 63) transmitted the following famous words well enough to be understood: "Mr. Watson, come here; I want you." This one instrument that worked enabled Bell to modify his others so they were all brought into operation.

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[49] *United States Reports*, 1887, vol. 126, pp. 1–584; Alexander G. Bell, *The Bell Telephone: The Deposition of Alexander Graham Bell in the Suit Brought by the United States to Annul the Bell Patents*, Boston, 1908; Catherine Mackenzie, *Alexander Graham Bell: The Man Who Contracted Space*, Boston and New York, 1928; F. L. Rhodes, *Beginnings of Telephony*, New York, 1929; A. G. Bell, U.S. patent 161739 (April 6, 1875). Many of Bell's instruments for harmonic telegraphy and for telephony are preserved in the Museum of History and Technology of the Smithsonian Institution. The Reis instrument that Henry showed Bell may be seen in the Museum (*USNM 180917*).

[50] Thomas A. Watson, *Exploring Life: The Autobiography of Thomas A. Watson*, New York and London, 1926.

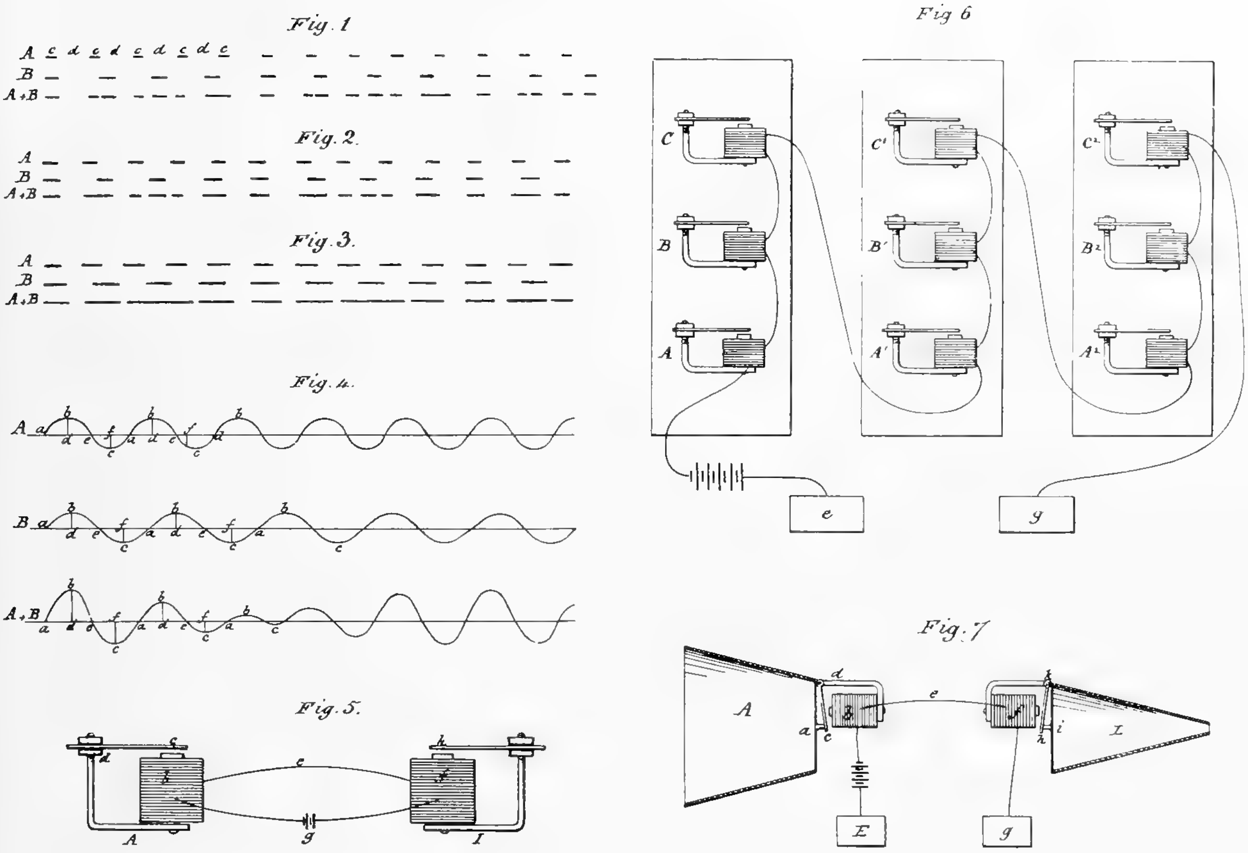

FIGURE 62.—Drawings from Bell's famous patent of 1876, showing how his invention could be used to transmit and receive both continuous and discontinuous sound waves. From U.S. patent 174465 (March 7, 1876).

Bell's backers deemed his progress sufficient for a demonstration in June 1876 of several forms of his membrane telephone (fig. 64) together with his multiple telegraph at the Philadelphia Centennial Exposition. It was at this exposition that the famous Dom Pedro incident occurred, which is now so familiar that it need not be repeated again.

Bell was so discouraged, however, by the poor efficiency of his membrane telephones that he felt it necessary to drop work on his multiple telegraph in order to devote all his time to the telephones. They would work moderately well over a short line, but the apparatus was delicate and did not articulate sounds distinctly enough for practical use. Bell never eliminated the necessity of shouting into his magneto telephone, but he did succeed in improving it somewhat. Early in October of 1876 Bell replaced the steel reed that he had been using on the membrane by a steel plate almost as large as the membrane and glued to it. About the same time Watson replaced the soft iron core of the electromagnet with a compound permanent magnet. After these changes were made, Bell and Watson tested the new apparatus between two rooms in the building where their laboratory was located and found they had no difficulty in carrying on a "sustained conversation." On October 9, 1876, "sustained conversation was successfully carried on for the first time upon a real line several miles in length."

These improvements inspired Bell a week later to replace the membrane by an all-metal diaphragm clamped around the edge. After placing the resulting structure in a box as large as a professional photographer's camera of the time, Bell and Watson tested this "box" telephone (fig. 65) over a line 4 or 5 miles long and found they could maintain a conversation.

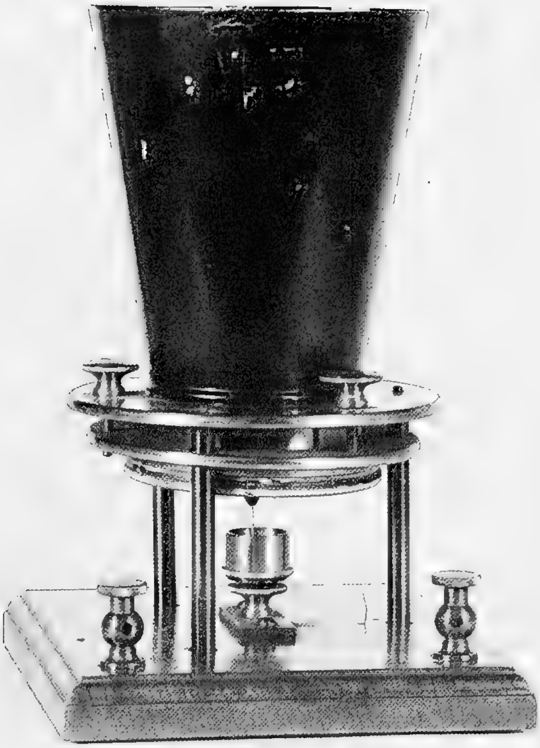

Figure 63.—Reproduction of Bell's liquid transmitter, his first successful instrument to transmit articulate speech (March 10, 1876). (*USNM 252600; Smithsonian photo 47876.*)

At the end of November they conducted tests on the new device over a 200-mile line running from Boston through Portland, Maine, and back to Salem. They found that some of their sentences could be understood if they shouted although no conversation could be carried on.

Bell's box telephone proved to be a better instrument than the one he had demonstrated at the Philadelphia Centennial, but further work was necessary on it, for it still was not ready for commercial use. Its output was weak even when speech was shouted into it. Moreover, the shouting had to be performed in a certain manner—the mouth had to be placed right against the steel diaphragm, and the words properly intoned. Unless these precautions were taken, the sounds emitted from the receiver had to be translated, which Watson did on several occasions. The box telephone reproduced music more successfully than speech.

On January 13, 1877, Bell applied for a patent on his box telephone, which was granted on January 30 as U.S. patent 186787 (fig. 66). Bell's second patent on the telephone became the fundamental one for the construction of receivers, just as the first one became the fundamental patent on the process of transmitting sound by electricity.

About the time Bell was working on his box telephone, a group of scientists at Brown University in Providence, Rhode Island, began work on this new instrument for communication by electricity.[51] During the winter of 1876–1877 and the spring of 1877, Prof. John Pierce, Prof. Eli Blake, Dr. William Channing, and several others at the university sought to reduce the dimensions of the telephone and to increase its efficiency. By April they had made their receiver portable, and by the following month they had evolved the hand receiver with its typical conical mouthpiece having a very shallow cavity between it and the thin iron diaphragm (fig. 67). In back of the diaphragm was a permanent bar magnet on which was placed the inducing coil. The intelligibility of speech as reproduced by the telephone was greatly increased by these changes, and the instrument was no longer so awkward to use. The group of scientists at Brown freely donated their modifications of the telephone to Bell without any restrictions or legal claims. Their modifications assisted Bell in producing the first commercial receiver. After the carbon transmitter had been introduced, the size and structure of this early receiving device remained typical of hand receivers for the next half-century.

Bell had also been seeking to reduce the size of his box telephone, and about this time he similarly produced a hand telephone.[52] By combining it with the modifications produced by the group at Brown, he was able to place a hand telephone in commercial use in June 1877.

Once an adequate instrument had been designed, the substitution of the telephone for the telegraph in local circuits spread rapidly. The first commercial telephone line was set up in April 1877 in Somerville,

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[51] Walter L. Munroe, "The Brown University 'Experimenters' and Their Receivers," *Brown Alumni Monthly*, 1939, vol. 39, pp. 279–282. Two of these instruments were recently donated to the Museum of History and Technology of the Smithsonian Institution (*USNM 316018, 316019*).

[52] Several of Bell's hand telephones are preserved in the Museum of History and Technology of the Smithsonian Institution (for example, *USNM 251554*).

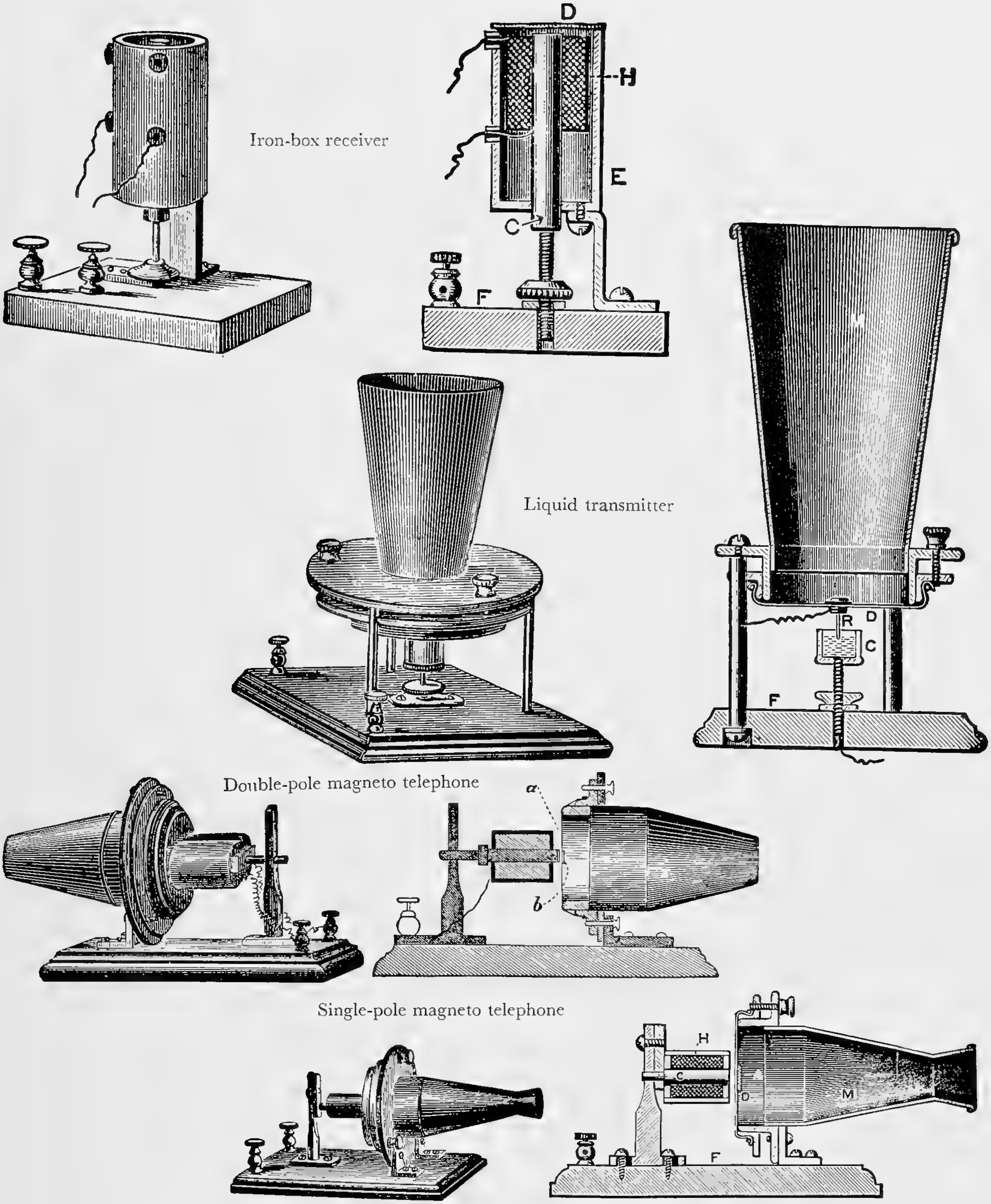

D
H
Iron-box receiver
E
C
F
Liquid transmitter
M
R
D
C
F
Double-pole magneto telephone
a
b
Single-pole magneto telephone
H
C
D
M
F

Figure 64.—Telephones exhibited by Alexander Graham Bell at the Philadelphia Centennial Exposition of 1876. From *The Bell Telephone: The Deposition of Alexander Graham Bell in the Suit Brought by the United States to Annul the Bell Patents*, Boston, 1908, pp. 97–100.

Massachusetts; it ran between the shop and the home of Charles Williams. A box telephone was used at each end of this 3-mile line. Requests for other telephones were rather slow in coming, but by June 1877 Bell was able to place his first order with Williams for 25 box telephones and 50 hand telephones. By the end of June there were 230 telephones in use; by the end of July, 750; and by the end of August, 1,300. In July 1877 Bell and his associates formed the Bell Telephone Company in order to exploit this new invention. However, as yet, they did not have an efficient transmitter.

The magneto telephone receiver had been capable of improvement and of becoming commercially practical. This was not, however, true of the magneto transmitter. Even if the person using the telephone

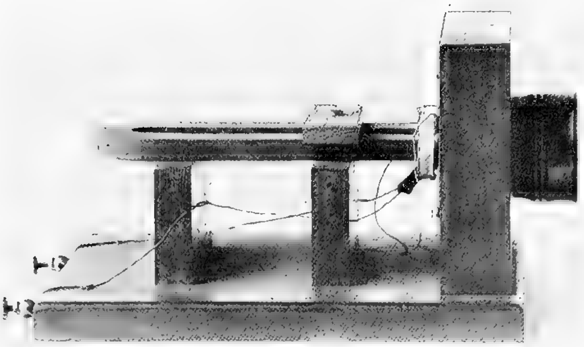


FIGURE 65.—Interior of the box telephone used by Bell and Watson in their experiments in the fall of 1876. (*USNM 308214; Smithsonian photo 17204–D.*)

Fig. 1

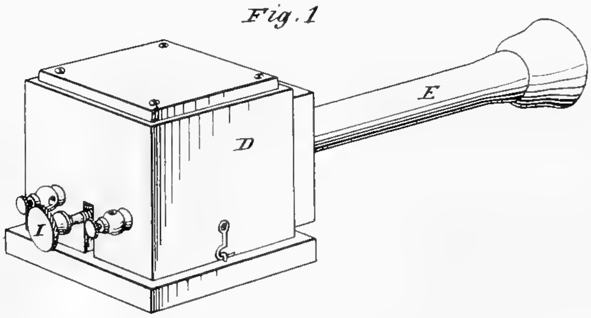


Fig. 2.

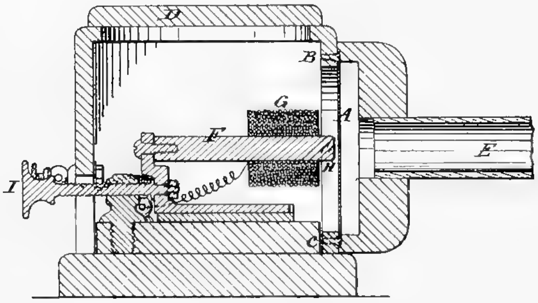


Fig. 3.

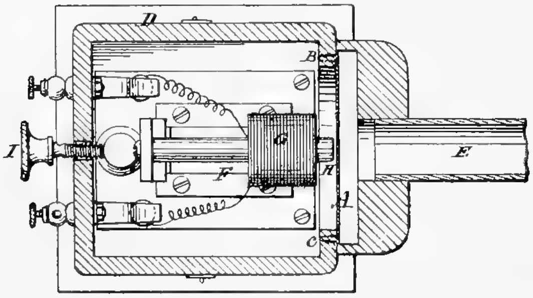


Fig. 4.

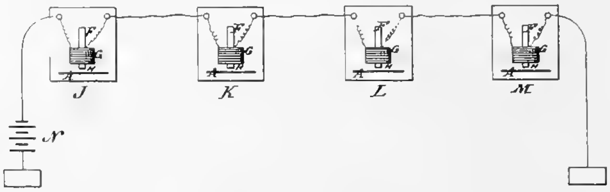


Fig. 5.

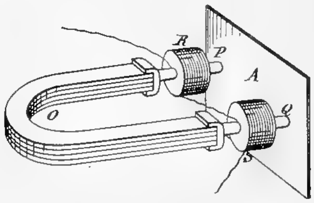


Fig. 6.

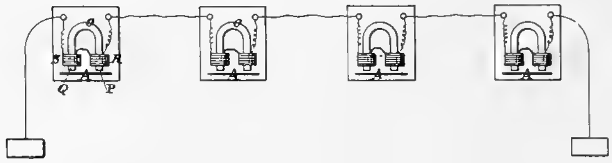


FIGURE 66.—Patent drawings of Bell's box telephone. From U.S. patent 186787 (January 30, 1877).

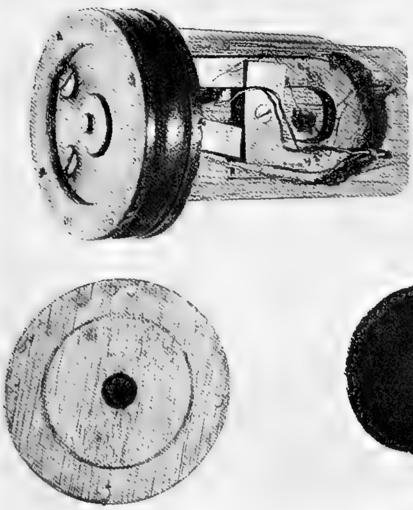
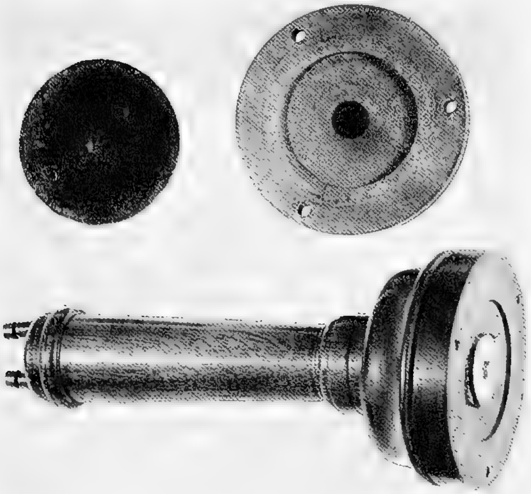


FIGURE 67.—Unassembled parts of the hand telephones worked out at Brown University. At the top is the first form; at the bottom, the second. (*USNM 306018, 306019; Smithsonian photos 45309, 45309–B.*)



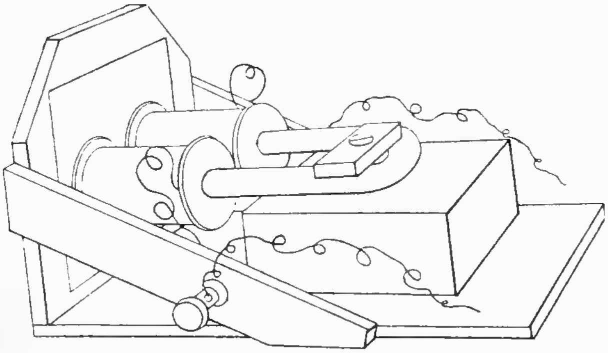


FIGURE 68.—Dolbear's first magneto telephone. From A. E. Dolbear, *The Telephone*, Boston, 1877.

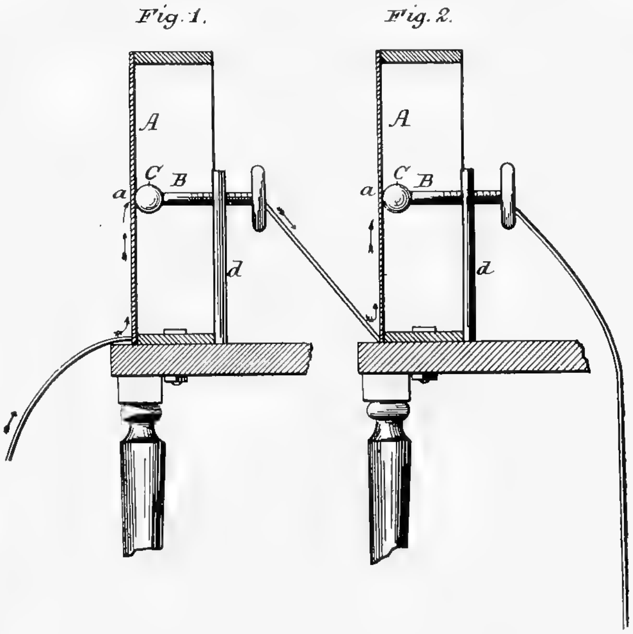


FIGURE 69.—Patent drawing of Berliner's telephone transmitter and receiver based upon a metal-to-metal contact. From U.S. patent 463569 (November 17, 1891).

shouted, the signals transmitted were too weak to travel any great distance. Also, if the telephone line picked up a certain amount of extraneous noise—which it usually did, especially after the introduction of electrical power lines—the weak signals produced by the magneto transmitter were drowned out. Bell's transmitter was for these reasons too inefficient for commercial use. If the Bell Company was to survive economically, another transmitter had to be found.

At the end of 1877 the Western Union Telegraph Company formed, in competition with Bell and his associates, the American Speaking Telephone Company. Western Union had not only bought up the

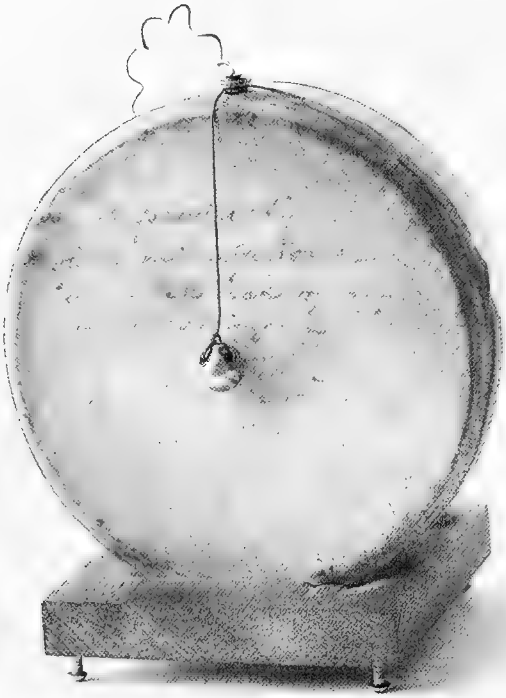


FIGURE 70.—Reproduction of Berliner's toy drum microphone. The contact was a needle that pierced a drum membrane against which a metal ball rested. (*USNM 309377; Smithsonian photo 42367.*)

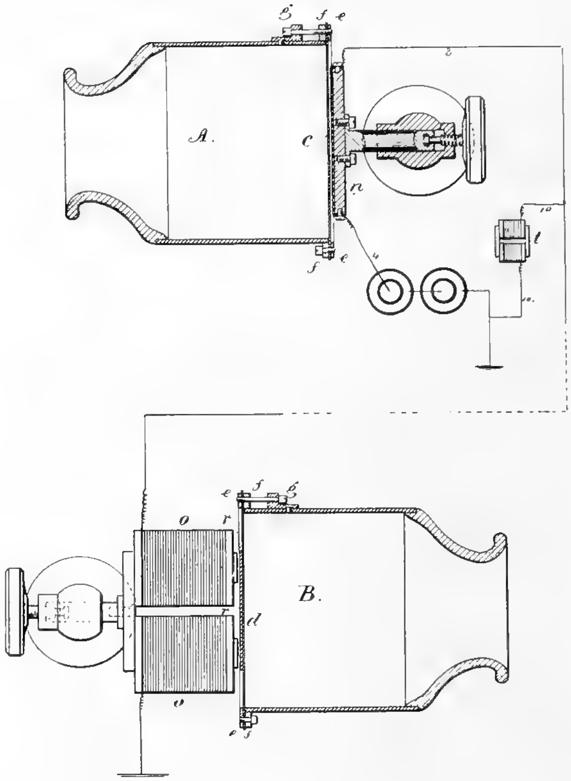


FIGURE 71.—Drawing from one of Edison's basic microphone patents, showing the use of a semiconductor as one of the microphone contacts. From U.S. patent 474230 (May 3, 1892).

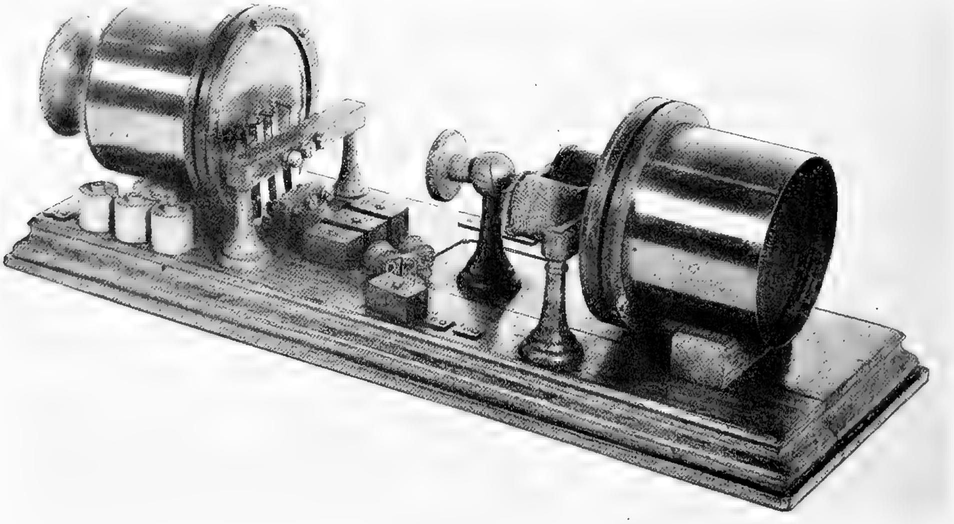


FIGURE 72.—Patent Office model of one of Edison's basic microphone patents, showing the use of multiple contacts. (*USNM 252622; Smithsonian photo 46777–A.*)

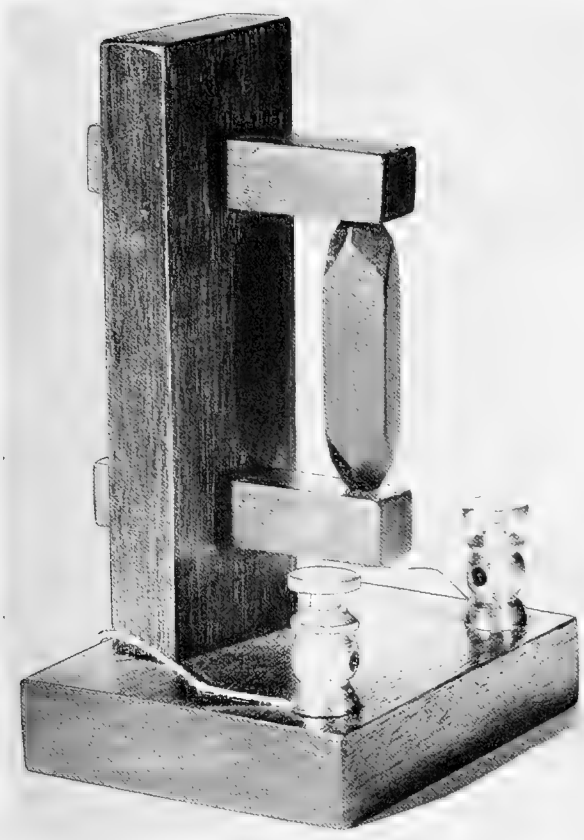


FIGURE 73.—Reproduction of Hughes microphone. (*USNM 315083–4.*)

telephone patents of inventors like Elisha Gray and Amos Dolbear [53] (see fig. 68), but had hired Thomas A. Edison to invent a new transmitter. As will be seen below, the new American Speaking Telephone Company ceased giving competition to the Bell Company in 1880.

Both the Bell Telephone Company and the Western Union Telegraph Company found a commercially practical transmitter in a device that modulated the current from a battery by varying the resistance of the circuit. The Bell Company obtained patent rights on such a transmitter from Emile Berliner and the Western Union Company from Edison. In the meantime other companies had also been formed to enter the telephone business and had applied for

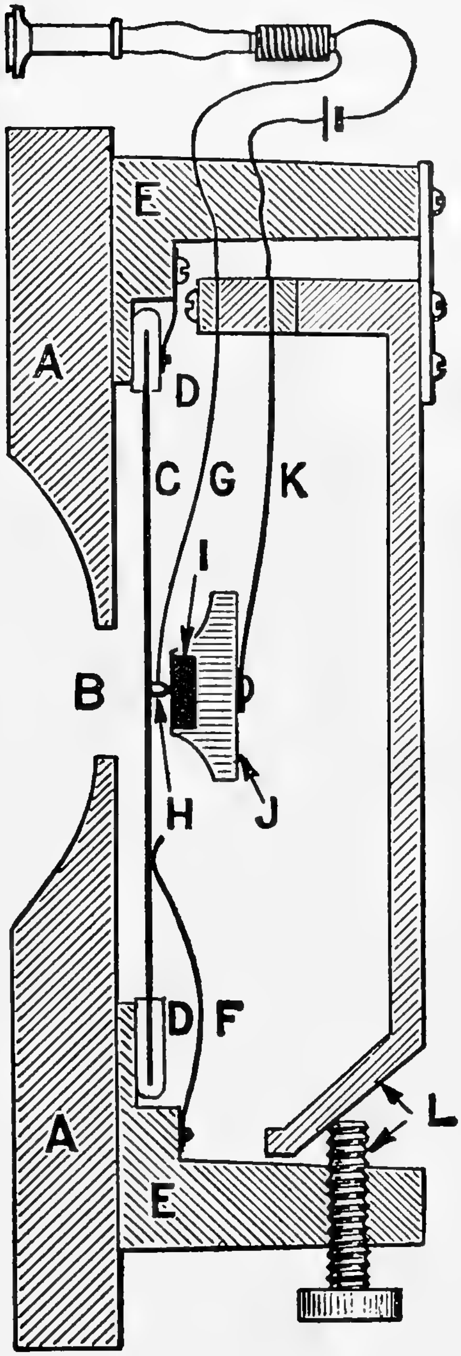


FIGURE 74.—Diagram of Blake telephone transmitter. The platinum bead is at *H* and the carbon block at *I*. Reprinted (with permission) from F. Rhodes, *Beginnings of Telephony*, Harper and Brothers, New York, 1929, p. 80.

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[53] Amos Dolbear, *The Telephone*, Boston and New York, 1877; "Researches in Telephony," *Proceedings of the American Academy of Arts and Sciences*, 1878–1879, vol. 14, pp. 77–91.

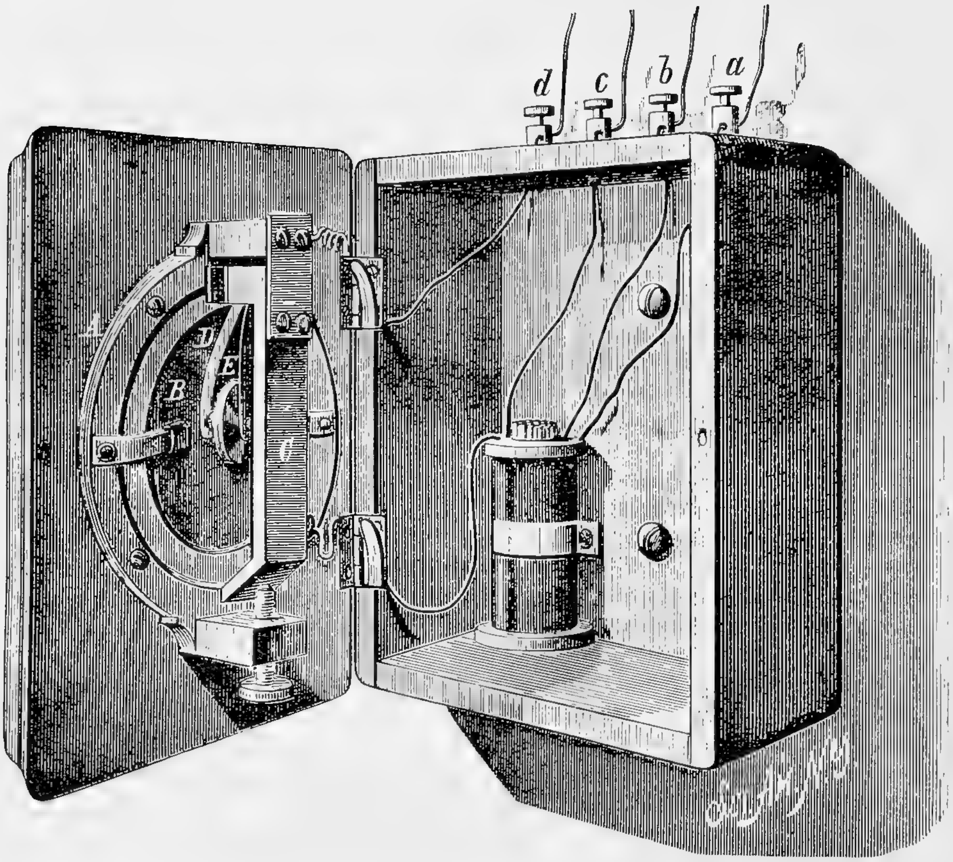

FIGURE 75.—Commercial type of Blake Telephone transmitter. From *Scientific American*, 1879, vol. 41, p. 274.

patents on their own transmitters. A long period of litigation ensued, which lasted until 1903.

Emile Berliner,[54] a German immigrant who had come to the United States in 1870, spent his spare time experimenting with electricity. On April 14, 1877, Berliner filed a caveat on a metal-to-metal imperfect contact transmitter (fig. 69) that was similar to that of the Reis telephone but of a more sturdy construction. In this transmitter, modulation was achieved by the variable resistance of the imperfect contact. After applying for a patent on this device on June 4, 1877 (U.S. patent 463569, November 17, 1891), Berliner sold his patent rights to the Bell Company. While few commercial instruments were manufactured on the basis of the Berliner patent, it was useful to the Bell Telephone Company in establishing claims to patent priority.

Thomas A. Edison was a well-known telegraph inventor whose ability to invent "to order" was exploited on several occasions during the struggle for control of the remunerative telephone patents. Edison had worked on the harmonic multiple telegraph, and much of his work ran parallel with that of Bell and Gray. In 1875 he devised an electromagnetic receiver similar to the receivers of Bell and Gray, and he subsequently found that this receiver could be used as part of a magneto telephone. Edison started his work in telephony in 1876, trying to change Reis' telephone into a commercial device by modifying the contacts. Edison obtained some success in this experimentation by placing a drop of water between the contacts; however, it was not until the spring of 1876, after replacing Reis' metallic contacts by semiconducting ones, that he was able to transmit sentences. In January 1877 Edison fur-

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[54] Frederic W. Wile, *Emile Berliner; Maker of the Microphone*, Indianapolis, 1926. Many of Berliner's instruments are preserved in the Museum of History and Technology of the Smithsonian Institution.

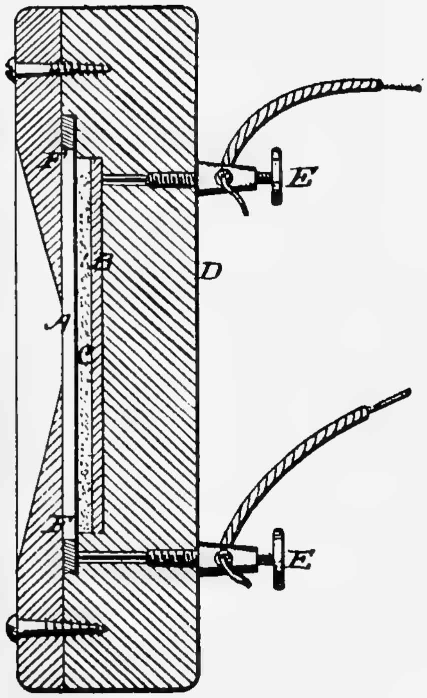

FIGURE 76.—Patent drawing of Hunnings' carbon granule telephone transmitter. From U.S. patent 246512 (August 30, 1881).

ther refined his approach by basing his experimentation upon the fact that the apparent resistance of semiconductors varied considerably with the pressure, and a few months later he created a successful transmitter. (See figs. 71, 72.)

Edison filed the applications for the patents[55] on the first of his many forms of the carbon transmitter on April 1 and 27 and July 20, 1877. Basically Edison's transmitter consisted of a mass of carbon in various shapes and textures, against which a vibrating diaphram pressed. Change of pressure on the diaphram brought a change of resistance of the carbon and so modulated the current. Edison's device soon proved to be better than Bell's magneto transmitter; and although it was insensitive by modern standards, shouting was no longer mandatory in order to carry on a telephone conversation. The Edison transmitter was rugged, and it gave a better quality of reproduction than Bell's instrument.

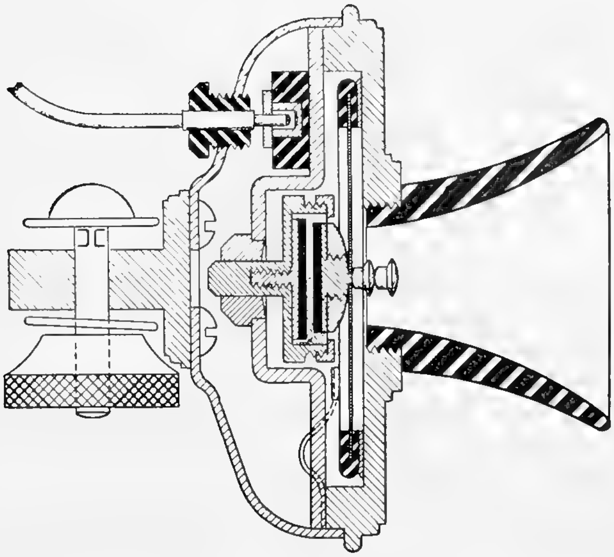

FIGURE 77.—Diagram of White's "solid-back" telephone transmitter. Reprinted (with permission) from F. Rhodes, *Beginnings of Telephony*, Harper and Brothers, New York, 1929, p. 81.

In England the carbon transmitter was suggested independently by David Hughes in 1878.[56] Hughes revived the term "microphone" to describe his variable contact transmitter with its remarkable sensitivity. Hughes' microphone (fig. 73) was constructed of several pieces of carbon that rested loosely on or against one another. This whole mass of carbon was mounted on a sounding box. When Hughes announced his discovery, he disclaimed any intention of taking out a patent because his laboratory model, although as sensitive as it was simple, was too erratic in performance to be practical.

In America applications for patents on other modulating transmitters were submitted, and it was soon found that there was duplication in their principles of operation and design. Because of various delays, Berliner's patent was not issued until 1891, and Edison did not receive his until 1892. Although the Patent Office originally ruled in Berliner's favor, in 1894, 1895, and 1901 successive courts declared his patent void because of the delays and because of

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[55] Thomas Edison, U.S. patents 474230 and 474231 (May 3, 1892) and 203016 (April 30, 1878); Prescott, *op. cit.* (footnote 48), pp. 218–234; *Bell's Electric Speaking Telephone*, New York, 1884, pp. 126–174. Patent Office models of some of Edison's microphones are preserved in the Museum of History and Technology of the Smithsonian Institution.

[56] David Hughes, "On the Physical Action of the Microphone," *Philosophical Magazine*, 1878, vol. 6, pp. 44–50.

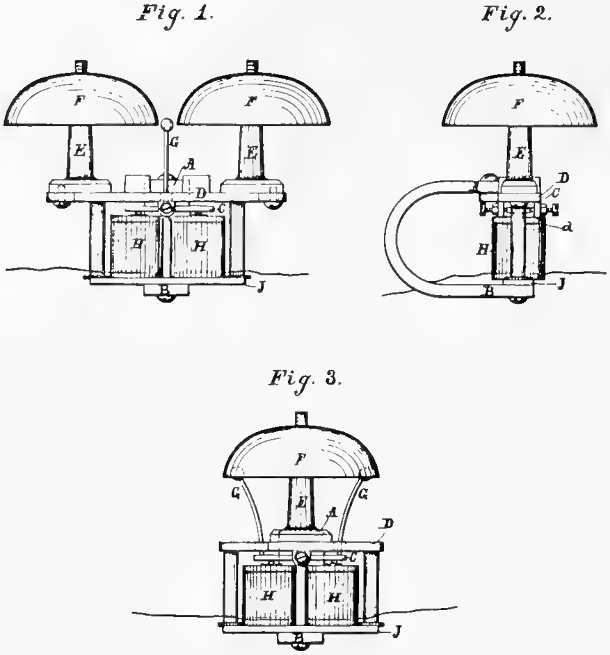

FIGURE 78.—Patent drawings of Watson's polarized ringer. From U.S. patent 210886 (December 17, 1878).

earlier claims to priority made by Bell and by Edison.[57] In 1903 the United States Supreme Court finally declared the Berliner patent valid but restricted the claims of this patent to metal electrodes.[58] In its 1903 ruling the Supreme Court decreed that Berliner's patent application disclosed invention but added nothing of practical value to the telephone. Because Berliner's patent was limited to the use of metal electrodes, it did not infringe on the use of carbon transmitters in telephones. Edison's claims to priority in the invention of the carbon transmitter were maintained throughout the lengthly litigation concerning telephone transmitter patents. However, by the end of the legal battle, the American patent rights on his transmitter were lost because his European patents had expired. When a European patent had expired, its American counterpart was also invalid.

But long before the courts had reached these decisions, commercially successful carbon transmitters had been invented and placed in operation. The first of these (figs. 74, 75) was designed by Francis Blake[59] early in 1878. In Blake's transmitter a platinum bead was fastened to the back of the diaphragm, and the diaphragm pushed the bead against a carbon block. Blake offered his transmitter to the Bell Company, and it was promptly purchased. At first this transmitter gave quite a bit of trouble until Berliner showed how a harder carbon block would improve it. This modification made it a more sensitive instrument than Edison's transmitter and capable of providing a more powerful signal than either the Bell or Edison device. After Blake's instrument was patented in England on January 20, 1879, and in the United States on November 29, 1881, it was used extensively for some years by the Bell Company as standard equipment.

The next steps in the development of the modulating transmitter were brought about by two inventors who made some changes in the shape and size of the carbon electrodes. An English clergyman named Henry Hunnings[60] replaced the single piece of carbon used in the Blake instrument by granules of coke. These granules were placed between the diaphragm and a metal back. Hunnings' English patent was issued September 16, 1878, and the American patent (fig. 76) was issued in 1881 to the American Bell Telephone Company. The Hunnings transmitter was quite efficient. It had the quality of Blake's transmitter but could carry more current than the Blake instrument. In 1886 Edison improved the Hunnings device by substituting granules of anthracite coal for the coke. This improvement fell within the claims of one of Edison's early patents on the carbon transformer, and he modified this patent accordingly.

The weakness of the granular carbon transmitter was that, with use, a packing of the granules occurred resulting in a loss of sensitivity. This problem was solved by replacing the metal back by a solid block of carbon. This improved device (fig. 77), patented by A. C. White on November 1, 1892 (U.S. patent 485311), is essentially the same as our present carbon transmitter.

In the meantime the Bell Company had consolidated its rights to the monopoly of the telephone business. In 1878 the American Bell Telephone Company felt that it was in a sufficiently strong position to take action against Western Union's entry into the field of telephony and accordingly brought suit against an agent of one of Western Union's subsidiary companies. After two years spent collecting testimony and preparing to defend this case, the Western Union lawyer recommended that it be settled out of court. In exchange for agreeing not to enter the telegraph business and for giving 20 percent royalties to Western Union for 17 years, the Bell people obtained full rights to all telephone patents held by Western Union (including those of Gray, Dolbear, and Edison), as well as the right to purchase Western Union's 56,000 telephones and its associated telephone exchanges. This settlement and the Supreme Court decision of 1887 gave the Bell company control of the telephone business for the remainder of the duration of the Bell patents.

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[57] *Federal Reporter*, 1895, vol. 65, pp. 86–91; 1895, vol. 68, pp. 542–570; 1901, vol. 109, pp. 976–1056.

[58] *Federal Reporter*, 1903, vol. 119, pp. 893–917.

[59] Francis Blake, U.S. patents 250126–250129 (November 29, 1881); British patent 229 (January 20, 1879).

[60] Henry Hunnings, British patent 3647 (September 16, 1878); U.S. patents 246512 (August 30, 1881) and 250250 (November 29, 1881).

At first the telephone simply replaced the telegraph in private-line telegraph circuits that already existed.[61] For instance, in May 1877 E. T. Holmes of Boston showed how the new instrument might be connected to a telegraph burglar alarm system. Telephones were connected to the central station of the system during the day, and telegraphs were connected at night. However, Holmes' demonstration lasted only a few weeks, for problems were involved in connecting many telephones with one another that could not be handled in a telegraph central station. The first telephone switchboard that was used for regular commercial service was installed in New Haven in January 1878. In the same year Thomas A. Watson added to the telephone system the polarized ringer (fig. 78), a device for signaling between stations and calling the operator. In 1879 H. L. Roosevelt patented the automatic switch (fig. 79) that notifies the operator when a telephone is in use. The remainder of the century brought many changes in the telephone system, including the multiple and the common battery switchboard, as well as some experimental beginnings of automatic switching.

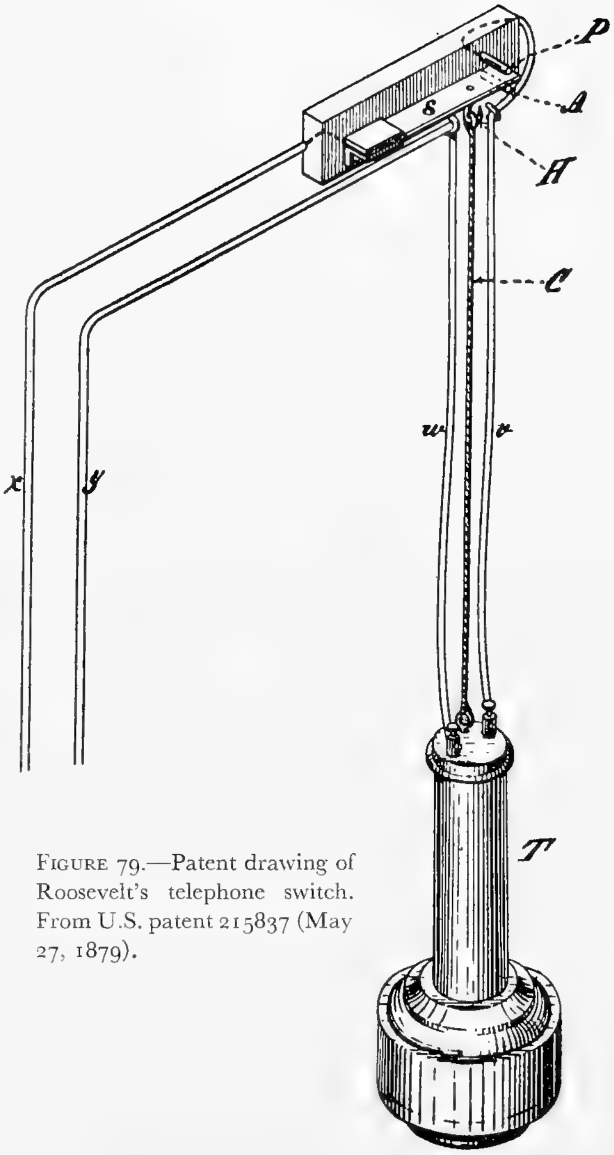

FIGURE 79.—Patent drawing of Roosevelt's telephone switch. From U.S. patent 215837 (May 27, 1879).

In the 1880's there was a great increase in the number of telephones. The area interconnected by telephone also increased. This increase in the area covered by telephones was made possible by the metallic circuit and by the introduction of hard copper wire for use in telephone lines.[62] In 1880 and 1881 the telephone company started replacing the single wire and ground circuit inherited from telegraphy with a twisted pair of metal conductors. About the same time a hard copper wire began to be used. This copper material was a more efficient conductor of electricity than the iron and steel wires that had been used in long spans up to this time. These new improvements made it possible to join New

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[61] Frederic L. Rhodes, *Beginnings of Telephony*, New York, 1929, pp. 147–188.

[62] *Ibid.*, pp. 66–136.

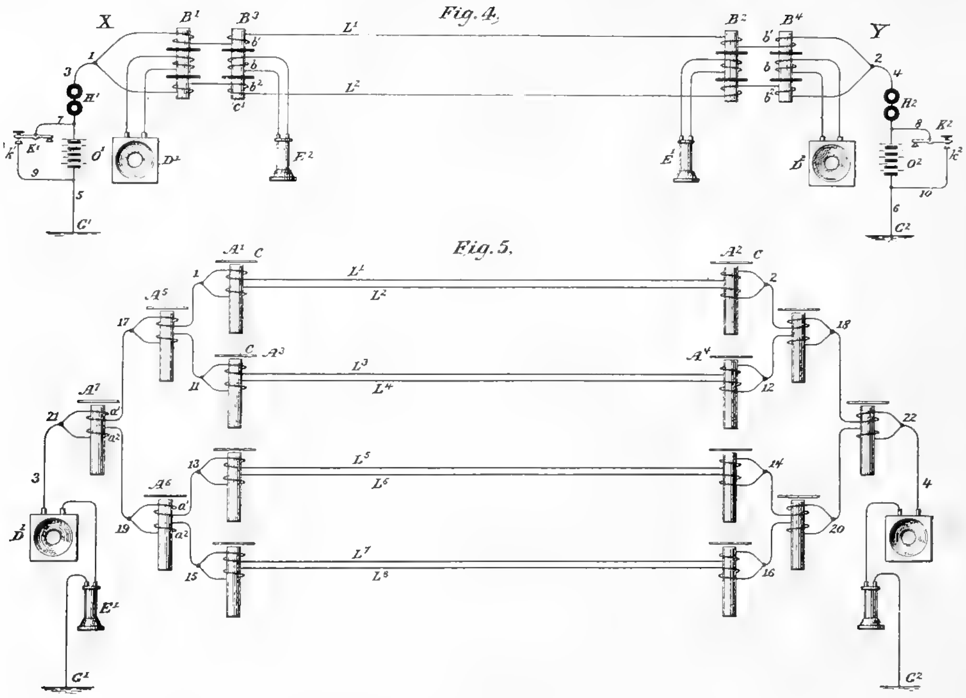

Figure 80.—Patent drawing of Carty's use of the "phantom" circuit for a combination telegraph and telephone line ("fig. 4") and for a system of telephones ("fig. 5"). From U.S. patent 348512 (August 31, 1886).

York with Boston and Philadelphia by the middle of the 1880's and New York with Chicago by 1892.

Some attempts were made to treat telephone lines as telegraph circuits and to duplex them.[63] In 1883 F. Jacob made an unsuccessful attempt to set up a bridge circuit for telephone lines, using resistances only.[64] One of the first steps toward the development of a practical bridge circuit was J. J. Carty's invention of the "phantom" circuit (fig. 80) in 1886. Carty's circuit used induction coils instead of resistances, and it enabled three telephone conversations to be carried on over two pairs of wires. However, this system was difficult to apply and so did not come into even limited commercial use until the winter of 1902–1903.

During the 1890's there were many steps—some of which were taken without any understanding of electricity, and some on a sound basis—toward a wireless telegraphy and wireless telephony, but, practically speaking, there were no commercial wireless systems in operation before 1900.

Those electrical communications systems that began as unwanted "philosophical toys" eventually became essential ingredients of 19th-century society in war and peace, in urban growth and national expansion, in stimulating the economic ties between nations, and in the corporate growth within nations. But these important developments are beyond the scope of this article, in which we have sought only to trace the invention and application of the new instruments in terms of the technology of the period.

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[63] *Ibid.*, pp. 189–195.

[64] F. Jacob, U.S. patent 287288 (October 23, 1883).

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THE DEVELOPMENT OF ELECTRICAL TECHNOLOGY IN THE 19th CENTURY:

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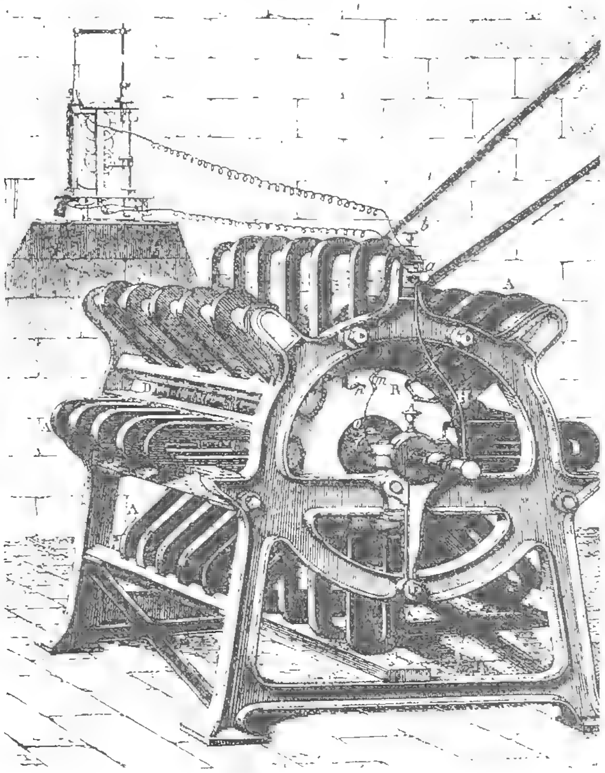
3. The Early Arc Light and Generator

by W. James King



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PAPER 30

THE DEVELOPMENT OF ELECTRICAL TECHNOLOGY IN THE 19TH CENTURY

III. THE EARLY ARC LIGHT AND GENERATOR

W. James King

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THE DEVELOPMENT OF ELECTRICAL TECHNOLOGY IN THE 19th CENTURY:

3. The Early Arc Light and Generator

by W. James King

In 1843 Louis Deleuil showed that he could light the Place de la Concorde in Paris with electricity by using Bunsen cells and charcoal electrodes. Only a few years later the first commercial successes of the electric light occurred when Staite, of England, and Duboscq, of France, used their arc lights in theatrical productions.

After Faraday discovered the induction of electric current he devised a magnetoelectric generator, in 1831. However, the practical development of the generator was slow. It was only after the dynamo principle of self-excitation had been applied to generators, in the 1860's, and after Jablochkoff showed that many arc lights could be connected to a single generator, in the 1870's, that the electric light became economically feasible.

American developments will be discussed in a subsequent article.

THE AUTHOR: *W. James King—formerly curator of electricity, United States National Museum, Smithsonian Institution—is associated with the American Institute of Physics.*

THE first commercially successful application of electricity in the 19th century—to electroplating—created a demand for electrical power that could be only partially satisfied by the expensive method of dissolving metals in acids. The second application of electricity, to communications, found adequate sources of power in such chemical cells, but not the next phase in the development of electrical technology. Even more so than in electroplating, the attempts to produce light by electricity required much sturdier and more potent sources of electrical current than chemical cells.

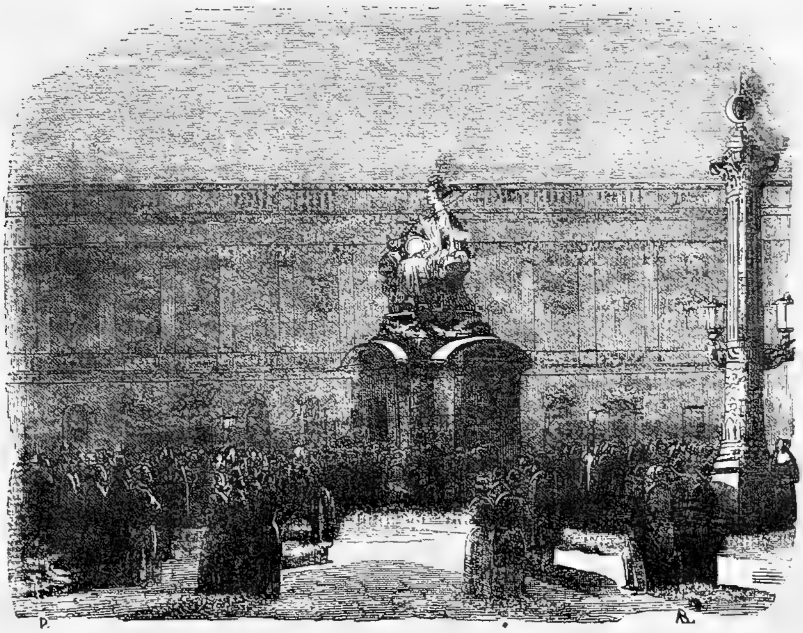

Figure 1.—Deleuil demonstrates his electric light on the Place de la Concorde in Paris, October 20, 1843. From *L'Illustration*, 1843, vol. 2, p. 132.

Although electric illumination could become commercially practical only after mechanical energy had been substituted for chemical energy in the transformation that produced electrical energy, still, the initial advances in the field of electrical light were made with power from chemical cells. By mid-century there were indications that such an application of electricity might be commercially profitable but it was clear that other sources of power had to be found.

Shortly after the voltaic cell was devised, it was found that the current from the cell could produce a number of strange new physical and chemical effects. Attempts to determine the different effects of voltaic electricity included studying the sparks obtained between various materials, which, Humphrey Davy found, became much brighter with charcoal than with metals. Using a battery of 500 double plates at the Royal Society, Davy announced in December 1808 that a glowing arc almost an inch long could be obtained in this manner. By using a 2,000-plate battery at the Royal Institution the following year, he obtained an arc three inches long.[1] In spite of its brilliance, no efforts were made to use the newly found "electric light" because of its impermanence.

At the same time, another source of electric light had been suggested in the incandescent glow of fine metallic wires when heavy currents go through them. But the same problems were found to occur with incandescent filaments as with arcs from charcoal. Up to the 1840's, any attempt to use the galvanic current as a practical source of light was futile because of the too-rapid consumption of the charcoal or of the incandescent wire and because the current from the chemical battery lasted for only a short time. An additional difficulty in using charcoal in an arc was that of maintaining the correct separation of the electrodes in the face of rapid and irregular burning.

The 19th century saw much experimentation and progress in public illumination, and after the invention of the Bunsen and the Grove cells experimenters began to examine seriously the possibility of using the new agency for this purpose. Some of the first successful attempts were made by the Parisian instru-

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[1] Humphrey Davy, "An Account of Some Experiments on Galvanic Electricity, Made in the Theater of the Royal Institution," *Journal of the Royal Institution of Great Britain*, 1802, vol. 1, pp. 165–167; "An Account of Some New Analytical Researches on the Nature of Certain Bodies, Particularly the Alkalies, Phosphorus, Sulphur, Carbonaceous Matter, and the Acids Hitherto Undecompounded; with Some General Observations on Chemical Theory," *Philosophical Transactions*, 1809, vol. 99, pp. 39–104. *Philosophical Magazine*, 1810, vol. 35, p. 463.

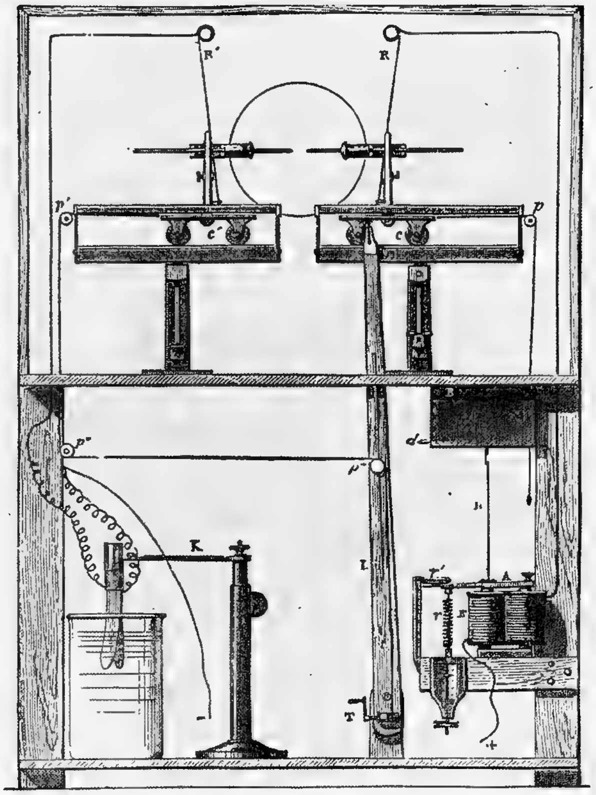

Figure 2.—Foucault's arc-light regulator of 1847. From E. Alglave and J. Boulard, *The Electric Light*, New York, 1884, p. 62.

ment-makers Deleuil, Archereau, and Duboscq during the 1840's.[2]

After a few private demonstrations in 1841, Louis J. Deleuil showed, in 1843, that he could light the Place de la Concorde by electricity (fig. 1).[3] The 200 Bunsen cells he placed below the statue of Lille produced a discharge between charcoal electrodes in an evacuated glass cylinder that was situated on the knees of the statue. The soft glow penetrated the slight fog on the evening of the demonstration, and the experiment was pronounced a success. Deleuil had been assisted in the trial by Henri A. Archereau who had used a similar method to light his dining room in 1843.[4] Archereau followed with other public demonstrations a short time later but without the feature of the evacuated globe. Nevertheless, such pioneer efforts were handicapped by the uneven burning of the carbons that made constant manual operation necessary for continuous performance.

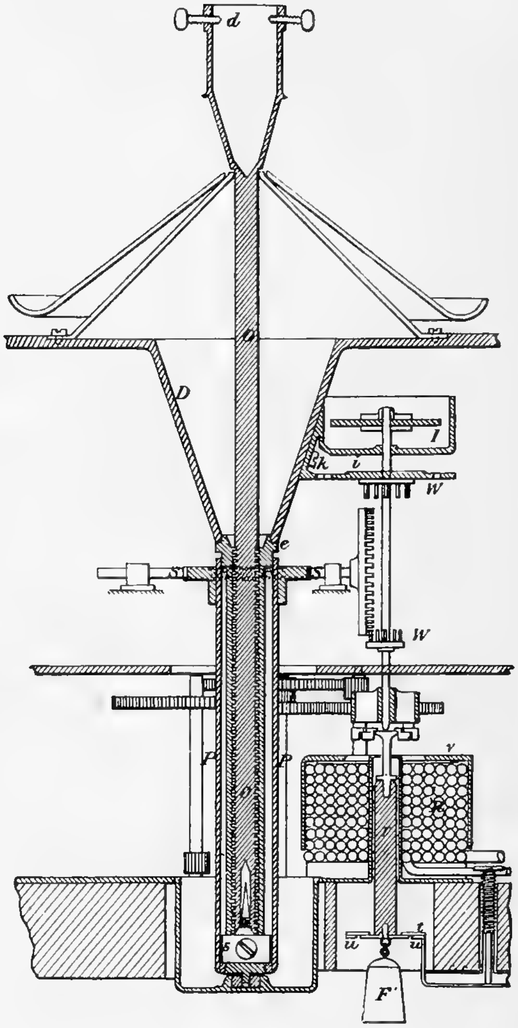

Figure 3.—Staite's 1847 regulator for changing the position of the lower carbon (placed in *d*) in his arc light. The upper carbon was fixed in position; the lower carbon's position was determined by a clockwork whose speed was controlled by a solenoid. From J. Dredge, *Electric Illumination*, London, n.d. (about 1882), vol. 1, p. 381.

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[2] "Eclairage," *La Grande Encyclopédie*, Paris, n.d., vol. 15, pp. 341–346; Eugène Defrance, *Histoire de l'éclairage des rues de Paris*, Paris, 1904; Louis Figuier, *Les Applications de la science à l'industrie et aux arts en 1855*, Paris, 1856, pp. 326–336.

[3] *Les Mondes*, 1863, vol. 2, p. 452; *L'Illustration*, 1843, vol. 2, p. 132.

[4] J. Balteau, M. Barroux, and Michel Prévost, *Dictionnaire de biographie française*, Paris, 1939, vol. 3, p. 381.

Léon Foucault initiated progress toward a solution in 1844 with his photometric studies on the radiation from a carbon arc. He discovered that an electrode that was consumed more uniformly and more slowly than charcoal could be made from the hard carbonaceous deposit formed in coke retorts. He then set to work to devise an automatic regulator for the arc, but, in 1848, he was surprised to read that W. Edward Staite of London had applied for a patent on a regulator that appeared to be based on the same principle as his.[5] Upon invitation by Foucault, a committee from the Académie des Sciences examined his laboratory and verified that his work was independent of Staite's. However, Foucault's automatic regulator (fig. 2) for the arc was too delicate and too complicated for use even in the laboratory, and it found little application until it was modified by Duboscq.

Staite had begun his work by demonstrating an automatic arc light in a hotel at Sunderland, Durham, in 1847. This light (figs. 3, 4) had finally worked so well that it is said to have remained in use for several years. Public exhibitions in 1848 and 1849 led to what one might consider the first commercial success of the electric light. In May 1849 a ballet called "Electra," especially composed for the purpose, introduced the arc light to the public at Her Majesty's Theater in London (fig. 5). The ballet was an instant hit, and a command performance was given for Queen Victoria a few weeks later. A similar application appeared about the same time across the Channel, where Foucault's arc lamp was used to simulate the rising sun in Meyerbeer's latest opera, "Le Prophète." [6]

Staite constantly improved his apparatus. In 1849 the average time for continuous operation was 45 minutes; two years later his arc light could run without interruption for 5 hours. He even demonstrated it to the Queen and to her court at the palace. Then he obtained a request in 1852 that seemed to promise a profitable commercial venture. The port of Liverpool asked him to set up a permanent installation of his lamps on a high tower so as to permit work to

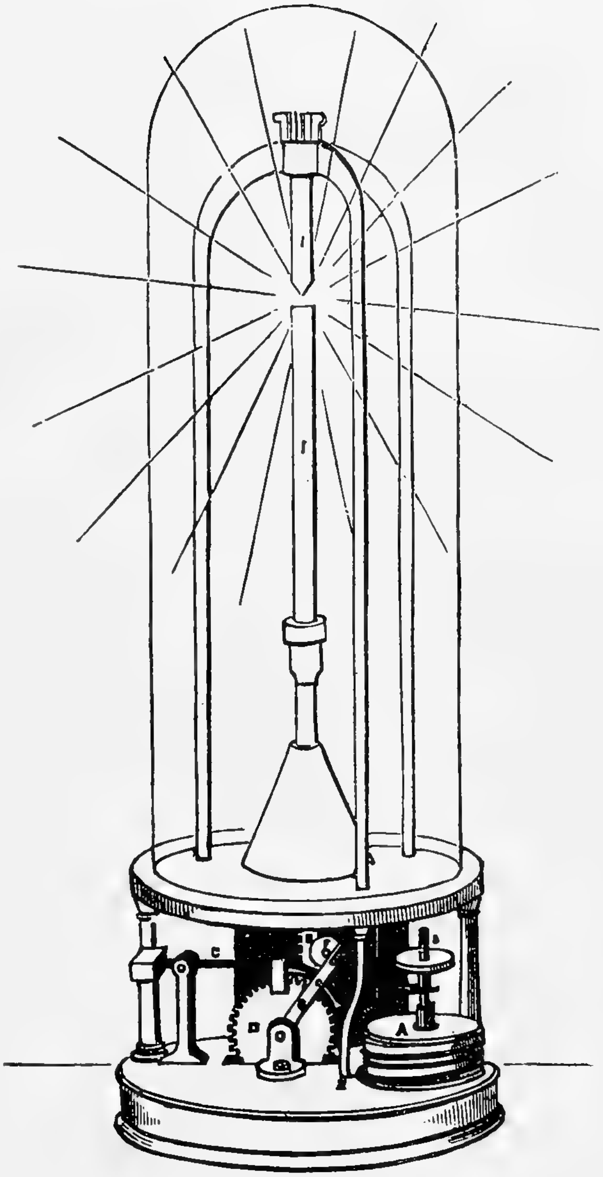

Figure 4.—Staite's arc light of 1848. From *Illustrated London News*, November 18, 1848, vol. 13, p. 317.

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[5] *L'Illustration*, 1849, vol. 13, p. 6; Léon Foucault, "Appareil destiné à rendre constante la lumière émanant d'un charbon placé entre les deux pôles d'une pile," *Comptes rendus*, 1849, vol. 28, pp. 68–69; Théodose du Moncel, *Exposé des applications de l'électricité*, Paris, 1856–1862, ed. 2 (5 vols.), vol. 3, pp. 217–219.

[6] Emile Alglave and J. Boulard, *La Lumière électrique, son histoire, production et son emploi dans l'éclairage public ou privé*, Paris, 1882, translated by T. O'Connor Sloane as *The Electric Light*, New York, 1884, pp. 22–23; *Mechanics Magazine*, 1847, vol. 46, pp. 621–622; 1848, vol. 48, p. 453; vol. 49, p. 382; *Illustrated London News*, 1848, vol. 13, pp. 317, 343, 368, 378; 1849, vol. 14, p. 58; *London Times*, November 2, 1848; *Illustrated London News*, 1849, vol. 14, p. 293; Jules A. Lissajou, in *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1868, ser. 2, vol. 15, p. 59. Although the *Illustrated London News* asserts the device was copied in France, Lissajou claims it was used on April 16, 1849, the opening date for Meyerbeer's opera.

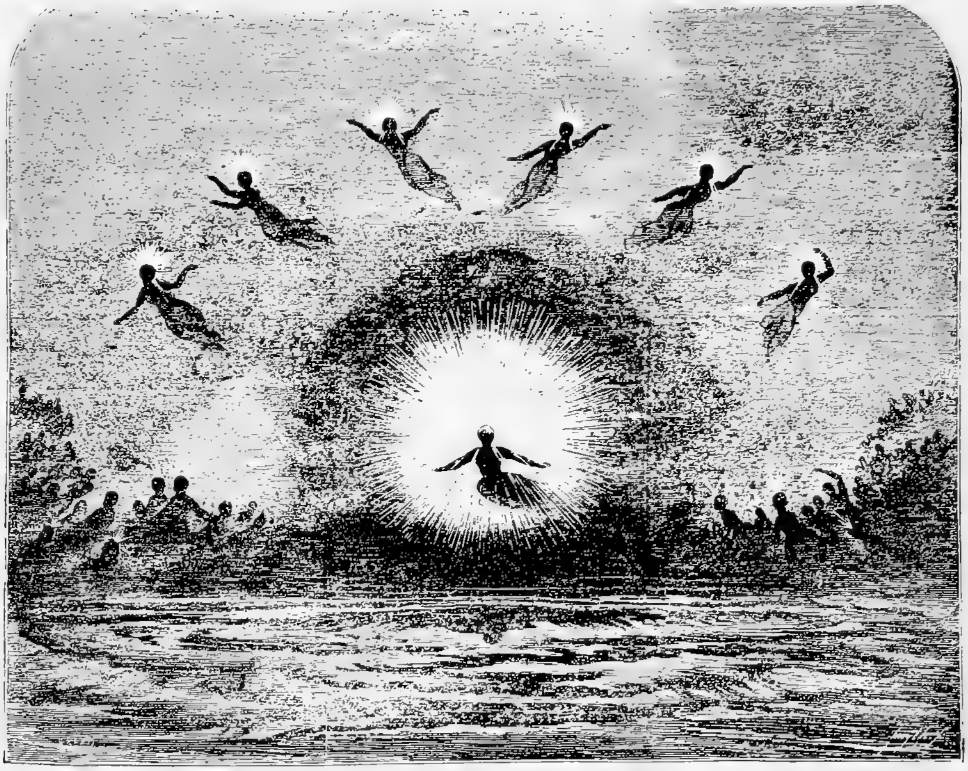

Figure 5.—Scene from the last act of the ballet "Electra, or the Last Pleaid." From *Illustrated London News*, May 5, 1849, vol. 14, p. 293.

be carried on at night. These preliminary results[7] were very encouraging, but Staite's death brought an end to the project.

A portion of Staite's success was due to his invention of a practical automatic regulator that eliminated the necessity of moving the carbons by hand as they were consumed (fig. 6).[8] The amount of current flowing through the arc controlled the spacing of the carbons by balancing a mechanical force with the attractive force of a solenoid. As the carbons burned, the arc became longer and the current became less due to the increased resistance. The decreased attractive force of the solenoid permitted the carbons to move closer together in Staite's 1847 regulator by controlling a clockwork and in his 1853 regulator by controlling the height of a float. This solenoid control came to be a basic feature in the design of all the later successful regulators. Other factors contributing to the success of Staite's lamp were the semi-enclosure of the arc in a chamber to reduce the consumption of the carbons (a feature that was not again used until the 1890's, but then with great success) and the use of the hard carbon from coke retorts rather than the much softer charcoal. Foucault's regulator was based on the same solenoid principle as that of Staite's, but it was set up horizontally so that, as the attractive force due to the solenoid became weaker due to the lengthened arc, a detent released a clockwork that moved the electrodes together.

In the meantime, other regulators had appeared (figs. 8, 9). In France, Archereau, in 1849, also invented a regulator that balanced the weight of the carbon electrode against the attractive force of a solenoid (fig. 10), but the system was too insensitive

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[7] *Mechanics Magazine*, 1849, vol. 50, pp. 538–539; 1850, vol. 52, p. 35; 1851, vol. 54, pp. 411–412; vol. 55, pp. 316–317; 1852, vol. 57, p. 217.

[8] British patents 11449 (November 12, 1846), 11783 (July 3, 1847), 12212 (July 12, 1848), 12772 (September 20, 1849), 634 (March 14, 1853); *Mechanics Magazine*, 1848, vol. 48, pp. 49–56; 1849, vol. 50, pp. 49–58, 73–80; 1850, vol. 52, pp. 246–248; *Illustrated London News*, January 1849, vol. 14, p. 58.

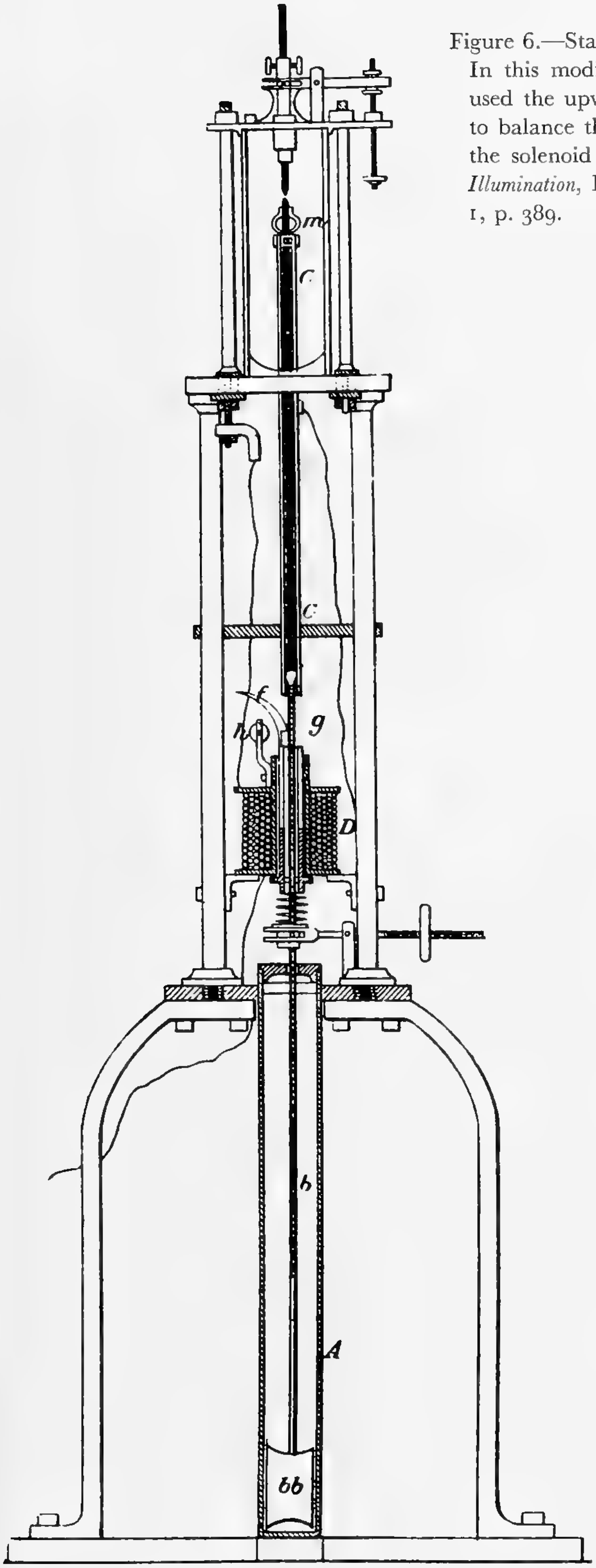

Figure 6.—Staite's arc-light regulator of 1853. In this modification of his invention Staite used the upward buoyancy of the float (*bb*) to balance the downward pull of the coil of the solenoid (*D*). From J. Dredge, *Electric Illumination*, London, n.d. (about 1882), vol. 1, p. 389.

and irregular in its action.[9] However, this regulator seemed so promising that after Archereau demonstrated it in a St. Petersburg square Czar Nicholas requested the Russian Academy of Sciences to investigate streetlighting by this method.[10] Then, in 1855, Archereau sought to illuminate the port of Marseilles with his arc lamp.[11]

In 1850 Duboscq simplified Foucault's regulator to the extent that it became sufficiently reliable for regular use in the theater as well as for laboratory and lecture demonstrations (figs. 11, 12). The use of the brilliant arc light became so necessary for spectacular effects that finally, in 1855, an entire room at the Paris Opera House was set aside for Duboscq's electrical equipment. The prizes at the Exposition Universelle of Paris in 1855 were handed out in the brilliance of this regulator, with one of the awards going to Duboscq for his invention; other prizes and honors followed successive improvements in the regulator.[12] However, the regulator was still too delicate, and there was a disadvantage in that the clockwork required winding.

Except for Staite's lamp, these early regulators were satisfactory only for a relatively short period of

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[9] British patent 7924 (February 12, 1849); Du Moncel, *op. cit.* (footnote 5).

[10] *Illustrated London News*, December 1, 1849, vol. 15, p. 362.

[11] *Les Mondes*, 1863, vol. 2, p. 452.

[12] Jules Duboscq, "Note sur un régulateur électrique," *Comptes rendus*, 1850, vol. 31, pp. 807–809; Edmond Becquerel, "Rapport . . . sur l'appareil photo-électrique de M. Jules Duboscq, opticien," *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1855, ser. 2, vol. 2, pp. 455–461; Hippolyte Fontaine, *Eclairage à l'électricité*, Paris, 1877, p. 11; *La Lumière électrique*, 1880, vol. 2, pp. 284–288; *Cosmos*, 1855, vol. 7, pp. 492–494; 1864, vol. 24, pp. 121–126; Du Moncel, *op. cit.* (footnote 5), vol. 3, pp. 221–231, 280; *L'Année scientifique*, 1856, vol. 1, pp. 485–486; *Mechanics Magazine*, 1857, vol. 67, p. 250; 1858, vol. 68, pp. 252–253; Jules A. Lissajou, in *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1859, ser. 2, vol. 6, p. 254.

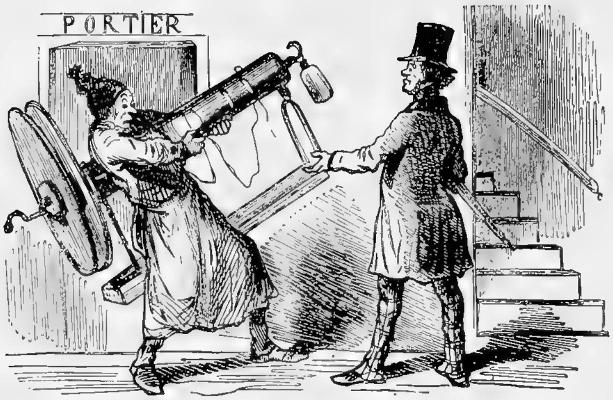


Figure 7.—How a French cartoonist imagined the lodger of the future would be given his electric "candle" by the concierge. From *L'Illustration,* September 30, 1848, vol. 12, p. 69.

time, and so other means of regulating the carbons were sought. Joseph Lacassagne and Rodolphe Thiers devised a differential arc light regulator in which the current resulting from the difference of two controlling circuits fed the moving carbon at the proper speed (figs. 14, 15). By using a battery of 60 Bunsen cells, Lacassagne and Thiers successfully illuminated a square in their home city of Lyons in 1855, and the following year they lit up the Arc de l'Etoile and the Avenue des Champs Elysées for four hours in a vain attempt to interest Napoleon III in their invention. After successful trials at Lyons again, where they used two lamps to light the Rue Impériale during the evenings for the entire month of March 1857, Lacassagne died; in the same year the Société d'Encouragement pour l'Industrie Nationale awarded a bronze medal for the Lacassagne and Thiers regulator. Thiers sought to exploit the

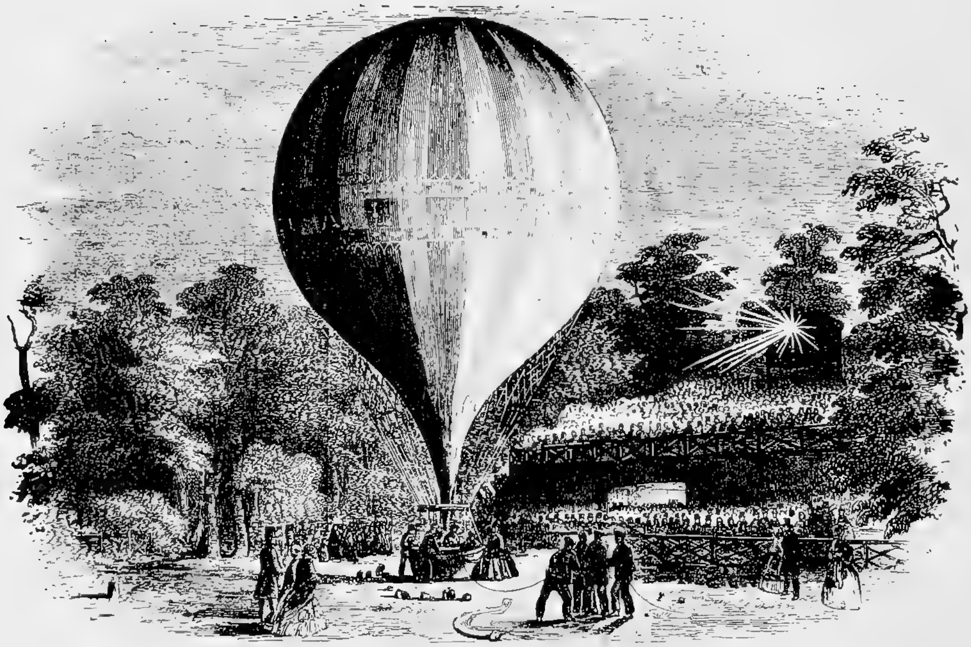
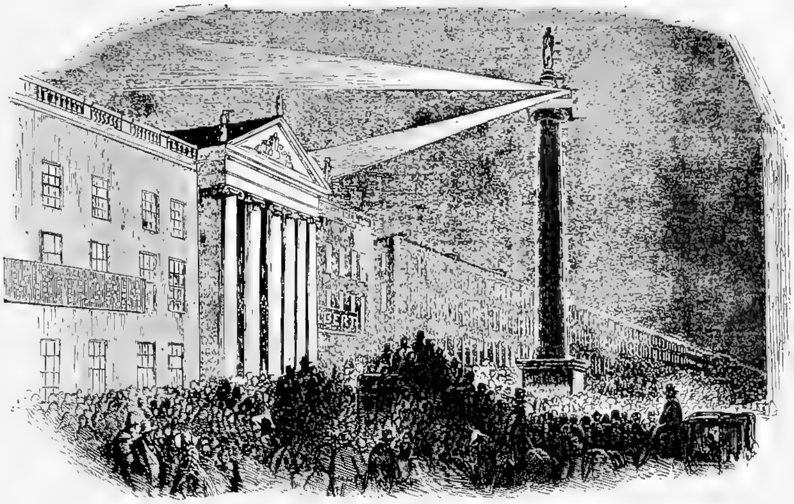


Figure 8.—Demonstration of the new electric light at a balloon ascension at The Vauxhall in London. From *Illustrated London News,* August 25, 1849, vol. 15, p. 144.

Figure 9.—Demonstration of the new electric light during a visit of Queen Victoria and Prince Albert to Dublin, Ireland. From *Illustrated London News*, August 11, 1849, vol. 15, p. 96.



invention after the death of his partner but without any signs of permanent success.[13]

Then, in 1857, Victor Serrin invented a regulator based on some of the best features of that of Duboscq, and it dominated the field for two decades in France and elsewhere (fig. 16).[14] Further refinements made in 1859 produced *le modèle suisse* (fig. 17) that proved its superiority over all others.[15] The heart of its reliability rested in the use of two driving systems balanced against one another through a linkage in the form of a parallelogram with one of the vertical sides fixed (fig. 18). As the upper carbon was consumed and lost weight a detent was released, permitting a clockwork to raise the mobile vertical side of the parallelogram and, in turn, to raise the other carbon. The shortened arc allowed a greater current to flow through a solenoid that tended to pull down the mobile side of the parallelogram by means of an armature attached to the linkage. In this manner, a new balance was constantly found as the carbons gradually disappeared. As we shall see below, Serrin's final regulator (fig. 19) was the one used in the most successful demonstrations of the electric light until the end of the 1870's. A regulator somewhat similar to that of Serrin was produced by Siemens, and it came into wide use in Germany and England.

Complaints often were made that the arc light was too glaring, although it was pointed out to such critics that so, also, was the sun. Nevertheless, the intensity of the arc light proved to be a stumbling block to the use of electricity for public lighting. Various efforts were made to reduce the brightness. The intensity of the arc light was reduced by placing it on very high supports, and various kinds of diffusers, such as frosted glass, were tried. Another possibility considered was that perhaps the electric light could be subdivided by placing several arc lights in the same circuit. If this could be achieved, the glow could be spread over a number of sources. Both Quirini and Deleuil asserted that they had placed

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[13] British patent 2456 (October 20, 1856); Edmond Becquerel, "Rapport sur un régulateur électrique et sur une lampe photo-électrique presentés par MM. Lacassagne et Thiers de Lyons," *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*,1856, ser. 2, vol. 3, p. 672, and 1857, ser. 2, vol. 4, pp. 524–547; Du Moncel, *op. cit.* (footnote 5), vol. 3, pp. 234–239; vol. 4, pp. 504–506; *Cosmos*, 1856, vol. 9, pp. 365–368; 1857, vol. 10, pp. 342–343, 538–539; 1859, vol. 15, pp. 200–202; 1861, vol. 19, p. 113; *L'Illustration*, 1856, vol. 28, p. 299; *Mechanics Magazine*, 1857, vol. 66, pp. 529–530; *L'Année scientifique*, 1858, vol. 2, p. 488; *Les Mondes*, 1863, vol. 1, pp. 311–312.

[14] *Les Mondes*, 1867, vol. 14, pp. 543–555; Du Moncel, *op. cit.* (footnote 5), vol. 4, pp. 492–500.

[15] French patent 38506 (October 23, 1858; addition, October 22, 1859); British patent 653 (March 15, 1859); Victor L. M. Serrin, "Régulateur automatique de lumière électrique," *Comptes rendus*, 1860, vol. 50, pp. 903–905; *Cosmos*, 1860, vol. 16, pp. 514–517; F. P. Le Roux, "Rapport sur . . . un régulateur automatique de lumière électrique présenté par M. Serrin," *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1861, ser. 2, vol. 8, pp. 647–654 (see also 1860, ser. 2, vol. 7, p. 317, and 1866, ser. 2, vol. 13); *Les Mondes*, 1866, vol. 11, pp. 666–668,

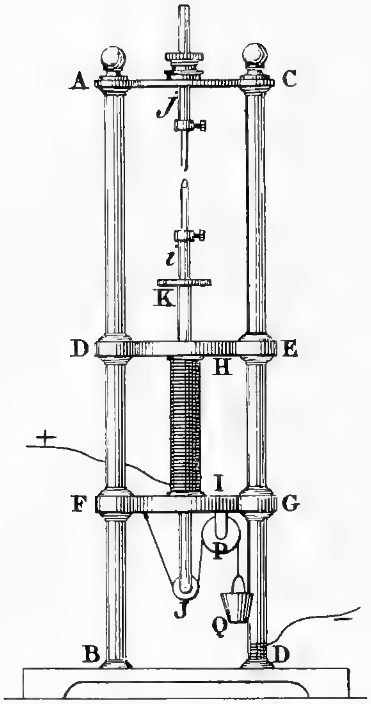

Figure 10.—Archereau's arc-light regulator. The downward weight of the lower carbon was balanced by the upward pull of the solenoid core. From T. du Moncel, *Exposé des applications de l'électricité*, Paris, ed. 2, 1856–1862, vol. 3, pl. 4, fig. 3.

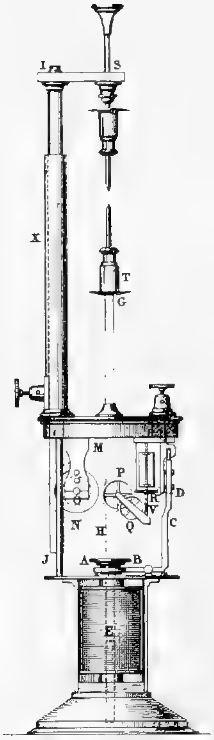

Figure 11.—Duboscq's version of the Foucault arc-light regulator. The rate of ascension of the lower carbon was controlled by a clockwork whose escapement was controlled by the solenoid (E). From T. du Moncel, *Exposé des applications de l'électricité*, Paris, ed. 2, 1856–1862, vol. 3, pl. 4, fig. 4.

several arc lights in the same circuit, the former in 1849 and the latter in 1855. However, such a circuit could be maintained only for a short time.[16] After considerable study, L. F. Wartmann, of Switzerland, asserted that the electric light could be subdivided but that the method depended on the system used in the distribution of the illumination.[17]

However, until the end of the 1870's, all regulators were inherently unstable when placed in the same circuit, except possibly one. When placed in series, if one went out, they all went out; and when placed in parallel, one tended to quench the others. The only kind of regulator that did not have this innate defect was that of Lacassagne and Thiers, but it is difficult to determine to what extent this advantage was realized in practice by the inventors.[18] At any rate, the consensus was that it was not possible to subdivide the electric light.

In the decade between 1855 and 1865 a number of attempts were made to use the arc light for military operations and for public celebrations. It has been said that the arc light was tried during the naval attack on Kinburn in 1855 during the Crimean War, and in 1859 during the Italian war of independence. Joseph Henry devised an arc light in 1863 that was intended to be used for the siege of Charlestown during the Civil War, and in the same year Boston celebrated Union victories by arc-light illumination. On the occasion of the visit of Queen Isabella II of Spain to Paris in 1864, Napoleon used 11 Serrin regulators to illuminate the fountains of

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[16] *Cosmos*, 1855, vol. 7, pp. 703–704; 1856, vol. 8, pp. 30–32.

[17] L. F. Wartmann, "Sur l'Eclairage électrique," *Bibliothèque Universelle de Genève, Archives des sciences physiques et naturelles*, 1857, vol. 36, pp. 323–334.

[18] Du Moncel, *op. cit.* (footnote 5), vol. 3, pp. 250–251.

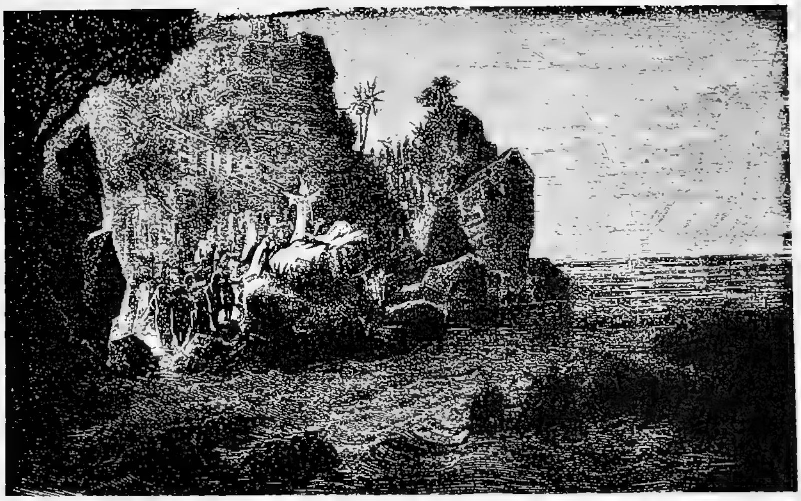

Figure 12.—Use of the Duboscq arc light to produce a rainbow for a scene in the opera "Moses" at the Paris Opera House in 1860. From *La Lumière électrique*, July 15, 1880, vol. 2, p. 287.

Versailles.[19] Nevertheless, neither the military nor peacetime applications of the arc light took root in contemporary technology. The problems of how to make carbons for the arcs and of how to maintain the carbons at the proper distance and in the same place were more or less solved by 1860, but such endeavors were premature and could have no lasting results until an adequate source of electrical power could be found.

Chemical cells had been used as a source of power for the arc lamp but they were admittedly quite expensive. A number of studies had been made showing just how much greater was the cost of producing light by Bunsen cells than by gas or oil, and E. Becquerel concluded that, in Paris, the cost of such light was at least six times that of gas.[20] Another factor that had to be considered was that the acids used constantly gave off noxious fumes and were dangerous for

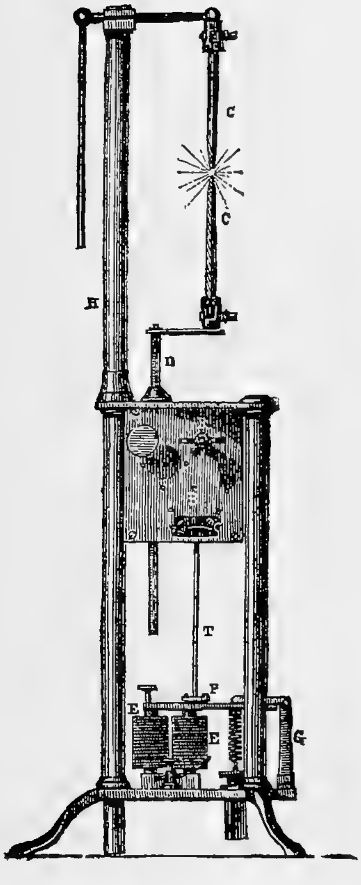

Figure 13.—A later version (1864) of the Duboscq arc-light regulator. From *Cosmos*, January 28, 1864, vol. 24, p. 122.

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[19] "Eclairage," *La Grande Encyclopédie*, Paris, n.d., vol. 15, pp. 341–346; Hippolyte Fontaine, *Eclairage à l'électricité*, Paris, 1879, ed. 2, p. 242 (this may refer to the use of electrically detonated mines in the defense of Venice rather than to the electric light; see *Journal of the Telegraph*, New York, 1868, vol. 1, no. 25, p. 3); Joseph Henry to Alexander Bache, August 21, 1863, in archives of the Smithsonian Institution; *Boston Daily Advertiser*, August 8, 1863; *American Journal of Science*, 1863, ser. 2, vol. 36, pp. 307–308.

[20] Becquerel, *op. cit.* (footnote 13); *Cosmos*, 1857, vol 9, pp. 417–420.

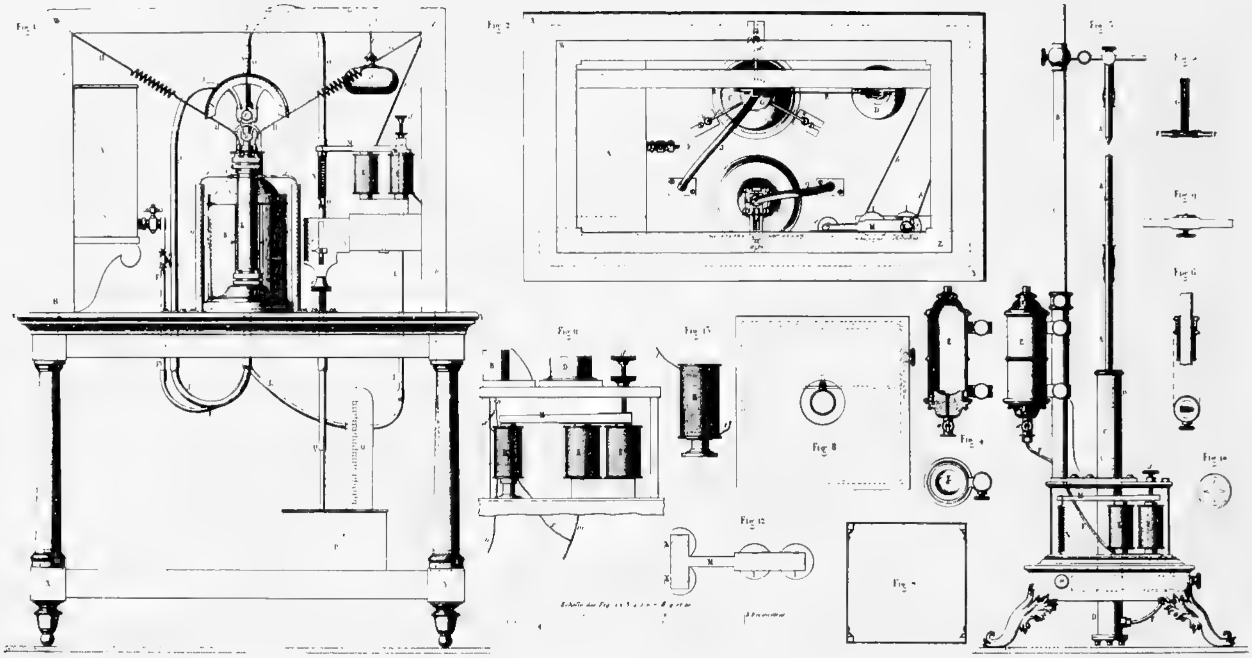

Figure 14.—Current regulator and arc-light regulator of Lacassagne and Thiers. From *Bulletin de la Société d'Encouragement pour l'Industrie Nationale,* 1857, vol. 4, pl. 113.

unskilled workmen to handle. Moreover, even with the best cells of the time, the power was such that the light was appreciably reduced after several hours use. If the light were to be maintained constant, a new battery had to be switched into the circuit. In addition, the cells were too bulky (at least 20 Bunsen cells had to be used for each arc lamp) and too fragile for any extensive application to the industrial arts.

There was a laboratory device on hand, however, that did not depend on the consumption of metals to produce electrical power but, instead, transmuted mechanical power into electrical. The reciprocal relation between mechanical motion and electrical current was discovered in the early 1830's, but almost half a century passed before it was possible to apply this knowledge to the commercial generation of electrical power. Such an application did not become possible until the device known as the dynamo was invented, but simpler generators were well known in the laboratory before that date. Once it had been shown that these generators could be used to supply power for illumination by electricity, a number of inventors sought to bring them from the laboratory into the field of commerce. This laboratory instrument was based on Faraday's discovery of electromagnetic induction, and we must briefly return to the 1830's to discuss the development of the generator.

Like Oersted, although for somewhat different reasons, Michael Faraday felt that all the forces of nature must be somehow related. In particular, if a certain relation exists between two different forces, the converse of that relation must also exist. Such considerations led Faraday to seek an effect opposite to that of Oersted—that of obtaining an electric current from magnetism. He finally discovered it in the relative motion of a magnet with respect to a closed circuit (fig. 20). Investigation of the same relation was pursued by Joseph Henry about the same time, but his delay in publishing the results has tended to obscure his contributions.[21]

Mechanical devices that continuously transform energy from a mechanical to an electrical form followed within a few months of Faraday's discovery of induction. One of the first such devices was

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[21] Michael Faraday, "Experimental Researches in Electricity," *Philosophical Transactions,* 1832, vol 122, pp 125–162; A. Fresnel, "Note sur des essais ayant pour but de décomposer l'eau avec un aimant," *Annales de chimie et de physique,* 1820, ser. 2, vol. 15, pp. 219–222; Joseph Henry, "On the Production of Currents and Sparks of Electricity from Magnetism," *American Journal of Science,* 1832, vol. 22, pp. 403–408.

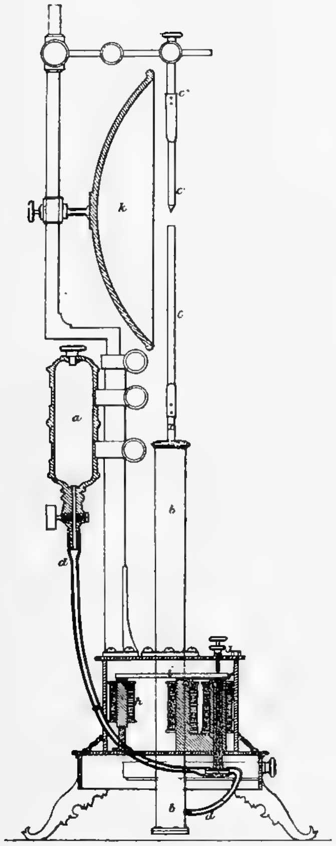

Figure 15.—Another form of the differential arc-light regulator of Lacassagne and Thiers. Two circuits—one permitting and one stopping the flow of mercury from the reservoir (*a*)—controlled the position of the float, to which the lower carbon was fixed. A similar differential principle formed the basis for all the later successful regulators. From J. Dredge, *Electric Illumination*, London, n.d. (about 1882), vol. 1, p. 392.

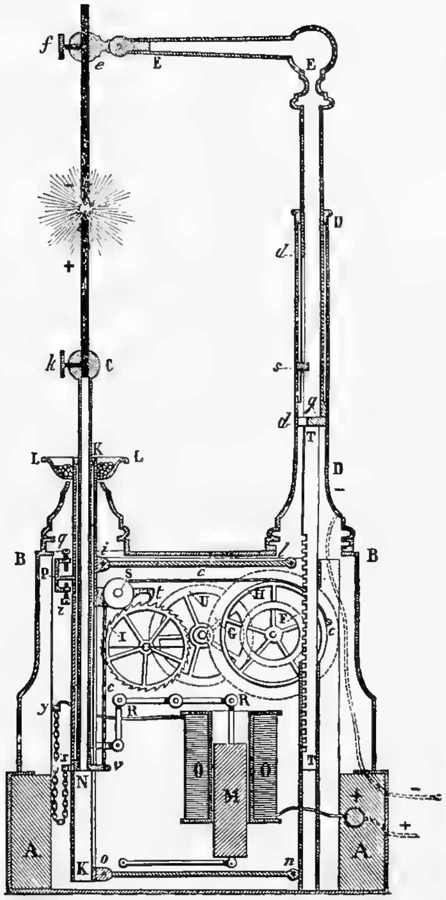

Figure 16.—One of the earliest (1857) versions of Serrin's arc-light regulator. From T. du Moncel, *Exposé des applications de l'électricité*, Paris, ed. 2, 1856–1862, vol. 4, p. 493.

invented by Faraday himself in November 1831. He called this new device a magnetoelectric generator, in contrast to the electrostatic generator; later, the term was shortened to "magneto." This first magnetoelectric generator was, interestingly enough, the converse of Barlow's "wheel," a simple electric motor. Faraday's generator could not produce sparks or electrolyze water, but it did deflect the needle of a galvanometer.

A somewhat more efficient device was produced by Hippolyte Pixii, who had been instrument-maker to D. F. J. Arago and A. M. Ampère for a number of years. Pixii's magneto generator (fig. 21), which was first demonstrated in a lecture by Ampère at the Sorbonne in September 1832, consisted of a 2-kg. horseshoe magnet mounted on a vertical axis that could be rotated before the poles of an electromagnet that acted as armature to the magnet. The electromagnet was about 8 cm. high and had 50 meters of copper wire on it. The alternate passage of first a north and then a south pole before the poles of the electromagnet produced an alternating current that went first in one direction along the wire and then the other, in contrast to the current from chemical cells that always went in the same direction. Although the resulting gases were mixed, Pixii's magneto

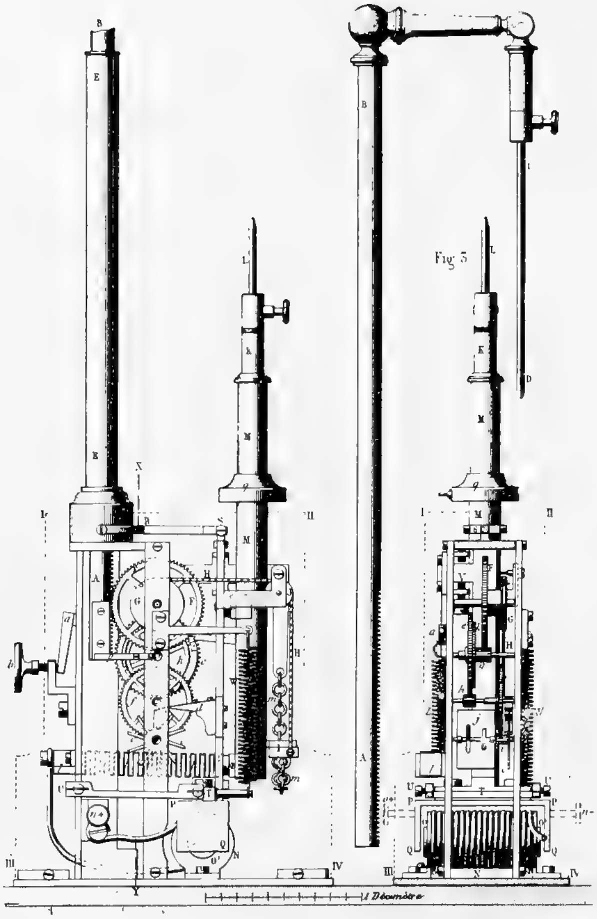

Figure 17.—Serrin's *modele suisse* arc-light regulator. From *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1861, vol. 8, pl. 234.

could electrolyze water and was a great improvement over Faraday's.[22]

In the month following his Sorbonne demonstration Ampère reported how Pixii had built a much larger generator than before and had modified Ampère's commutator switch so that it could be used with the generator (fig. 22).[23] A cam on the axis of the armature actuated the commutator that reversed the directions of the alternations at the appropriate time so as to obtain a more or less unidirectional current. The magneto now provided a current similar to that from the chemical cell, and the gases resulting from the electrolysis of water were in the correct proportions.

Since it was also possible to rotate the coils making up the armature and to keep the magnets stationary, such modifications soon appeared. One of the first of these was described in a report given by the Rev. William Ritchie in March 1833 on a magnetoelectric generator (fig. 23) that he had worked out during the previous summer.[24] Ritchie's armature, in the form of a disk that rotated about an axis perpendicular to its plane, consisted of four coils, 90° apart, that were mounted between two wheels with the axes of the coils parallel to the axis of the supporting wheels. When the armature was rotated, the coils passed in succession between the poles of a permanent magnet and produced an alternating current. In order to obtain a unidirectional or direct current from the rotating armature, Ritchie devised a commutator switch that was mounted directly on the axis of the armature.

Other, more practical forms of the Pixii magneto generator were devised a few years later by instrument-makers Joseph Saxton of Washington and Edward Clarke of London.[25] Their magnetos became quite popular for laboratory demonstrations and for medical experiments. Saxton modified Pixii's generator by

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[22] Jean N. P. Hachette, "Nouvelle Construction d'une machine électromagnétique," *Annales de chimie et de physique*, 1832, vol. 50, pp. 322–324, and "De l'Action chimique produite par l'induction electrique; décomposition de l'eau," *Annales de chimie et de physique*, 1832, vol. 51, pp. 72–74; Charles Jackson, "Notice of the Revolving Electric Magnet of Mr. Pixii of Paris," *American Journal of Science*, 1833, vol. 24, pp. 146–147; *Gehler's physikalisches Woerterbuch*, Leipzig, 1836, new ed., Band 6/2, pp. 1177–1180.

[23] André M. Ampère, "Note de M. Ampère sur une expérience de M. Hippolyte Pixii, relative au courant produit par la rotation d'un aimant, à l'aide d'un appareil imaginé par M. Hippolyte Pixii," *Annales de chimie et de physique*, 1832, vol. 51, pp. 76–79.

[24] William Ritchie, "Experimental Researches in Electro-Magnetism and Magneto-Electricity," *Philosophical Transactions*, 1833, vol. 123, pp. 313–321.

[25] Joseph Saxton, "Description of a Revolving Keeper Magnet, for Producing Electrical Currents," *Journal of the Franklin Institute*, 1834, vol. 13, pp. 155–156; Edward M. Clarke to the editors, *Philosophical Magazine*, 1836, vol. 9, pp. 262–266; "A Description of a Magnetic Electrical Machine," *Annals of Electricity*, 1837, vol. 1, pp. 145–155; "Reply of Mr. E. M. Clarke to Mr. J. Saxton," *Philosophical Magazine*, 1837, new ser., vol. 10, pp. 455–459; "Account of a Series of Experiments Made with a Large Magneto-Electrical Machine," *Transactions and Proceedings of the London Electrical Society*, 1837–1840, vol. 1, pp. 73–76.

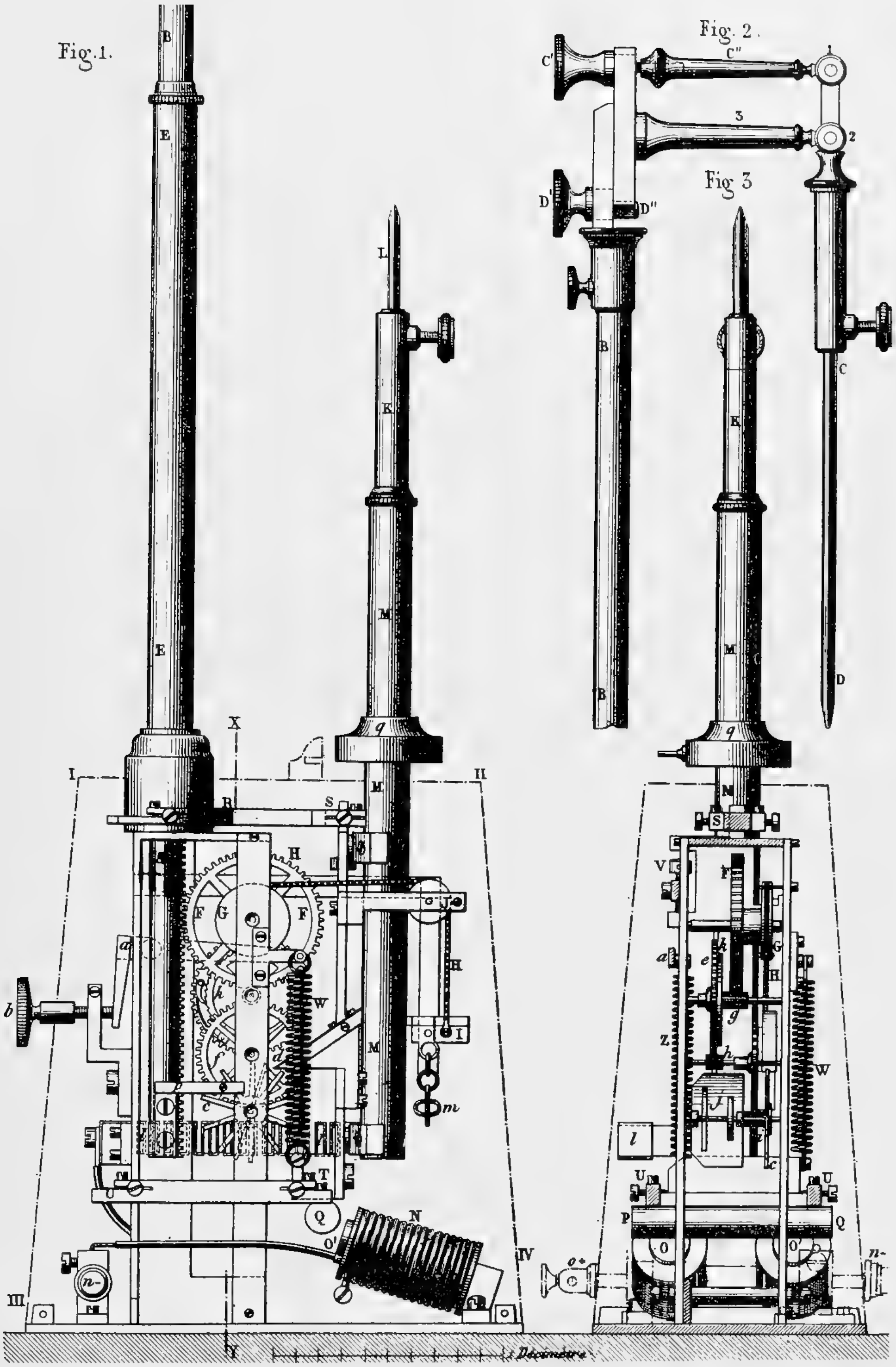
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Figure 18.—Improved version (1867) of Serrin's arc-light regulator. From *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1867, vol. 14, pl. 371.

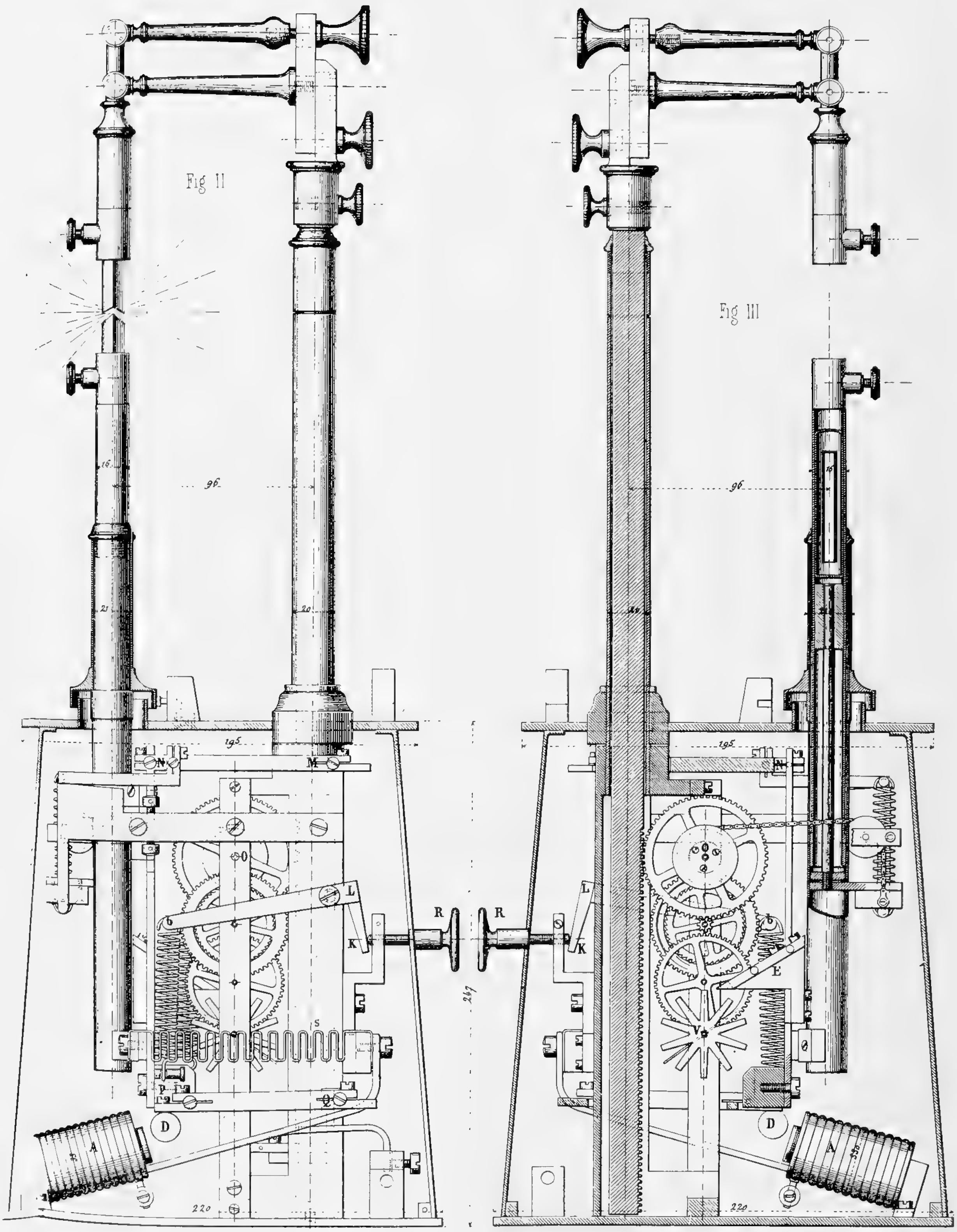
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Figure 19.—Final version (1876) of Serrin's arc-light regulator. From *Revue industrielle,* May 3, 1876, p. 181, pl. 12.

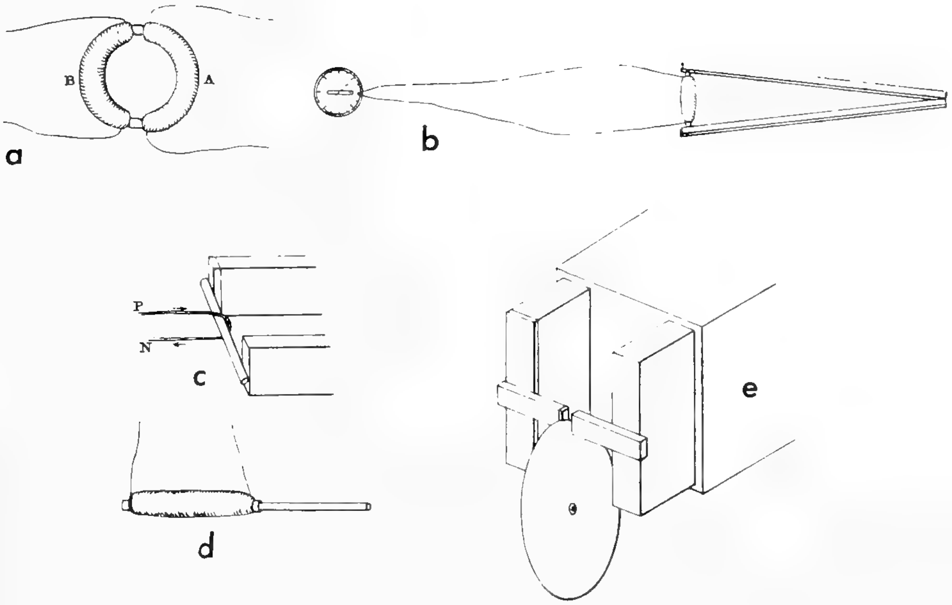

Figure 20.—Some of the various means used by Faraday to induce an electric current by magnetism: (*a*) coil to induce a momentary current in another coil by making or breaking the galvanic circuit in the first coil, (*b*, *c*) inducing a momentary current by making or breaking a magnetic circuit, (*d*) inducing a momentary current by moving a magnet through a coil of wire, and (*e*) inducing a continuous current by rotating a conducting disk in a magnetic field. The last was the converse of the Barlow wheel experiment. From *Philosophical Transactions*, 1832, vol. 122, pl. 3.

using three instead of two coils, by replacing the single magnet by a compound one, and by placing the axis of the instrument horizontally instead of vertically (fig. 24). Clarke used only a pair of coils, but sought to increase the current by rotating the coils beside the poles instead of in front of the poles as in the Pixii and Saxton machines. Clarke made two sets of coils for his magneto, one of fine wire for high voltage and the other of coarse wire for large currents (figs. 25, 26).

Charles Page, of Washington, increased the output of Clarke's magneto by increasing the intensity of the magnetic field. He placed another compound magnet parallel to that of the Clarke machine and then rotated the coils between the two compound magnets (figs. 27, 28). Such devices were made commercially

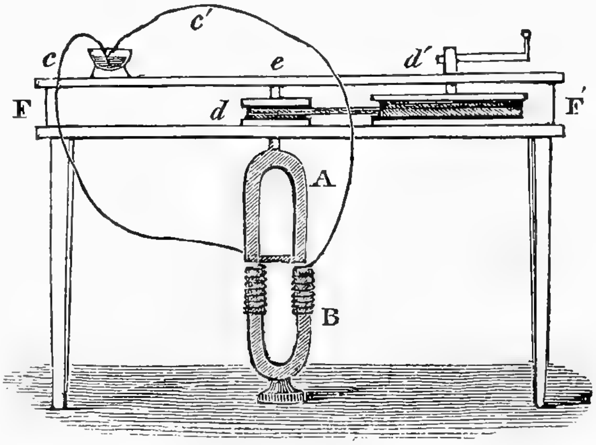

Figure 21.—Pixii magneto generator, without commutator. From *American Journal of Science*, April 1833, vol. 24, p. 146.

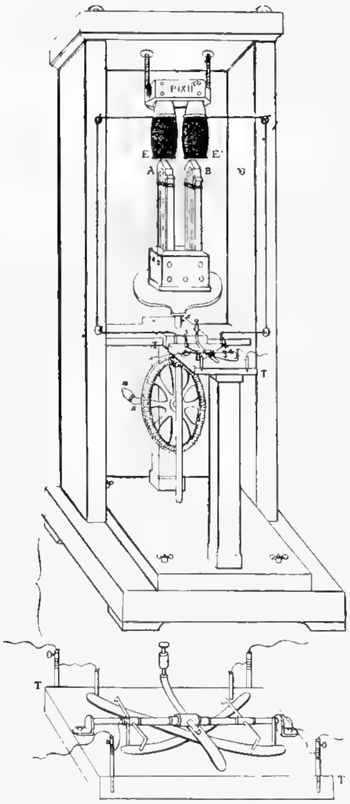

Figure 22.—Pixii magneto generator with Ampère's commutator, which is shown enlarged at the bottom of the figure. From H. W. Dove and L. Moser, *Repertorium der Physik,* Berlin, 1837, vol. 1, pl. 2.

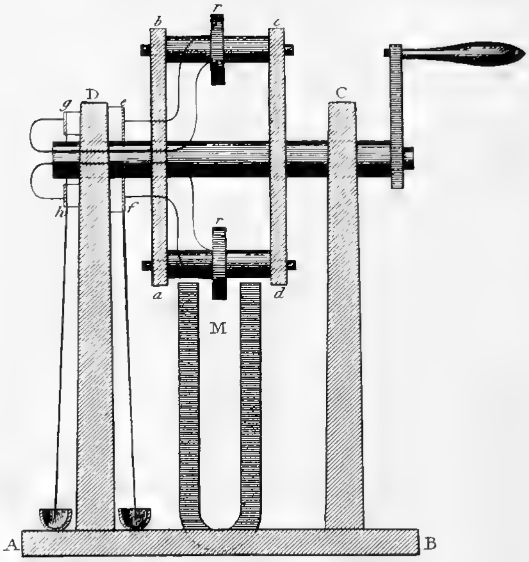

Figure 23.—Ritchie's magneto generator. The armature was shaped in the form of a disk, in which the coils (*r*) passed in succession between the poles of the magnet (M). The commutator is at *efgh.* From William Ritchie, "Experimental Researches in Electro-Magnetism and Magneto-Electricity," *Philosophical Transactions,* 1833, vol. 123, pl. 7 (opposite p. 316).

by Daniel Davis, of Boston, beginning in the spring of 1838.[26]

Most of the preceding instruments of the 1830's were essentially laboratory instruments constructed for experimental purposes. One of the earliest commercial applications of magneto generators was made by John S. Woolrich of Birmingham, England, in the following decade. In his patent application of 1841, Woolrich described how Saxton generators could be modified for electroplating, and his method seemed feasible enough to be tried by the Elkington firm in Birmingham, the same English firm that had already pioneered in electroplating.[27]

Three years later Woolrich designed a more ambitious generator (fig. 29) that was basically similar to Ritchie's. Coils and magnets were added to the Ritchie apparatus so that now a disk armature of eight uniformly spaced coils rotated between the poles of four magnets spaced 90° apart. The whole was built in a wooden framework that was 5 feet 4 inches high, 6 feet wide, and 2 feet deep. Faraday is said to have inspected Woolrich's generator and to have been delighted with this application of electromagnetic induction. The device was sold to the Prime Plating Company, of Birmingham, who used it for many years.[28]

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[26] Charles Page, "New Magnetic Electrical Machine of Great Power, with Two Parallel Horse-Shoe Magnets, and Two Straight Rotating Armatures, Affording Each, in an Entire Revolution, a Constant Current in the Same Direction," *American Journal of Science,* 1838, vol. 34, pp. 163–169; Daniel Davis, *Manual of Magnetism,* Boston, 1847, ed. 2, pp. 277–282.

[27] British patent 9431 (August 1, 1841); *Mechanics Magazine* 1843, vol. 38, pp. 145–149.

[28] *Industrial Britain,* November 1938, no. 74, p. 1; J. Hamel, "Colossale magneto-elektrische Maschine zum Versilbern und Vergolden," *Journal fuer practische Chemie,* 1847, vol. 41, pp. 244–255.

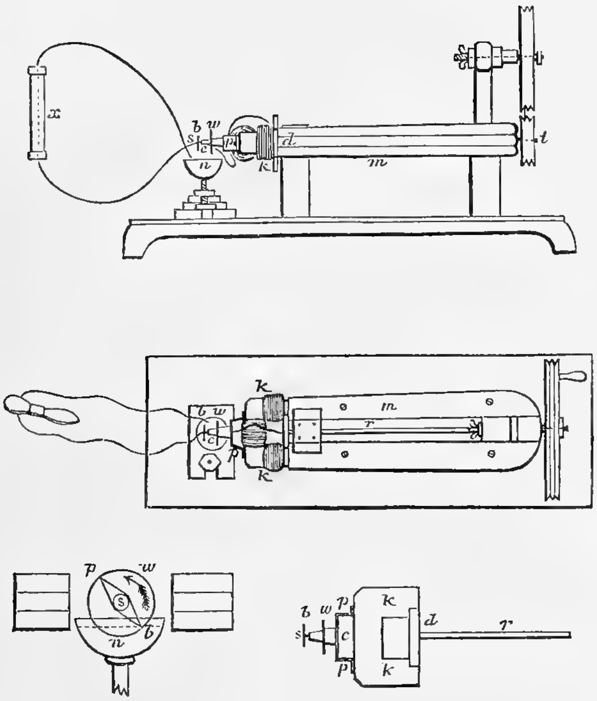

Figure 24.—Saxton's magneto generator. From *Journal of the Franklin Institute*, 1834, vol. 13, p. 155.

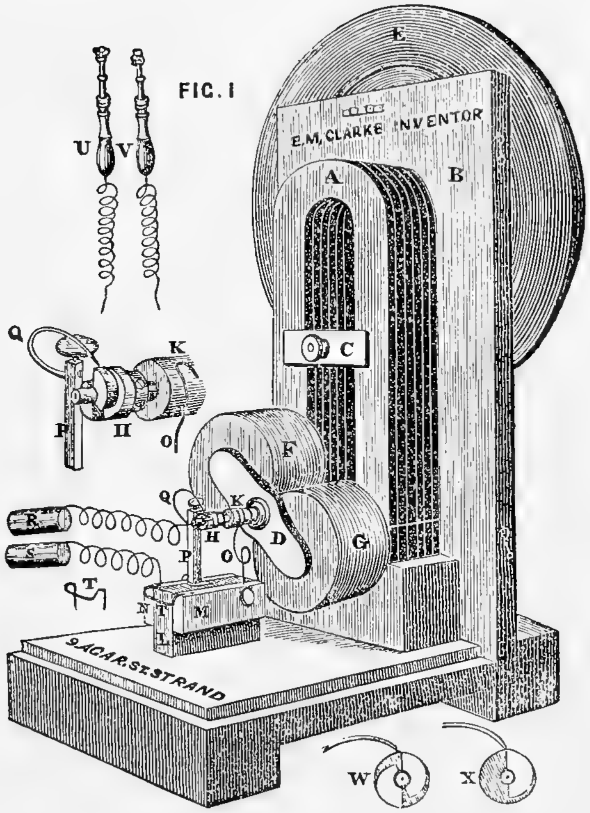

Figure 25.—Clarke's magneto generator. From *Annals of Electricity*, January 1837, vol. 1, p. 146.

Although Elkington felt that the magnetoelectric machine did not replace the voltaic cell, Woolrich, during the following decade, constructed similar machines (figs. 30, 31) for Elkington[29] and a few other electroplating companies in Birmingham.[30] In 1851, William Millward, of Birmingham, patented a machine [31] (fig. 32) that was very similar to Woolrich's.

A few years later a more important application of the magnetoelectric machine was demonstrated—one that had many implications for the future. Frederick H. Holmes showed, in 1853, that a magneto might be used to run an arc light, much to the surprise of the well known authority on electricity, E. Becquerel.[32] The latter subsequently declared that "none but a fool or an Englishman would have believed it possible."

After several years of experimentation, Holmes patented in 1856 a multiple disk armature machine consisting of many Woolrich generators mounted in a single frame (fig. 33).[33] Instead of one disk armature that rotated between the poles of a single bank of permanent magnets, Holmes spun six disk armatures on a common axis between seven parallel banks of permanent magnets. Every other disk was displaced through a small angle so as to reduce the fluctuations of the total induced current. The

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[29] *Mechanics Magazine*, 1849, vol. 51, pp. 271–272; *Illustrated London News*, October 2, 1852, vol. 21, p. 295.

[30] Samuel Timmins, *Birmingham and the Midland Hardware District*, London, 1866, pp. 488–494.

[31] British patent 13536 (February 28, 1851).

[32] D. K. Clark, *The Exhibited Machinery of 1862*, London, 1864, pp. 286, 431; J. H. Gladstone, "Lighthouse Illumination by Magneto-Electricity," *Quarterly Journal of Science*, 1864, vol. 1, pp. 70–75; *Les Mondes*, 1864, vol. 4, pp. 57–61.

[33] British patent 573 (March 7 and September 6, 1856). This is not the first patent of a Woolrich disk armature machine. As noted earlier in this paper, William Millward took out a patent on a single disk armature machine in 1851. Later this paper will discuss a patent on a multiple disk armature machine taken out in 1852 by E. C. Shepard for Florise Nollet.

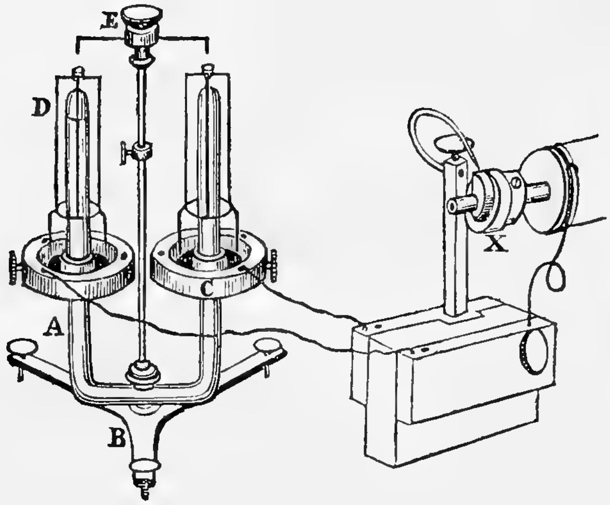
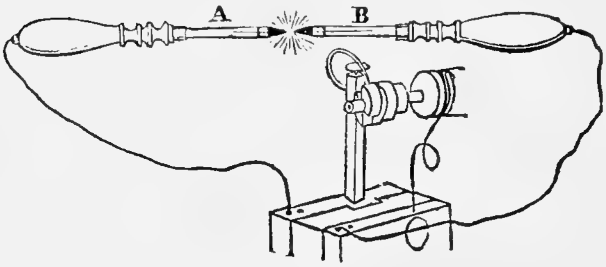


Figure 26.—Clarke's use of his magneto generator to produce rotary motion (top) and an arc between charcoal points (bottom). From *Annals of Electricity*, January 1837, vol. 1, p. 154.



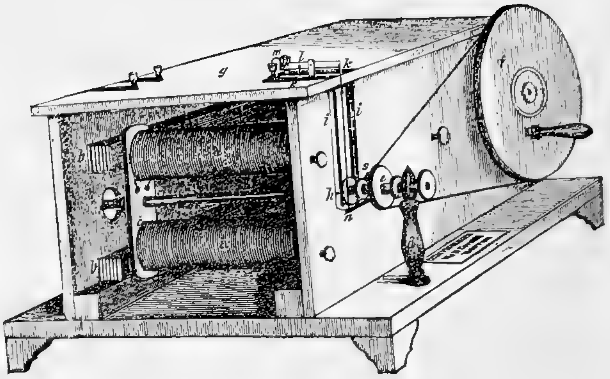


Figure 27.—Davis' first version of Page's magneto generator. From Charles Page, "New Magnetic Electrical Machine . . . ," *American Journal of Science*, July 1838, vol. 34, p. 164.

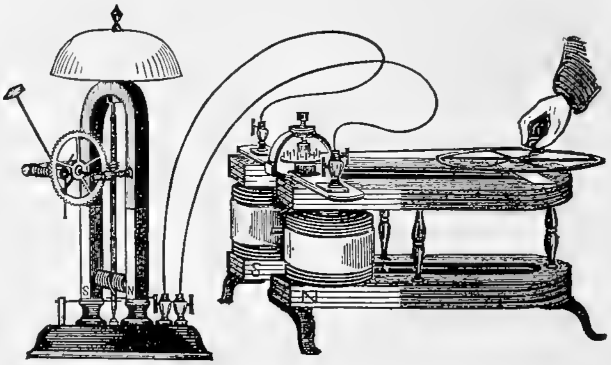


Figure 28.—Davis' improved version of Page's magneto generator, shown here ringing a bell. From D. Davis, *Manual of Magnetism*, Boston, ed. 13, 1869, p. 281.

current collectors were rollers that touched the commutator bars; they were placed about 60° apart, with their positions controlled by the speed of rotation.

In February 1857, Holmes suggested a possible application for the new electric light system. While considerable progress had been made during the 19th century in increasing the safety of marine commerce, the measures taken were still insufficient. Several decades earlier the Fresnel lens system had been added to the improved Carcel lamp, and new fuels had been discovered that gave a brighter light; although the effectiveness of the lighthouses was thereby increased, they were still inadequate. In 1867 the British Board of Trade reported that in one year 1,333 lives and 2,513 vessels were lost in the inland and coastal waters of Great Britain.[34]

Holmes submitted his suggestion to Trinity House, the agency responsible for lighthouses along the coast of England, and proposed to the Elder Brethren of the organization that the combination of arc-light and magnetoelectric machines be used for lighthouses. Although Faraday, who was the scientific advisor to Trinity House at the time, had not been previously convinced of the practicality of the electric light, Holmes so persuaded him that, in May 1857, John

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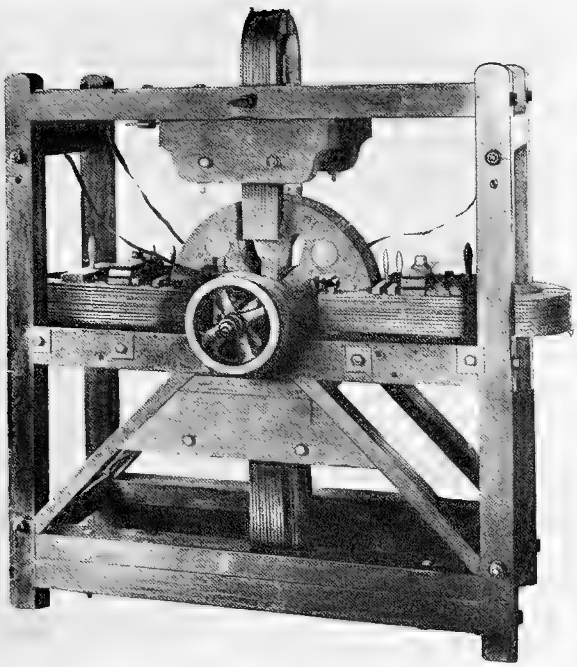
[34] A. G. Findlay, "On the Progress of the English Lighthouse System," *Journal of the Society of Arts*, 1858, vol. 6, pp. 238–249; *Cosmos*, 1868, ser. 3, vol. 3, pp. 691–693.



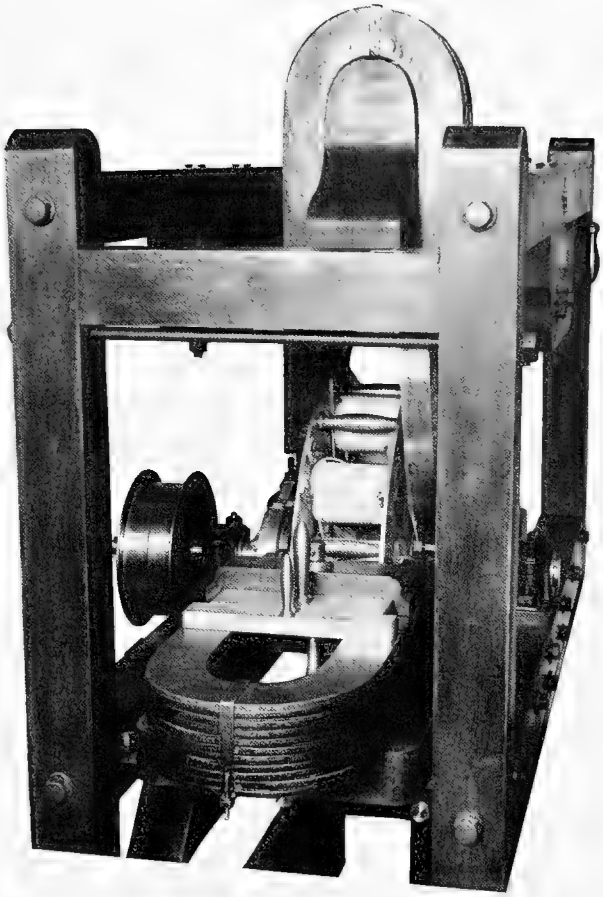


Figure 29.—The first magneto generator designed by Woolrich. It was constructed in 1844. Photos courtesy of Department of Science and Industry, City Museum and Art Gallery, Birmingham, England.

Tyndall, Faraday's associate, could proudly write to the editor of the French scientific publication *Cosmos* that he was the first person to be informed by Faraday of a new application of electricity that "consists of an electric light which is truly splendid and which can be immediately employed for illuminating lighthouses."[35]

Faraday's approval was the result of some demonstrations that Holmes made for Faraday and the Trininty House Light Committee in March 1857 in the latter's experimental "lantern" at Blackwall, near London (fig. 34). It was agreed that a more extensive trial was to be made in a lighthouse, but that Holmes would have to redesign his equipment in order to meet the strict conditions imposed by the Elder Brethren.

The machine used at Blackwall was based on Holmes' patent of the previous year. It had five banks of stationary electromagnets and six rotating disks mounted on a common arbor driven by a 2½-hp. steam engine at 600 r.p.m. There were 6 compound magnets per disk and 24 electromagnets per bank, and the generator was provided with a commutator. The machine was quite large, measuring 5 feet square and 4½ feet high and weighing 2 tons.[36] As a result of the conditions imposed, it now had to be directly coupled to the steam engine, to run at a much lower speed, and to have a sufficiently low electrical output so that it would not be dangerous to the personnel using the equipment. It seems quite

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[35] *Cosmos*, 1857, vol. 10, pp. 535–536. See also *Mechanics Magazine*, 1849, vol. 51, pp. 271–272.

[36] F. H. Holmes, "On Magneto-Electricity, and its Application to Lighthouse Purposes," *Journal of the Society of Arts*, 1863, vol. 12, pp. 39–43; James N. Douglass, "The Electric Light Applied to Lighthouse Illumination," *Minutes of Proceedings of the Institution of Civil Engineers*, 1879, vol. 57, pp. 77–165; Gustave Richard, "L'Eclairage électrique des côtes d'Angleterre et d'Australie," *La Lumère électrique*, 1882, vol. 7, pp. 294–300, 327–329, 341–345, 410–414, 460–464, 480–484.

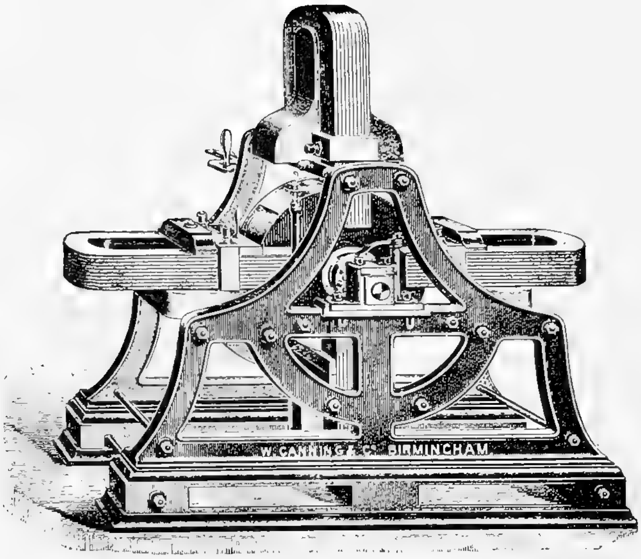

Figure 30.—Woolrich's second magneto generator, made in 1851. From W. H. Carbutt, "Early Electro-Plating Machines," *The Metal Industry*, new ser., February 1914, vol. 12, p. 61.

probable that a good part of Holmes' later difficulties stemmed directly from these restrictions.

Holmes sought to meet the requirements imposed by Trinity House by reversing the role of the permanent magnets and the electromagnets, and by increasing the strength of the magnetic field between the two. He filed for a patent on the revised form of his generator in 1857 (fig. 35).[37] In the new version, two disks bearing the electromagnets were rotated between three banks of stationary permanent magnets. The steam engine was shown in the patent drawing as directly coupled to the generator. The number of permanent magnets was increased from 6 per disk to 20 per bank and the coils from 24 per bank to 80 per disk. The air gap between the electromagnets and the permanent magnets was considerably reduced.

Two machines of the preceding design were tried at the relatively new South Foreland lighthouse on the eastern end of the Straits of Dover. They were about twice as large as those used in the preliminary trials at Blackwall, each being 9¼ feet wide, 5½ feet deep, 9 feet 6 inches high, and weighing 5¼ tons. Each generator was coupled directly to a 3-hp. steam engine that drove it at the maximum permissible speed of 90 r.p.m. A Duboscq regulator maintained the carbons of the electric arc at the proper distance.

The trials began on December 8, 1858, but results were unsatisfactory and they were discontinued; they were started again in March 1859 and continued until the early months of 1860. The arc was apt to go out several times during a night, so that an extra attendant was required just to watch it, but the light could be started again at a touch. After Faraday examined the arc in April 1859 he declared that "Holmes has practically established the fitness and sufficiency of the magneto-electric light for lighthouse purposes."[38] Faraday recommended that Holmes' system be permanently installed and tried under actual operating conditions in a lighthouse for a much longer period of time. Also, he reported publicly on the results of Holmes' system in a lecture given in March 1860 before the Royal Institution, again declaring the result of the experiment to be successful.[39] The point source proved to be admirably adapted to the Fresnel lens system, and the arc light that was so glaring proved to be visible at greater distances than an oil flame. But there was still the problem that had to be faced with all new inventions: whether the initial capital investment might prove to be too great and whether the equipment could be economically maintained. No final decision on its use had been made, for there was the "matter of expense and some other circumstances to be considered."

In the meantime Holmes had devised a regulator similar to that of Serrin. The Holmes system was exhibited in the lighthouse at Dungeness (fig. 36) at the western end of the Straits of Dover in February 1862,[40] but it was not permanently installed until June 6, 1862, because three more men had to be added to the personnel at the lighthouse and it was difficult to obtain competent keepers. The machinery used was the same as that installed at South Foreland.

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[37] British patent 2628 (April 14, 1858).

[38] *Electrician*, London, 1862, vol. 3, p. 67; 1863, vol. 3, p. 288; vol. 4, pp. 78–79. See also Holmes, *op. cit.* (footnote 36) and Richard, *op. cit.* (footnote 36).

[39] Michael Faraday, "On Lighthouse Illumination—The Electric Light," *Proceedings of the Royal Society*, 1858–1862, vol. 3, pp. 222–223; *Electrician*, London, 1863, vol. 4, pp. 68, 122–124.

[40] Holmes, *op. cit.* (footnote 36); Richard, *op. cit.* (footnote 36).

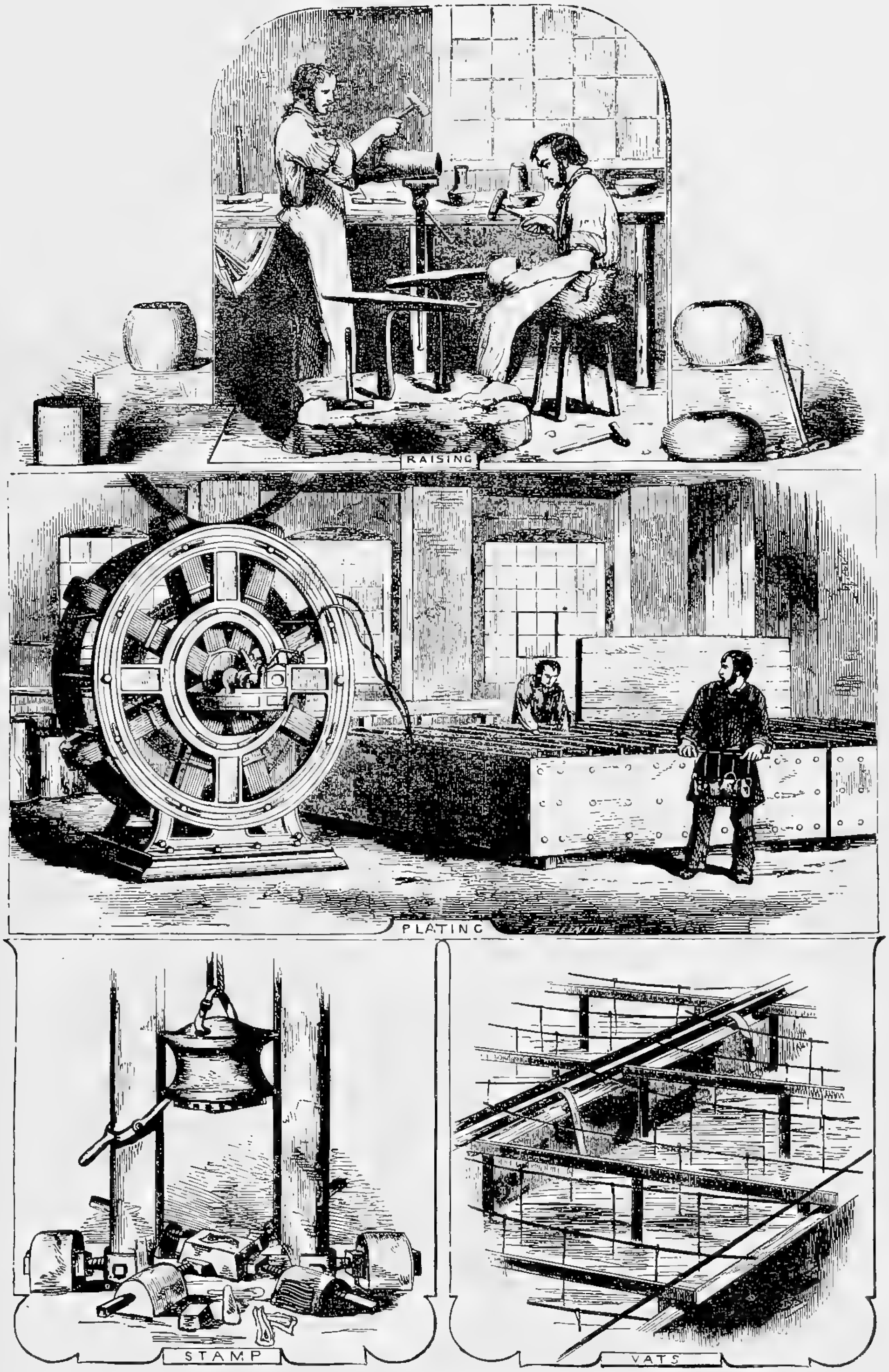
RAISING
PLATING
STAMP
VATS

FIGURE 31.—Another form of Woolrich's generator as used in electroplating by Elkington and Company in 1852. From *The Illustrated Exhibitor and Magazine of Art*, 1852, p. 296.

The mean intensity of the beam at the focus was determined to be about 670 candles, while the total intensity was evaluated at about 19,000 candles. The electric light at Dungeness remained in intermittent use for a dozen years, but the combination of an inefficient commutator, frequent mechanical breakdowns, and untrained personnel finally led Trinity House to replace it with an oil light in 1874.

Meanwhile similar efforts made across the Channel in France proved more successful. These attempts were begun by Florise Nollet, professor of physics at the Ecole Militaire in Brussels and a descendant of Abbé Nollet, the famous 18th-century electrical demonstrator. In 1849 Florise Nollet added to his many inventions a version of the Saxton magneto that could be used either to produce hydrogen and oxygen for a Drummond light by the electrolysis of water or to heat a thin carbon rod to incandescence in a vacuum.[41] He then proceeded to design a multiple disk armature generator (fig. 37) which, like Holmes' generator, was basically similar to that of the Woolrich machine.[42]

Nollet's magneto had not yet been constructed when he died in 1853, but his specifications then were being considered by a company that called itself the Electric Power Corporation, with headquarters in Genoa. That company obtained the drawings of Nollet's proposed generator and sought to exploit it in a kind of perpetual motion project. The generator would be used to electrolyze water, and the resulting gases would be used in turn to produce more electricity in a Grove gas battery. After inveigling money out of quite a few prominent people, including Napoleon III, and starting to build six machines according to Nollet's plans, the company was exposed as a fraud.[43] Holmes was one of those called in to recommend a possible use for the abandoned magnetoelectric machines, and it was at this time he suggested they be utilized for arc lights.

Nollet's patent was sold towards the end of 1855, and the Société l'Alliance was formed with Auguste Berlioz as director and with Joseph van Malderen, who had been a coworker of Nollet's, as chief engineer. The new company redesigned Nollet's generator (fig. 38) and sought to place it in commercial use.[44] The first attempt was made in 1856 at the illuminating gas plant located at the Hôtel des Invalides, where the generator was used to provide hydrogen and oxygen by means of electrolysis.[45] This generator was formed of six banks of permanent magnets, with eight magnets radially arranged in each bank, and with the open ends of the magnets pointing towards the axis. There were five disk armatures that rotated between the banks of the permanent magnets (fig. 39). The 16 coils on each disk were connected in series, and the disks could be connected to give either high current or high voltage. In spite of the new company's efforts, the generator was not very successful and no further commercial applications were tried for several years.

An effort was made about this time to obtain some theoretical understanding of the Alliance machines. F. P. Le Roux studied the variation of the current with the external resistance, the variation of voltage with the speed, and the efficiency of an Alliance machine at the Conservatoire des Arts et Métiers in Paris (fig. 40).[46] He found that some two-thirds of the energy from the engine driving the generator was lost internally in the generator. In addition to recommending certain values for the resistance of the generator, he also pointed out that much energy was lost through the production of sparks by the commutator. At the suggestion of Professor Masson, the commutator was removed from the Alliance generator and the efficiency was found to be much greater.[47] Instead of direct current, the generators

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[41] British patent 13302 (October 24, 1850); *Mechanics Magazine*, 1851, vol. 54, pp. 358, 362–364, 410–411.

[42] French patent 11649 (April 26, 1851; addition, April 24, 1852); British patents 14197 (July 6, 1852) and 1587 (July 1, 1853).

[43] *L'Electricité*, 1881, vol. 4, p. 154.

[44] Frank Geraldy, "Les Eclairages électriques à Paris, système de l'Alliance," *La Lumière électrique*, 1880, vol. 2, pp. 259–262. It seems possible that the Compagnie l'Alliance was formed at a later date; Rittershaus mentions 1859 in his article "Zur Geschichte der Dynamo-Maschine" in *Der Civilingenieur*, 1893, neue Folge, vol. 39, p. 350. British patent 2987 (December 2, 1857); French patent 21590, (July 10, 1858; additions, March 14 and December 17, 1859, August 9, 1865, and December 7, 1866).

[45] F. P. Le Roux, "Mémoire sur les machines magnéto-électriques," *Comptes rendus*, 1856, vol. 43, pp. 802–805; Du Moncel, *op. cit.* (footnote 5), vol. 1, pp. 361–364; *L'Année scientifique*, 1858, vol. 3, pp. 80–84.

[46] F. P. Le Roux, "Etudes sur les machines magnéto-électriques," *Bibliothèque Universelle de Genève, Archives des sciences physiques et naturelles*, 1856, vol. 33, pp. 198–213.

[47] Théodose du Moncel, *L'Eclairage électrique*, Paris, 1879, ed 2, p. 59. E. Allard (in *Les Phares: Histoire, construction, éclairage*, Paris, 1889) says Van Malderen suppressed the commutator.

Plan in Section
FIG. 1.

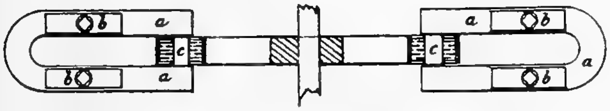
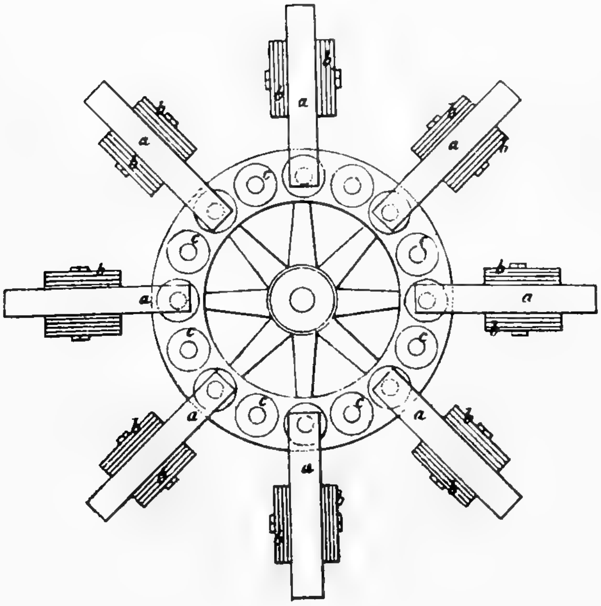


Figure 32.—Patent drawing of Millward's magneto generator, 1851. From British patent specification 13536, February 28, 1851.

Side View
FIG 2



were redesigned for the production of alternating current: one end of the coils on each armature was connected to the axis and the other was connected to an insulated sleeve on it (fig. 41). It was found that a greater amount of current was produced if the resistance of the coils were reduced by winding more turns in parallel on each of the 16 spools on the armature. Preliminary results from the new design were so encouraging that the first 5-disk machine constructed since 1856 was demonstrated at the Hôtel des Invalides in the early spring of 1859.[48] Unlike Holmes' constant experimentation, no further changes in the design of the Alliance machine were made. The only modifications were in the number of disks in the machine, with six seeming to have been the largest practical number on a single arbor, although Jamin and Roger apparently used a 9-disk machine in 1868.

The Société l'Alliance was sufficiently confident of its redesigned machine to consider public demonstrations, and Berlioz was very energetic in seeing that proper occasions were found. In the late fall of 1860 a combination of the Serrin regulator and the Alliance machine was tried on the Dauphin's steam frigate,[49] and it proved successful "in spite of the size of the equipment." In the spring of 1861 two 6-disk machines driven by a 4-hp. steam engine were used for public illumination of the Arc de Triomphe at the Place du Carrousel; other demonstrations were carried out at the Place du Palais Royal early in the summer, and civil authorities tested but rejected the light for street illumination.[50] In the following year a 4-disk machine shown at the London Exhibition of 1862 produced an arc light of 125 Carcel units mean intensity when driven by a 1½-hp. steam engine at 300 r.p.m. The Société l'Alliance was awarded a medal for that performance.[51]

When combined with the Serrin arc light (fig. 42), the new Alliance generator proved it could produce

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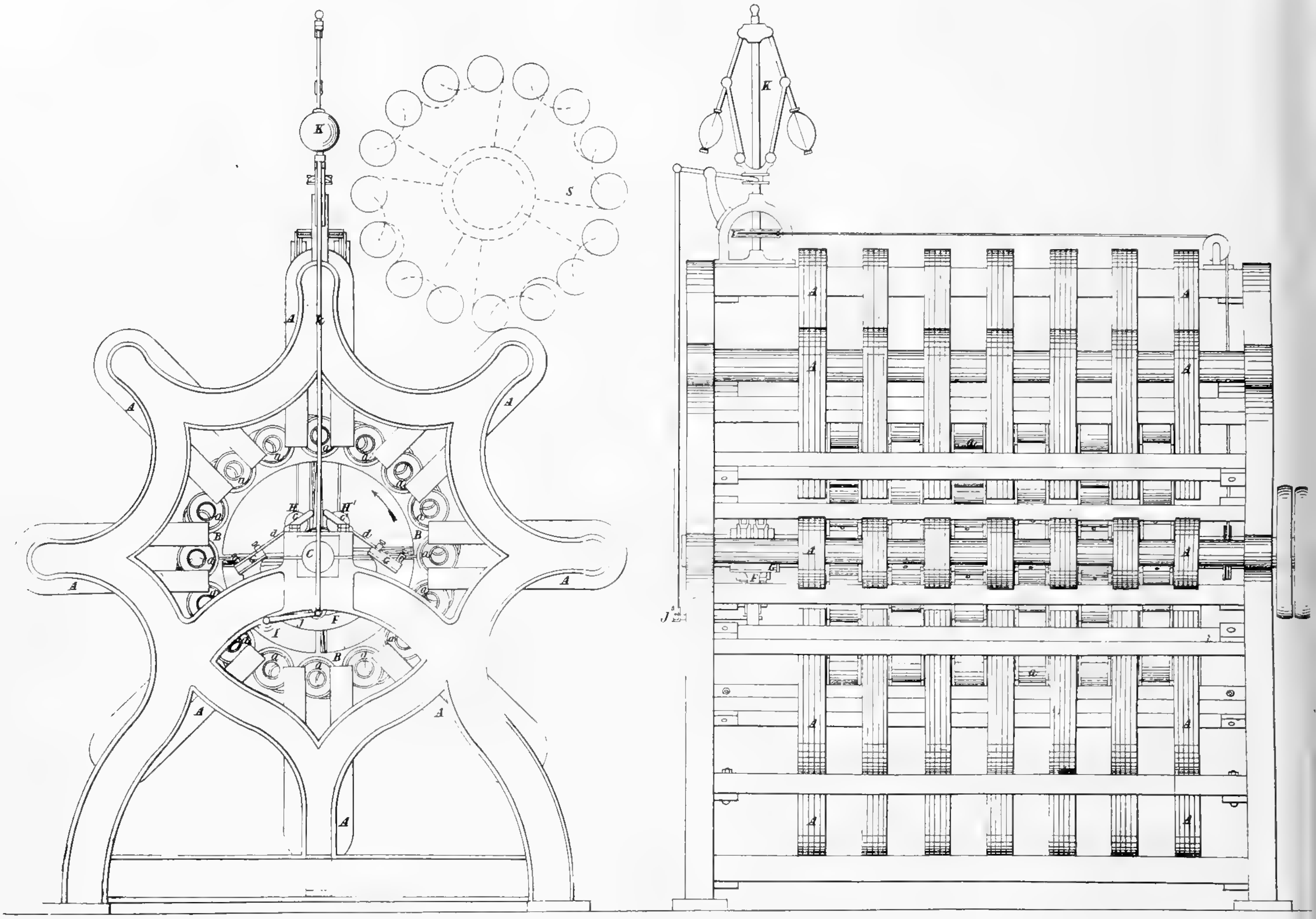
[48] *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1859, vol. 6, p. 189; Du Moncel, *op. cit.* (footnote 5), vol. 4, pp. 39–47; vol. 5, pp. 102–104.

[49] *Cosmos*, 1860, vol. 17, p. 427.

[50] *Annales télégraphiques*, 1861, vol. 4, p. 84; 1862, vol. 5, pp. 505–520; *Bulletin de la Société pour l'Encouragement de l'Industrie Nationale*, 1861, vol. 8, pp. 181–182; *Cosmos*, 1861, vol. 18, pp. 197–200; vol. 19, p. 29; *L'Illustration*, 1861, vol. 37, p. 347; *L'Année scientifique*, 1862, vol. 6, pp. 48–52.

[51] *Dinglers polytechnisches Journal*, 1863, vol. 167, pp. 104–111; *Cosmos*, 1862, vol. 20, pp. 686–694; Daniel K. Clark, *The Exhibited Machinery of 1862*, London, 1864, pp. 288–289.



relatively steady illumination with few breakdowns, but it could be used only where unusual conditions justified its high initial cost. Such conditions were to be found in the French lighthouse service, where it was to have more success than Holmes' machine had had in England.

When the arc light first appeared in the theater in 1848, the French administration of public works, which was entrusted with lighthouse service, began to consider the possibility of using this new form of illumination. At first, that body experimented with running the arc light by means of chemical cells, but when the experiments of Faraday and Holmes were brought to its attention in 1857, the feasibility of the magnetoelectric machine was considered. However, no action was taken until the director of the French lighthouse administration, Léonce Reynaud, and his chief engineer, E. Allard, visited Holmes' installation at South Foreland in April 1859. After hearing of the increased efficiency of the commutatorless Alliance machine, Reynaud decided to obtain one for experimentation. By the fall of 1859 the Alliance machine was being tested for possible use in the French lighthouse system. After careful study, Reynaud submitted an extensive report early in 1863 on its possible brightness, the distance from which it could be seen, and the economic advantages of its use in a lighthouse. He found that a 6-disk machine produced an arc of 180 to 190 Carcel units mean intensity when driven by a 2-hp. steam engine, and

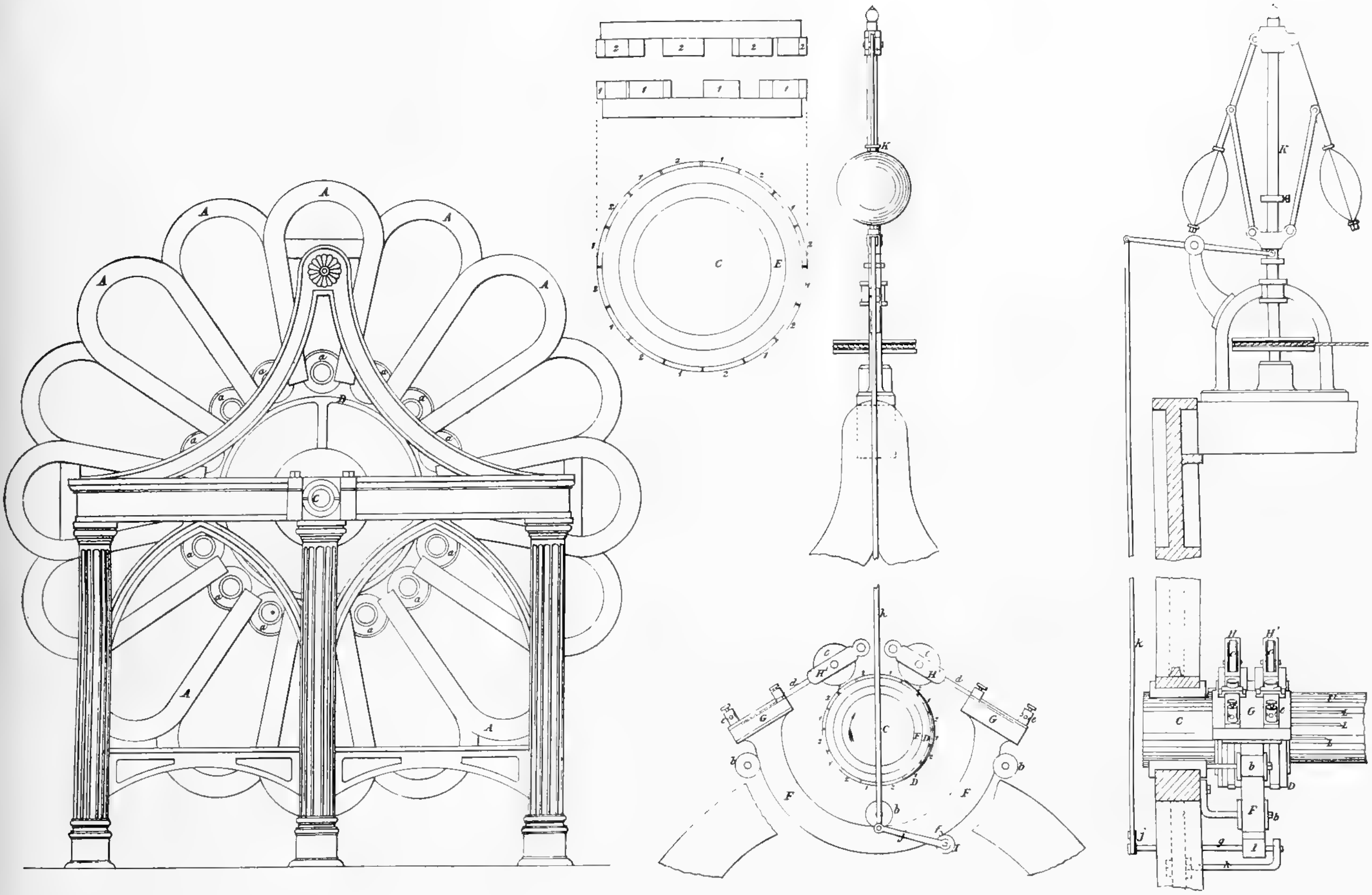


FIGURE 33.—*On facing page and above:* Patent drawings of Holmes' magneto generator of 1856. Note the current collectors and the speed regulator on the machine. From British patent specification 573, March 7, 1856.

he recommended that the government purchase a pair of Alliance machines for actual trial in a lighthouse of the first-order.[52]

In a short time the Alliance-Serrin combination began to appear in some of the lighthouses along the coast of France. Following Reynaud's report, on July 14, 1863, two 6-disk machines were ordered for Cap de la Hève near the port of Le Havre (figs. 43–45).[53] They had the usual combination of 16 electromagnets in each disk and eight permanent magnets in each of the seven banks of magnets. When the machine was driven by a 2-hp. steam engine at 400 r.p.m. the engineers found that about 190 Carcel units were produced in the arc. The south lighthouse on the cape

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[52] *L'Illustration*, 1863, vol. 42, p. 190; J. H. Gladstone, "Lighthouse Illumination by Magneto-Electricity," *Quarterly Journal of Science*, 1864, vol. 1, pp. 70–75; *Cosmos*, 1859, vol. 15, pp. 511–512; Faye, "De l'Application des feux électriques aux phares et à l'illumination à longue portée," *Comptes rendus*, 1861, vol. 52, pp. 375–377, 413–415; Léonce Reynaud, "Rapport sur l'application de la lumière électrique à l'éclairage des phares," *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1863, ser. 2, vol. 10, pp. 496–504. Fontaine (*op. cit.*, footnote 12, p. 352) gives one Carcel unit as 7.4 English candles, and other values of the period ranged between 7.5 and 9.5 candles. The current value of the Carcel unit is 9.6 English standard candles (*Smithsonian Physical Tables*, Washington, 1954, rev. ed. 9, p. 92).

[53] *Les Mondes*, 1863, vol. 1, pp. 691–694; *Cosmos*, 1863, vol. 23, p. 115; *L'Illustration*, 1863, vol. 42, p. 190; *L'Année scientifique*, 1864, vol. 8, pp. 63–74.

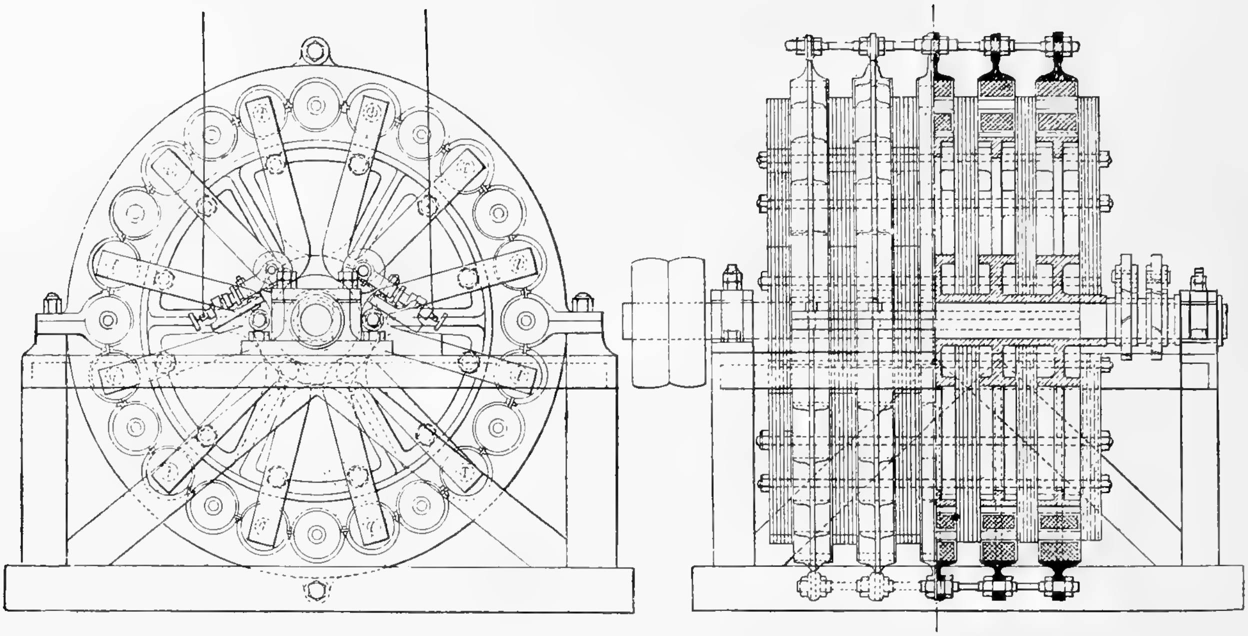

Figure 34.—Holmes' experimental magneto generator that was demonstrated at Blackwall. From *La Lumière électrique*, September 23, 1882, vol. 7, p. 298.

went into operation on December 26, 1863, and the results were so encouraging that a pair of the machines were installed in the north lighthouse in 1865.[54]

Le Roux, in published preliminary engineering reports on the success of the installation at the lighthouses, questioned the reliability of the new system, pointing out that, despite previous hopes, the light from the arc was not much brighter than that from oil; also, Reynaud, in a formal report to the French government, concluded that the two lighthouses were too expensive for ordinary use but were valuable where great brilliance was required.[55] Notwithstanding these objections, another installation was made at Cap Gris Nez, near Calais, in February 1869, and other Alliance installations were made outside France—when the Suez Canal was opened in 1869 a lighthouse using Alliance equipment was set up at Port Said, and two years later a similar installation was made at Odessa, in southern Russia.[56] The brightness of the arc had been increased, and it was now claimed to be 300 Carcel units.

No more French installations were made in the decade following the Franco-Prussian war, but in January 1880 there was a proposal to install electric lighting in all the first-order lighthouses along the coast of France. Palmyra, a city at the mouth of the Gironde River, and Planier, an island in the Mediterranean near Marseilles, each obtained an electric lighthouse in 1881. In the following year the French government made a large appropriation for the installation of 46 electric lighthouses along the coast.[57]

About this time electric lighthouses—but not of the Alliance system—began to appear outside Europe.

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[54] *Les Mondes*, 1864, vol. 4, pp. 57–61; A. Guerout, "L'Eclairage électrique du Port du Havre," *La Lumière électrique*, 1881, vol. 4, pp. 132–136; *Cosmos*, 1866, ser. 2, vol. 4, pp. 7–11; *L'Année scientifique*, 1866, vol. 11, pp. 48–56.

[55] F. P. Le Roux, "Les Machines magnéto-électriques françaises et l'application de l'électricité à l'éclairage des phares," *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1867, vol. 14, pp. 677–711, 748–790; Léonce Reynaud, "Expériences comparatives des deux systèmes d'éclairage des phares à l'huile et à la lumière électrique, considérés au point de vue économique," *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1867, vol. 14, pp. 776–779; *Cosmos*, 1866, vol. 4, pp. 7–11.

[56] *Cosmos*, 1870, ser. 3, vol. 6, pp. 103–104; *L'Année scientifique*, 1870–1871, vol. 15, pp. 50–51; "Lighthouse," *Encyclopedia Britannica*, New York, 1911, ed. 11, vol. 16, p. 641.

[57] Allard, *op. cit.* (footnote 47), pp. 325–383; "Note sur quelques objections relatives à l'emploi de la lumière électrique dans les phares," *Annales des ponts et chausées, mémoires et documents*, 1882, vol. 1, pp. 489–502; A. Guerout, "L'Eclairage électrique des côtes de France," *La Lumière électrique*, 1881, vol. 5, pp. 25–35.

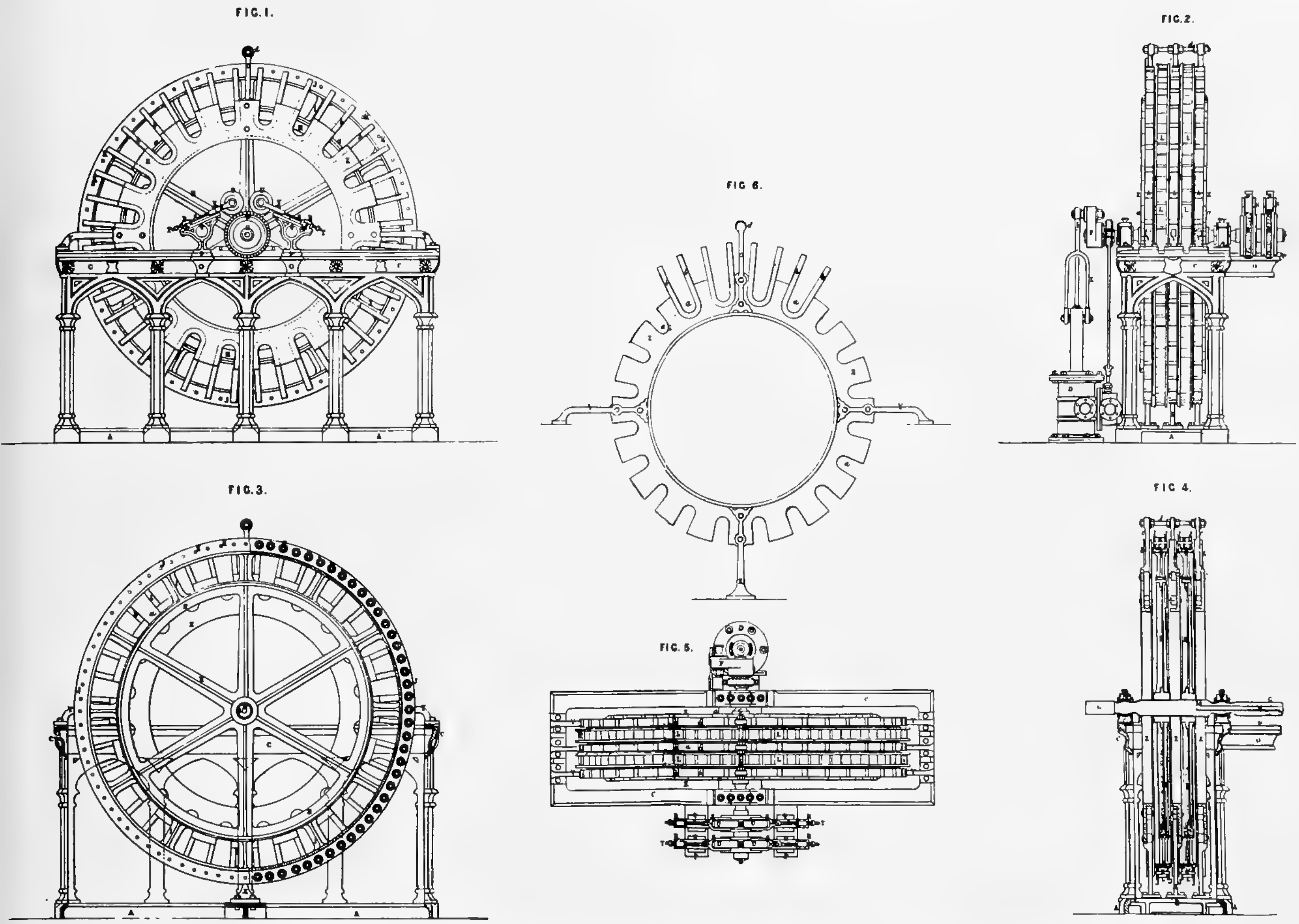

Figure 35.—Patent drawing of Holmes' magneto generator of 1857. The magnets rotated, rather than the armature. From British patent specification 2628, October 14, 1857.

The first one in the New World was set up at Rio de Janeiro in 1882, and Australia obtained one at Macquarie, in the Bay of Sidney, in the same year.[58]

The lighthouse was not the only application to navigation that the persistent Berlioz found for his magneto generator. Prince Napoleon again tried it on his yacht in the spring of 1867, and it proved to be so advantageous for traveling at night and for signaling that, after some further experimentation, it was installed permanently; a frigate of the French navy's Mediterranean fleet and the transatlantic passenger liner *St. Laurent* were equipped with the Alliance system in 1868; and a public demonstration of the magneto generator was tried at the Gare de l'Est and pronounced to be satisfactory.[59]

However, it should not be thought that the Alliance system had replaced chemical cells in public illuminations. The Fêtes des Souverains held by Napoleon III in 1868 in the French capital used chemical cells as the source of power for the 32 Serrin regulators illuminating the Tuileries,[60] and Baron Hausmann used the same means to enable the laborers to work through the night during his modernization of Paris.[61]

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[58] Richard, *op. cit.* (footnote 36); John Hopkinson, "The Electric Lighthouses of Macquarie and of Tino," *Minutes of Proceedings of the Institution of Civil Engineers*, 1886, vol. 87, pp. 243–260.

[59] *Les Mondes*, 1867, vol. 13, pp. 405–406, 492; 1868, vol. 16, pp. 488–494, 594–595, 700–702; vol. 18, pp. 51–52, 130, 325–327, 458–459, 593–594, 637–639; 1869, vol. 19, pp. 238–239; vol. 20, pp. 605; vol. 21, pp. 471–472; 1870, vol. 23, pp. 466–467.

[60] "Eclairage," *La Grande Encyclopédie*, Paris, n.d., vol. 15, pp. 341–346; Defrance, *op. cit.* (footnote 2).

During the 1860's the Alliance machine with a commutator was also tried in other enterprises. An attempt was made to use the generator instead of chemical cells in the telegraph central power station and it, too, was declared a success, although not as complete a one as the attempt made in Prussia, "since France was larger."[62] In 1868, the famous Parisian electroplating firm of Christofle sought to imitate its competitor, the Elkington firm with its English generators, by using the Alliance machine for plating.[63]

Some of the first experiments conducted at the Sorbonne's new physical laboratory in 1868 were concerned with the Alliance machine.[64] J. C. Jamin and G. Roger continued the work of Le Roux and gave experimental proof for the usual assumption that each coil on the disk armature was equivalent to a chemical cell. The output of the generator could then be calculated by applying Ohm's law to a battery of cells, each of which produced a certain voltage and had a certain fixed internal resistance. Jamin and Roger also investigated the relationship between the energy necessary to drive the generator and the heat produced in the external circuit. Some insight into the cost of the electric light can be obtained from their finding that 100 liters of gas must be consumed in the gas engine driving the generator in order to maintain an electric arc at the same intensity as a gas burner using one liter of gas per minute.

Before the Alliance machine gave way before the superior Gramme machine (discussed below), it played a role, although a minor one, in the defense of Paris during the Franco-Prussian War.[65] Arc-light stations were installed in the various forts circling the city, and each was provided with four electricians and with equipment garnered from instrument-makers, telegraph offices, and laboratories. Bunsen cells were used in most of these stations, but the brightest light of all, at the Moulin de la Galette, obtained its power from an Alliance machine. The arc lights were not very effective, but they did help to prevent surprise attack and to discourage sappers during the night.

When Holmes heard of the French commutatorless machines, he sought to produce machines of a similar type. After filing his first patent specification on an alternator in 1867 (fig. 46), he filed two other patents, one in 1868 and one in 1869.[66]

In 1867 Holmes constructed two alternators (fig. 47) for a new lighthouse to be erected on the northeastern coast of England at Souter Point, near Newcastle. Before installation the new units were sent to the Paris exhibition of 1867 where, at first, they failed to work. Seven banks with eight permanent magnets per bank and six disk-armatures with 16 electomagnets per disk constituted the 3-ton machine, which was 6 feet long, 4 feet 4 inches wide, and 5 feet 6 inches high. About 3 hp. was required to drive the machines at 400 r.p.m. and to produce 1,520 cp. Almost four years elapsed before the machines were in use; they were first turned on in January 1871. But the expenses were only half that at Dungeness, and, most important, the lights were constantly in service. Eight years later two similar machines were installed in each of the two lighthouses at South Foreland.[67]

By 1882 there were five electric lighthouses in England and four in France. However, not all of these used the Alliance or the Holmes machines, for serious competition had appeared. The lighthouse at Planier used the more efficient modification of the Alliance machine invented by De Meritens (fig. 48),[68] but a still more serious competitor of the magneto generators was the new dynamo generator. By the time the first lighthouse dynamo was installed, in the channel at Lizard Point in 1878, the dynamo generator already had begun to dominate in the field of electric light.

Before turning to the story of the dynamo, it might be of interest to compare the performance of the two magneto generators, the Alliance and the Holmes

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[61] *Journal of the Society of Arts*, 1868, vol. 16, p. 826.

[62] *Les Mondes*, 1867, vol. 15, p. 702.

[63] *Les Mondes*, 1867, vol. 13, pp. 405–406; 1868, vol. 16, p. 177.

[64] Le Roux, *op. cit.* (footnote 87); *Cosmos*, 1868, vol. 2, pp 6–7; Jules Jamin and Gustav Roger, "Sur les Machines magnéto-électriques," *Comptes rendus*, 1868, vol. 66, pp. 1100–1104, and "Sur les Lois de l'induction," *Comptes rendus*, 1868, vol. 66, pp. 1250–1252.

[65] *L'Année scientifique*, 1874, vol. 18, pp. 430–434; *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1870, vol. 17, pp. 659–665.

[66] British patents 2307 (February 10, 1868), 2060 (December 23, 1868), and 1744 (December 3, 1869).

[67] See Douglass, *op. cit.* (footnote 36) and Richard, *op. cit.* (footnote 36).

[68] French patent 123766 (April 10, 1878; additions, May 8 and June 26, 1878); Du Moncel, *op. cit.* (footnote 47), pp. 85–88; *Engineering*, 1879, vol. 28, pp. 372–373.

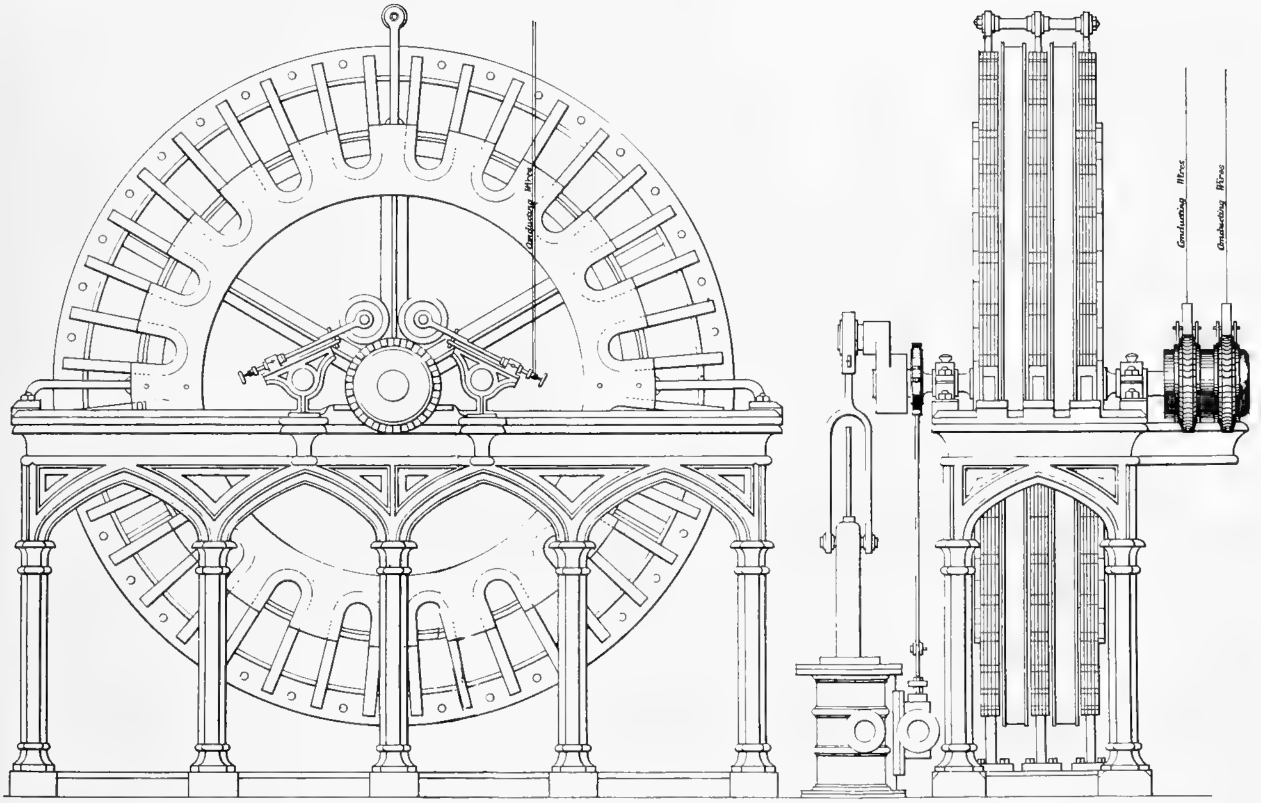

Figure 36.—Side and end elevations of Holmes' magneto generator that was installed at Dungeness. From *Minutes of Proceedings of the Institution of Civil Engineers*, 1878–1879, vol. 57, pl. 5.

machines, with that of the dynamo generator. At the time the magnetoelectric machines were in commercial use, the system of practical electrical units had not been worked out; consequently, what little information is available is not always meaningful, but at least one can obtain some sense of the relative merits of the equipment.

One method of measuring the output of an electrical machine was to determine it in terms of the chemical cell. In tests made in 1862 it was shown that a 4-disk Alliance machine was equivalent to 64 Bunsen cells.[69] The tests that Jamin and Roger performed in 1863 showed that a 6-disk Alliance machine produced a voltage equal to that of 226 Bunsen cells when the disks were connected in series and, as might be anticipated, a voltage equal to 38 Bunsen cells when the disks were connected in parallel.[70]

Also, one could obtain a crude comparison of the efficiency of various machines by determining the amount of light that each machine produced per unit horsepower. However, these comparative estimates are necessarily nominal because the candlepower of the arc and the horsepower necessary to produce the candlepower were not measured together, at least until 1880; consequently, such estimates should be considered with caution. Another factor that casts doubt on these estimates is that the figures were used to sell the generators rather than to represent scientific measurements. Nevertheless, the figures are indicative of the order of magnitude, and they became

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[69] *Cosmos*, 1862, vol. 20, pp. 686–694.

[70] Jamin and Roger, *op. cit.* (footnote 64).

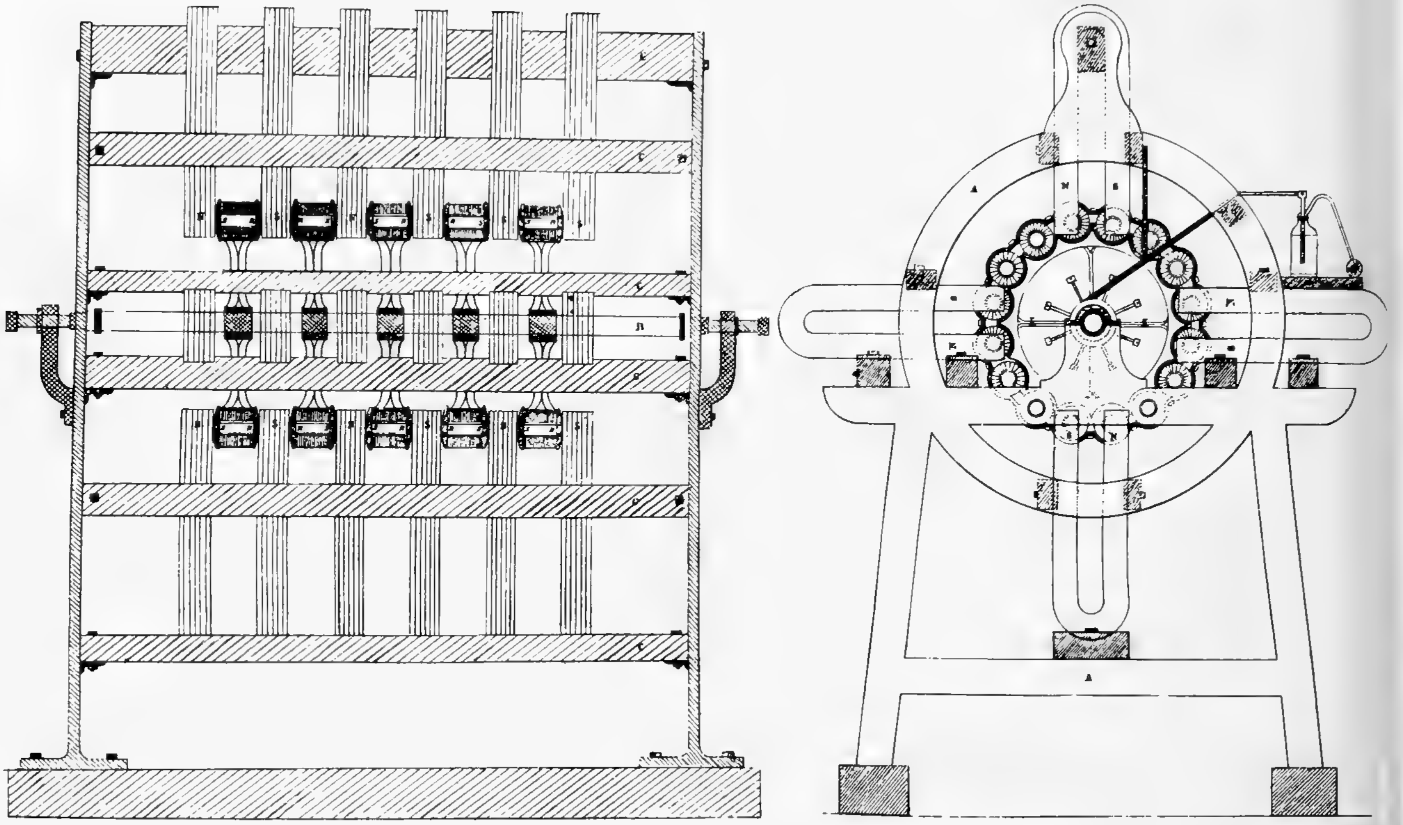

Figure 37.—*On facing page and above:* Patent drawings of Nollet machine, 1853. From British patent specification 1587, July 1, 1853.

more accurate as the 1880's were approached. Such figures for the Alliance machine during the decade of the 1860's are as follows:

Year	*Number disks*	*Carcel units per hp.*	*Reference*
1860	6	55–65	*Cosmos,* 1860, vol. 17, p. 427.
1861	6	65	*Cosmos,* 1861, vol. 18, pp. 197–200, 646–647.
1862	4	85	*Annales Telegraphiques,* 1862, vol. 5, pp. 505–520.
1863	6	90–95	Reynaud, *op. cit.* (footnote 52).
1866	6	65	Le Roux, *op. cit.* (footnote 55).

Of the preceding figures, probably only those for 1866 are adequate for the purpose. (An analogous comparison of electroplating generators can be worked out by determining how much metal was deposited for unit time.)

Similar measurements performed in the middle of the following decade led to the first careful comparison of the older magnetoelectric machines and the newer dynamoelectric machines. (That such a test first occurred a decade after the enunciation of the principle of self-excitation serves to demonstrate the slowness with which the commercial electric generator developed.) Holmes had suggested the use of the new kind of generator early in 1869, and had even constructed a pair for the South Foreland lighthouse that year.[71] However, despite the fact that the dynamos produced a much brighter light than Holmes' magneto generators in the tests, the Elder Brethren of Trinity House held it to be wiser to choose

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[71] Douglass, *op. cit.* (footnote 36).

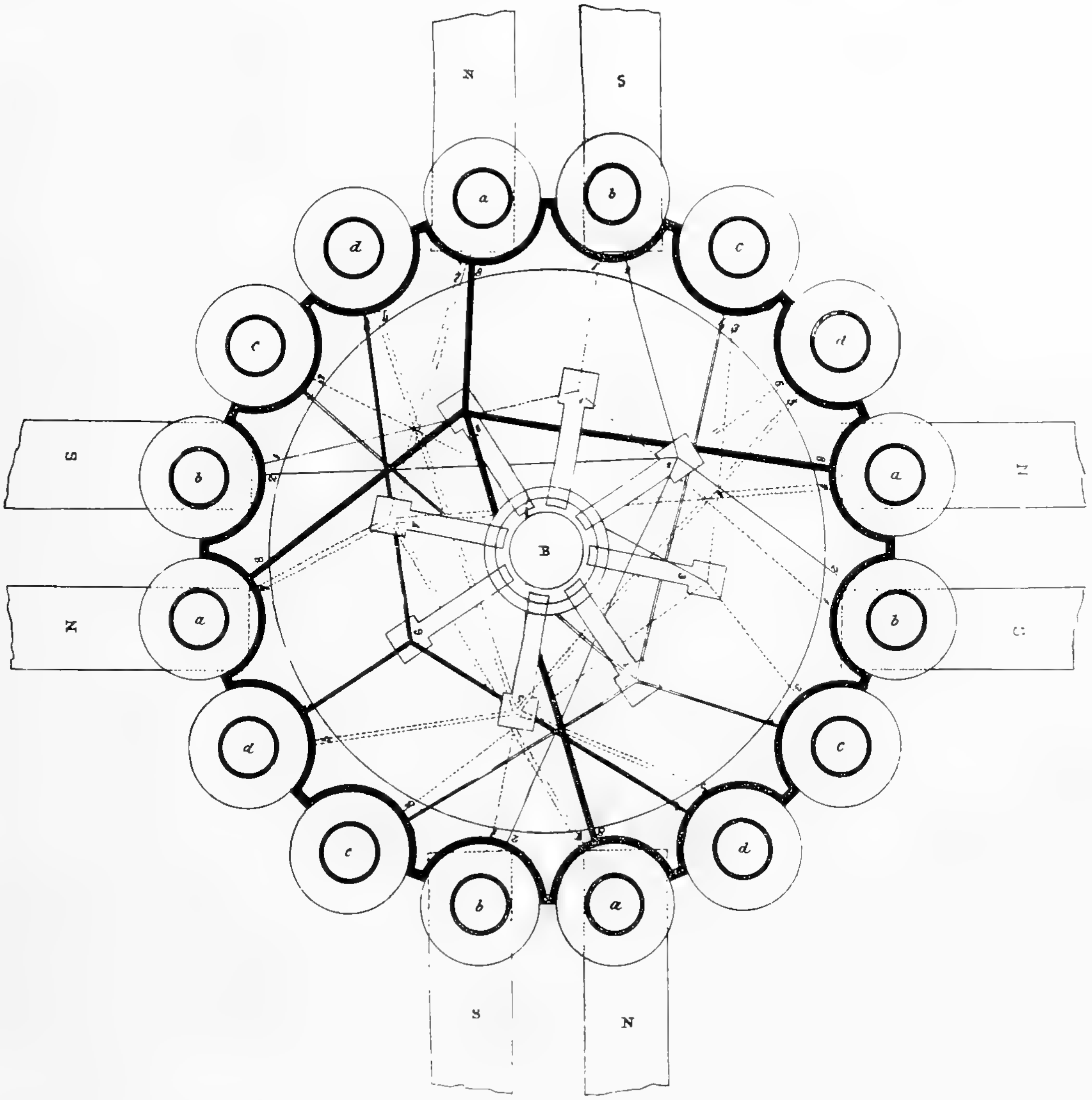

TABLE 1.—*Results of the trial competition of generators in winter of 1876–1877.*

Generator	Length	Breadth	Height	Cost (£)	Weight (tons)	H.p. absorbed	R.p.m.	Light (candles)		Candles/h.p.		Order of merit
								Condensed	Diffused	Condensed	Diffused	
Holmes	4′ 11″	4′ 4″	5′ 2″	750	2½	3.2	400	1520	1520	480	480	6
Alliance	4′ 4″	4′ 6″	4′ 10″	500	1¾	3.6	400	1950	1950	540	540	5
Gramme, no. 1	2′ 7″	2′ 7″	4′ 1″	300	1¼	5.3	420	6660	4000	1260	760	4
Gramme, no. 2	2′ 7″	2′ 7″	4′ 1″	300	1¼	5.7	420	6660	4000	1260	760	4
Siemens, large	3′ 9″	2′ 5″	1′ 2″	265	½	9.8	480	14820	8930	1510	910	3
Siemens, small, no. 58	2′ 2″	2′ 5″	10″	75	⅙	3.5	850	5540	3340	1580	950	2
Siemens, small, no. 68	2′ 2″	2′ 5″	10″	75	⅙	3.3	850	6860	4140	2080	1250	1

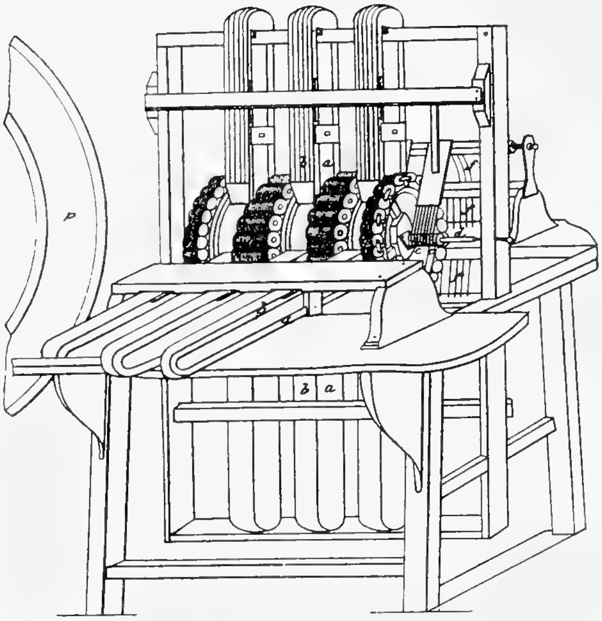

Figure 38.—One of the first forms of the Alliance machine. Note the brushlike current collectors. Reproduced, with permission of the publisher, from O. Mahr, *Die Entstehung der Dynamomaschine* (vol. 5 of *Geschichtliche Einzeldarstellungen aus der Elektrotechnik*, Berlin, J. Springer, 1941), p. 89, fig. 61.

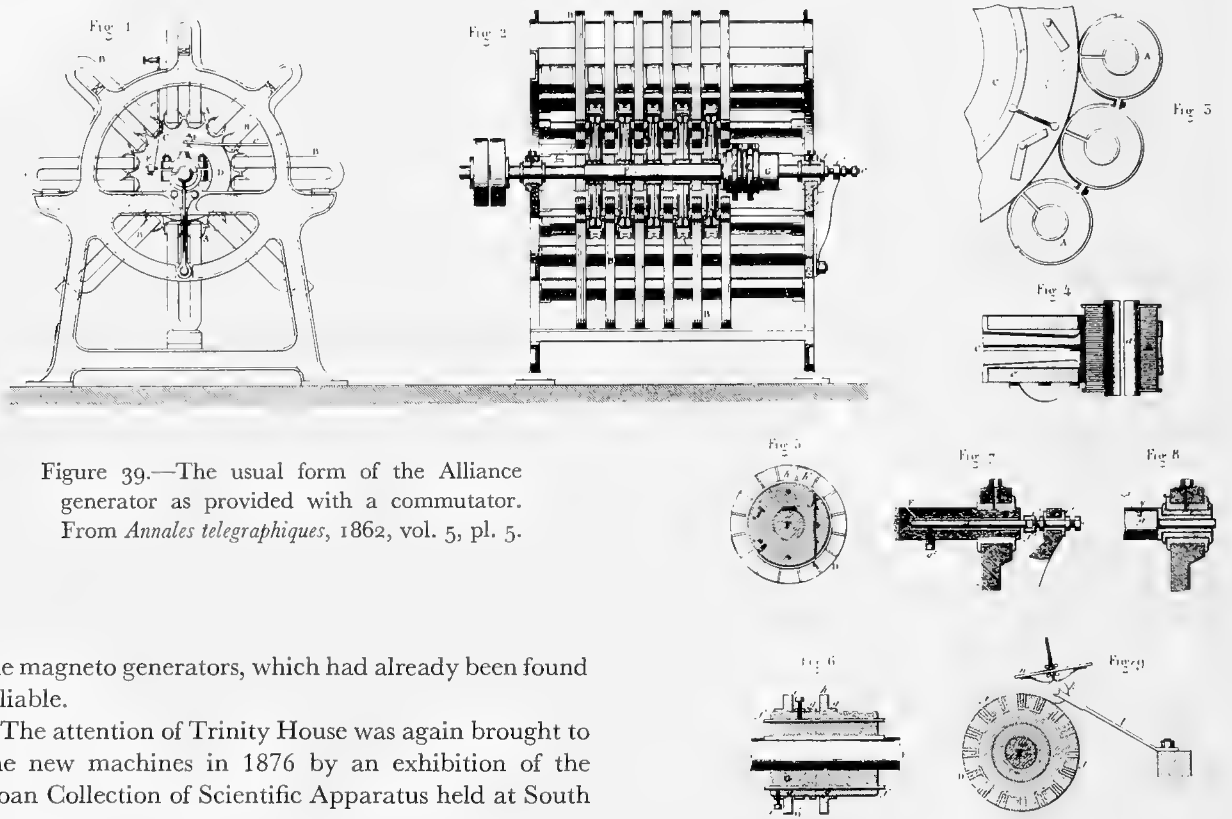

Figure 39.—The usual form of the Alliance generator as provided with a commutator. From *Annales telegraphiques*, 1862, vol. 5, pl. 5.

the magneto generators, which had already been found reliable.

The attention of Trinity House was again brought to the new machines in 1876 by an exhibition of the Loan Collection of Scientific Apparatus held at South Kensington. There one could see the dynamos of Gramme and Siemens together with the magnetos of the Société l'Alliance and of Holmes. Trinity House thereupon invited the manufacturers to a trial competition to determine the kind of apparatus best suited for the new lighthouse at Lizard Point. The tests were held at South Foreland during the winter of 1876–1877 under the joint supervision of Professor Tyndall, successor to Faraday as scientific adviser to Trinity House, and James N. Douglass, chief engineer of Trinity House.

The results of these tests (see table 1) showed the new dynamo to be far superior to the magneto generator.[72] Of the two dynamos, the Siemens

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[72] John Tyndall, "Report on Electric Illumination," *Engineering*, 1877, vol. 24, p. 303; James N. Douglass, "Report on Electric Illumination," *Engineering*, 1877, vol. 24, pp. 333, 351; Richard Higgs and John Brittle, "Some Recent Improvements in Dynamo-Electric Apparatus," *Minutes of Proceedings of the Institution of Civil Engineers*, 1878, vol. 52, pp. 36–98.

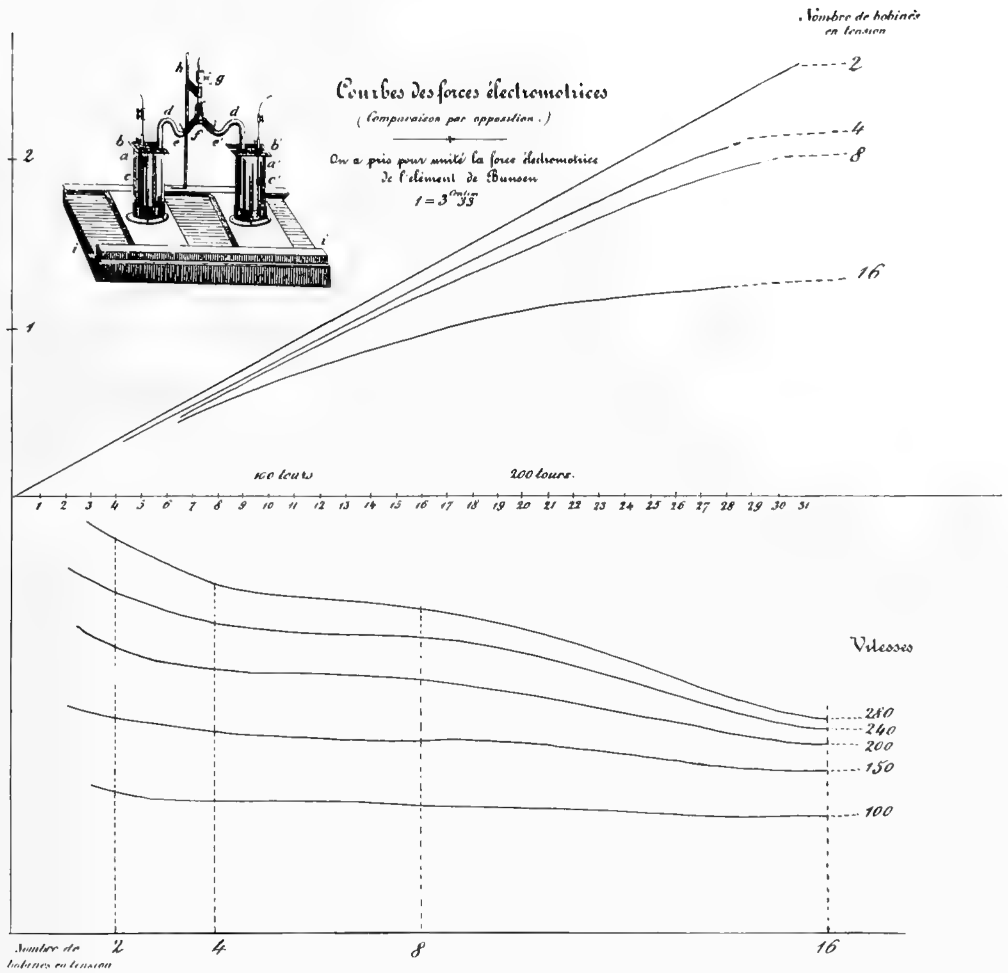

Figure 40.—Results of Le Roux's study of the relation between the speed of rotation and the voltage (open circuit) for varying numbers of coils on the armature of an Alliance generator. From F. P. Le Roux, "Etudes sur les machines magnéto-électriques," *Archives des sciences physiques et naturelles*, 1856, vol. 33, figs. 1–3 (following p. 263).

proved itself to be electrically and mechanically superior. In addition to being cheaper as well as less bulky, the Siemens dynamo could produce twice as many candles per horsepower as its best magneto competitor. By examining the tabulation, the respective proportions of the Holmes magneto and the Siemens dynamo can be seen to be as follows: bulk, 114 to 1; weight, 28 to 1; total light produced, 1 to 5; light produced per horsepower, 1 to 4; cost per unit of light, 9 to 1. Obviously, the magneto generator could not compete with the new dynamo generator, and Trinity House decided to install the Siemens dynamo instead of the Holmes generator at Lizard Point.

Hippolyte Fontaine, of the Gramme firm, protested to the editor of *Engineering* that the trials were unfair, since the Gramme machine used in the tests was the 1874 model rather than the new *type d'atelier* (actually, the company had refused to submit a model). Fontaine quoted Tresca—who had tested the new Gramme machine—as having found that 2 hp. produced 7,000 candles. Fontaine further went on to describe

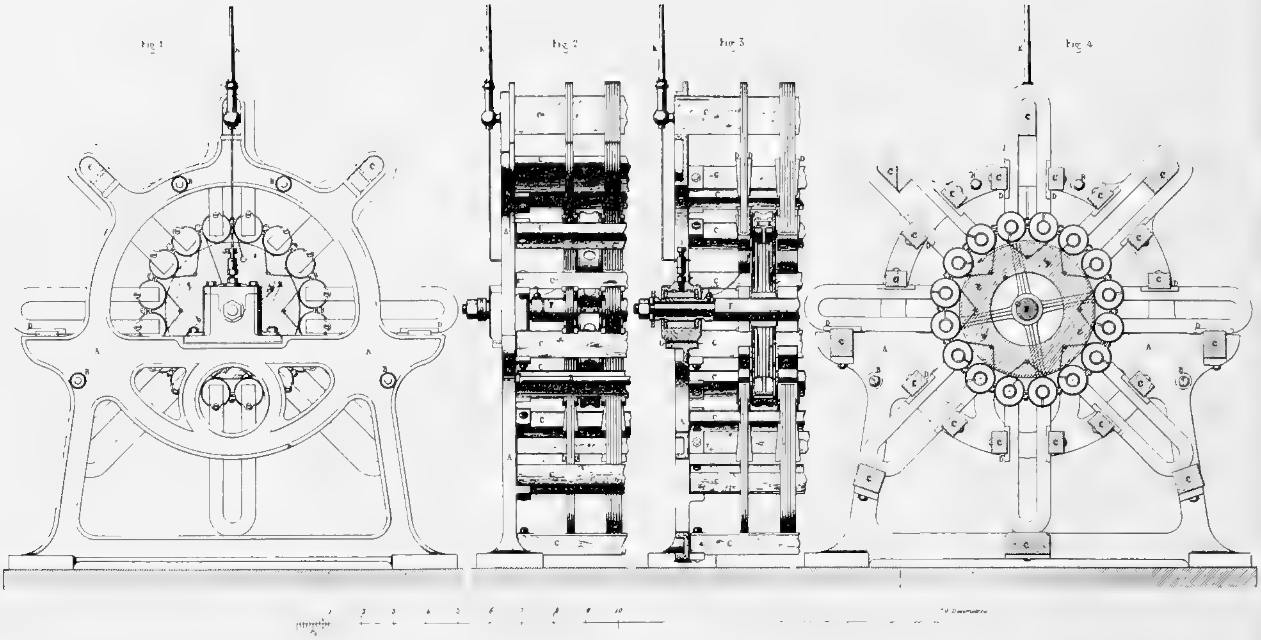

Figure 41.—Details of Alliance magneto generator, without commutator. From *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, ser. 2, 1867, vol. 14, pl. 370 (facing p. 804).

the machine as costing £100, as being 2 feet long, 1 foot 2 inches wide, and 2 feet high, and as weighing 360 pounds.[73] Actually, the results cited were overly sanguine on Fontaine's part—Tresca found that the 300-Carcel-unit dynamo required 2.8 hp. and the 1,850-Carcel-unit machine required 7.7 hp. This would result in 107 and 240 Carcel units per horsepower, which still seems quite high.

The central testing depot of the French lighthouse administration carried out similar tests of the Alliance, De Meritens, and Gramme machines during the years 1880–1882.[74] As can be seen from the following

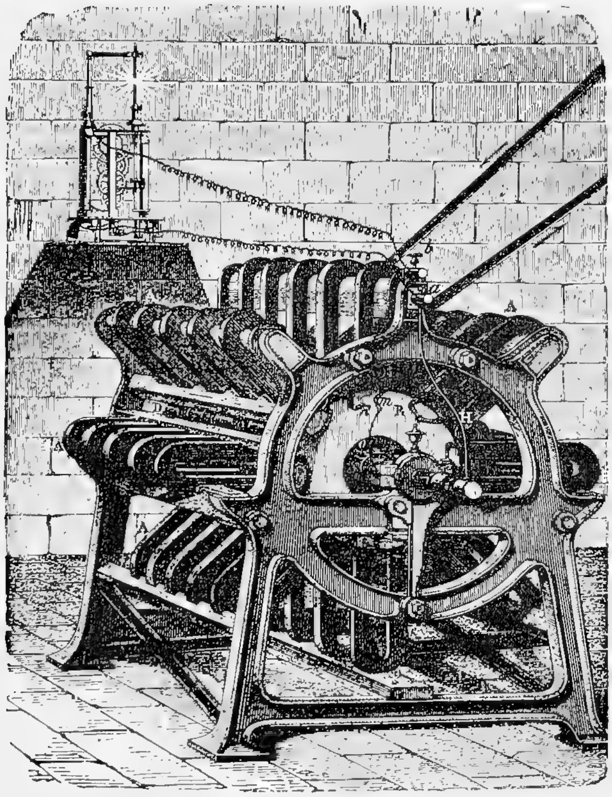

Figure 42.—Alliance generator being used to drive an arc light. From *Bulletin de la Société d'Encouragement pour l'Industrie Nationale,* ser. 2, 1867, vol. 14, fig. 16 (p. 692).

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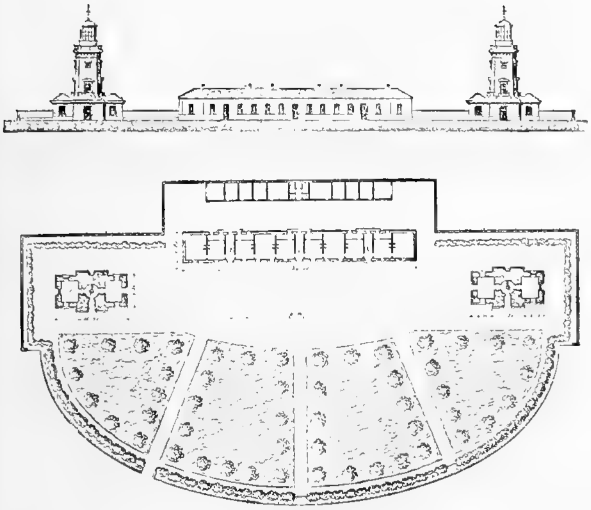
[73] *Engineering,* 1877, vol. 24, p. 322 (see also letter from Charles Ball, p. 348); Henri E. Tresca, "Compte rendu des expériences faites pour la détermination du travail dépensé par les machines magnéto-électrique de M. Gramme, employées pour produire de la lumière dans les ateliers de MM. Sautter et Lemonnier," *Comptes rendus,* 1876, vol. 82, pp. 299–305.

[74] Allard, *op. cit.* (footnote 47), pp. 339–348.



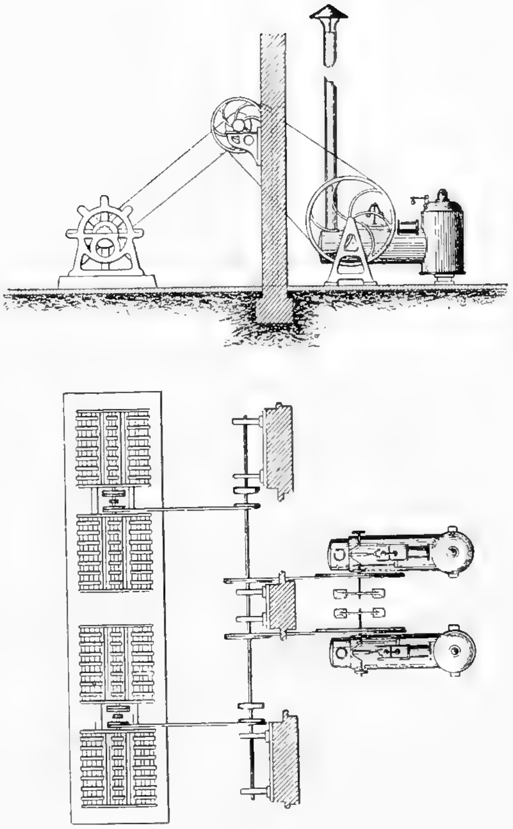


FIGURE 43.—*Above,* Double lighthouse at Cap de la Hève outside the harbor of Le Havre. *At right,* Arrangement of the steam engines and the Alliance generators in the south lighthouse. From E. Allard, *Phares et balises,* vol. 5 of *Les Travaux publics de la France,* L. Reynaud, ed., Paris, 1883, pp. 59, 109.

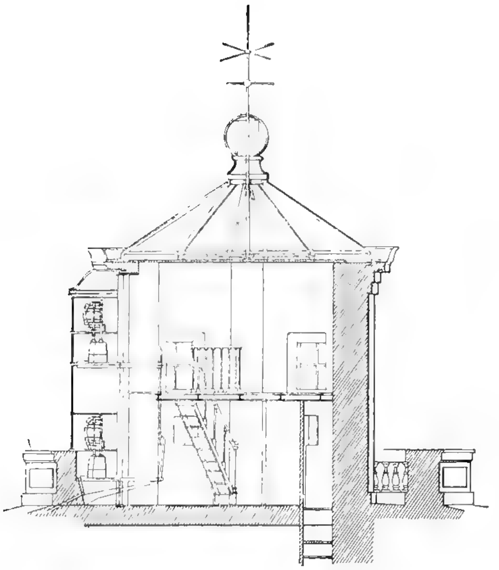
tabulation, the Alliance generator produced approximately the same carcels per horsepower as it had in the South Foreland tests, the Gramme dynamo had improved somewhat, and the De Meritens magneto, surprisingly enough, proved to be about as efficient as the Gramme machine:

Generator	*R.p.m.*	*Mechanical hp. absorbed*	*Mean spherical intensity (Carcels)* *Total*	*Per hp.*
Alliance	450	4. 6	275	60
Gramme, large	550	11. 5	1010	88
Gramme, small	600	5. 5	493	91
Gramme, improved small	680	4. 2	342	81
De Meritens, low speed	431	5. 8	537	93
De Meritens, high speed	827	11. 9	1015	85

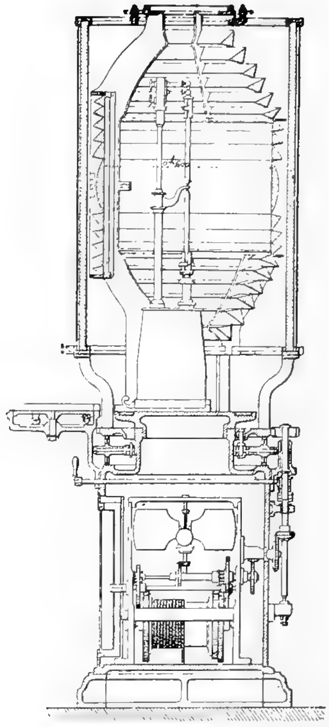
From these figures and from the results of other tests that are mentioned below, it can readily be seen that the dynamo was a great advance over the older machines in terms of bulk, weight, candles produced per horsepower, and initial cost. Despite such advantages, the magnetoelectric machine was not displaced by the dynamoelectric machine until the end of the 1870's, and even then not completely.

The changes that made possible a mechanically and electrically more efficient generator were introduced into experimental machines during the very slow commercial expansion of magneto generators in the 1860's. These basic modifications were changes in the design of the armature, the substitution of electromagnets for permanent magnets as a means of producing the field, and the introduction of self-excitation where the current induced in the armature passed through the field coils and produced the field in which the armature is placed. The last modification was the one that is considered characteristic of the dynamo. Although it took over a decade for these innovations to be combined in one machine, they laid the foundation for the modern dynamo.

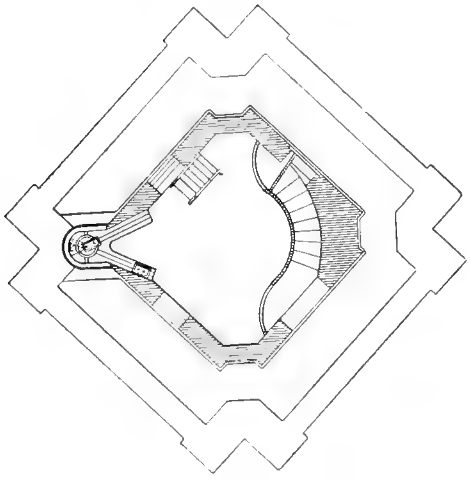
The first basic improvement in the form of the armature was due to Werner Siemens, at that time a well-known telegraph inventor and one of the partners in the Siemens and Halske firm in Berlin. In 1856 he replaced the disk armature that had been used in practically all the previous machines by a much simpler one shaped like a weaver's shuttle, with



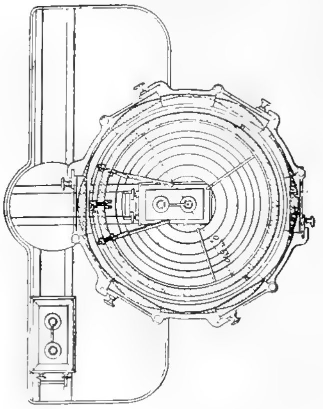
Coupe verticale.



Élévation.



Plan.



— Plan.

Figure 44.—Details of the arrangement of the arc light in the lighthouse at Cap de la Hève. From E. Allard, *Phares et balises,* vol. 5 of *Les Travaux publics de la France,* L. Reynaud, ed., Paris, 1883, pp. 110, 111.

an H cross-section.[75] The wire was wound longitudinally into the cavities in the armature and the ends of the wire were led out to a commutator divided into two parts. The armature was spun on its long axis between rounded-out cavities in the poles of the field magnets (fig. 49).

This shuttle-type armature was more efficient mechanically than the disk armature. Because of its more compact form, the shuttle armature could be driven with less power than could a disk armature of

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[75] British patent 2107 (provisional specification filed September 10, 1856); Werner Siemens, "Ueber eine neue Construction magneto elektrischer Maschine," *Annalen der Physik und Chemie,* 1857, vol. 101, pp. 271–274.

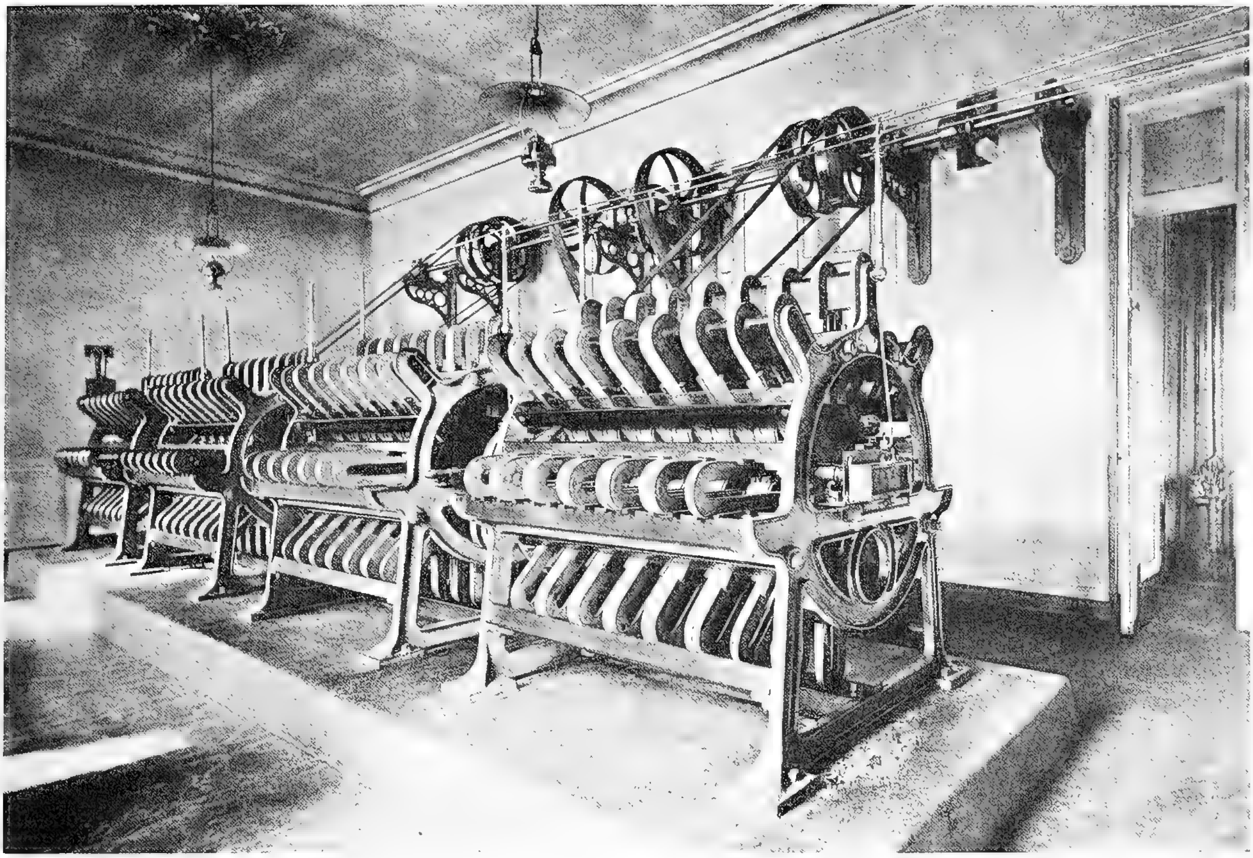

Figure 45.—Generator room in the south lighthouse at Cap de la Hève, showing the two sets of Alliance generators. From E. Allard, *Phares et balises*, vol. 5 of *Les Travaux publics de la France*, L. Reynaud, ed., Paris, 1883, 48th plate at end of volume.

the same weight. Also, the more compact form made possible a more rigid structure, and Siemens could reduce the air gap between the magnetic pole and the armature to a very small amount, thus increasing the magnetic flux cut by the wires of the armature as well as the speed of rotation. Moreover, the armature was located between the poles where the flux density was greatest instead of beside the poles where the flux density was much less. Consequently, the over-all electrical efficiency was increased to the point where the heating of the armature became a problem for the first time. Because of these advantages, the shuttle armature was used in the most successful generators of the next decade or so. Siemens applied his shuttle generator to operate an indicator telegraph.

Another innovation that seemed to promise still greater efficiency was the ring armature, first devised by a man named Elias in the 1840's (fig. 50). Antonio Pacinotti, a student at the University of Pisa, again invented such an armature for an electric motor in 1863 (figs. 51, 52) but his call to military duties prevented him from developing it.[76] The practical development of the ring armature was due to Zénobe T. Gramme who, in 1870, patented a magneto generator with a toroidal core of soft iron wire that had many coils of copper wire wound around the core and

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[76] Antonio Pacinotti, "Descrizione di una macchinetta elettromagnetica," *Il Nuovo Cimento*, 1863, vol. 19, pp. 378–384; "Sur une Machine électromagnétique, construite en 1860, d'après le même principe que la machine de M. Gramme," *Comptes rendus*, 1871, vol. 73, pp. 543–544; Franklin L. Pope, "The Genesis of the Modern Dynamo—Antonio Pacinotti," *Electrical Engineer*, 1892, vol. 14, pp. 259–262, 283–284, 307, 339–341.

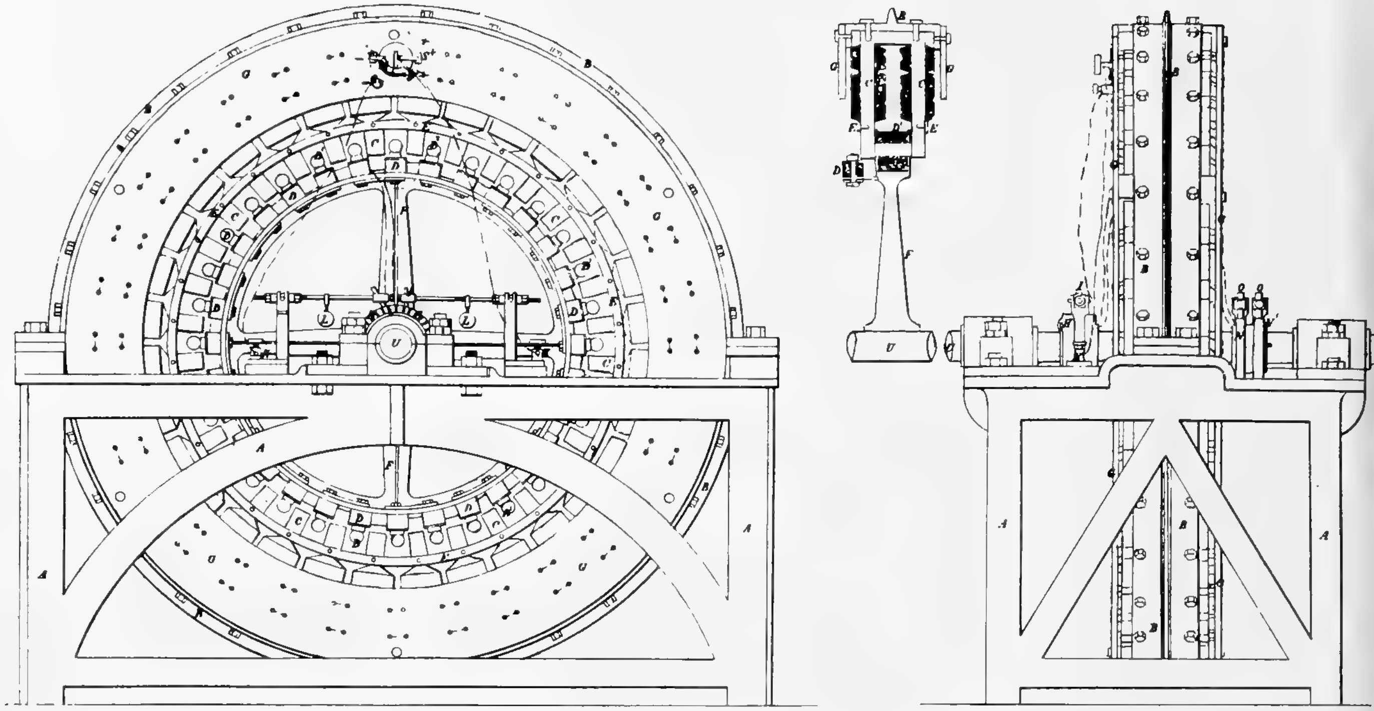

Figure 46.—Patent drawing of Holmes' alternator of 1867. From British patent specification 2307, August 10, 1867.

joined so as to form one continuous closed coil.[77] Connections from the many subdivisions of the coil led to the numerous corresponding commutator bars on the axis of the armature (figs. 53–55).

While the shuttle armature of Siemens was more efficient than the Alliance disk armature, much current was wasted in the open-circuit coil in commutation; that is, in the reversal of the direction of the current at each revolution which led to sparking at the brushes. Gramme's closed circuit coil, with its many-part commutator, mitigated the problem of commutation and produced a steadier output. In addition, Gramme's armature had a considerable advantage over the Siemens armature in that it did not become excessively hot. However, since the wire on the inside of the ring armature was shielded by the wire on the outside, not all the coil was useful in producing the output current and the resistance of the armature was greater than it need be.

The most efficient armature, and the basis of the modern one, is the drum armature, which was worked out in March 1872 by Friedrich von Hefner-Alteneck, chief engineer at the Siemens and Halske factory in Berlin and first exhibited at the Vienna Exposition of 1873 (fig. 56). Von Hefner-Alteneck devised an armature with a method of winding that minimized the unproductive end-turns that did not cut the magnetic field, but his armature still retained the advantage of the Gramme ring in commutation. Instead of winding the wire about a torus, Von Hefner-Alteneck wound the wire about the outside of a drum-shaped armature. If he had threaded the turns through the interior of the cylinder, it would have been topologically the same as winding a torus; instead, he passed the wire directly across the end faces of the cylinder to a point on the opposite lateral wall. This resulted in only the end-turns not cutting the lines of force. The relative amount of unproductive wire was further reduced by making

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[77] French patent 87938 (November 22, 1869; additions, April 11, 1870, and February 27, 1872; the first addition concerned the ring armature); British patent 1668 (June 9, 1870).

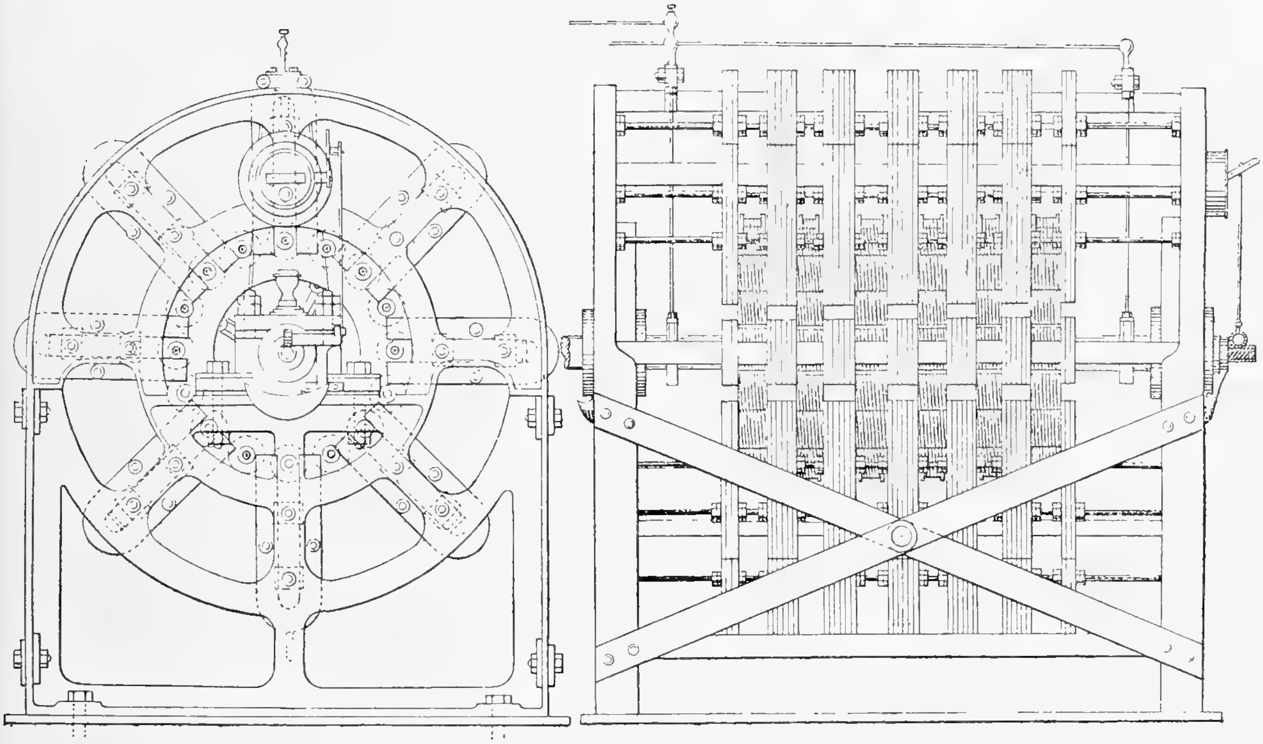

Figure 47.—Holmes' alternator at the Souter Point lighthouse. From *La Lumière électrique*, October 7, 1882, vol. 7, p. 341.

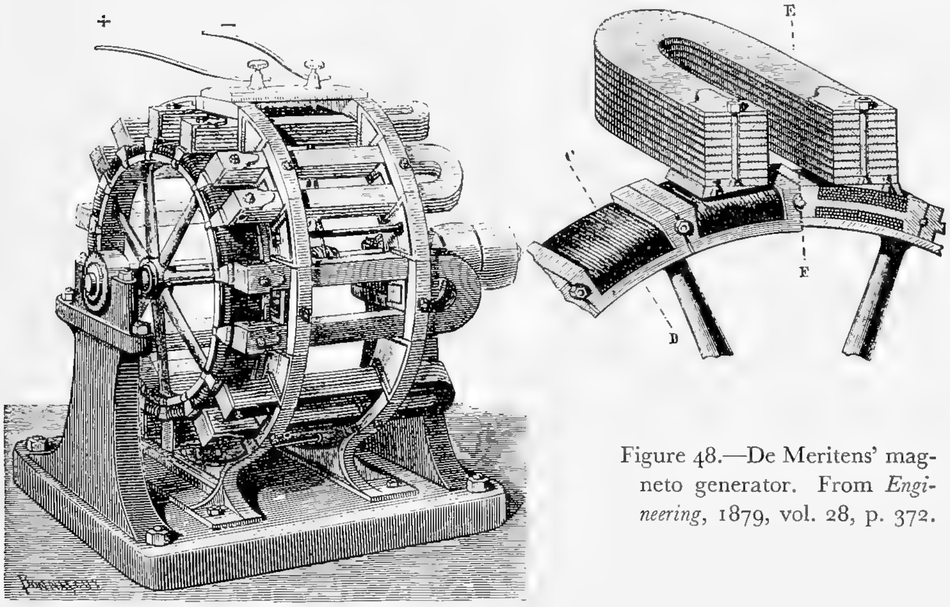

Figure 48.—De Meritens' magneto generator. From *Engineering*, 1879, vol. 28, p. 372.

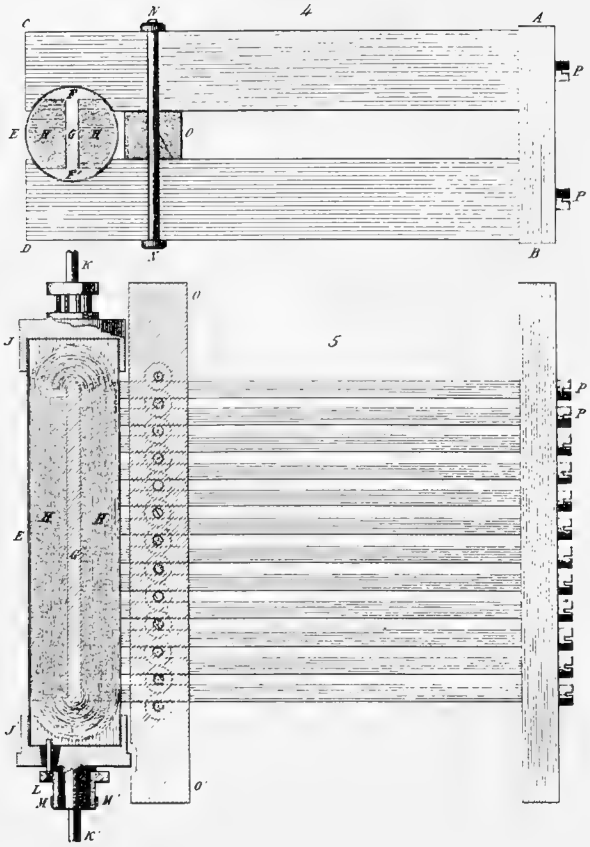

Figure 49.—Siemens' magneto generator, using his shuttle armature. The armature coil (*HH*) was wound upon the armature core (*FGF'*). From E. W. Siemens, "Ueber eine neue Construction magnetoelektrischer Maschinen," *Annalen der Physik*, 1857, vol. 101, fig. 2.

the cylinder long with respect to the diameter. Another modification was that, instead of the single coil of wire as in the Siemens armature, there were now 16 coils that had their terminals reversed twice each revolution. The 2-part commutator of Siemens was accordingly replaced by a 16-part one. The coils were interconnected at the commutator bars so as to form a single closed-circuit coil.[78]

Nevertheless, heating of the armature was a considerable problem in the original design of 1873.

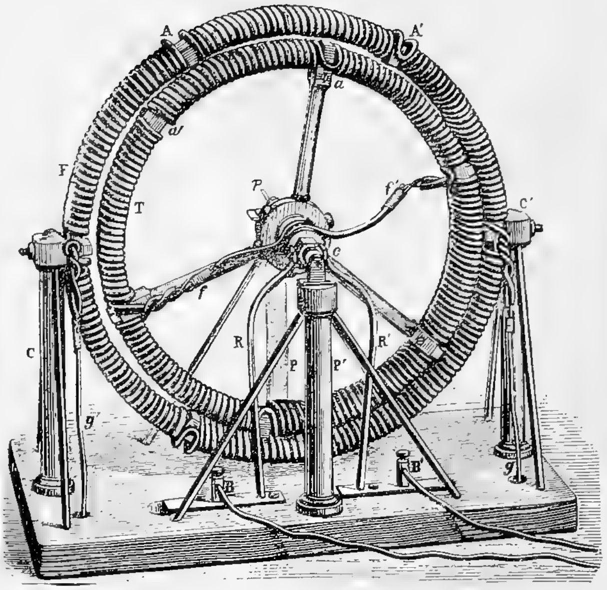

Figure 50.—Ring armature devised by Elias in the 1840's. It was designed for a motor rather than for a generator. From *La Lumière électrique*, 1882, vol. 7, p. 14, fig. 13.

In order to avoid this, Von Hefner-Alteneck fixed the soft iron core of the armature and rotated the coils. Siemens tried to reduce the temperature by water cooling and by laminating the armature, but the former method was too awkward to be practical, and the latter one was unsuccessful at the time.

Very few drum armature dynamos were made and sold; however, the 1876 exhibition in South Kensington showed that these originally unpromising generators had been reduced to practice. The tests of Tyndall and Douglass proved them to be the most efficient of all the units they compared. The armature no longer overheated as it had in the earlier stages of its development, and its output was more constant. In addition, provision was made to reduce sparking at the commutator by including an arrangement for shifting the position of the brushes.

At first the drum armature did not seem as practical as the ring armature, for it was quite difficult to wind the coils on the drum and to insulate the successive coils from one another; so, the advantage of the many-part commutator of Gramme seemed lost. In addition, ventilation was much easier for the ring than for the drum, particularly when the drum was a solid rather than a hollow cylinder.

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[78] British patent 2006 (June 5, 1873); French patent 99828 (July 5, 1873; addition, June 21, 1878); *Engineering*, 1873, vol. 16, p. 490; Higgs and Brittle, *op. cit.* (footnote 72); James Dredge, ed., *Electric Illumination*, London, 1882, vol. 1, pp. 275–293.

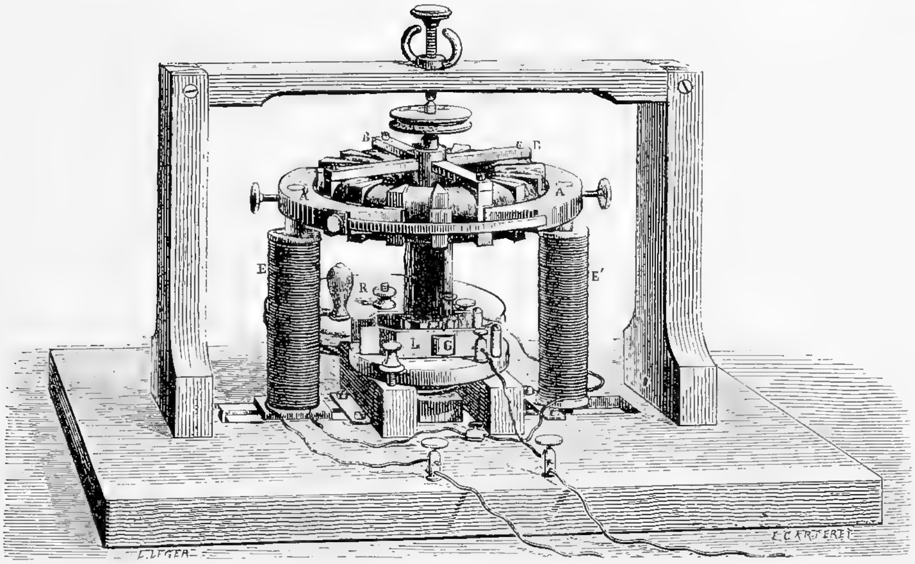

Figure 51.—Pacinotti's ring armature, as used in a motor, with a field produced by electromagnets. Pacinotti found he could use the machine as a generator by replacing the field electromagnets with permanent magnets. From *La Lumière électrique*, 1882, vol. 7, p. 15, fig. 14.

But the inherent advantages of the drum armature were greater. After it was discovered that the coils could be inserted in slits on the core and better methods of laminating the core and of winding the coils were introduced, the drum armature was put to use; it has remained in use to the present time.

But the production of current in all these early generators was hampered considerably by the lack of sufficiently strong fields. Charles Wheatstone had introduced electromagnets into the generator that he used for his telegraph of 1845, but this arrangement was generally deemed too clumsy as it required chemical cells in addition to the generator itself.[79] In 1864, Henry Wilde patented a generator in which a magneto was substituted for the chemical cells (fig. 57). The current from the magneto was then used to excite the electromagnet field coils of another generator. One motor drove both magneto generator and electromagnet generator.[80] A few years later William Ladd simplified the double structure by combining the two separate fields in one unit (fig. 58). Wire was wound around permanent bar magnets which were placed parallel to and above each other. An armature was rotated between each pair of poles at the end of the magnets. One armature provided current for the coils on the permanent magnets and so added to the latter's field while the output current was taken from the other armature.[81]

When demonstrated at the Paris Exhibition of 1867, both Wilde's and Ladd's machines produced

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[79] British patent 10665 (May 6, 1845).

[80] British patent 3006 (June 4, 1864); Henry Wilde, "Experimental Researches in Magnetism and Electricity," *Philosophical Magazine*, 1866, ser. 4, vol. 32, pp. 148–152, and 1867, ser. 4, vol. 34, pp. 81–104; *Les Mondes*, 1866, vol. 11, pp. 319–324, 373, 629–636; vol. 12, pp. 24–26; Théodose du Moncel, *Exposé des applications de l'électricité*, Paris, 1872–1878, ed. 3 (5 vols.) vol. 2, pp. 226–230.

[81] William Ladd, "On a Magneto-Electrical Machine," *Philosophical Magazine*, 1867, ser. 4, vol. 33, pp. 544–545; "On a New Form of Dynamo-Magnetic Machine," *Reports of the British Association for the Advancement of Science*, 1867, vol. 37, pp. 13–14; "On a Further Development of the Dynamo Magneto Electric Machine," *Reports of the British Association for the Advancement of Science*, 1868, vol. 38, pp. 19–20; Du Moncel, *op. cit.* (footnote 80), vol. 2, pp. 230–234.

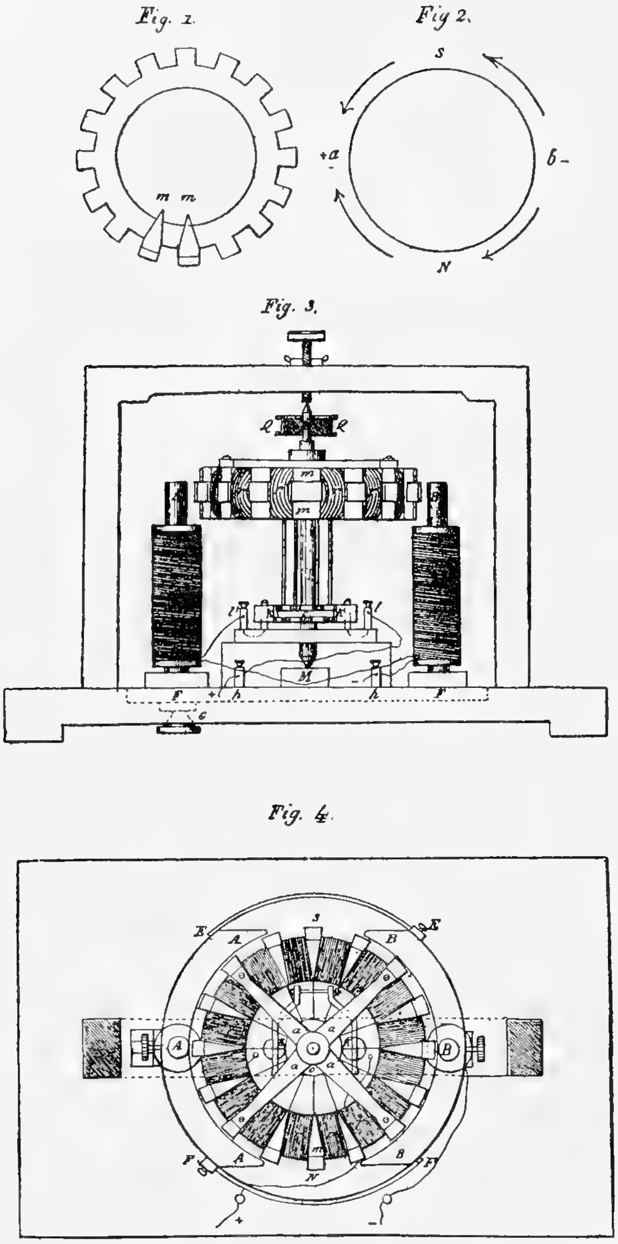

Figure 52.—Pacinotti's illustrations in the original pamphlet describing his machine, as reproduced in *Electrical Engineer*, September 21, 1892, vol. 14, p. 260.

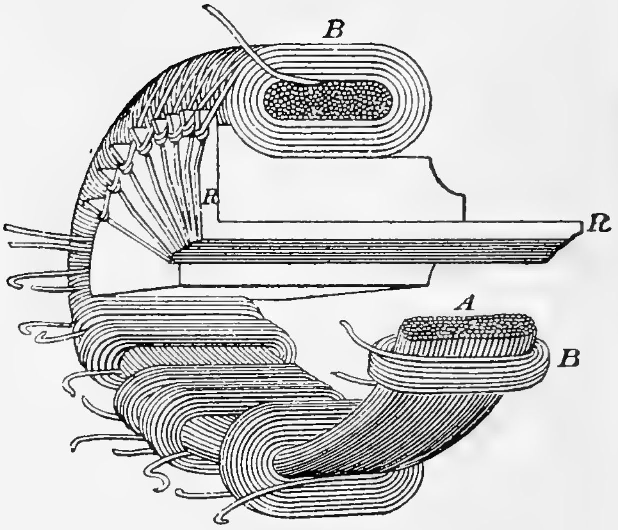

Figure 53.—Gramme's ring armature, showing the many coils (*B*) that were connected to commutator plates (*R*). From S. P. Thompson, *Dynamo-Electric Machinery*, ed. 2, London, 1886, p. 116.

sufficient power to maintain an arc light, to the great astonishment of the spectators. The small size of these generators provided a striking contrast to the bulky magneto generators of the Holmes and the Alliance systems that also were exhibited. The Wilde machines were so promising that within two years the Alliance company had purchased the French patent; the Scottish commission for lighthouses was trying them in an installation; and the Elkington firm in England was using a number of them for electroplating.[82]

However, by that time the next step—that of self-excitation—had been taken, and the machines of 1867 already were potentially outmoded. Some isolated efforts at self-excitation had been made by Søren Hjorth[83] of Denmark in 1851, by Wilhelm Sinsteden[84] of Germany in 1861, and by Moses

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[82] *Les Mondes*, 1867, vol. 14, pp. 161–165; 1869, vol. 21, pp. 152–154; 1871, vol. 26, pp. 94–96.

[83] British patent 2198 (provisional specification filed October 14, 1854); Sigurd Smith, *Søren Hjorth, Inventor of the Dynamo-Electric Principle*, Copenhagen, 1912.

[84] Wilhelm Sinsteden, "Ueber die Anwendung eines mit einer Drahtspirale armirten Stahlmagnets in der dynamo-elektrischen Maschine," *Annalen der Physik und Chemie*, 1869, vol. 137, pp. 289–296.

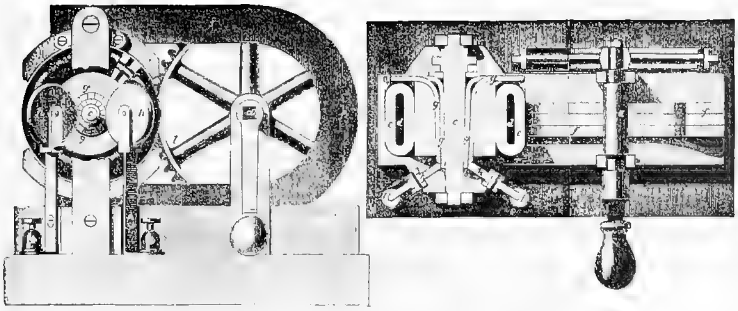


Figure 54.—Gramme's magneto with his ring armature. Note the disk-shaped current collectors. From *Chronique de l'industrie*, April 17, 1872, p. 84.

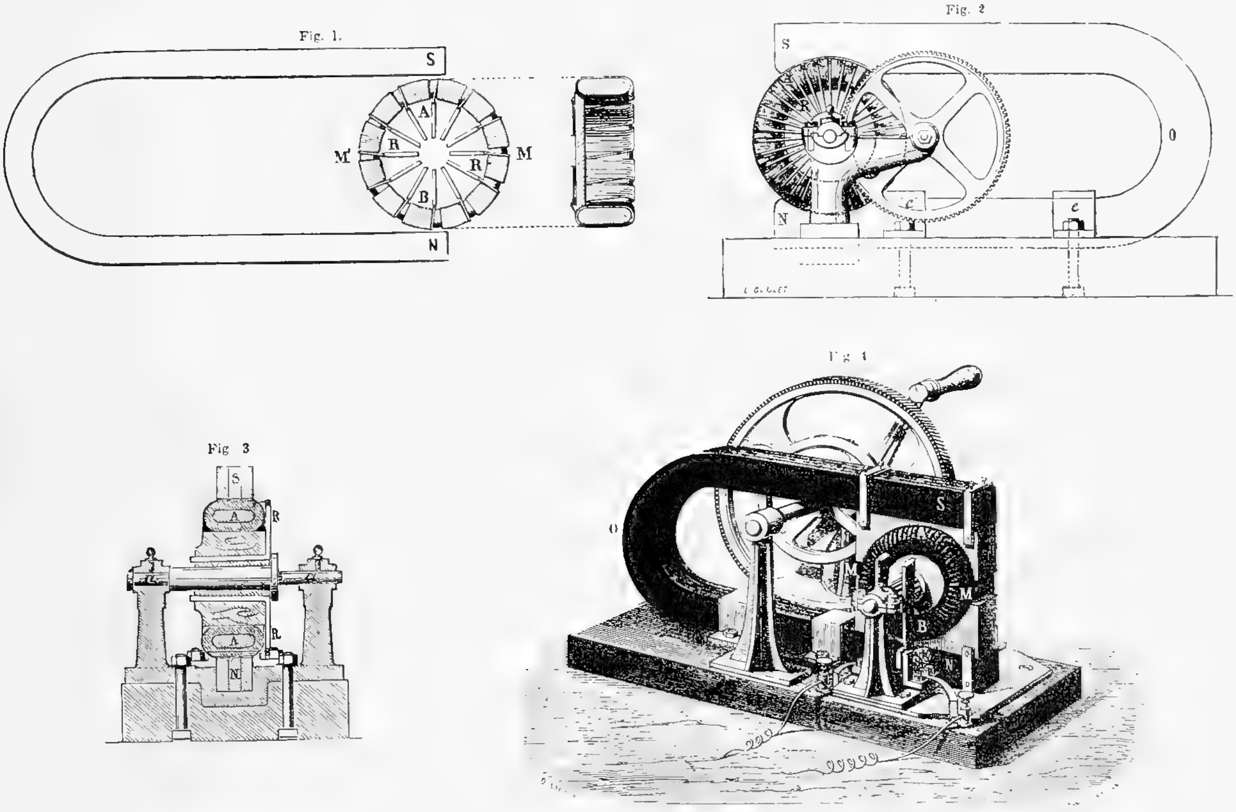


Fig. 1.
S
A
R
M'
M
R
B
N
Fig. 2
S
R
O
N
C
C
Fig 3
S
A
R
A
R
N
Fig 4
O
S
M
M
B
N

Figure 55.—A slightly later version of Gramme's magneto with ring armature, showing the many-part commutator and the use of wire brushes as current collectors. From *Chronique de l'industrie*, August 13, 1873, p. 223.

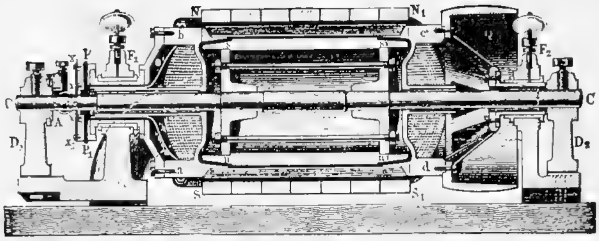
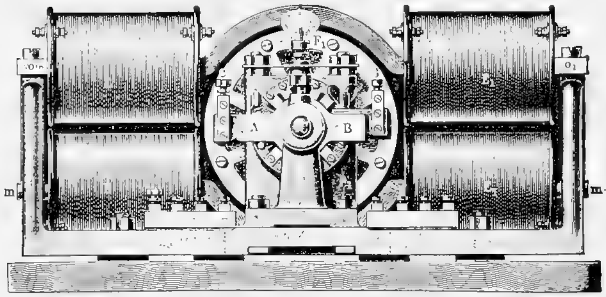


Figure 56.—Two views of the Von Hefner-Alteneck dynamo with drum armature as shown at the Vienna Exhibition of 1873. The armature core (s–s_1, n–n_1) is fixed and the armature windings (coiled on *abcd*) rotate. From J. Dredge, *Electric Illumination*, London, n.d. (about 1882), vol. 1, p. 278.



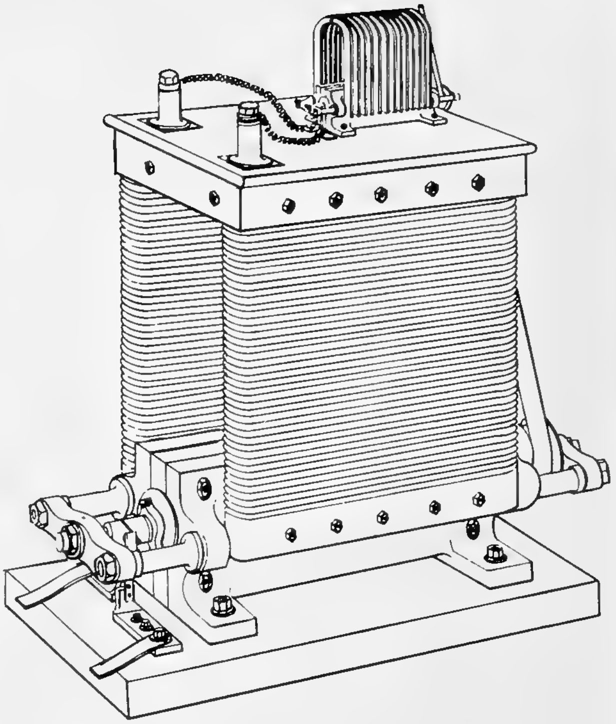


Figure 57.—Wilde's application of a magneto generator to provide the electromagnet field of a second generator. From *Philosophical Magazine*, 1867, vol. 34, pl. 2.

Farmer[85] of the United States in 1865 but their work did not lead to further development. A few years later, in 1867, the principle of self-excitation was simultaneously enunciated by Charles Wheatstone,[86] by S. Alfred Varley,[87] and by Werner Siemens (figs. 59–61).[88] The discoveries of Wheatstone and Siemens were even announced at the same meeting, in London.

The basic theory of self-excitation is simple. All iron is magnetized to some extent, however slight it may be, and it is sufficient to induce some current in the armature of an electromagnet generator when the armature is rotated between the poles of the electromagnet before any current flows through the electromagnet and before the core of the electromagnet is "magnetized." If connections are made so that this current passes through the electromagnet, it will increase the magnetic field in which the armature turns, and this in turn increases the induced current, and so on. Under proper conditions, the process will continue until the core of the field magnet

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[85] H. Wilde, "On Siemens' and Wheatstone's Magneto-Electric Machines," *Proceedings of the Literary and Philosophical Society of Manchester*, 1867, vol. 6, pp. 103–107; George B. Prescott, *Dynamo-Electricity*, New York, 1884, p. 123.

[86] *Philosophical Magazine*, 1867, ser. 4, vol. 33, pp. 471–474.

[87] British patent 3394 (December 24, 1866); also, *Engineering*, 1877, vol. 24, pp. 322, 348.

[88] Werner Siemens, "Ueber die Unwandlung von Arbeitskraft in elektrischen Strome ohne Anwendung permanenter Magnete," *Monatsberichte der Koeniglichen Akademie der Wissenschaften zu Berlin*, 1867, pp. 55–58; C. William Siemens, "On the Conversion of Dynamical into Electrical Force without the Aid of Permanent Magnetism," *Philosophical Magazine*, 1867, ser. 4, vol. 33, pp. 469–471; British patent 261 (filed January 31, 1867); Adolf Thomälen, "Zur Geschichte der Dynamomaschine," *Beiträge zur Geschichte der Technik und Industrie*, 1917, vol. 7, pp. 134–168. For an excellent introduction to the early history of the dynamo, see Otto Mahr, *Die Entstehung der Dynamomaschine*, vol. 5 of *Geschichtliche Einzeldarstellungen aus der Elektrotechnik*, Berlin, 1941, pp. 129–140.

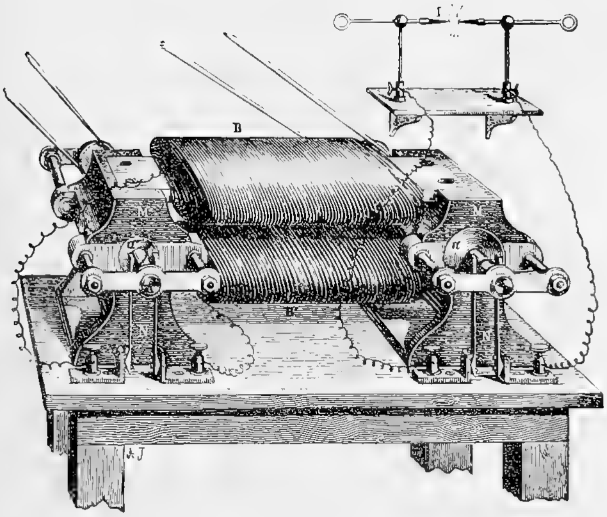

Figure 58.—Ladd's combination magneto-electromagnet generator as used to drive an arc light. From *La Lumière électrique,* 1882, vol. 7, p. 13, fig. 12.

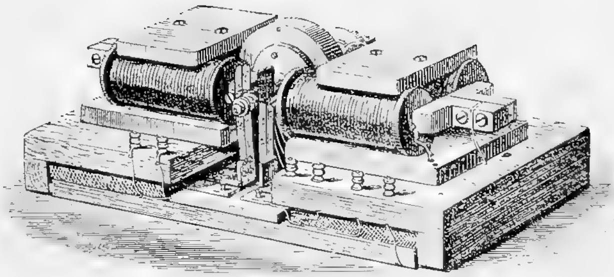

Figure 60.—Varley's dynamo of 1866. From J. Dredge, *Electric Illumination,* London, n.d. (about 1882), vol. 1, p. 138.

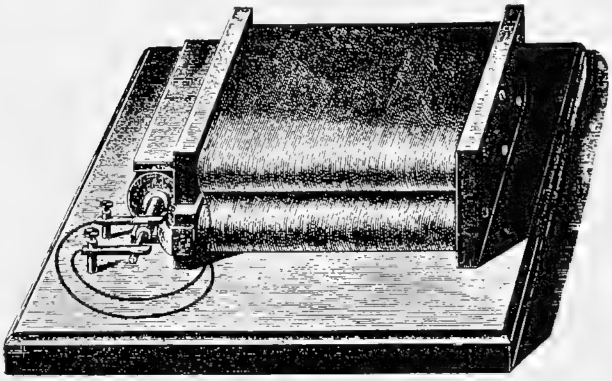

Figure 61.—Siemens' dynamo of 1866. From A. Thomälen, "Zur Geschichte der Dynamo-Maschine," *Beiträge zur Geschichte der Technik und Industrie,* 1916, vol. 7, p. 141.

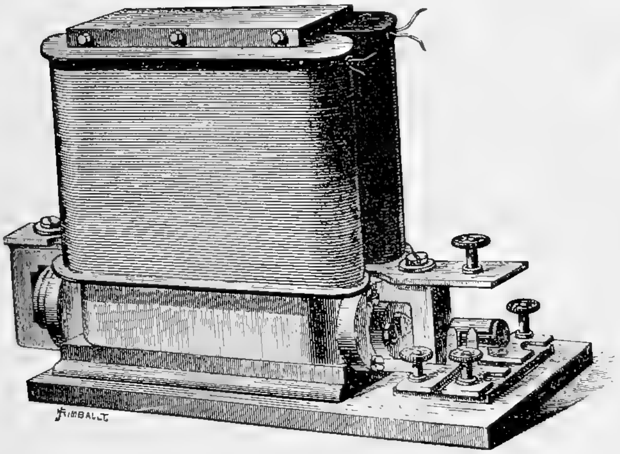

Figure 59.—Wheatstone's dynamo of 1866. From J. Dredge, *Electric Illumination,* London, n.d. (about 1882), vol. 1, p. 137.

is magnetically saturated and no further increase in current is possible at that particular speed of armature rotation. The distinctive term "dynamo-electric machine," in contrast to the usual term "magneto-electric machine," was applied to this new kind of generator by Werner Siemens in his announcement of the new principle. Since then, the term has been shortened to "dynamo."

Gramme was the first to make the dynamo a success commercially.[89] He was a Belgian carpenter who worked with a compatriot, Joseph van Malderen, at the shop of the Société l'Alliance as model-maker. As Gramme's interest in electricity grew, he left the shop to further his education and to become an instrument-maker by working with Ruhmkorff and then Disdéri (or, some say, Froment). He finally turned to working out his own ideas, and his first

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[89] O. Colson, "Zénobe Gramme: Sa Vie et ses oeuvres," *Wallonia,* 1903, vol. 11, pp. 261–279; Jean Pelseneer, *Zénobe Gramme,* Brussels, 1944, ed. 2.

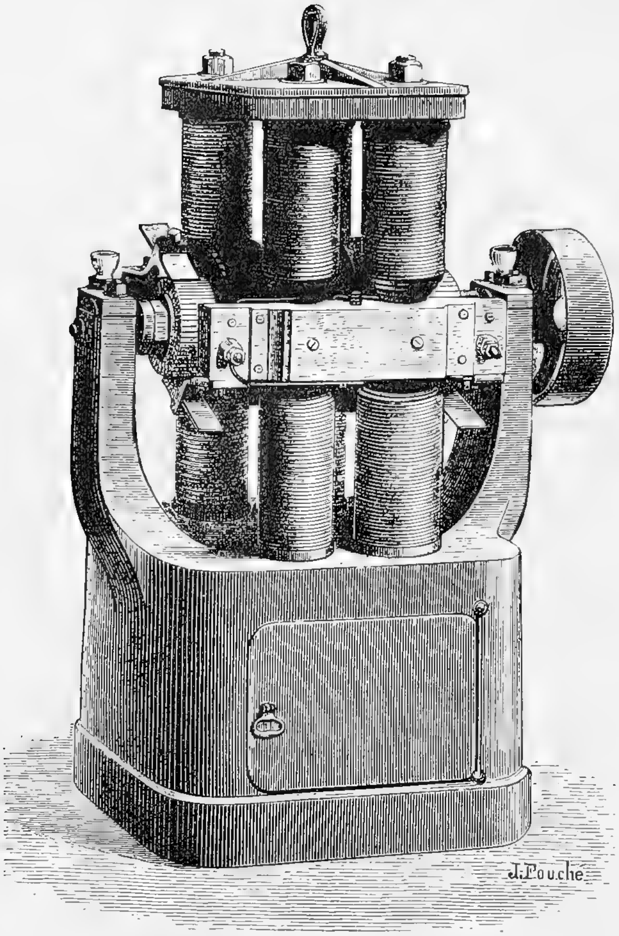

Figure 62.—Gramme's first commercial dynamo for electroplating. From *Revue industrielle,* November 25, 1874, p. 406, fig. 5.

inventions of the 1860's were based on magneto-electric machines of the multiple-disk Woolrich type, although one of the specifications in his patent of February 26, 1867, implied self-excitation.[90] As mentioned previously, he patented the ring armature in 1870.

With the Count d'Ivernois as financial backer, and Hippolyte Fontaine as the director, the Société des Machines Magneto-électriques Gramme was founded sometime during the winter of 1870–1871 to manufacture a generator with the new type of ring armature; however, the Franco-Prussian war and its consequences delayed the entrepreneurs for a time. Instead the Société commissioned the instrument-maker Bréguet to make magneto generators with a ring armature in the early 1870's for laboratory and small shop use.[91] The experience gained by varying the form of these small magneto generators served as a guide in the later construction of the Gramme dynamo.

In 1871 Gramme presented to the Académie des Sciences a generator based on Ladd's design but with Gramme's ring armatures instead of Siemens' shuttle armatures. A parallel pair of horizontal bar-electromagnets, one above the other, had ring armatures between the poles at each end of the pair. One ring armature supplied current for the electromagnets and the other supplied the output current. An article appearing in the *Comptes rendus* brought the new kind of armature to the attention of the scientific world and served to stimulate several investigators to try to determine how the current was induced in it.[92]

Gramme patented in 1872 a machine that combined the use of the ring armature, wire brushes to collect the current from the armature, and field excitation by a magneto, the armature of which was on the same arbor as that of the electromagnet generator. By the end of that year the first commercial Gramme generator appeared on the market (figs. 62, 63).[93] While this machine was still based on the design of Ladd's apparatus, the modifications considerably improved the efficiency. Instead of using bar-electromagnets arranged horizontally, Gramme used cylindrical electromagnets and arranged them verti-

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[90] French patent 75172 (February 26, 1868; additions, November 21, 1868, and August 13, 1869).

[91] *Chronique de l'industrie,* 1872, vol. 1, pp. 84, 179–180; Du Moncel, *op. cit.* (footnote 80), vol. 2, pp. 219–222; Alfred N. Bréguet, "Gramme's Electro-Magnetic Machine," *Engineering,* 1872, vol. 13, p. 289.

[92] Z. T. Gramme, "Sur une Machine magnéto-électrique produisant des courants continus," *Comptes rendus,* 1871, vol. 73, pp. 175–178; Théodose du Moncel, *op. cit.* (footnote 80), vol. 2, pp. 538–544; "Note sur les courants induits résultant de l'action des aimants sur les bobines d'induction normalement à leur axe," *Comptes rendus,* 1872, vol. 74, pp. 1335–1339; J. M. Gaugain, "Sur les Courants d'induction developpés dans la machine de M. Gramme," *Comptes rendus,* 1872, vol. 75, pp. 138–141, 627–630, 828–831; *Engineering,* 1871, vol. 12, pp. 87, 173.

[93] French patent 87938 (addition of February 27, 1872); Z. T. Gramme, "Sur les Machines magnéto-électriques Gramme, appliquées à la galvanoplastie et à la production de la lumière," *Comptes rendus,* 1872, vol. 75, pp. 1497–1500; *Chronique de l'industrie,* 1873, vol. 2, pp. 86–87, 99, 223–224.

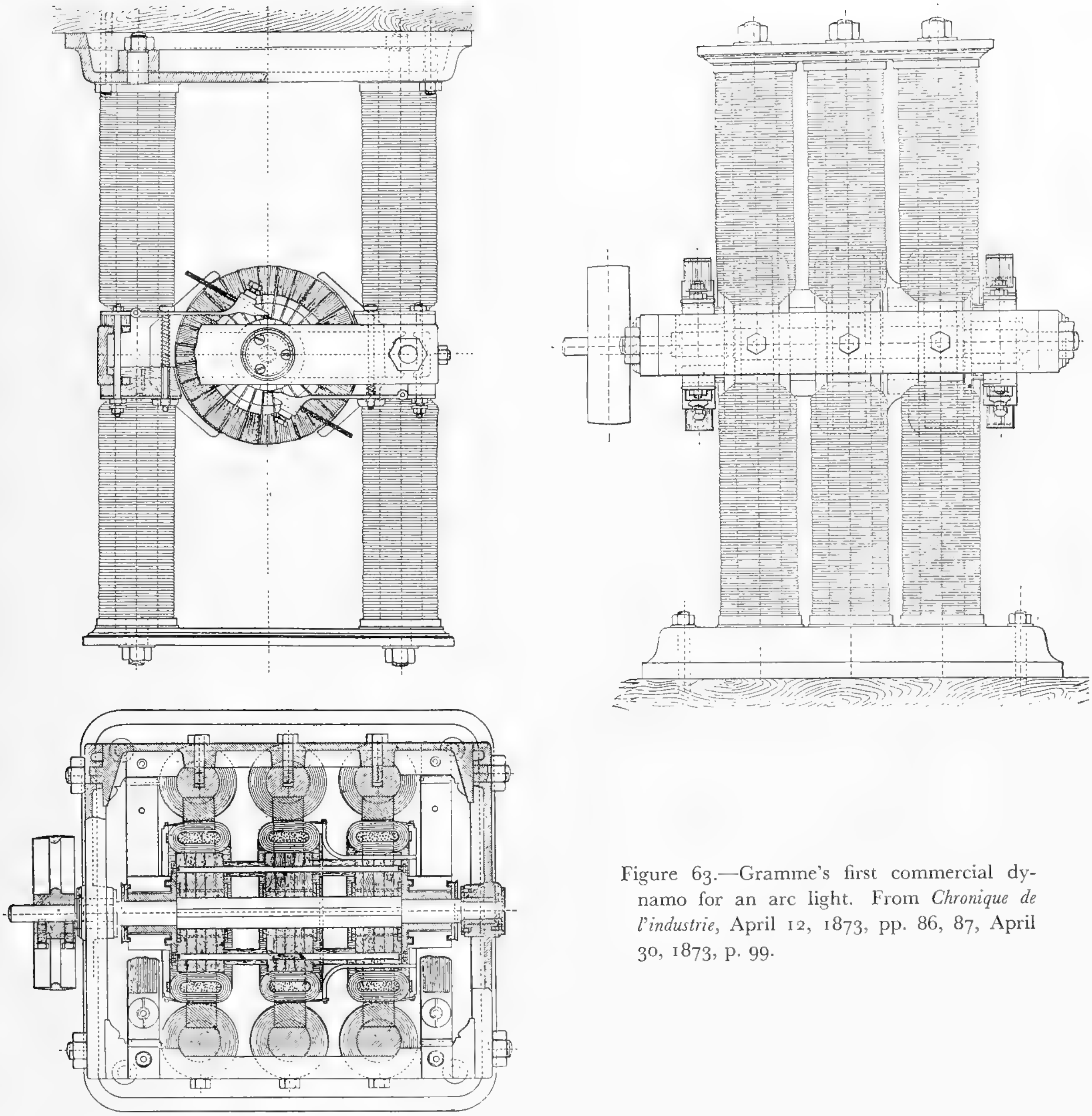

Figure 63.—Gramme's first commercial dynamo for an arc light. From *Chronique de l'industrie,* April 12, 1873, pp. 86, 87, April 30, 1873, p. 99.

cally, and instead of leaving the magnetic circuit open at the ends, he completed the circuit by placing cast-iron plates across the top and bottom of the electromagnets. He provided for the gap in the magnetic circuit in which the armature rotated by leaving a space in the middle of each of the cores of the electromagnets where there were no turns of the field coils. Crescent-shaped pole-pieces were attached to this bare area so as to shunt the magnetic field from one electromagnet to the other and thereby pass through the armatures. The armatures were mounted on a common axis perpendicular to that of the electromagnets and they rotated between the concave faces of the pole-pieces. One of the armatures produced the current for the electromagnets of the other armatures, and brushes of silver-plated copper wire collected the current induced in them.

The generators were made in two forms, one of low

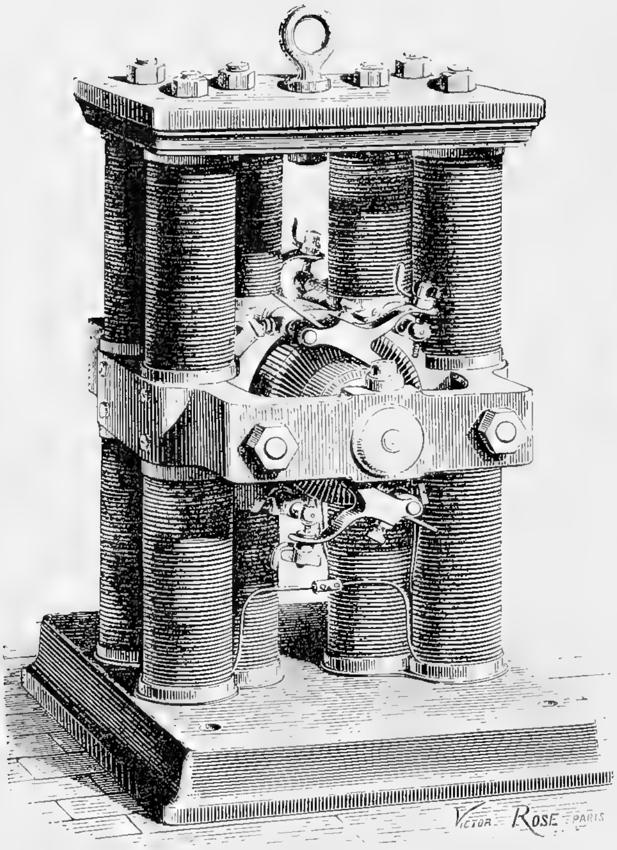

Figure 64.—Gramme's arc-light dynamo, 1874 version. From *Revue industrielle*, November 25, 1874, p. 408.

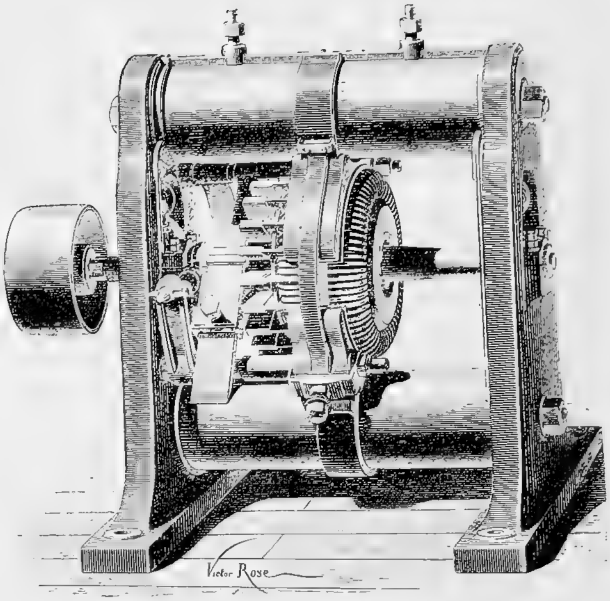

Figure 65.—Gramme's first form of the *type d'atelier* dynamo for electroplating. From *Revue industrielle*, November 25, 1874, p. 407.

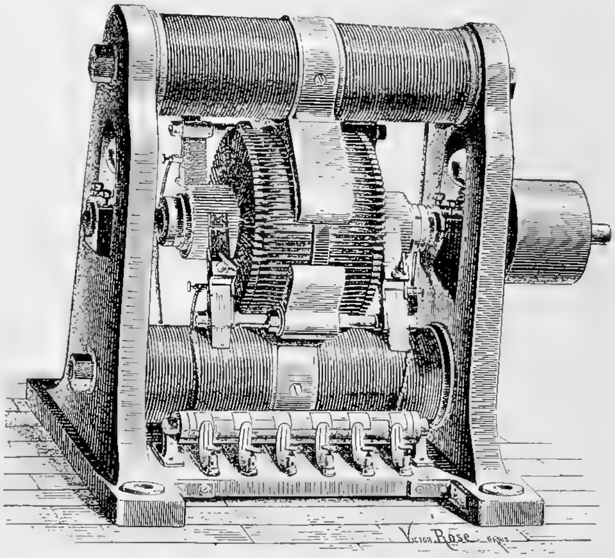

Figure 66.—Gramme's first form of the *type d'atelier* dynamo for arc lights. From *Revue industrielle*, November 25, 1874, p. 409.

resistance with coarse wire on the armature for electrochemical purposes, and one of high resistance with fine wire on the armature for use with arc lights. The high-current electrochemical machine had two armatures on a common axis and four electromagnets. It weighed about 750 kg., measured 0.8 meters square by 1.3 meters high, and required 175 kg. of copper wire. When driven by a 1-hp. engine at 300 r.p.m. it produced about 150 amperes at 2 volts, which implied an efficiency of about 40 percent. The high-voltage arc-light machine used three armatures and six electromagnets. It weighed about 1,000 kg. and measured 0.8 meters square and 1.25 meters high. The electromagnets required 250 kg. of copper wire and the armature required 75 kg. of copper wire. When driven by a 4-hp. engine at 300 r.p.m. the machine produced a light of about 850 Carcel units, about four times as much as the

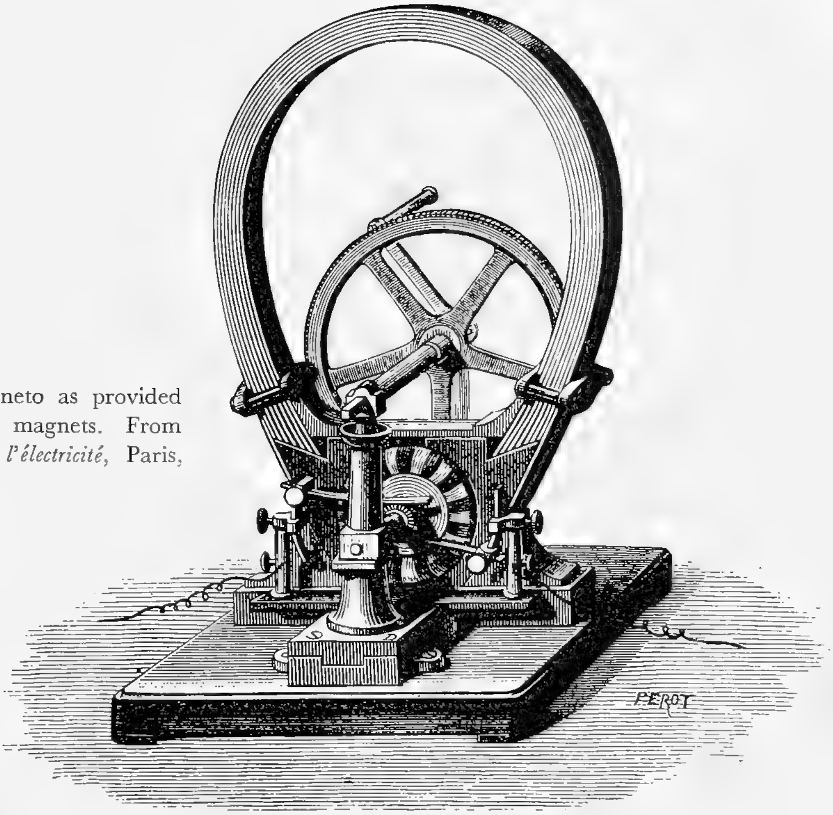

Figure 67.—Gramme's magneto as provided with Jamin's compound magnets. From H. Fontaine, *Eclairage à l'électricité*, Paris, 1877, p. 104.

6-disk Alliance machine. The voltage was equal to that of 105 normal Bunsen cells, and the current was equal to that of 5 such cells. Roughly speaking, such power implied an efficiency of 50 percent. The cost of the machine was £400 in England. Arc-light demonstrations were made in the new Clock Tower of Parliament in London in 1873, but since the machine was quite apt to overheat the arc lights were discontinued in favor of gas.[94]

At the beginning of 1874, Gramme cut down the size and considerably increased the efficiency of both the high-resistance and low-resistance generators by relying completely on the principle of self-excitation.[95] The new model, called the *type d'atelier* (figs. 65, 66), reduced the number of armatures to one and reduced the number of electromagnets necessary to supply the field. The electromagnets were still cylindrical in form but were placed horizontally, with one above the other, as in the original Ladd generator. The axis of the single armature was horizontal and in the same vertical plane as the electromagnets instead of being perpendicular as in the Ladd machine. As before, the magnetic circuit was completed by cast-iron plates at the ends. Other changes made it possible to increase the speed of rotation without excessive heating of the armature.

One electrochemical model and two arc-light models were now produced. The electrochemical machine (fig. 65) weighed 177.5 kg., measured 0.55 meters square by 0.60 meters high, and used only 47 kg. of copper wire for both armature and field. When driven by a ⅔-hp. motor at 500 r.p.m. it would produce the same amount of current as its predecessor. Two sizes of the arc-light machine were made—a large one based on the previous vertical arrangement of the electromagnets (fig. 64) and a small one based on the new horizontal arrangement of the *type d'atelier* (fig. 66). The large arc-light machine used six electro-

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[94] *Engineering*, 1873, vol. 15, pp. 291–292.

[95] Z. T. Gramme, "Sur les Nouveaux Perfectionnements apportés aux machines magnéto-électriques," *Comptes rendus*, 1874, vol. 79, pp. 1178–1182; Alfred N. Bréguet, "Machine magnéto-électrique de M. Gramme," *Revue industrielle*, 1874, vol. 3, pp. 405–410; *Engineering*, 1874, vol. 18, pp. 412–414.

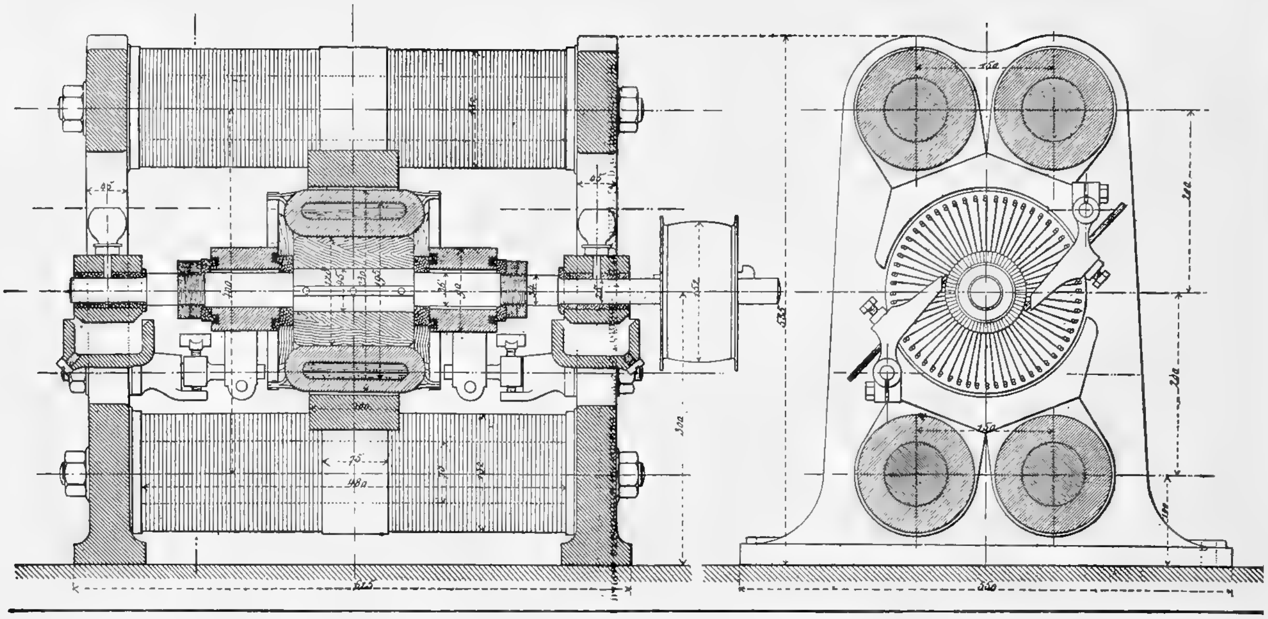

Figure 68.—Gramme's 1876 *type d'atelier* dynamo for use with arc lights. From *Revue industrielle,* February 9, 1876, p. 57.

magnets grouped in the form of a triangle on each side of the armature, and each group had a common pole-piece. This machine weighed 700 kg. and measured 0.90 meter square by 0.65 meter high. There were 180 kg. of copper wire on the electromagnets and 40 kg. on the armature. This large generator normally produced a light of 500 Carcel units, but it was claimed that this amount of light could be almost doubled by increasing the speed of the generator. The smaller machine weighed 183 kg. and measured 0.55 meter square by 0.60 meter high. There were 47 kg. of wire on both armature and field. The armature on the small arc-light machine was what Gramme termed *dédoublé,* that is, there were two windings on the single core with a set of commutator bars on each side of the form (fig. 66).[96] These two windings could then be connected so as to double the current or to double the voltage. The intensity of the arc light at 900 r.p.m. was 200 Carcel units. Small lecture magnetos using Jamin's compound magnets also were produced at this time (fig. 67).

Later improvements enabled Gramme to reduce the cost and increase the efficiency of his generators still

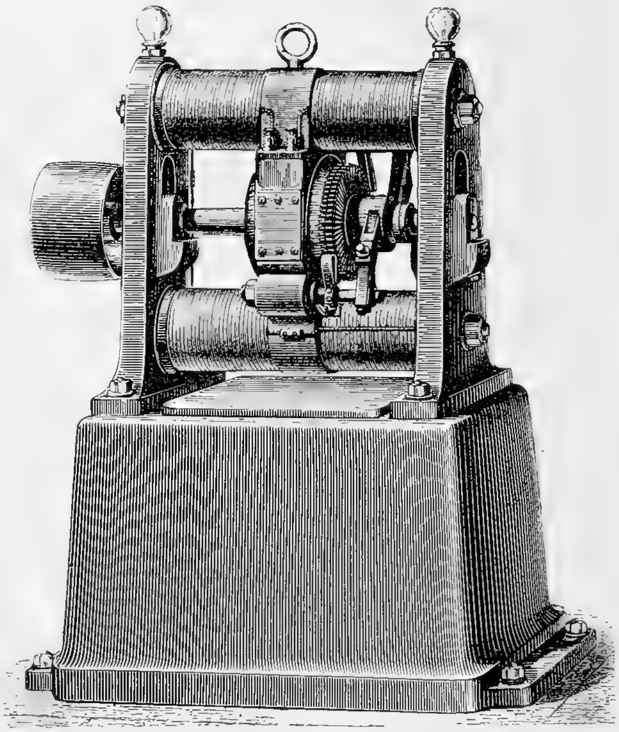

Figure 69.—Gramme's 1877 *type d'atelier* dynamo for use with arc lights. From *Revue industrielle,* May 2, 1877, p. 173.

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[96] Alfred N. Bréguet, "Note sur la machine Gramme à l'anneau dédoublé," *Revue industrielle,* 1876, vol. 5, pp. 106–110.

further. In 1876 a smaller and lighter version of the *type d'atelier* generator appeared that weighed 180 kg. and measured 0.60 meter high, 0.35 meter wide, and 0.65 meter long (fig. 68).[97] There were 28 kg. of copper wire on the electromagnets and 4.5 kg. on the armature. When driven by a 2-hp. motor at 820 r.p.m. the generator would produce 200 Carcel units; when driven by a 3-hp. motor at 920 r.p.m. it would produce 400 Carcel units. Another model was brought out in 1877 (figs. 69, 70).

Table 2 gives the values claimed by the French manufacturer for three of the *type d'atelier* models in January 1879 (fig. 71).[98]

Both C and D models had *dédoublé* armatures, so that the two halves of the generator could be connected in quantity (parallel) or in tension (series). In the tabulation, C(T) refers to model C connected in tension, D(Q) to model D connected in quantity, and A(2) to two model A generators. For some reason, the manufacturer gave the light intensity for model A in candles and for models C and D in Carcel units.

By his later improvements Gramme had converted the electric generator from a laboratory curiosity or an awkward magnetoelectric machine into a fully practical dynamo, ready for commercial exploitation. In 1874, four Gramme generators were sold; by 1875, 12 had been sold; by 1876, 85; by 1877, 350; by the middle of 1878, 500; and by 1879, over 1,000. Mechanically, the Gramme dynamo was efficient, compact, and durable; electrically, unlike previous dynamos, it produced a relatively constant output that was greater than that of any previous one, except possibly the Siemens machine. Although the efficiency seems to have ranged between 80 and 90 percent and the main application, until the end of the 1870's, was in the electrochemical industries, the electric light and even the transmission of power was now a possibility.[99]

TABLE 2.—*Manufacturer's claims for three* type d'atelier *models in January 1879.*

Model	*Price* (£)	*Length-width-height* (*inches*)	*Weight* (*lbs.*)	*R.p.m.*	*Hp.*	*Light*	*CP/HP*
A	80	27½ x 15¾ x 22¾	407	900	2.5	6300	2400
A(2)	160	39 x 19½ x 15¾	748	900	5.0	14000	2800
C(Q)	240	29 x 21½ x 25½	858	1250	8.0	2500	310
C(T)	211	29 x 21½ x 25½	858	700	5.0	1500	300
D(Q)	360	37½ x 31½ x 33½	2200	550	12.0	4000	300
D(T)	360	37½ x 31½ x 33½	2200	300	7.0	2000	290

A short time after the commercial appearance of these new dynamos, the world of inventors discovered that such generators could be used as electric motors. This was not a new principle; it had been latent, if not explicit, in all the previous work on generators and motors. Gramme had even noted this in his 1870 patent. However, it was a relatively new theory that a dynamo could be so used, and it was soon found that a better motor than ever before could be produced. The usual story is that the discovery was an accidental one—one of the workers at the Vienna Exhibition of 1873 happened to connect two Gramme dynamos together and found that one generator could drive the other as an electric motor. Hippolyte Fontaine promptly made such an arrangement part of the Gramme exhibit. A centrifugal pump was driven by a Gramme motor that received its power from a Gramme dynamo three-quarters of a mile away; the pump, in turn, supplied a small waterfall (fig. 73). Fontaine was prompt in publicizing his finding that 1 hp. could be transmitted over wires in this manner with an efficiency of about 50 percent. At the Philadelphia Centennial Exposition of 1876, Gramme dynamos were shown running arc lamps, electroplating, and driving another Gramme dynamo as a motor; and by 1879 Fontaine could assert for this process an over-all efficiency of about 63 percent

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[97] Z. T. Gramme, "Recherche sur l'emploi des machines magnéto-électriques à courants continus," *Comptes rendus*, 1877, vol. 84, pp. 1386–1389; Hippolyte Fontaine, "Eclairage à l'électricité," *Revue industrielle*, 1877, vol. 6, pp. 173–174; 1878, vol. 7, pp. 248–250; *op. cit.* (footnote 12), *passim; Engineering*, 1879, vol. 28, p. 64.

[98] Douglass, *op. cit.* (footnote 36), p. 129.

[99] Fontaine, *op. cit.* (footnote 12), p. 89; *Engineering*, 1878, vol. 25, p. 526; M. Mascart, "Sur les Machines magnéto-électriques," *Journal de physique*, 1877, vol. 6, pp. 203–212, 297–305; 1878, vol. 7, pp. 79–92, 363–377; Felix Auerbach and O. E. Meyer, "Ueber die Ströme der Gramme'schen Maschine," *Annalen der Physik und Chemie*, 1879, vol. 8, pp. 494–514; 1880, vol. 9, pp. 676–679; E. Hospitalier, "Sur le Rendement électrique des machines gramme," *La Lumière électrique*, 1879, vol. 1, pp. 114–117.

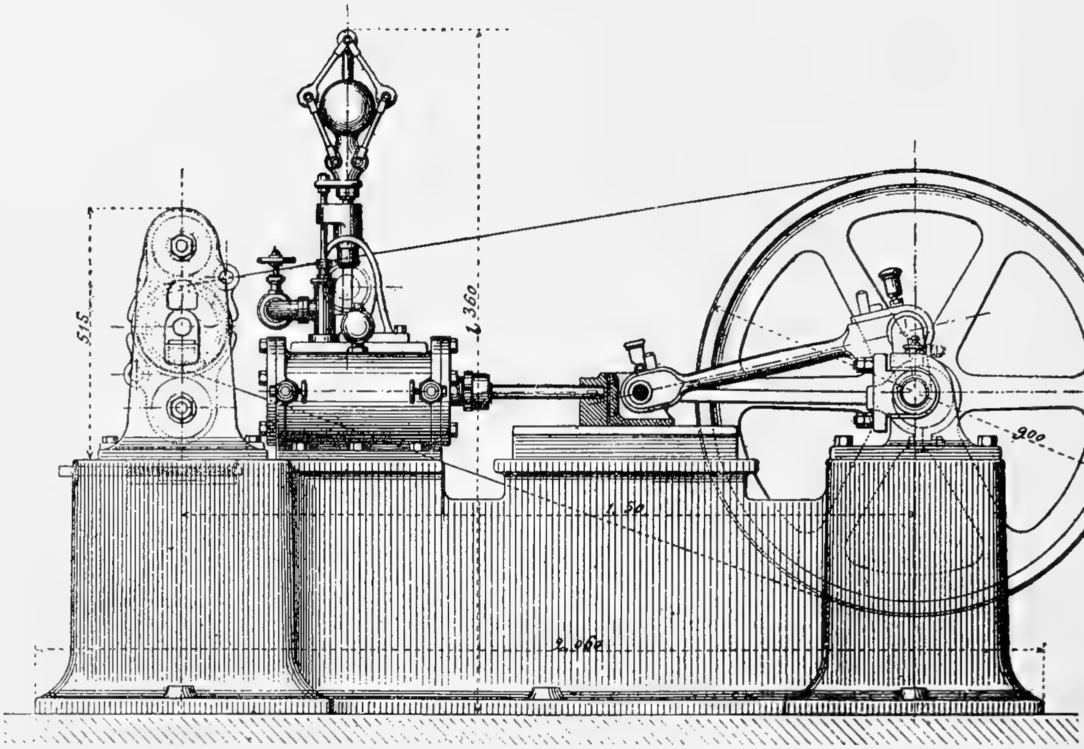

Figure 70.—Gramme's 1877 *type d'atelier* dynamo as driven by a steam engine. From *Revue industrielle*, May 9, 1877, p. 182.

instead of 50 percent (fig. 72).[100] With such examples, a new phase in electrical technology seemed to be opening.

The introduction of the Gramme dynamo into commerce and industry had repercussions in both Europe and America. As mentioned earlier, the firm of Siemens and Halske had exhibited the drum armature in a magneto detonator for mines and in an alternator excited by a separate magneto generator at the Vienna Exhibition of 1873 (fig. 74). A few units with a drum armature were made in the next few years for commercial use, but these, while comparing very favorably with the Gramme dynamo, did not really enter commerce until 1877, after the reports of Tyndall and Douglass[101] were published. In the following two years the English Siemens firm sold more than £60,000 worth of these units.[102] It was probably because of this increasing competition that Gramme countered with his new *type d'atelier* model.

The commercial Siemens machine of the late 1870's (figs. 75–77) had about the same external appearance as the machine displayed at the Vienna Exposition.[103] As with Gramme's early dynamos, it was based on the Ladd machine. A pair of flat bar-electromagnets was placed horizontally, and the axis of the armature was perpendicular to the plane of the electromagnets instead of lying in it, as in Gramme's *type d'atelier*. Since the electromagnets were placed close together,

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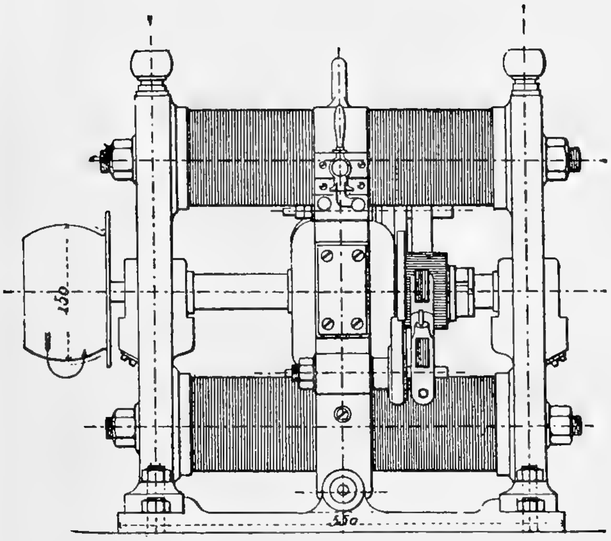
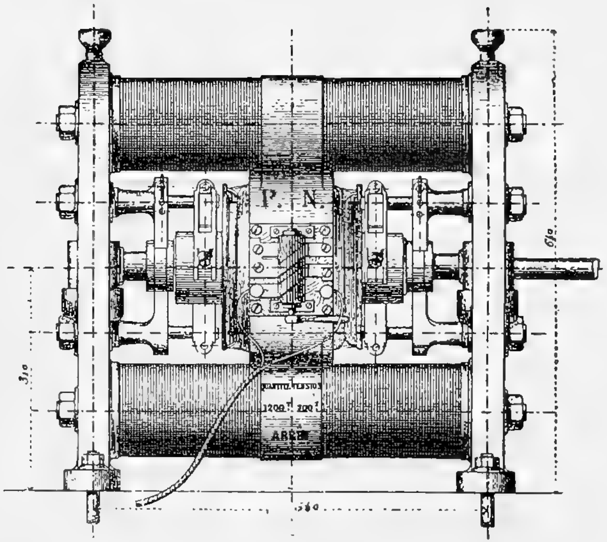
[100] Fontaine, *op. cit.* (footnote 12), pp. 89, 109; *op. cit.* (footnote 19), pp. 127–128; Alfred N. Bréguet, "Notes of Experiments on the Electric Currents Produced by the Gramme Magneto-Electric Machine," *Reports of the British Association for the Advancement of Science*, 1874, vol. 44, pp. 33–34; *L'Illustration*, 1933, vol. 186, p. 411; *Engineering*, 1879, vol. 28, pp. 416–418.

[101] Tyndall, *op. cit.* (footnote 72); Douglas, *op. cit.* (footnote 72).

[102] *Engineering*, 1879, vol. 28, p. 102.

[103] British patent 2006 (June 5, 1873); Du Moncel, *op. cit.* (footnote 80), vol. 5, pp. 525–532; Higgs and Brittle, *op. cit.* (footnote 72); Fontaine, op. cit. (footnote 19); Dredge, *op. cit.* (footnote 78), pp. 275–287.





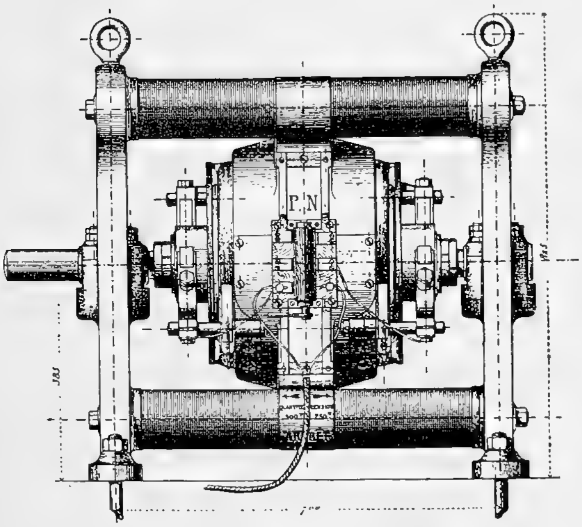


Figure 71.—Gramme's Model A (*top left*), Model C (*above*), and Model D generators of 1879. From *Minutes of Proceedings of Institution of Civil Engineers*, 1879, vol. 57, pp. 126, 127.

the midsection of the cores was pushed aside to form a circular arch to permit the armature to be placed between them. The magnetic circuit was completed by vertical iron plates at the ends. One of the first exact measurements on the efficiency of a dynamo was made by John Hopkinson when he determined the efficiency of the Siemens generator and found it to range between 88 and 90 percent, depending on the amount of current drawn.[104] The Siemens firm also constructed motors (fig. 77d, e).

Higgs and Brittle, two of the men associated with William Siemens in the construction of the English Siemens dynamo, obtained the results[105] shown in table 3 on the three models that the English firm produced.

J. N. Shoolbred made a comparison of the three models of the Siemens machine and the three models of the Gramme *type d'atelier* in 1878.[106] See table 4. As can be readily seen, the Gramme dynamo proved to be superior in each of the three sizes compared. Since all models presumably were tested under the same conditions, and presumably without any bias, these values should be more objective than the others cited.

Another evaluation of the two kinds of machines

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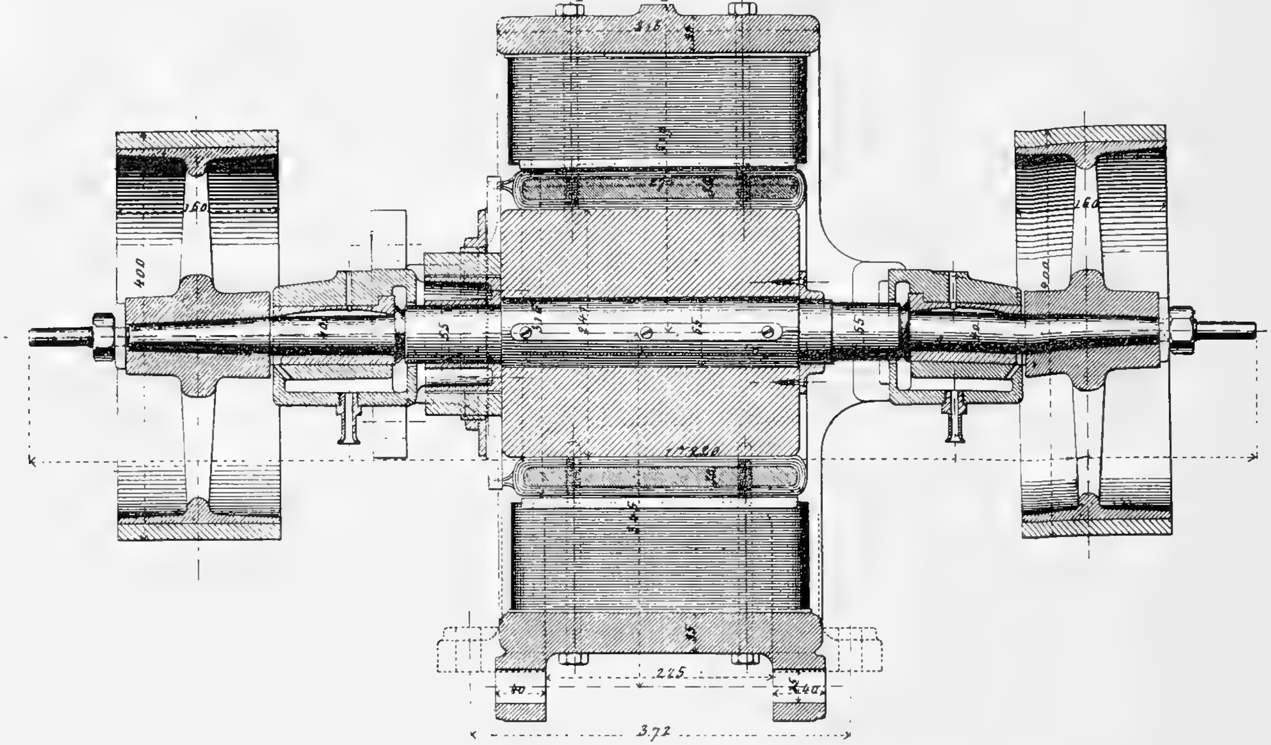
[104] John Hopkinson, "On Electric Lighting," *Proceedings of the Institution of Mechanical Engineers*, 1879, pp. 238–249.

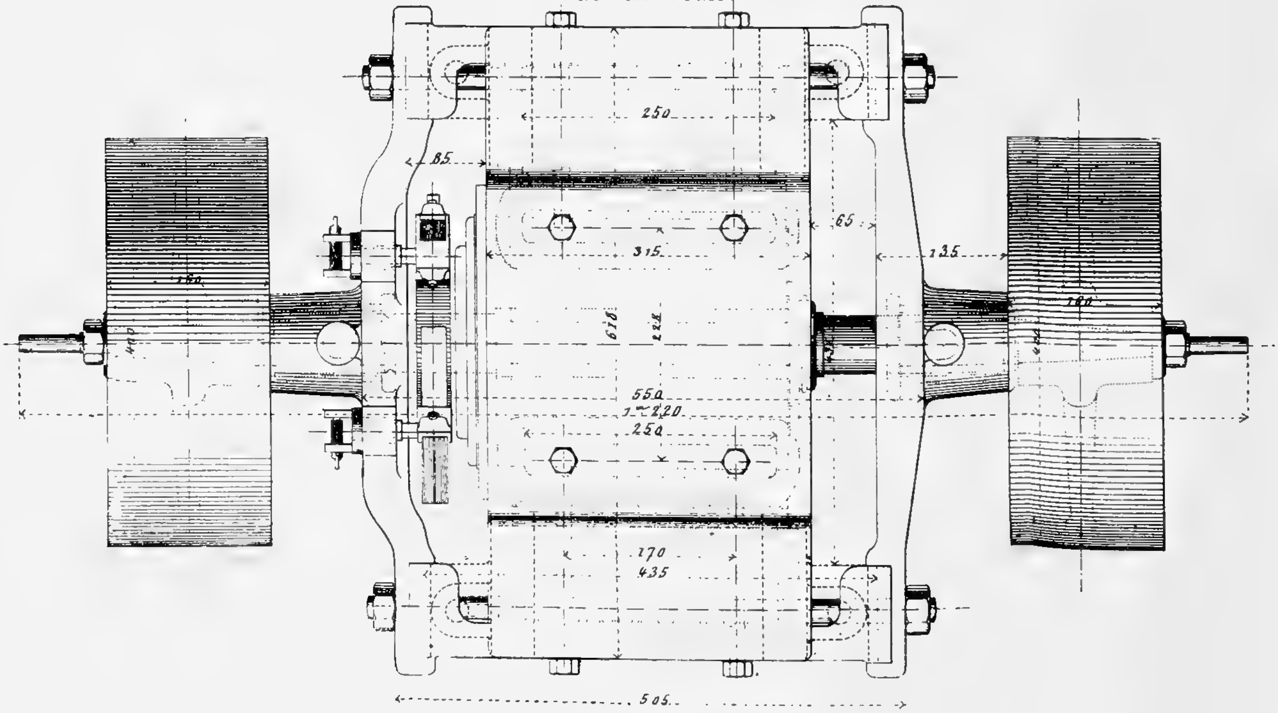
[105] Higgs and Brittle, *op. cit.* (footnote 72).

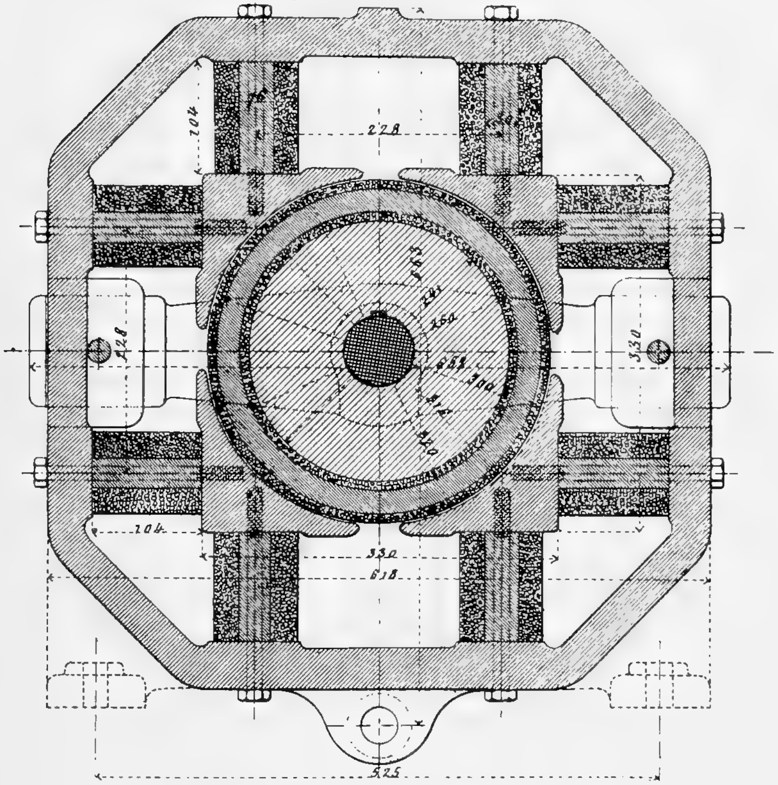
[106] J. N. Shoolbred, "On the Present State of Electric Lighting," *Engineering*, 1878, vol. 26, pp. 362–365.

Coupe longitudinale


315
160
400
40
55
65
94
1=220
225
40
40
3.72

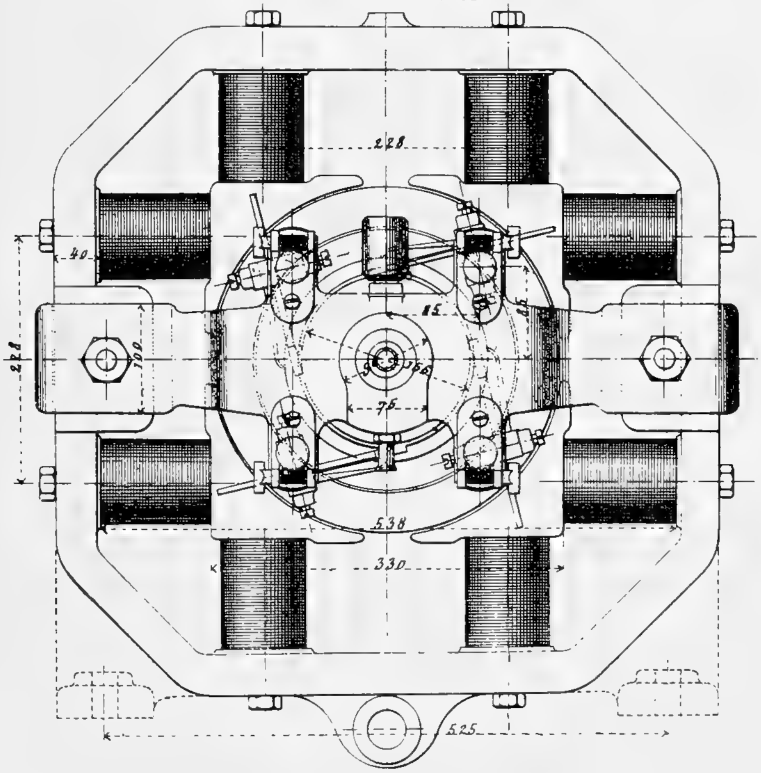
Vue en Plan


250
85
65
315
135
160
160
400
618
228
550
1=220
250
170
435
505



Coupe transversale

104
228
128
330
104
330
618
525



Vue de Profil

228
40
100
85
75
538
330
525

Figure 72.—Further steps in the transmission of power: Gramme motors of 1879. From *Revue industrielle,* November 19, 1879, pl. 23.

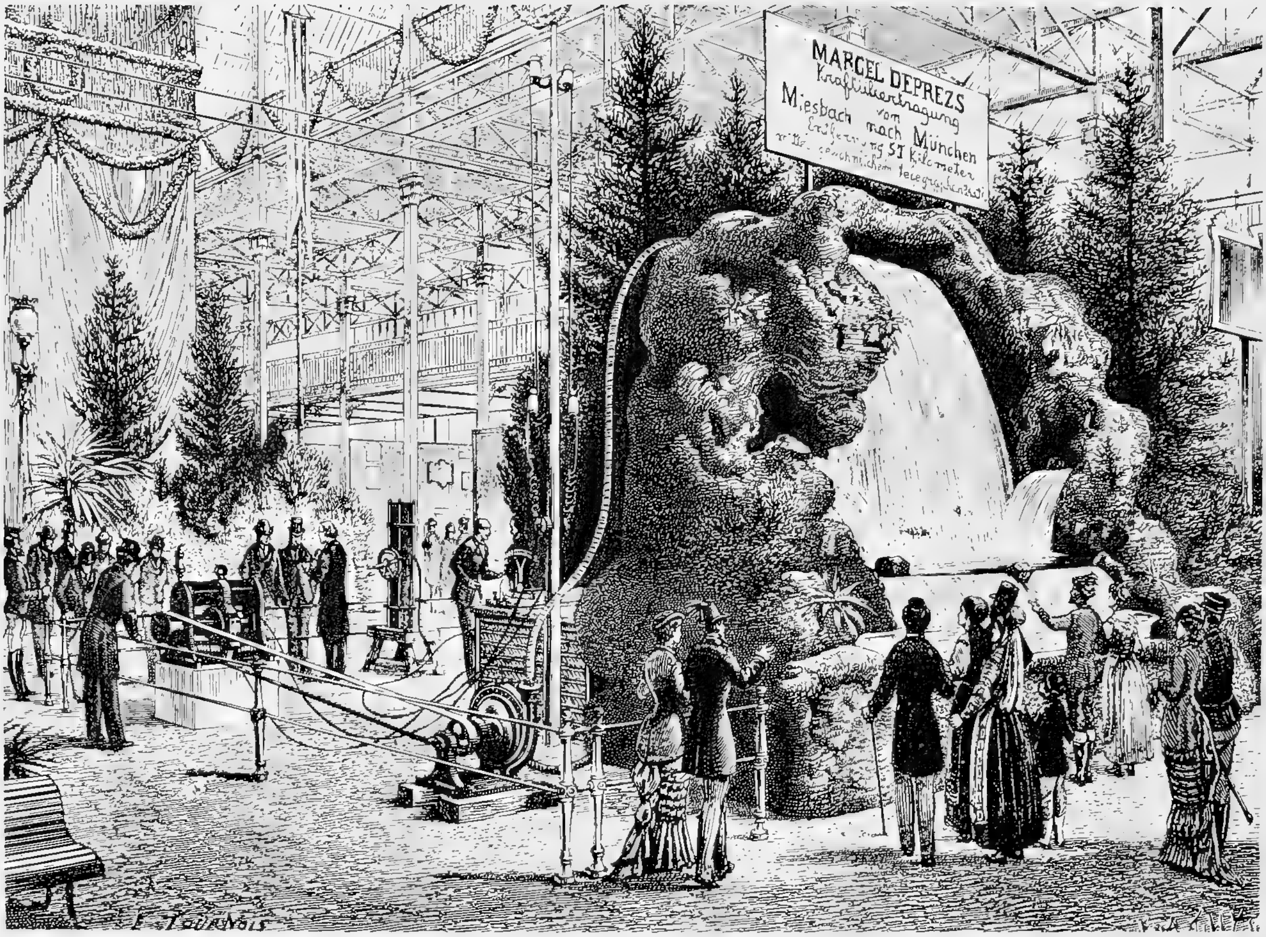


Figure 73.—Marcel Deprez repeats Fontaine's demonstration showing that electric power could be transmitted at a distance. Deprez transmitted his power 57 kilometers to drive a Gramme motor belted to a centrifugal pump at the Munich Exposition of 1882. From *La Lumière électrique,* 1883, vol. 8, p. 131.

was made the following year at the school of military engineering in Chatham, England.[107] See table 5.

The two Siemens model B machines were connected in parallel, as were the two Gramme model A generators. While the results are not directly comparable with those of Shoolbred, nevertheless they again suggest the electrical superiority of the Gramme dynamo. On the other hand, the reported efficiency

TABLE 3.—*Data on three models of an English Siemens dynamo produced by Higgs and Brittle.*

Model	*Length-width-height (inches)*	*Weight (lbs.)*	*R.p.m.*	*Light (candles)*	*Hp.*	*CP/HP*
A	25 x 21 x 8.8	298	1100	1000	1. 5–2. 0	500–670
B	29 x 26 x 9.5	419	850	4000	3. 0–3. 5	1150–1330
C	44 x 28.3 x 12.6	1279	480	14800	9–10	1480–1650

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[107] "Bericht über Versuche mit elektrischen Lichtapparaten seitens der Militair-Ingenieurschule in Chatham in den Jahren 1879–1880," *Elektrotechnische Zeitschrift,* 1881, vol. 2, pp. 67–71, 105–110.

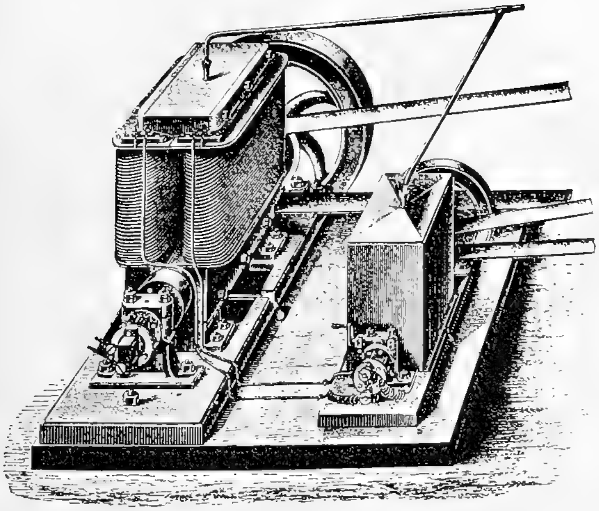

Figure 74.—The Siemens and Halske alternator with external exciter, as shown in Vienna Exhibition of 1873. From A. Thomälen, "Zur Geschichte der Dynamomaschine," *Beiträge zur Geschichte der Technik und Industrie*, 1916, vol. 7, p. 149.

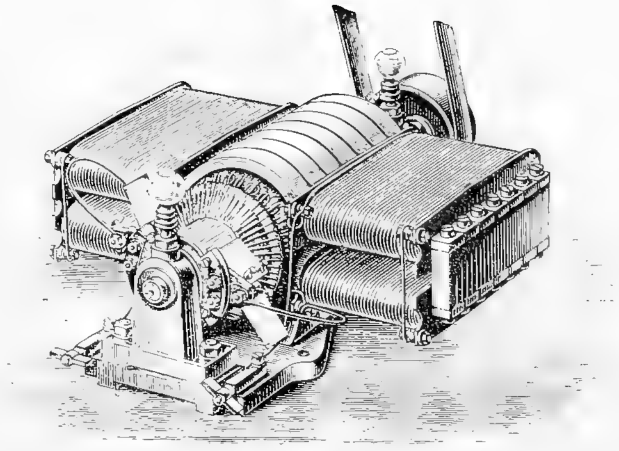

Figure 75.—The Siemens and Halske dynamo of 1876. From J. Dredge, *Electric Illumination*, London, n.d. (about 1882), vol. 1, p. 280.

Table 4.—*Shoolbred's comparison of three models of the Siemens machine and three models of the Gramme* type d'atelier, *1878.*

Machine and model	*R.p.m.*	*Candles*	*Hp. to drive*	*Candles/Hp.*	*Weight*	*Cost(£)*
Siemens, Model A	850	1200	2	600	250	70
Siemens, Model B	650	6000	4	1500	375	112
Siemens, Model C	360	14000	8	1750	1150	250
Gramme, Model M	1600	2000	1. 5	1333	150	70
Gramme, Model A	900	6000	2. 5	2400	375	100
Gramme, Model C	700	15000	5	3000	800	300

Table 5.—*Evaluation of the Siemens and Gramme dynamos at Chatham, England, in 1879.*

Machine and model	*R.p.m.*	*Candles*	*Hp. to drive*	*Candles/Hp.*	*Cost (£)*	*Efficiency (%)*
Siemens, Model B, two	680	19140	13. 4	1430	244	73
Gramme, Model A, two	875	18300	9. 6	1920	160	88
Gramme, Model C	1200	19500	9. 5	2050	240	85
Gramme, Model D	500	27500	15. 1	1820	360	89
Gramme, Model D	475	22500	12: 7	1770	360	88

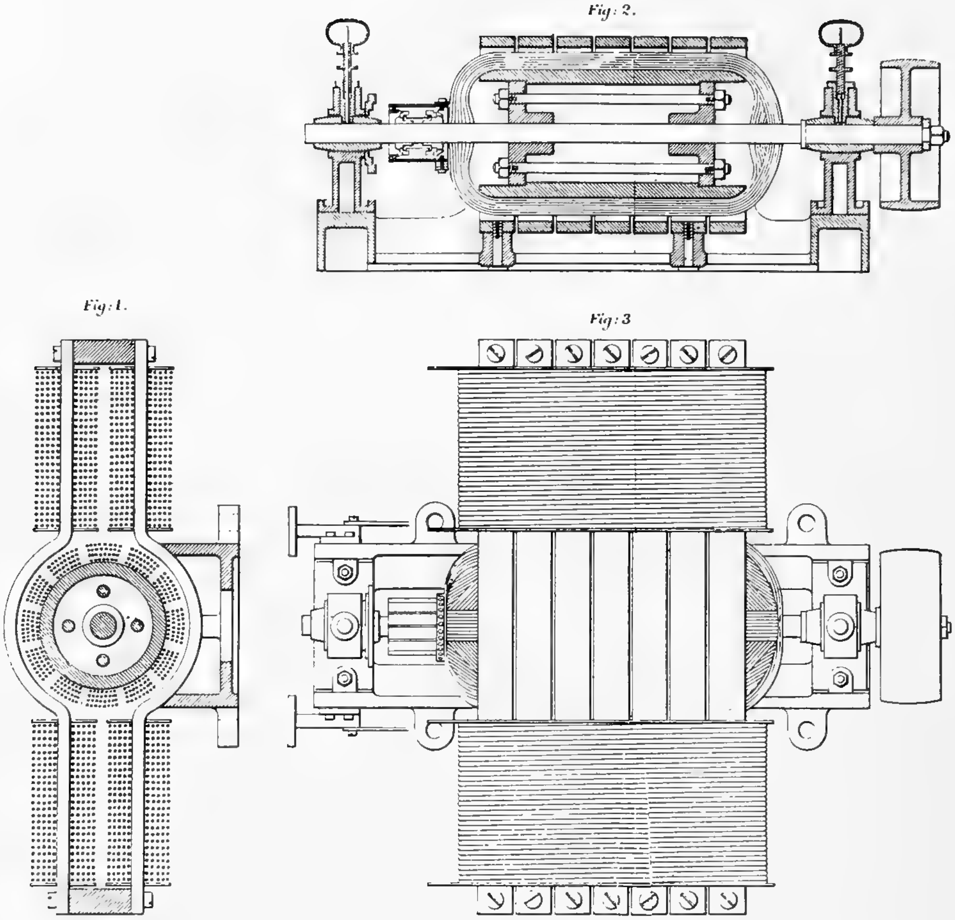

Figure 76.—Details of the Siemens and Halske dynamo of 1876. For clarity, the brushes have been omitted in the drawing. From R. W. H. P. Higgs and J. R. Brittle, "Some Recent Improvements in Dynamo-Electric Apparatus," *Minutes of the Proceedings of the Institution of Civil Engineers*, 1878, vol. 52, pp. 36–98, pl. 1.

of the Gramme dynamos is quite close to that of the Siemens dynamo as measured by Hopkinson and others.

Up to this point, three-quarters of the way through the 19th century, the electric light was possible, but it was not very practical commercially. Serrin's regulator could be used but it was so delicate that adjustment was difficult, and it was both mechanically and electrically complicated. Only one arc lamp could be used as a load in the circuit of the generators then in use; to place two regulators in the same circuit would, in effect, prevent either one from working. Moreover, the arc light was too bright for any purpose other than illuminating large areas, some means had to be found of "subdividing" it so that the brilliancy of a single arc lamp in a single circuit could be spread over many lamps of weaker intensity in the same circuit. Practical electrical generators had been invented, but the initial expense of plant installation—which was that of a gas or steam engine plus the electrical generator and the other electrical equipment that could only be used for a single light—was prohibitive for ordinary purposes (figs. 78, 79). Some means had to be found whereby such a large capital investment could be used for a number of lights that would be of lesser intensity than

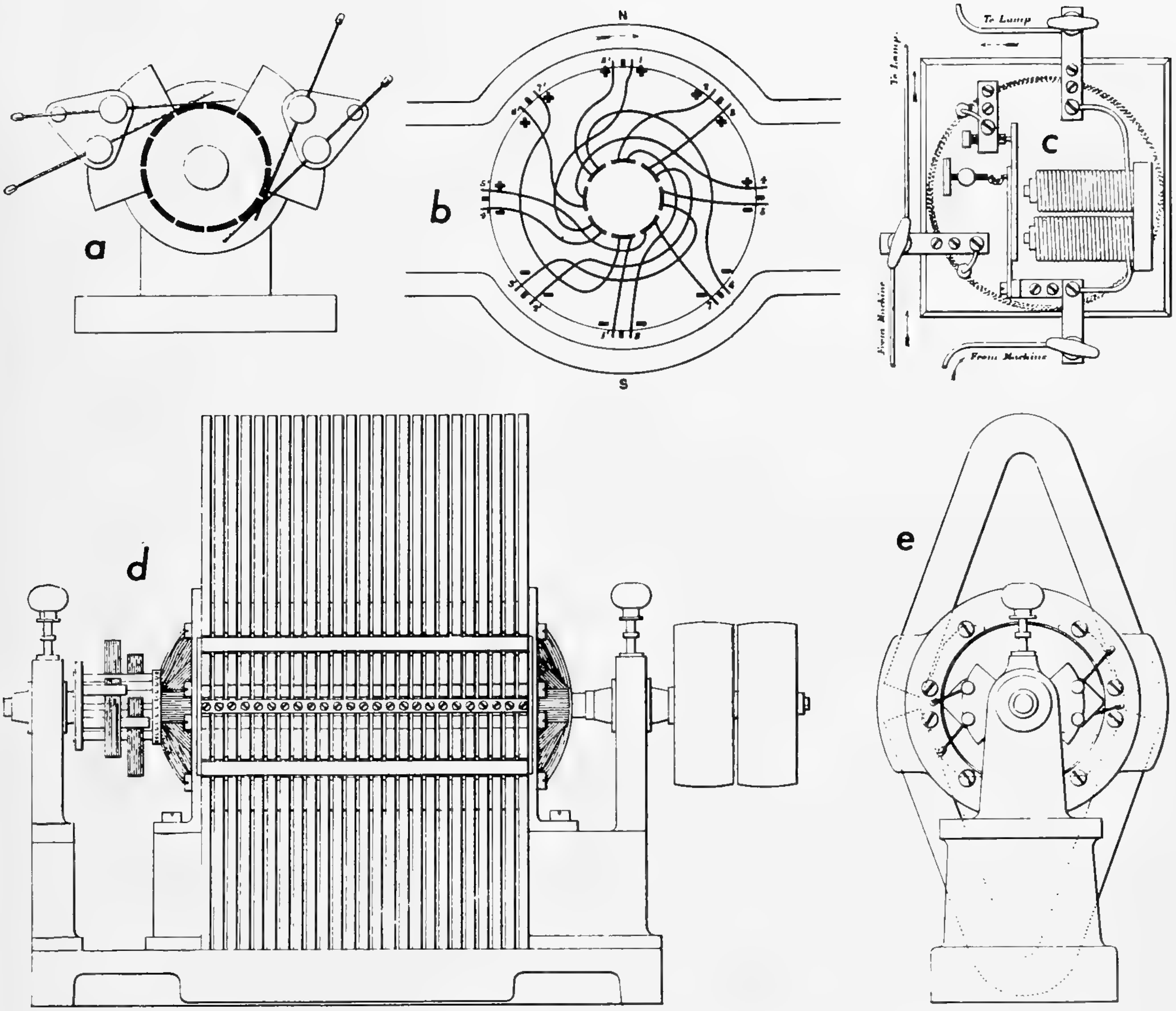

Figure 77.—*a*, Brushes and commutator; *b*, armature connections, and *c*, output regulator for the Siemens and Halske dynamo of 1876; *d*, *e*, views of a Siemens and Halske motor of the same date with a permanent magnet field and drum armature. From R. W. H. P. Higgs and J. R. Brittle, "Some Recent Improvements in Dynamo-Electric Apparatus," *Minutes of the Proceedings of the Institution of Civil Engineers*, 1878, vol. 52, pp. 36–98, pl. 1.

the current form of the arc light and that would all be on the same circuit. This was the problem of the subdivision of the electric light.

The first significant step towards the solution of this problem was made by a Russian military engineer named Paul Jablochkoff.[108] He had retired from the army in order to devote himself to the invention of an electrical light and decided to visit the Philadelphia Centennial Exposition of 1876. However, he tarried in Paris in order to visit Bréguet's electrical shop, where both Gramme dynamos and Serrin regulators were constructed; and he was so fascinated by what he saw that he never finished his journey. Instead, he found employment at Bréguet's

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[108] "Jablochkoff," *La Grande Encyclopédie*, Paris, n.d., vol. 20, p. 1152; *Electrician*, London, 1894, vol. 32, pp. 663–664.

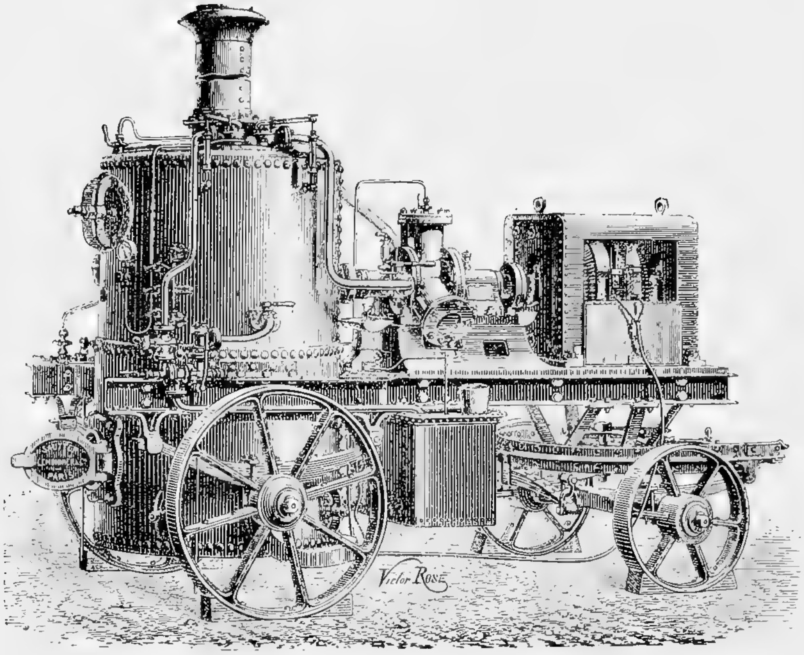
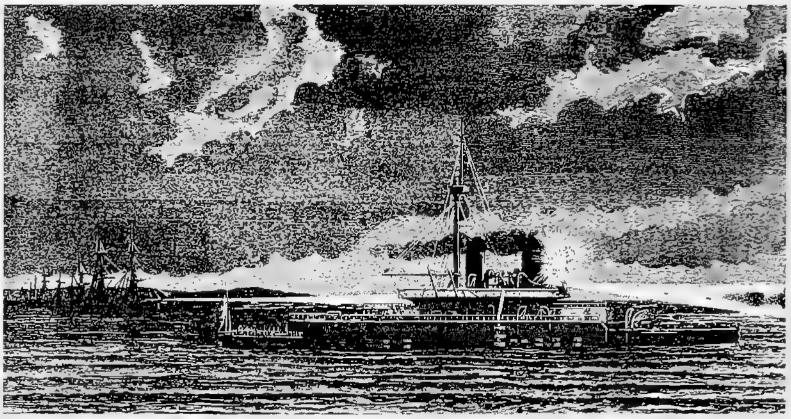


Figure 78.—Mobile arc-light unit, using a Gramme generator. From *Chronique de l'industrie*, 1879, p. 93.

Figure 79.—Arc light on HMS *Thunderer*. From *La Lumière électrique*, October 1882, vol. 7, p. 347.



shop and stayed there for a number of years. After patenting a novel kind of electromagnet, he turned to the electrical lamp, and the innovations he introduced gave a tremendous impetus to the commercial application and exploitation of the dynamo.

Jablochkoff found a means of producing a carbon arc that regulated itself without the use of any mechanism.[109] He based his lamp (called a "candle") on the circumstances that if two carbons are placed side by side and parallel to one another, and so close that an arc could form at the ends, it would continue to burn until the carbons were entirely consumed. An insulating material—first kaolin and then a mixture of barium and calcium sulphates—was used to separate the two electrodes. The role of the spacer, called a "colombin," is not clear; apparently it provided some of the glow, and perhaps it reduced the voltage necessary to maintain the arc. Direct current was first tried, but since the positive electrode in an arc burns twice as fast as the negative, alternating current was used to make both burn at an equal rate. Each "candle" provided a light equal to that from 200 to 500 standard candles, depending on the generator and the particular circuit (fig. 80).

With this device, Jablochkoff solved two of the problems of the subdivision of the electric light—that of placing several lights in the same circuit and that of reducing the intensity of the arc light. Although the "candles" flickered somewhat and only lasted for one or two hours, the light was whiter and brighter than that from gas, and it was not as blinding as that from the ordinary arc light. As used in an onyx globe (fig. 81), it gave a broad and diffused glow that seemed to have been occasionally on the pinkish side. Since there was no mechanism to be constantly fluctuating in the circuit and causing unstable operation of the other lamps, several "candles" could be placed in a single circuit. To further increase the subdivisibility of a circuit of electric "candles," Jablochkoff first tried to use condensers and then

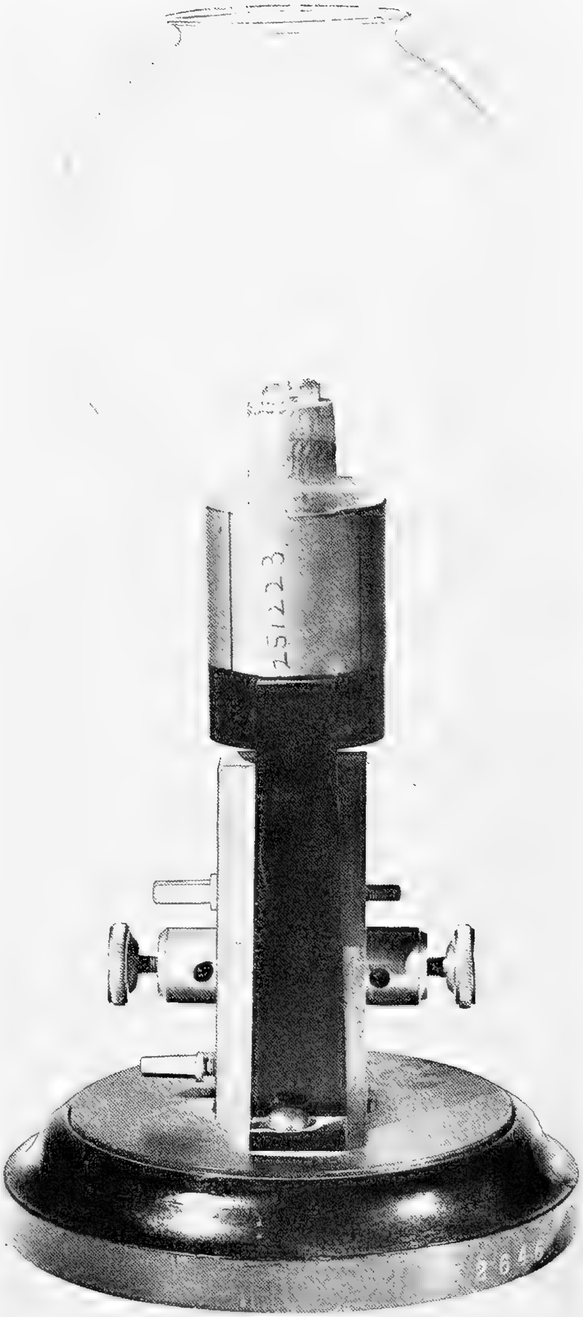


Figure 80.—U.S. Patent Office model of the Jablochkoff candle. (*USNM 252646, Smithsonian photo* 8899–*A*.)

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[109] French patent 112024 (filed March 23, 1876; additions, September 16, October 2, October 23, November 21, 1876, March 31, 1877, March 11, 1879); British patent 3552 (September 11, 1876); L. Denayrouze, "Sur une Nouvelle Lampe électrique imaginée par M. Jablochkoff," *Comptes rendus*, 1876, vol. 83, pp. 813–814; Du Moncel, *op. cit.* (footnote 80), vol. 5, pp. 472–475, 515–518; *Engineering*, 1878, vol. 26, pp. 125–127; William E. Langdon, "On a New Form of Electric Light," *Journal of the Society of Telegraph Engineers*, 1877, vol. 6, pp. 303–319.

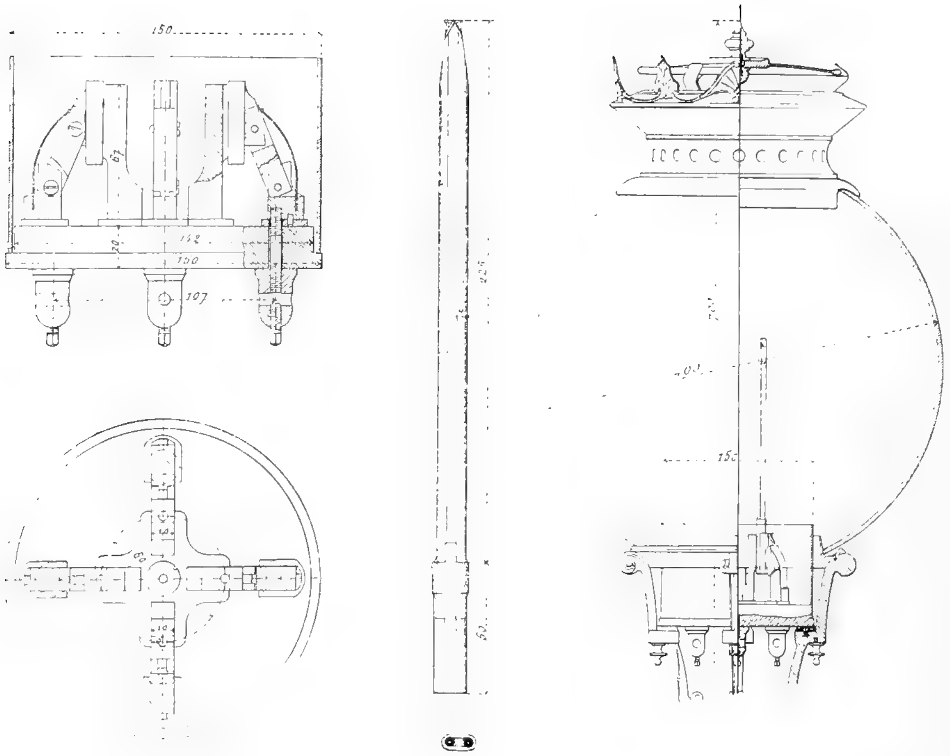

Figure 81.—Drawing of the Jablochkoff candle, candle holder, and onyx globe. As each candle was consumed, another of the four candles in the base was manually switched into position. From *Review industrielle*, June 5, 1878, p. 223.

transformers (fig. 82) in the circuit, but he found no definite advantages.[110] The primaries of the transformers were strung in series in the circuit of the generator and the "candles" were similarly placed in series in the secondaries of the various transformers.

The Jablochkoff "candle" made possible the first electric illumination on a broad commercial scale.

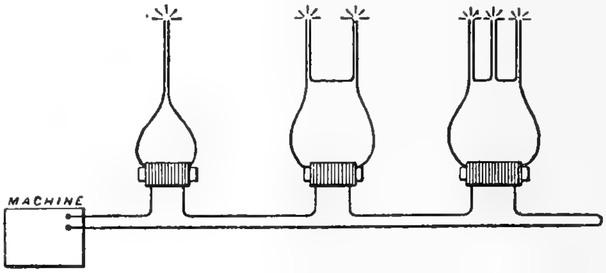

Figure 82.—Circuit diagram showing how Jablochkoff used transformers for the subdivision of his electric lights. From *Engineering*, October 14, 1881, vol. 32, p. 391.

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[110] L. Denayrouze and P. Jablochkoff, "Divisibilité de la lumière électrique," *Comptes rendus*, 1877, vol. 84, pp. 750–752; P. Jablochkoff, "Application des bouteilles de Leyde de grande surface pour distribuer en plusieurs points l'effet du courant d'une source unique d'électricité avec renforcement de cet effet," *Comptes rendus*, 1877, vol. 85, pp. 1098–110; British patent 1996 (May 22, 1877); French patent 120684 (October 11, 1877; addition, October 12, 1878); *Engineering*, 1881, vol. 32, p. 391.

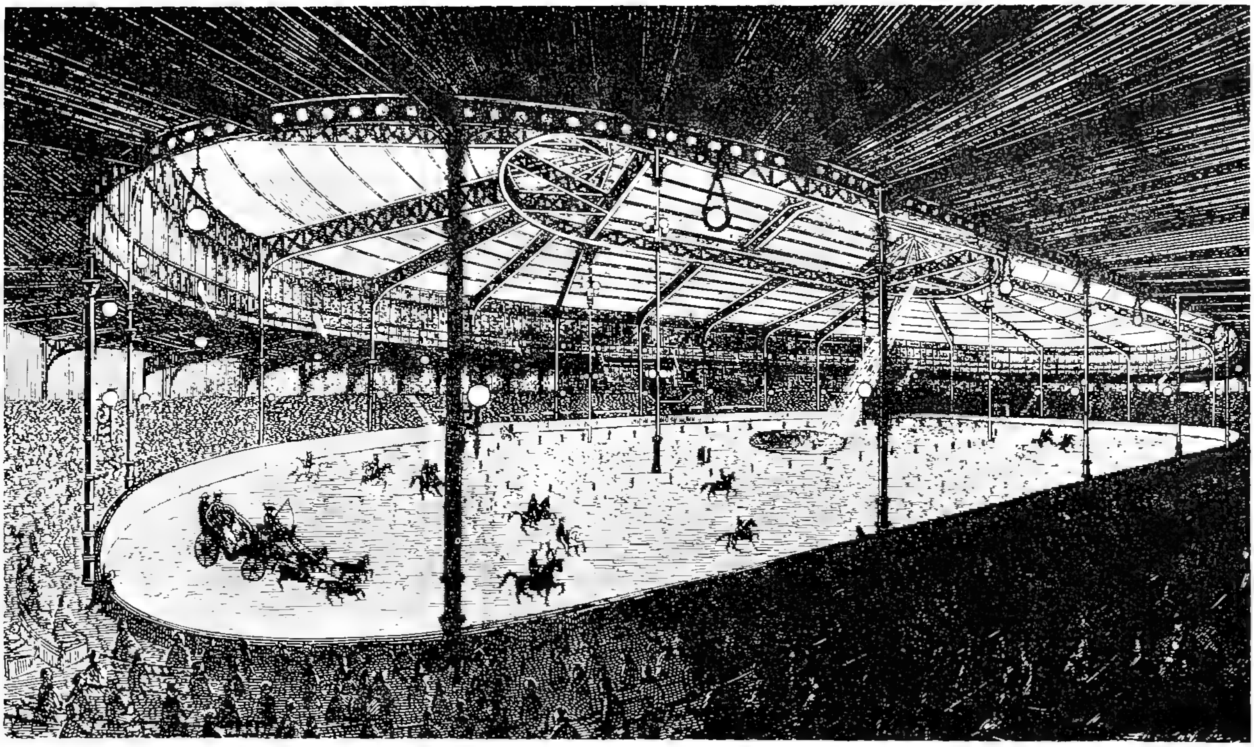


Figure 83.—The interior of the Hippodrome in Paris as lighted by Jablochkoff candles. From E. Alglave and J. Boulard, *The Electric Light*, translated by T. Sloane, New York, 1889, p. 104, fig. 66.

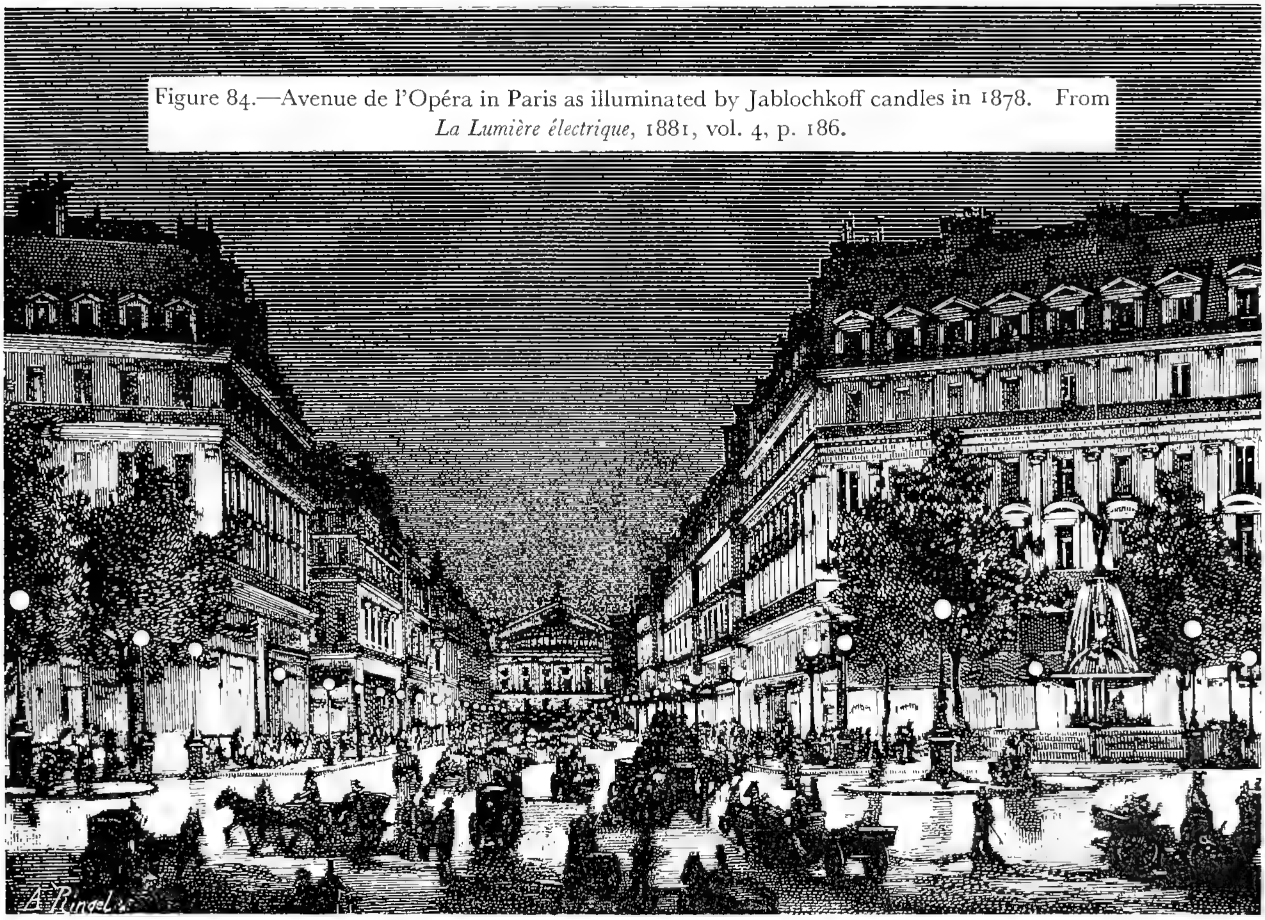


Figure 84.—Avenue de l'Opéra in Paris as illuminated by Jablochkoff candles in 1878. From *La Lumière électrique*, 1881, vol. 4, p. 186.

Fig. 1.

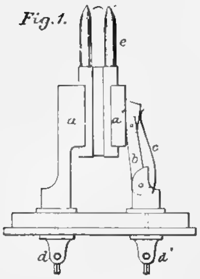


Fig. 2.

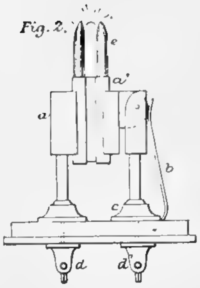
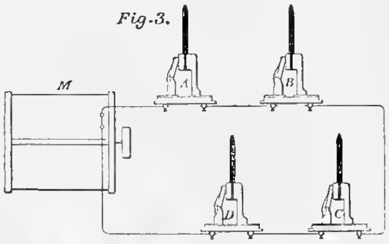


Fig. 3.



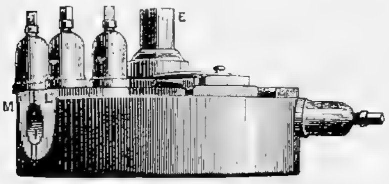


FIG. 6.

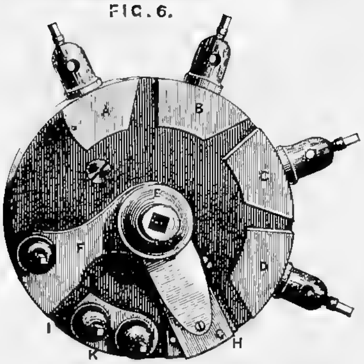


Fig. 7.

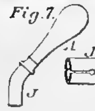
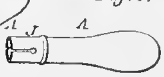


Fig. 8.



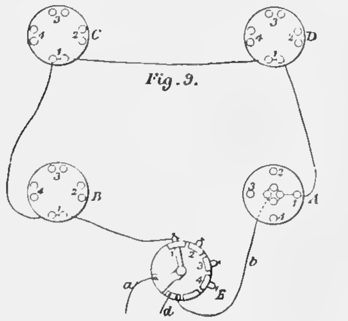

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Fig. 9.
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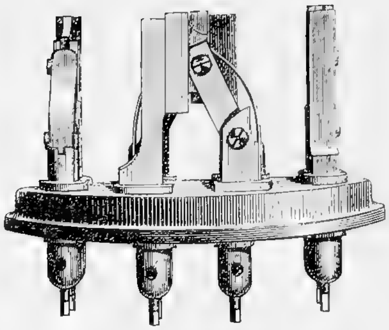
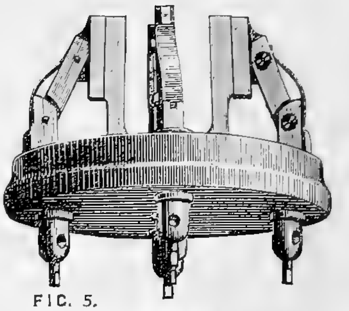


FIG 4



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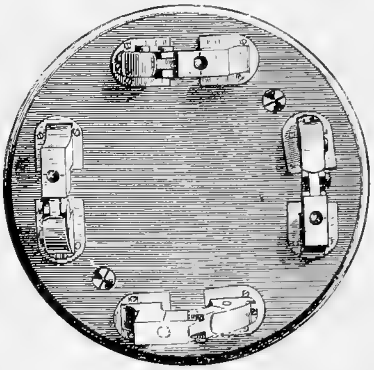


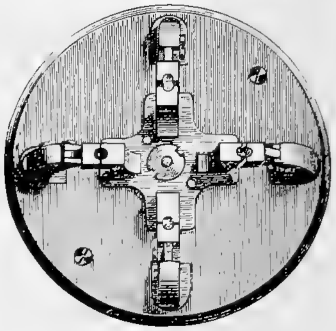
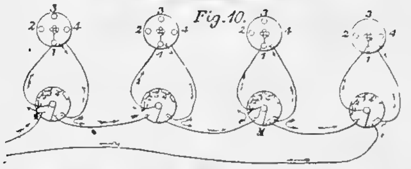
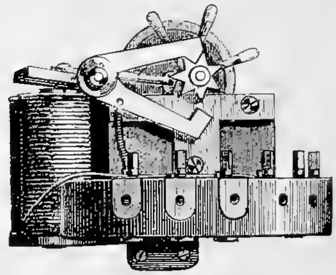


Fig. 10.





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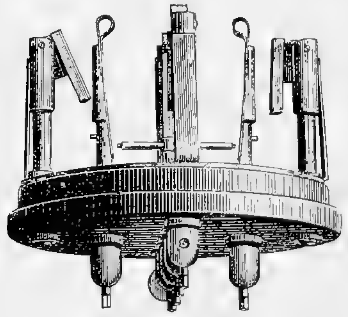
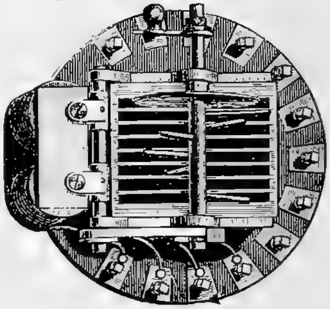
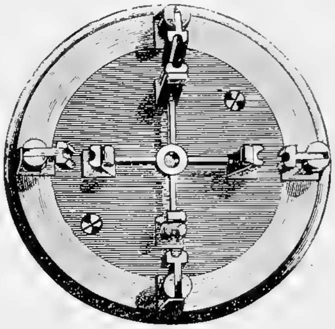


FIG. 11





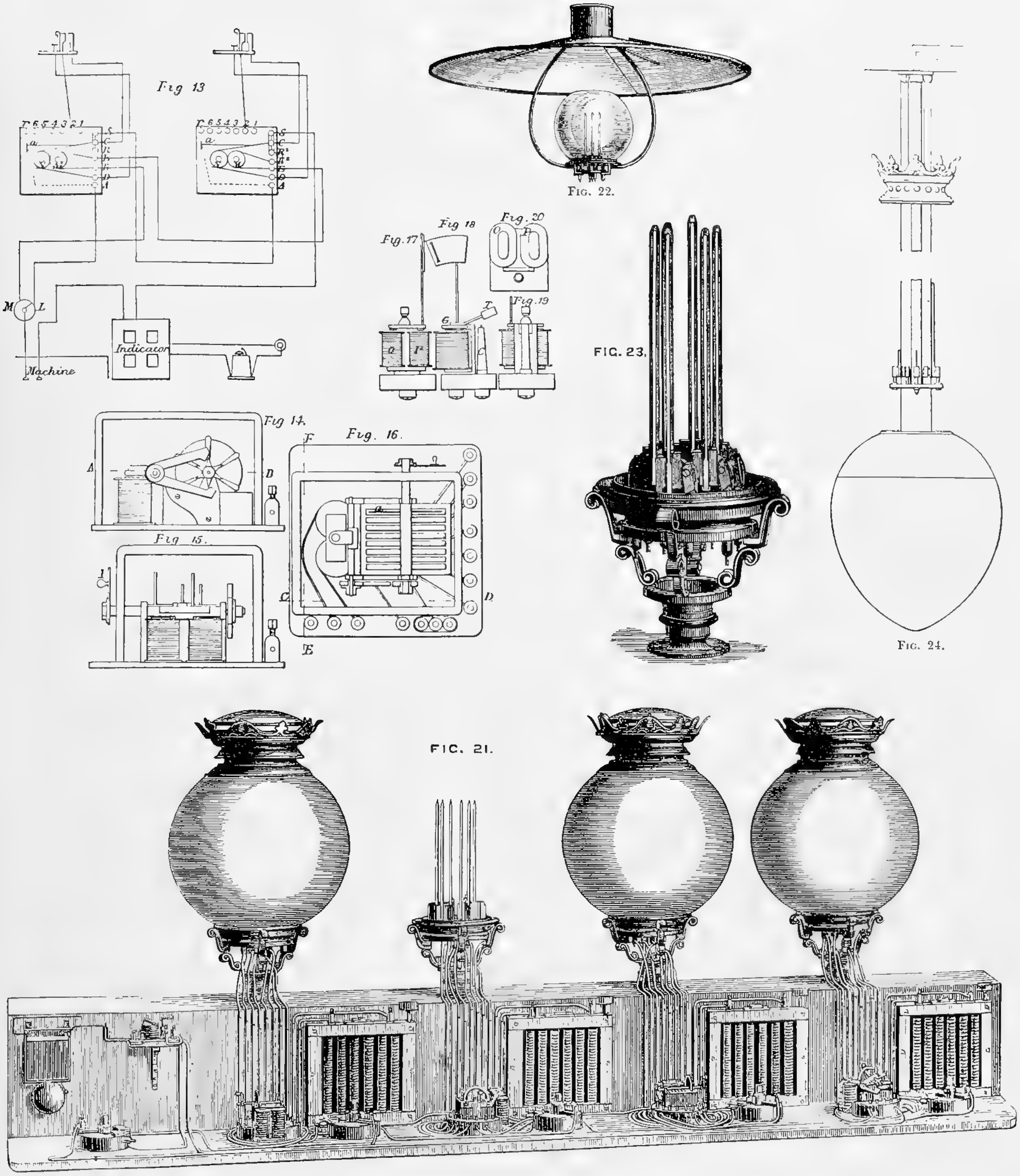


Fig 13
Indicator
Machine
M
L
Fig 14.
A
B
Fig 15.
Fig. 16.
F
C
D
E
Fig. 17
Fig 18
Fig. 20
Fig. 19
Fig. 22.
FIG. 23.
Fig. 24.
FIG. 21.

Figure 85.—The Jablochkoff system of electric lighting as applied in London in 1881. Automatic switches connected another candle into the circuit when one burned out. From *Engineering*, September 23, 1881, vol. 32, pp. 300, 301.

Fig. 1. Coupe ABC.

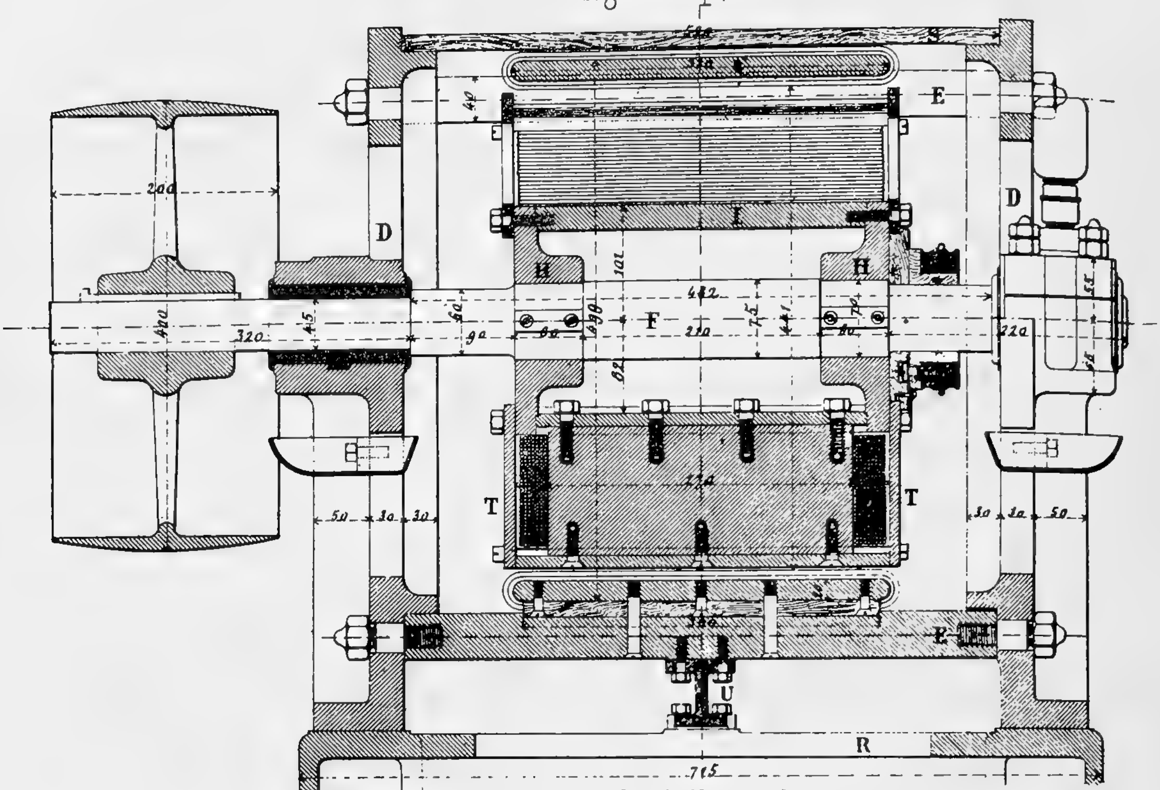
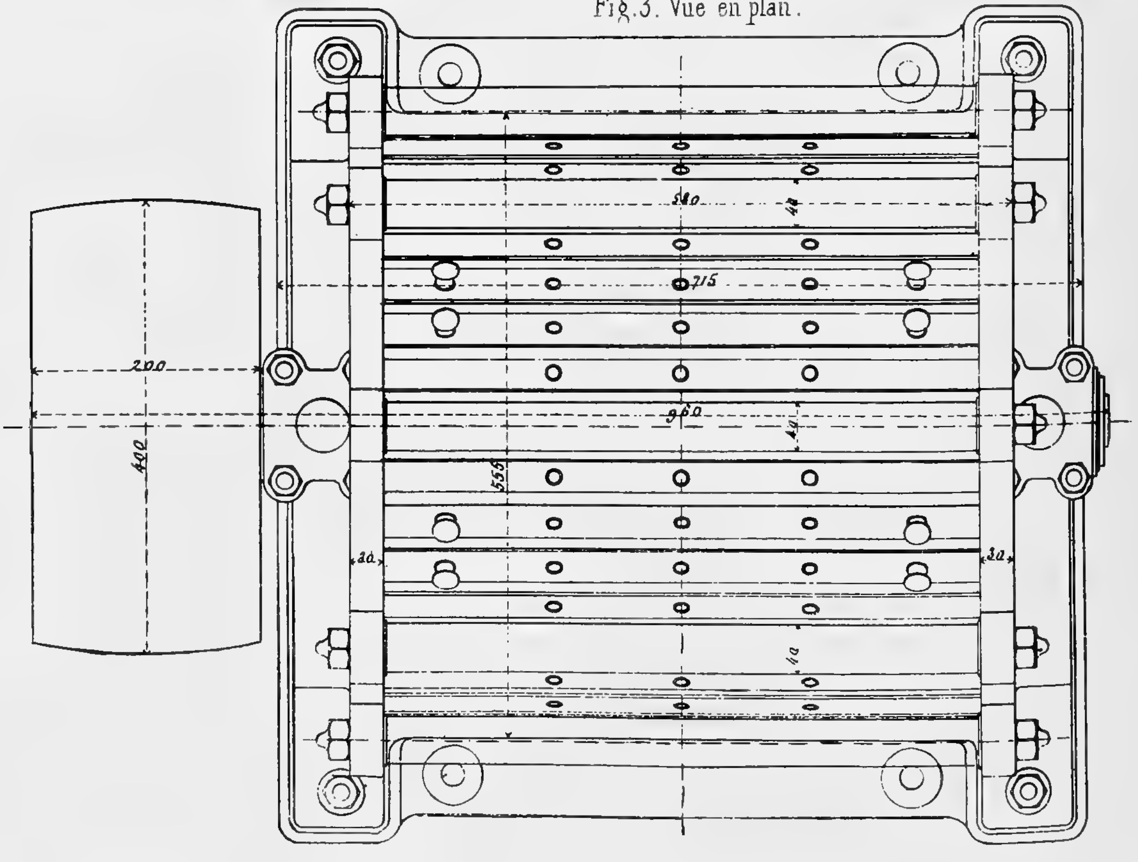

580
330
40
E
D
D
I
H
H
101
482
200
400
320
45
60
90
80
80
F
210
75
141
70
80
220
55
55
82
220
T
T
50
30
30
30
30
50
380
E
E
U
R
715

Fig. 3. Vue en plan.


580
40
715
200
960
400
40
555
30
30
40

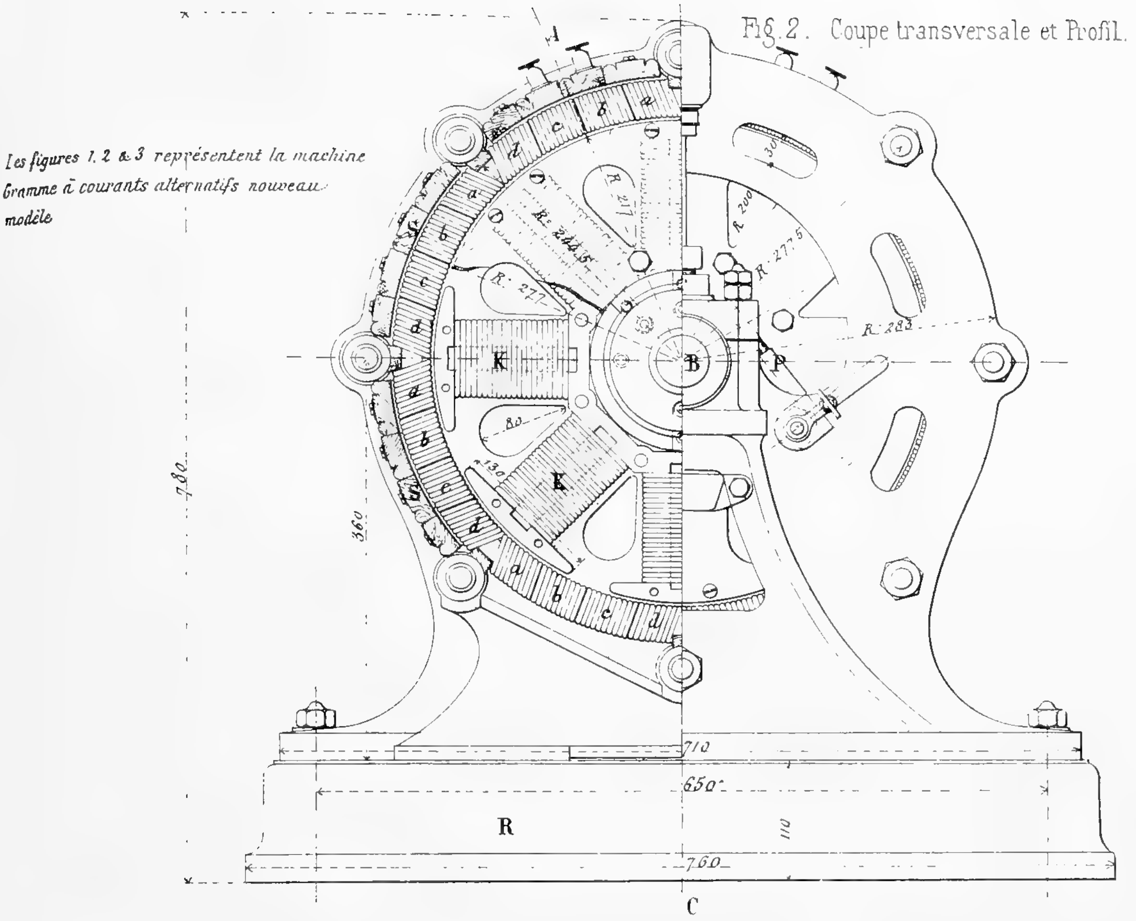


Fig. 2. Coupe transversale et Profil.
Les figures 1, 2 & 3 représentent la machine Gramme à courants alternatifs nouveau modèle
a
b
c
d
S
K
B
P
R
C
R. 277
R. 244.5
R. 200
R. 277.5
R. 283
30
80
130
780
360
710
650
760
110

Figure 86.—*On facing page and above:* Gramme's alternator of 1878 for a 4-circuit Jablochkoff candle system, with four candles per circuit. The current for the rotating field was supplied by a separate *type d'atelier* exciter. From *Revue industrielle*, June 5, 1878, pp. 226–227, pl. 12.

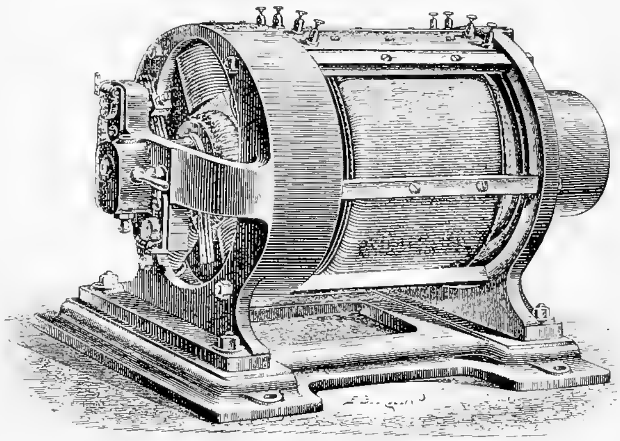
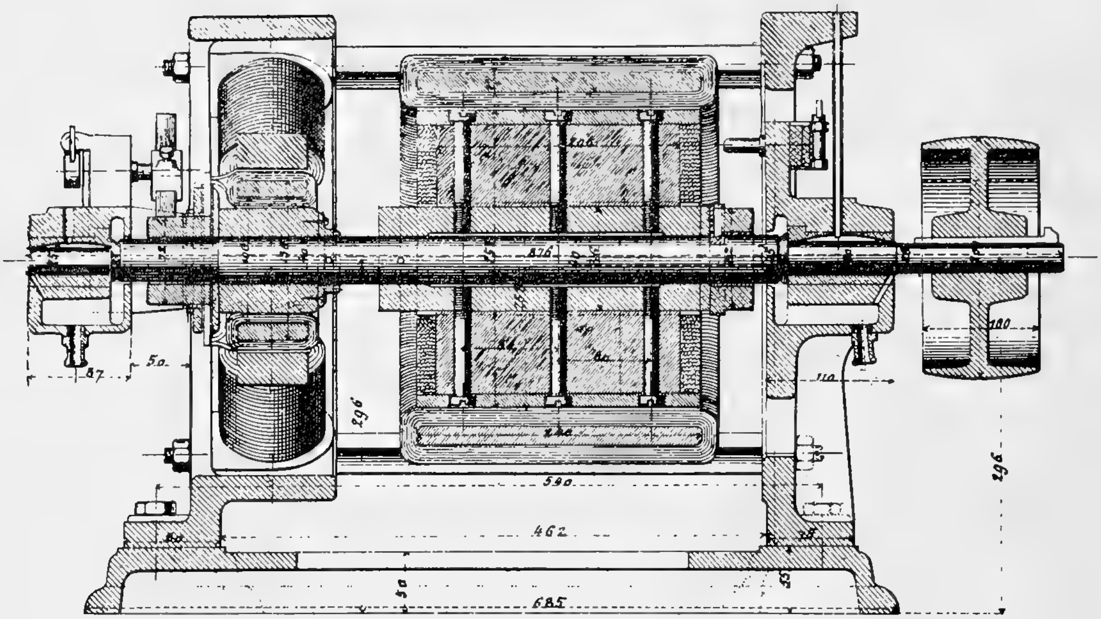
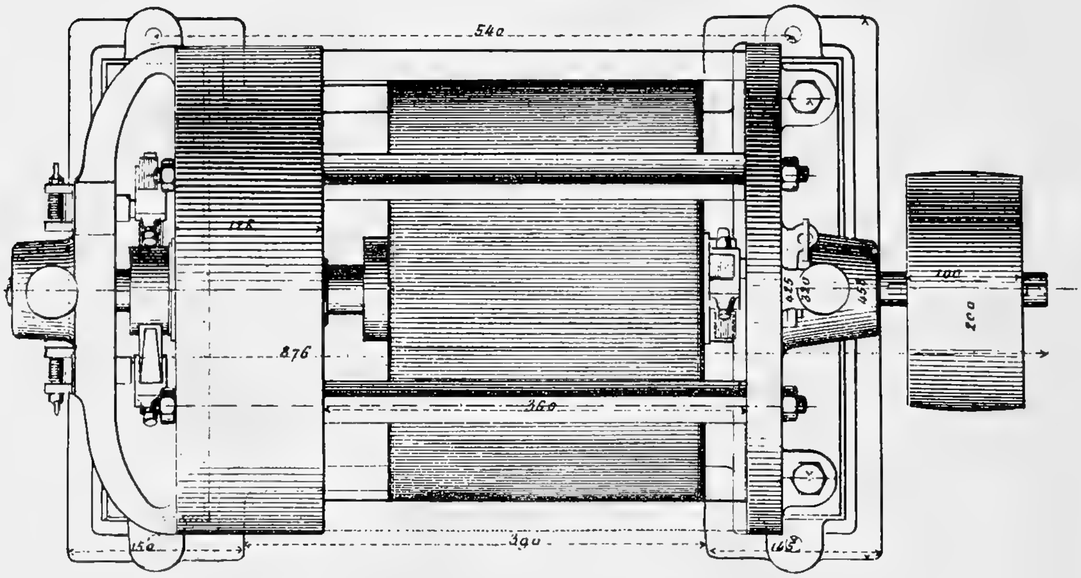


Figure 87.—Gramme's self-excited alternator (1880) for the Jablochkoff candle system. From *Revue industrielle*, February 11, 1880, p. 53.

Coupe longitudinale

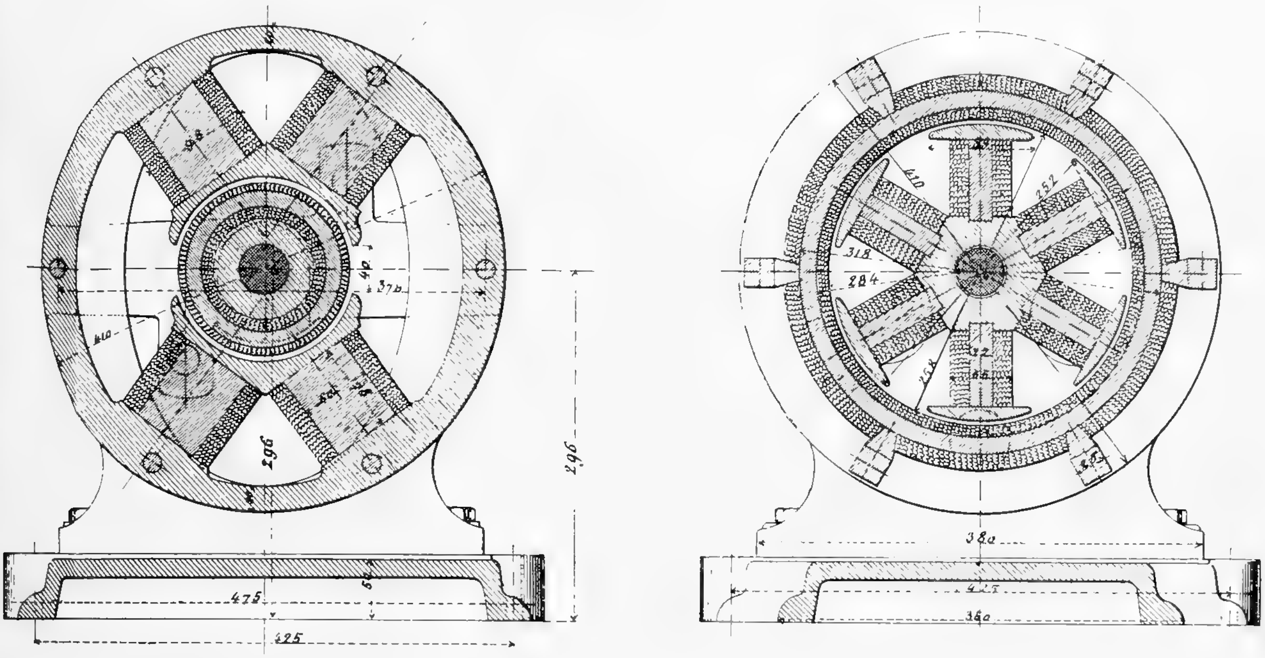

876
87
50
296
100
110
296
540
462
80
685
50

Plan.


540
176
876
360
425
320
450
100
200
150
390
165

Coupe transversale
par la bobine à courant continu.

Coupe transversale
par la bobine à courant alternatif


410
296
475
425
380
318
284
252
32

Vue du côté de l' excitatrice.

Vue du côté de la Poulie

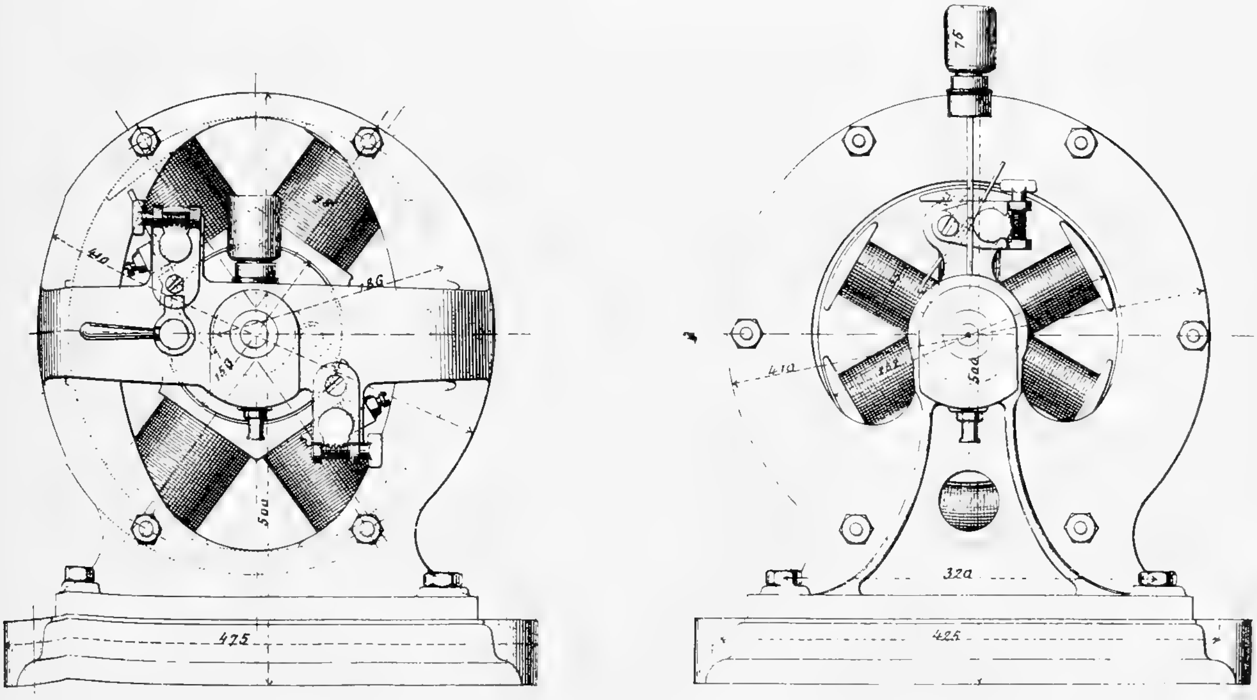

75
410
500
150
86
320
425

Figure 88.—*On facing page and above:* Details of Gramme's self-excited alternator of 1880. From *Revue industrielle*, February 11, 1880, pp. 56–57, pl. 3.

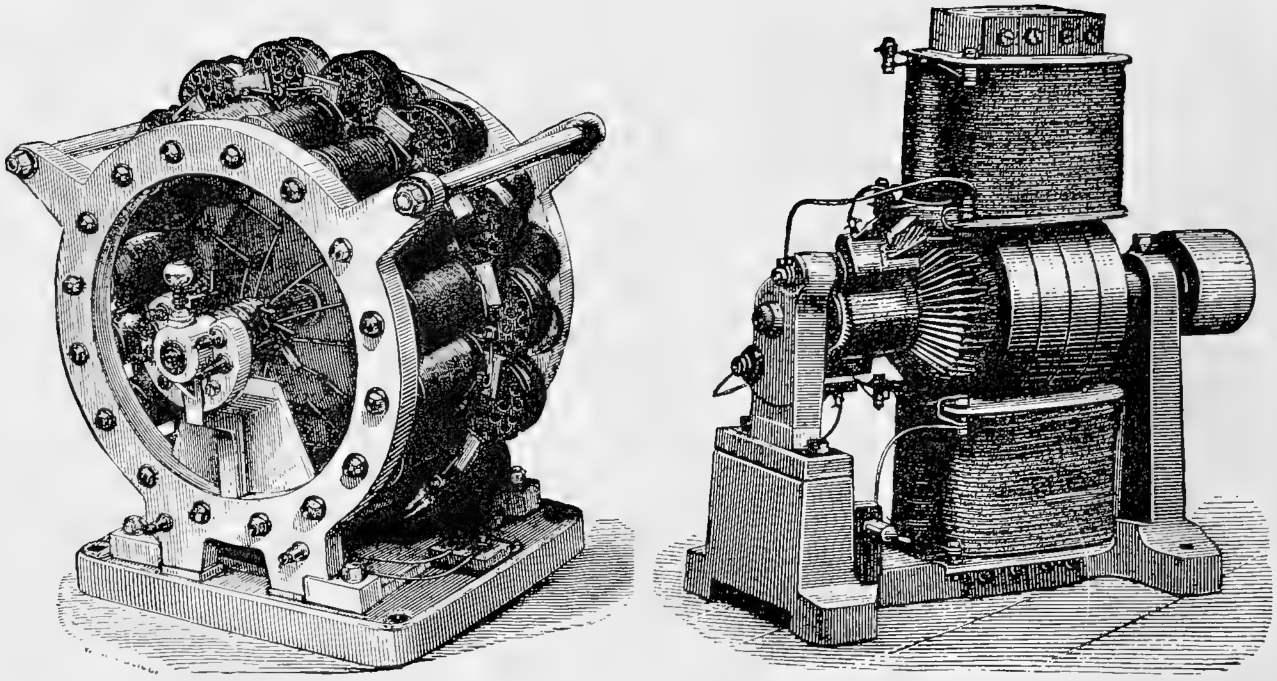


Figure 89.—Siemens' alternator (left), and separate exciter, for use in a Jablochkoff candle system. From J. Dredge, *Electric Illumination*, London, n.d. (about 1882), vol. 1, figs. 272, 273.

In April 1877, 16 of the "candles" were placed in the Grands-Magasins du Louvre in Paris. The Parisian Hippodrome followed a short time later with a system that included both Serrin regulators and Jablochkoff "candles"; however, this system was installed by Hippolyte Fontaine instead of Jablochkoff's Société Générale d'Electricité (fig. 83). Electric illumination moved from the laboratory to the stock market when the Avenue de l'Opéra and the Place de l'Opéra were lighted by 62 of these new devices in May 1878 for the Paris Universal Exhibition of 1878 (fig. 84). The grand total of some 300 "candles" along the boulevards and in public buildings made apparent to all the newest of the wonders of electricity; accordingly, the price of gas stocks dropped 10 percent. In December 1878 the Municipal Council of Paris decided to try the "candles" for public illumination, in competition with gas, for one year.[111]

London imitated the example of Paris a short time later. After trying the Jablochkoff system on an experimental scale at Billingsgate Market, in December 1878 the municipal government installed 20 "candles" along the Thames Embankment and 16 along the Holborn Viaduct; they were placed about 50 yards apart. The system proved to be so satisfactory that, in May 1879, 20 more "candles" were added along the Embankment, and in October of the same year 10 were placed on Waterloo Bridge. By 1880 subdivision of the electric light had proceeded to the point that a single central power station at Charing Cross fed over 75 "candles" in one system that extended 1 mile northeast along the Thames Embankment to Waterloo Bridge and Holborn Viaduct and in another that extended 1 mile southwest to Victoria Station.[112] The mechanical and electrical details of the system were further refined during the following year (fig. 85).

---

[111] *Les Mondes*, 1877, vol. 42, pp. 709–710; 1879, vol. 48, pp. 221–222; *Engineering*, 1877, vol. 23, pp. 366, 384–385; 1878, vol. 26, pp. 24, 479; 1879, vol. 27, pp. 104–105, 415; *La Lumière électrique*, 1880, vol. 2, pp. 229–230, 301–305; 1881, vol. 4, pp. 185–188; *Revue industrielle*, 1877, p. 369; Fontaine, *op. cit.* (footnote 19), pp. 215–216; Defrance, op. cit. (footnote 2).

[112] *Engineering*, 1878, vol. 26, pp. 494; 1880, vol. 29, p. 268; *Revue industrielle*, 1880, vol. 9, p. 148; Berly, "Notes on the Jablochkoff System of Electric Lighting," *Journal of the Society of Telegraph Engineers*, 1880, vol. 9, pp. 135–161.

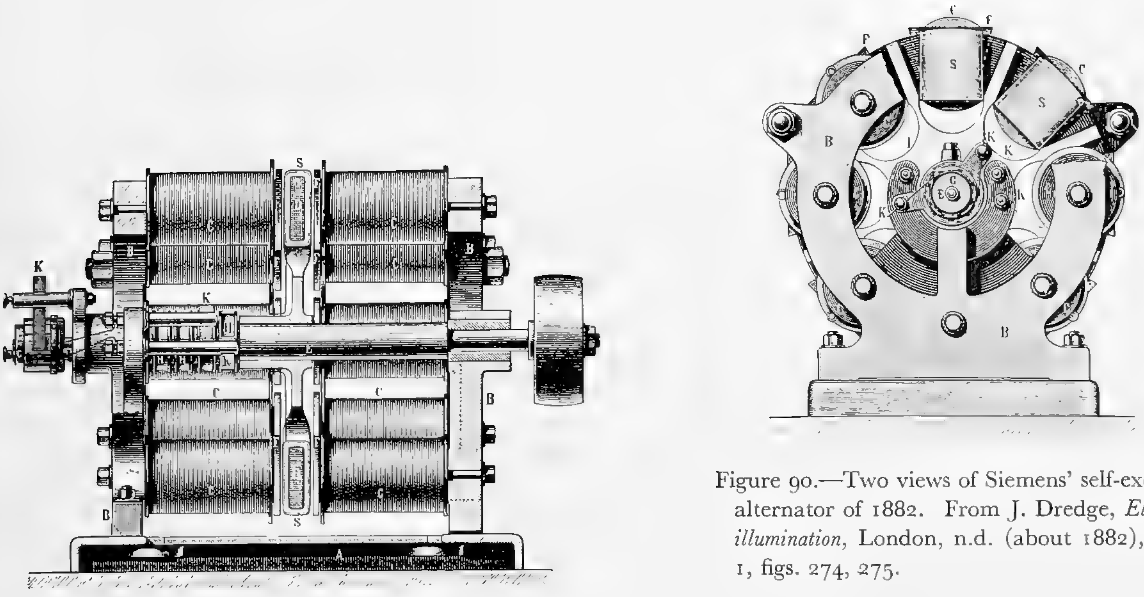


Figure 90.—Two views of Siemens' self-excited alternator of 1882. From J. Dredge, *Electric illumination*, London, n.d. (about 1882), vol. 1, figs. 274, 275.

At first the Alliance machine was used to supply the power, and this allowed the now rather moribund Société l'Alliance to continue its existence. However, it was soon found that the Gramme generators were more efficient.[113] In addition, with his usual ingenuity, in 1878 Gramme devised alternating current generators for 4, 16, and later 32 "candles" (fig. 86).[114] One *type d'atelier* dynamo was used to provide the current for the electromagnet field coils of one or more alternators. These last had a rotating field, with 8 radial poles, and a stationary armature. The coils were grouped on the stator so that a number of circuits (normally with four "candles" per circuit) could be taken off a single alternator. Each "candle" provided about 100 Carcel units, and, as the following tabulation shows, each consumed about 1 hp.:

Candles	*Length/width/ height (cm.)*	*Weight (kg.)*	*R.p.m.*	*Hp.*	*Cost* (£)	*Cost* (*francs*)
16	89 x 86 x 78	650	600	16	400	10, 000
6	70 x 40 x 52	280	700	6	200	5, 000
4	55 x 40 x 48	190	800	4	100	2, 500

Two years later, in 1880, Gramme devised his *machine auto-excitatrice*, which combined both the alternator of 1878 and a 4-pole dynamo within a single frame (figs. 87, 88).[115] Two sizes were manufactured—a small model weighing 280 kg. and requiring 4 hp. to supply 12 "candles," and a large one weighing 470 kg. and requiring 8 hp. to supply 24 "candles." The light from each "candle" was from 20 to 30 Carcel units. Apparently this *machine auto-excitatrice* was not patented.

The Siemens dynamos also were used in the Jablochkoff system to excite the Gramme alternator. However, it was not long before the Siemens firm had designed its own alternator (fig. 89) and had a Paris agent who supplied it in quantity. The construction of the Siemens alternator was essentially that of the Woolrich machine, with electromagnets substituted for the permanent magnets and with a disk armature rotating between two stationary rings of electromagnets.[116] Depending on the size of the machine, there

---

[113] *Les Mondes*, 1877, vol. 42, pp. 346–347; vol. 43, p. 779.

[114] French patent 120649 (October 23, 1877; additions, December 3, 1877, and September 1, 1879); British patent 953 (March 9, 1878); *Revue industrielle*, 1878, vol. 7, pp. 222–224; *Engineering*, 1878, vol. 26, pp. 63–66; 1881, vol. 32, pp. 251–253, 275–277, 299–302, 326–329, 353–355; Fontaine, *op. cit.* (footnote 19), pp. 161–166.

[115] *Revue industrielle*, 1880, vol. 9, pp. 53, 56–57: *La Lumière électrique*, 1880, vol. 2, pp. 88–89; *Engineering*, 1880, vol. 29, p. 136.

[116] German patents 2245 (March 9, 1878) and 3383 (April 3, 1878); French patents 123307 (March 20, 1878) and 12479 (May 27, 1878); British patent 3134 (August 8, 1878); *La Lumière électrique*, 1879, vol. 1, pp. 25–26; *Engineering*, 1879, vol. 27, pp. 181–182.

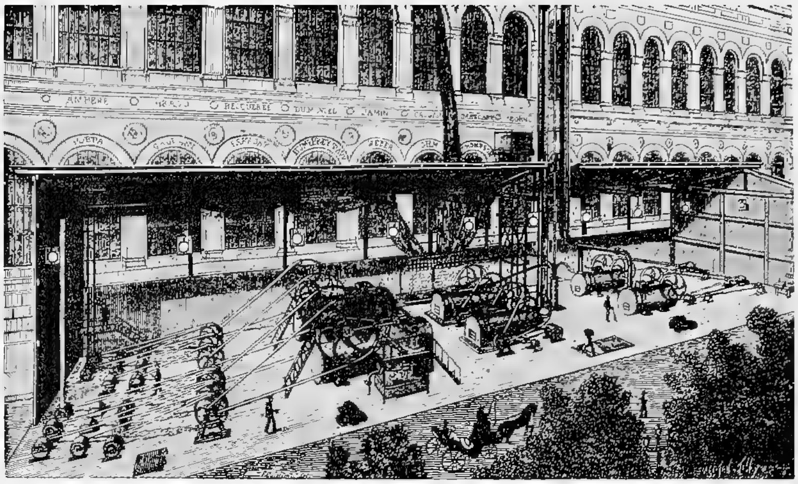


Figure 91.—Central station of Jablochkoff electric light system (1880) for illuminating an exposition of paintings in Paris. From *La Lumière électrique,* June 15, 1880, vol. 2, p. 228.

were 8 or 16 electromagnets in each of the stationary rings and in the disk armature. The alternator was constructed in three sizes—4-, 8-, and 16-light machines that, with their exciters, required, respectively, 4, 7, and 13 hp. The smallest machine was cited as providing a light of 300 candles from each of the four "candles." The Siemens firm also manufactured a self-excited alternator (fig. 90).

For a while it seemed as if the Jablochkoff system might be the solution to the problem of the electric light. During the next few years its application expanded quite rapidly; in addition to its use in cities (figs. 91, 92) it was utilized to light the cabins of ships. But the sudden rise of this new device came to an almost equally as sudden halt as more economic means of subdividing the electric light were developed.

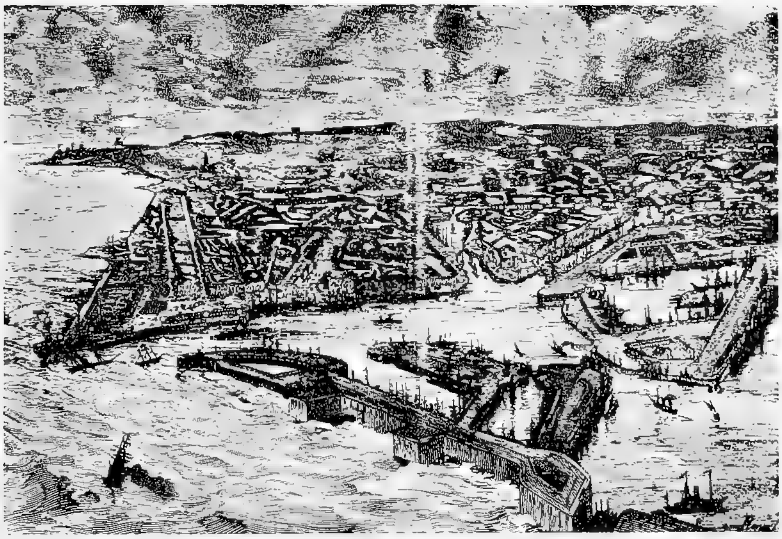


Figure 92.—The harbor at Le Havre as illuminated by Jablochkoff candles. From *La Lumière électrique*, July 30, 1881, vol. 4, p. 135.

Nevertheless, the Jablochkoff system showed that a single central station could provide electrical power at a number of different locations. Also, some of the most essential problems of distribution were tackled; even the use of transformers was attempted. Most important, the Jablochkoff system showed that the subdivision of the electric light was possible, and it attracted the attention of financiers to this new form of investment. The system soon was replaced by others that were electrically and economically more feasible, but, in the meantime, another phase of electrical technology had been added to the growing list that already included electrochemistry and electrical communications.

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