seen. The destructive tornado of May 27, which tore asunder and scattered the massive masonry of the approaches to this bridge, failed to disturb the equilibrium of the steel arches themselves; and no finer tribute was ever paid to the skill of the bridge engineer than is offered in the photographic reproduction which we present on another page.

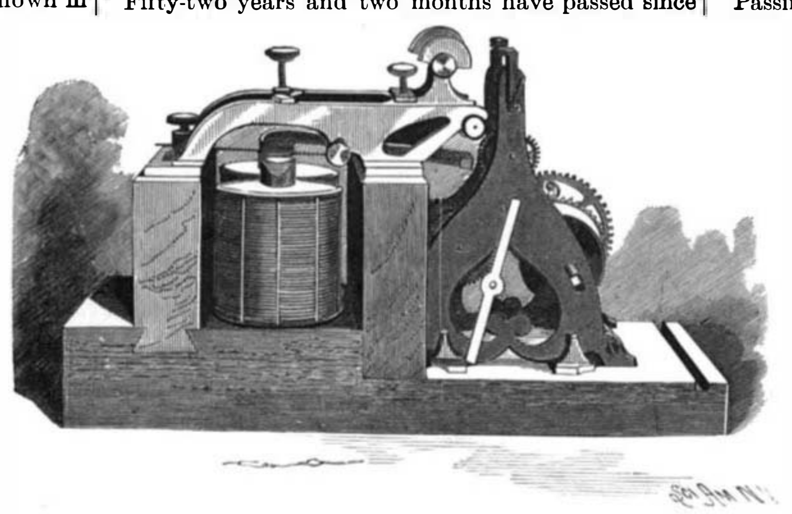
The scientific methods of bridge design and construction adopted by Captain Eads have been elaborated by subsequent engineers, until bridge designing is to-day perhaps the most exact branch of the engineering profession. The calculation of the strains in steel trusses is now a matter of mathematical certainty and precision. The various erratic forms of trusses have fallen into disuse, and a standard type of great excellence has survived, one of the latest examples of which is shown in the engraving on another page of the Merchants' Railroad Bridge at St. Louis, built in 1890 by the Union Bridge Company, of New York. The Merchants' bridge comprises three main spans, 517 feet 6 inches long, and six deck spans of 125 feet. The trusses are built entirely of steel and are pin connected, the tension members being steel eye bars, and the compression members consisting of built-up lattice posts and chords. The floor beams and stringers are plate steel girders, the latter being riveted at their ends to the bottom of the posts and vertical ties.

The distinctive features of this system of bridge construction are the concentration of material in large members, the great width of panel and height of truss, and the method of connecting the members at each panel point by means of a large, carefully turned and fitted steel pin. As compared with the European practice of riveting, the American practice conduces to greater accuracy of design and construction, and greater rapidity of erection. The Merchants' bridge, which contains 11,000,000 pounds of steel, and whose granite piers extend 70 feet below the water, was commenced and completed within thirteen months.

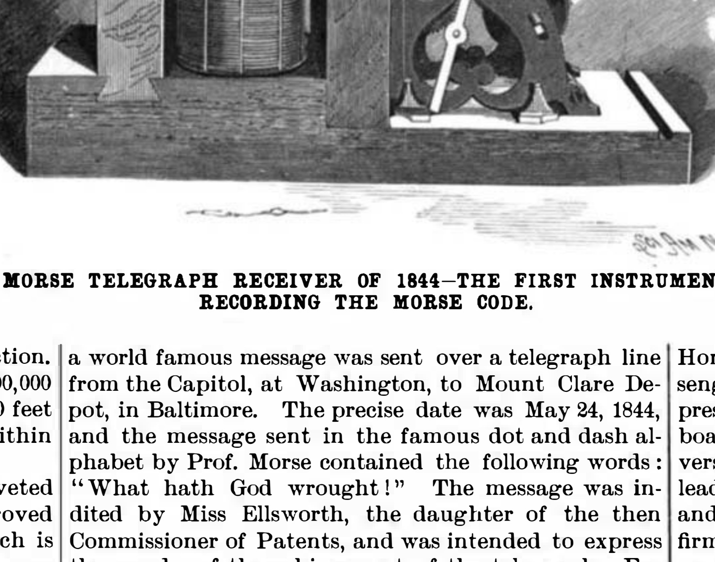
The superiority of the pin-connected over the riveted system of bridge construction has been clearly proved in the erection of cantilever bridges, a type which is now extensively used by American and European builders, and of which the great Forth bridge of Sir Benjamin Baker, with its two 1,710 foot spans, is the most monumental example. In its simpler forms, the cantilever is exceedingly ancient. There are bridges in China which are hoary with age whose construction is based upon this principle. The most valuable feature of the cantilever, as compared with the truss bridge, is the facility with which it lends itself to the crossing of rivers and ravines, where the depth of water or other natural features render it impossible to erect any temporary falsework. Perhaps the most notable early use of the cantilever system of erection in America was seen in the building of the above mentioned Eads bridge at St. Louis, where equilibrating portions of the steel arches were built out simultaneously on each side of the piers and tied back to them with steel ropes. Two of the best known cantilever bridges in America are the Niagara River bridge and the Poughkeepsie bridge across the Hudson River. The Niagara bridge has a clear span between towers of 470 feet, with an intermediate truss 120 feet long. Poughkeepsie bridge has three cantilever spans of 548 feet and two connecting spans of 525 feet each. The latter were erected by the aid of falsework, and the cantilevers were then built out in the usual manner. The bridge is designed to withstand a wind pressure of thirty pounds per square foot of surface, and to carry a uniform train load of 3,000 pounds per foot on each track, preceded by two 85 ton locomotives.

No treatise on American bridge building, however brief it may be, can fail to make mention of the development of the wire suspension bridge. Among many other notable bridges of this type are the Niagara suspension bridge, of 821 feet span, the Covington and Cincinnati bridge, of 1,057 feet span, and the Allegheny bridge, with its two spans of 344 feet, all of which were designed by that gifted engineer, the late John A. Roebling, who subsequently raised an enduring monument to his genius in the design and erection of the great East River bridge, uniting the cities of New York and Brooklyn.

This noble structure is too familiar to call for more than a recapitulation of its leading features. The main span is 1,595½ feet long, and the total length, with the approaches, is 3,455 feet. The foundations for the towers were carried down 78 feet below high water by the pneumatic process, and the towers themselves extend 272 feet above high water, making a total height, from foundation to capstone, of 350 feet. The four cables, 15 inches in diameter, are of steel wires laid parallel and wrapped. The floor of the bridge is stiffened with four steel trusses, and carries two carriageways, two standard railway tracks and one footway.



MORSE TELEGRAPH RECEIVER OF 1844—THE FIRST INSTRUMENT RECORDING THE MORSE CODE.



MORSE FIRST MODEL—PENDULUM INSTRUMENT OF 1837, SHOWING THE RECORDING RECEIVER (1), PORTRULE (2), TYPE (3), AND EXAMPLE OF CHARACTERS PRODUCED (4 and 5).

The trains are operated by a steel cable, and they carry an immense traffic, the total in 1894 amounting to 43,000,000.

Great as are the proportions of this bridge, it is likely, before long, to be surpassed by the proposed railroad bridge across the Hudson River, at New York, which is to have a main span of 3,254 feet, carried on twelve steel wire cables, 23 inches in diameter. The suspension towers, which will be built of steel plates and angles, will reach to a height of 587 feet above the water. It is not too much to say that this bridge, which is to carry six railroad tracks, side by side, will be the noblest constructive feat of any age or clime.

THE TELEGRAPH.

Fifty-two years and two months have passed since a world famous message was sent over a telegraph line from the Capitol, at Washington, to Mount Clare Depot, in Baltimore. The precise date was May 24, 1844, and the message sent in the famous dot and dash alphabet by Prof. Morse contained the following words: "What hath God wrought!" The message was indited by Miss Ellsworth, the daughter of the then Commissioner of Patents, and was intended to express the wonder of the achievement of the telegraph. For this edition of the SCIENTIFIC AMERICAN, marking, as it does, fifty years of the invention and progress of the scientific world, no more appropriate motto could be chosen, for it seems as if the last fifty years definitely showed man's powers and proved adequate to measure his ability. For the first suggestions of the telegraph we can go far back to the days of Otto van Guericke, whose experiments of transmitting through a conductor an ell in length an electric disturbance from his frictional machine with its globe of sulphur excited by rubbing against the hand is well known.

Coming down later, however, we find attempts directly made in the line of telegraphy. In 1727, Stephen Gray, of the Charter House, London, transmitted electrification through a wire 700 feet, suspended in the air by silk threads. Other experiments of the same sort were made by different investigators. Twenty years later a wire stretched across the Thames was used, and the length gradually increased until we find the same investigator using wire 10,600 feet long in his experiments, and a year later Benjamin Franklin experimented with a wire stretched across the Schuylkill River.

A letter in the Scot's Magazine in 1753, signed by C. M., suggests an electric telegram operated by a frictional electrical machine; and in 1774, at Geneva, Lesage erected a telegraph line of 24 insulated wires, each corresponding to a letter of the alphabet. Many other attempts were made and signals were transmitted by static excitation produced by frictional machines. At the beginning of the present century the voltaic battery was invented. The investigators had at once an instrumentality for maintaining a current through a wire, by which the decomposition of water could be brought about, magnets attracted and other phenomena produced, and, in 1808, the Munich Academy of Science received from Sommering a communication describing a telegraph containing thirty-five wires, one for each letter of the alphabet and one for each number. At the transmitting end arrangements were provided for passing currents through any one of the wires. At the receiving end the electros were immersed in acid, and, completing the circuit, caused the evolution of bubbles of hydrogen. Each tube corresponded to a letter or a number.

Passing by many other attempts, we find, in 1839, the Wheatstone telegraph, fairly effectual, producing its signal by means of what are practically galvanometer needles. A bell alarm was used to call the operator. To produce a powerful enough sound, Wheatstone used a relay circuit, the first one in the history of the art. Henry, in 1832, had, as one result of his experiments in electricity, used the electric magnet in a signaling telegraph, and for him is claimed the glory of being the inventor of the first electro-magnetic telegraph.

Samuel F. B. Morse was born in Charlestown, Mass., on the 27th of April, 1791, but a little over a mile from Franklin's birthplace. He was educated as an artist, and won high triumphs as such, but was marked as a lover of science from his earliest days. His life was subject to more than the usual vicissitudes of an artist's existence. After traveling extensively in Europe and studying there, we find him sailing on the packet ship Sully, for the harbor of New York, in 1832. Philip Hone, in his interesting diary, states that among the passengers on his ship was S. F. B. Morse, the artist and president of the National Academy of Design. On board the ship Morse had his interest excited by a conversation in which Dr. Charles T. Jackson was the leader, who spoke of some of the wonders of electricity and of the electrical magnet. This seems to have fixed firmly in Morse's mind the idea that an electric telegraph could be constructed with the electric magnet as a basis. It engrossed his mind throughout the voyage, and during the six weeks which it lasted he jotted down in his note book different sketches of a proposed system of electrical telegraphy. He practiced his art and experimented with the telegraph, the latter, during the next few years, gradually wooing him from his brush. Prof. Daniel, of London, in 1835 invented the constant current battery, which proved a powerful adjunct to Morse's work. He was confronted at once with the difficulty that the current became enfeebled on too long a line, and used the relay circuit to overcome this trouble. In 1837 he explained his invention to Prof. Leonard D. Gale, of the University of the City of New York, who assisted him by his scientific counsel, and in the same year he interested in it Alfred Vail, a son of Judge Stephen Vail, proprietor of the Speedwell Iron Works, Morristown, N. J. An agreement was entered into between them, Vail supplying the money. The American patent was obtained on October 3, 1837, and Vail in secret quarters at the iron factory worked upon the invention.

Morse's original telegraph provided a pendulum carrying a pencil or marking device in constant contact with a strip of paper to be drawn beneath the point by machinery. As long as inactive, this would make a straight line upon the paper. The pendulum carried also an armature, and an electric magnet was placed near the armature. A current passed through the magnet would draw the pendulum to one side. On being released the pendulum would return, and in this way any amount of zigzag marks could be made on the paper as it traveled with the pencil constantly pressing upon it. Vail made some changes in the device and substituted for the pendulum and marking pencil the familiar lever with pencil of the more modern type of Morse machine, and substituted for the zigzag line the dot and dash alphabet.

In 1839 Morse began the hardest period of his life. He was dependent for his living upon what he could earn as a professor of art. At one time he went twenty-four hours without food. Toward the close of 1841, he writes that he has not a cent in the world, but affirms that he will not run in debt. In the next year he submerged in the New York Harbor between Castle Garden and Governor's Island a wire which he had insulated and sent signals through it. The experiments were repeated at Washington in a canal, in December of the same year, and Morse, in describing his experiments in 1844, announced his belief that signals could and would be sent across the Atlantic Ocean by electromagnetic telegraph. Sick, and tired at heart, agitating for an appropriation from Congress to test his invention, Morse found himself in December, 1842, with his personal funds reduced to 37 cents and feeling ready to abandon the whole subject indefinitely. Aid from the government was at hand, however, and a bill recommending the appropriation of $30,000 in aid of the telegraph was passed by Congress.

Soon after this work was begun on a line between Baltimore and Washington, and among those concerned in its erection was Ezra Cornell, the founder of the Cornell University. An attempt was made to lay the wire underground, and after an expenditure of nearly all the appropriation, this plan was abandoned and an aerial line was started. In seven weeks the work was completed, and the famous message was sent. It was written upon a strip of paper with an embossing point which simply indented the paper with dots and dashes.

Morse had conceived the idea of the relay circuit and had used in the early telegraphs a relay either as an extension of the line or as a local circuit. His great idea was to produce marks making a record of every message sent, and this idea seems to have been at the base of his work. One of his troubles consisted in accurately opening and closing the circuit in order to produce his alphabet. He used metallic type for the purpose with indented faces so shaped as to open and close the circuit at proper times and for proper periods, for the production of the desired markings. Each letter constituted a separate type, which was mounted on a portrule. When this was filled with type representing the message, it was drawn under the contact point. Then, as a simplification of this, two contact points close together were used, between which a wedge was thrust by hand, so as to open and close the circuit. Again, a keyboard was devised with a separate key like a piano, for each letter, but eventually, about 1844, the plain key, such as used to-day, was adopted. After the sending of the famous message in 1844, on April 1, 1845, the line between Baltimore and Washington was opened for public business under the auspices of the Post Office. One cent for every four characters was charged, and during the first four days one cent was received. After a week the receipts had risen to one dollar. Telegraph lines were slowly put up, but in 1846 the system was still experimental. In 1845 New York and Philadelphia were connected, in 1846 Philadelphia and Baltimore were connected. The government had rejected the purchasing of the Morse invention, so everything had to be done by private enterprise. The first ten years following 1846 were devoted to the exploitation of the new invention, and gradually more and more lines were added until, in 1856, what has been described as a straggling web of lines under the control of thirty or forty rival companies, working different apparatus under different patents, covered the more populous area of the country. Dividends were not paid except by one or two of the companies, and the prospects were anything but bright.

During these ten years inventors had not been idle. Morse's system required but little; the relay, the hand key and the alphabet and mechanism for reproducing the alphabet were all in existence in 1846, and since then little has been done with the Morse system proper in the way of addition. In the way of suppression the most important thing of all has been done. Various marking devices had been tried — pencil, embossing point, pen and inking wheel. Morse's apparatus was adapted for any of these devices, but after a while the clerks and attendants on instruments learned to read them by the sound made by the marking lever, and, in spite of threats of instant dismissal, they persisted in doing so when not watched. Morse was violently opposed to it, naturally regarding the recording device as the very soul of his instrument. Vail, who throughout figures as the entirely disinterested, self-sacrificing coadjutor of Morse, and who by many is considered as much the inventor of the Morse system as Morse himself, was the first to yield and devise, by simple suppression of parts, the well known sounder, converting the Morse telegraph into an acoustic one.

Other inventors took the subject in hand, all basing their work for the most part on the production of a record. Bain used chemical decomposition to produce a stain from a piece of paper, which, running in dots and dashes, would convey a message. To produce the dots and dashes he used a long strip of paper, previously perforated, which was drawn between two contact points. A short perforation produced a stain upon a corresponding strip of paper, giving a dot, while a long perforation produced a dash. Over and over again these devices have been applied in the most highly developed rapid transmission apparatus of the present day. Royal House devoted his energies to the development of a printing telegraph, but was estopped by Morse from the use of a relay. He performed the heavy work of his printing apparatus by pneumatic power, which was simply controlled by the telegraph line, and most curiously, in his attempt to produce a sensitive sounder, he described in one of his patents, long antedating Bell's invention, what is to all intents and purposes a Bell telephone, only he never imagined for a moment that it could be made to speak, and the microphone was still lacking to make it a practical invention.

We have seen that the early Baltimore and Washington line had Ezra Cornell as one of its constructors. In 1856 the amalgamation of the many companies then in existence was proposed and carried out through the agency of Hiram Sibley, the founder of the Sibley School of Science at Cornell University. Thus we find this great university intimately connected with the early days of the telegraph. The scheme was termed a crazy one; it was said to be like collecting all the paupers in the State and arranging them into a union so as to make rich men of them; but it was done.

The records of the business of the Western Union, originally so named because it was intended to be a union of Western telegraph companies, have been tabulated since 1867. It had, in that year, 46,270 miles of poles and cables and 85,291 miles of wire were in use; and 5,879,282 messages were transmitted. The receipts were $6,568,925.36. Its profits were $2,624,919.73. In 1895, with 189,714 miles of poles and cables, and 802,651 miles of wire, with 58,307,315 messages sent, receipts of $22,218,019.18 were shown, with a profit of $6,141,389.21. Since 1868 the average tolls per message had fallen from $1.047 to $0.307 per message. The Western Union represents about seven-eighths of the business of the United States, and by its wires, cables and connections any part of the world can be reached. Next to it in importance comes the other great American company—the Postal Telegraph. This and the Western Union do almost all the telegraphic business of the United States.

It would be too great a task to attempt to catalogue, much less describe, the many inventions in telegraphy. The genius of Edison, Delaney, Stearns and others has made it possible to send a number of messages simultaneously in both directions on the same wire. The British Postmaster-General states in a recent report that on a line on which in 1870 the highest speed by Wheatstone automatic was 60 to 80 words a minute, 600 words a minute is now possible. The old Bain principle of electric decomposition and the use of a perforated ribbon drawn between contact points to produce the dot and dash making contacts have reappeared in various instruments. Even the old Morse pendulum, giving its zigzag line, is the prototype of the siphon recorder used in ocean telegraphy.

Construction is receiving more and more attention. The Western Union Company are putting in hard drawn copper wire in place of iron on trunk lines, with the most satisfactory results. Over 10,000 miles of such wire is now in use. It relieves the strain on the poles, owing to its lightness, and its electrical superiority makes it work under very adverse meteorological conditions.

In the production of current, dynamos have been in some cases substituted for batteries with the best results. Time service is carried on throughout the United States from the Washington Naval Observatory. The telegraph business in this country, in spite of the sparsely settled districts and long distances of transmission, is made to show a profit. In England, where it is run by the government, and where it is calculated that of 70,000,000 messages per annum, some two-thirds are sent from or to London, a large annual deficit is shown.

PHYSICS.

Fifty years ago the science of physics was in a very peculiar condition. Mayer, about 1842, and Joule, 1843–1845, had given to the world their determinations of the mechanical equivalent of heat, laying the corner stone of the entire structure of modern physics. An immense amount of other data had been determined by methods which were hampered by inevitable inaccuracies, but which were accepted and utilized to the utmost by scientists of those days. In one point of theory hopeless confusion existed, on account of the want of an adequate distinction between force and energy. Physicists had gradually acquired the doctrine of the indestructibility of energy, and it was expressed in the so-called doctrine of the conservation of force. This supposed law was promulgated as one of the great triumphs of science, but it was not satisfactory. The comments of scientists upon it and their troubles in trying to reconcile facts with it make curious reading to-day when we know that force can be created and annihilated at will, and when we have learned to distinguish definitely between force and energy. After years of work the distinction was formulated and a threefold system of units was established for physics; the members of the system were force, work and energy. They were definitely distinguished, one from the other, and at once the great doctrine of the conservation of energy, unproved as it may be, obtained universal acceptance by men of science, and to-day is universally used as a working hypothesis. Faraday was one of those who had trouble with the doctrine of the conservation of force. He was an intimate friend of Clerk Maxwell, and utilized the mathematical genius of his friend in his work, and it was Maxwell who, working on the theory of dimensions, did much to definitely fix the relations of force, work and energy in all the formulæ of physical units which have sprung from the theory in question. It is impossible to dwell too strongly on this point in the development of physics during the last fifty years. Until force was accurately distinguished from energy the doctrine of the conservation of energy could not be utilized, and it is precisely on this doctrine that the whole of modern physics is constructed. It would be fair to term the theory the greatest discovery of the century in physics. The theory of dimensions is a necessary comment upon it, putting it into precise shape with due results.

The battle between the undulatory and the corpuscular theories of light had waged hotly, Newton and Young being the rival authorities appealed to, but the last fifty years have seen the undulatory theory universally accepted, and, in connection therewith, have seen the theory of electricity based on the luminiferous ether and its disturbances also accepted. Light and electricity thus were brought into near relations with each other, and a sort of conviction was established that no substance transparent to light could be a conductor of the electric current—something remarkably verified by the allotropic forms of carbon. Again we find the name of Clerk Maxwell, the developer of the electro-magnetic theory of light, foremost in the work of establishing the unity of natural science.

In 1850 Fizeau announced the success of his determination of the velocity of light by a physical test, using his rotating mirror to displace the apparent reflection of an electric spark. His results were close to the truth, and subsequent determinations by astronomical as well as by physical methods have but slightly affected them.

Mayer and Joule had developed the modern theory of heat, so that during the last fifty years comparatively little of basic work was possible. Melloni's work on what was called radiant heat, which comes nearly within our period, is an interesting example of old methods. The identification of this "radiant heat" with light phenomena is a direct growth of a recent period. Now it is treated as a particular phase of ether waves and the term itself is rejected. If the ether waves are long enough, they produce "obscure light," if the expression may be allowed, the old radiant heat. If of a certain range of length, the optic nerve is affected and light is produced. If still shorter, they cease to affect it again. Light becomes a subjective phenomenon, treated under the subject of ether waves. Chevreul's monumental work on color phenomena belongs to the light-producing division of ether waves, largely in the order of subjective phenomena.

Sound has been the subject of extensive research, Helmholtz's analysis of the physiological basis of music, published in 1862, marking perhaps the greatest epoch in the recent development of the subject. Mathematics, physiology and experiment were all devoted to the accomplishment of his great task, and the effect of overtones in giving its distinguishing quality to a note was formulated. By the use of a telescoping resonator Helmholtz succeeded in determining precisely what overtones existed in any given sound, and then by producing simultaneously the fundamental and overtones previously determined he reproduced mechanically the sound in question. This gave the analysis and synthesis of a sound. Koenig may be cited as a developer of apparatus for such study, some of his acoustic apparatus being a true scientific triumph.

Faraday's work has done much to elucidate the physics of electricity, and the magneto-generator of currents and the electric motor were natural sequences thereof. Physicists developed the subject and constructed motors with electro-magnetic fields, until gradually the conception of a self-exciting dynamo arose, and soon currents of high intensity began to be produced by self-contained generators. Then came the greatest discovery of all, that a machine adequate in its revolutions to generate a current would, if a current were passed into it from an outside source, generate mechanical energy. This convertibility of the dynamo into a motor was a beautiful sequence of the doctrine of the conservation of energy, and at once enabled us to convert mechanical energy into electrical energy and vice versa.

Spectrum analysis is justly considered an achievement in physics, and in the hands of astronomers it has led to the discovery of double stars and the determination of the velocity of the motions of stars receding from or approaching to the earth. Helium was, in 1872, announced as a probable constituent of the sun from lines in its spectrum. Recently Ramsay has identified it in the gas given off with argon from the mineral cleveite.

The discovery of argon, as the result of a physical investigation, is one of the triumphs of modern science. It was found by Rayleigh and Ramsay that nitrogen gas from the atmosphere was of higher specific gravity than that from chemical compounds. The hitherto unknown constituent of the air, argon, was discovered and a new element was added to the list, an element which mankind had been breathing unsuspectedly for all time. The acuteness of the millionaire scientist of the last century, Cavendish, is shown in his paper on nitrogen, in which it is almost certain that he describes the discovery of argon. He only dared to suggest the existence of any such gas; his suggestions slumbered for over a century.

The work done by the different scientists in physics during the last years is too vast to bear repetition. Every branch of the subject has been worked up to the highest state of development; throughout every phase of investigation the definite mathematical relations of physical units, of time, space, force, work, energy and others, appear as the guides. The physicist has worked