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ALFRED MARSHALL MAYER

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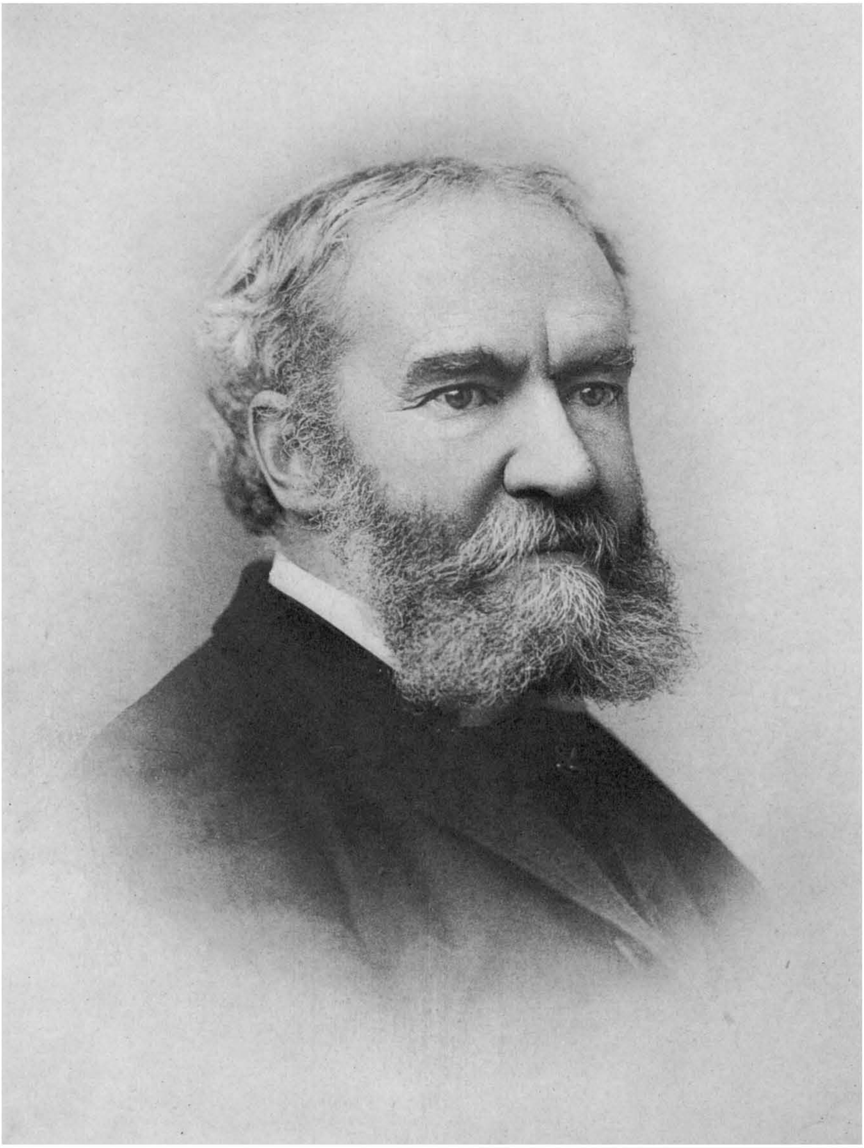

Alfred M. Mayer

ALFRED MARSHALL MAYER.

ALFRED MARSHALL MAYER was born in his father's house on Franklin street, then the fashionable quarter of Baltimore, on November 13, 1836. His father, Hon. Charles Frederick Mayer, a Senator of Maryland, was attorney for the Baltimore and Ohio Railroad and other corporations of that day, and as a lawyer had for years maintained one of the most successful practices in the city.

Since the mental traits of men of science are apt to become well known, it is of interest to trace their probable origin in ancestry, and in this case the quest seems not wholly fruitless. On his paternal side, the family which was of remote Swiss origin, had for centuries been citizens of the free city of Ulm, in Württemberg, and the records of their births, marriages, and deaths appear in the registers of the ancient Lutheran Münster of this quaint old city by the Danube. In all this long record there is nothing either of genius or of degeneracy, for generation after generation pursued the even tenor of its modest way, respected, and at times even honored by its fellow-townsmen as presidents and captains of their guilds, but all the while unknown beyond the narrow confines of the medieval walls of Ulm.

Thus it was when Christian Mayer, a grandfather of the subject of this biography, emigrated to Baltimore in 1784, and having inherited a fortune, large for the day, from his uncle and father, became a leading East Indian ship owner and merchant, at the same time serving his king as Consul General of Württemberg in the then newly created United States. Sober, honest, industrious, well educated, but unimaginative, conservative, and in all things in accord with the tradition of his Lutheran extraction was Christian Mayer—a man among whose hundreds of carefully copied letters not one touch of humor appears. Fortunately, however, he married in America a woman in whose veins there flowed the blood of the Huguenot, and like a ripple over a placid lake there came a change in the spirit of his descendants.

Her son, Brantz Mayer, uncle of the subject of this biography, was a man of wide culture, known in his day as a writer upon Mexico and upon the slave trade, but now chiefly remembered as the founder of the Maryland Historical Society. Charles, the father of Alfred M. Mayer, was noted for his knowledge not only of law but of many unrelated subjects; but his high reputation as an attorney rested upon a remarkably analytical ability, which enabled him to win success in presenting intricate cases before justices of the supreme and other high courts. As an orator facing an ordinary jury he was somewhat out of his element, for in thought and speech he was apart from the masses of his time, and while few were more widely known for their charity and kindness of heart, yet there was to be observed in him that aloofness of the student which caused him to look upon the average of humanity as hardly of his kind, while on the other hand he cherished and maintained the warm regard of that small circle of congenial and cultured spirits in whose companionship he found his highest pleasures.

Eliza Blackwell, who was the second wife of Charles F. Mayer, became the mother of Alfred M. Mayer. She was of Scotch-Irish blood, highly connected in the land of her ancestors, and her charms were those of the gentlewomen of the Emerald Isle. Endowed with a courtly grace and blessed by an impulsive, kindly heart, she felt rather than reasoned, loved rather than analyzed, and in the full enjoyment of the present she gave perhaps too little thought to the possibilities of the future. In common with the custom of the "Old South," the sons were placed each in his separate suite of rooms in the top story of the great rambling homestead, and thus they grew into manhood, each in his own inevitable way, perhaps too little heeded by parents or elders.

This peculiar system, or perhaps lack of system, had, however, one cardinal virtue to recommend it, permitting as it did free play to the development of individual characteristics. Thus Frank busied himself with art, and his room became a studio, while his younger brother, Alfred, plunged into the pursuit of all things scientific, from collections of insects to the study of the stars.

The children were sent at first to private schools and later to the conveniently situated Catholic College of St. Mary's, in Baltimore. Science had no place in these schools, and from the first Alfred was in rebellion against a system of education which forced him into endless translations of ancient languages and obliged his serious attention to the miraculous lives of the saints. His father had cherished one dominant idea respecting the son's career: he was to be a lawyer; hence his names, Alfred, the great lawgiver, and Marshall, the greatest expounder of the law in America. Finding that law had no place on the horizon of his son's thought, the father largely lost interest in the task of his higher education as something all but foredoomed to failure.

Thrown back upon his own intellectual resources, the son, whom others could not teach, trained himself. His rooms became filled with scientific apparatus of his own making, while assiduously, intensely, and quite alone he laid thus early the foundations for his elevation to science. It was fortunate that at about this period Prof. Joseph Henry, Secretary of the then newly founded Smithsonian Institution, visited Baltimore and, being the guest of Charles F. Mayer, was induced to ascend to the attic to see the apparatus. A friendship which endured throughout life arose between the great student of nature and the boy. It was through Henry's influence that Mayer secured the collegiate positions which enabled him to pursue the subjects he loved to investigate, and throughout the best and most fruitful years of his life Henry remained the master upon whom he looked and of whom he spoke with reverence as "his father in science."

The novice who struggles against his environment seems doubly unfortunate if surrounded by evidences of affluence. Poverty at least grants its freedoms, for there is nothing of social prejudice to live down; but the engineering sciences in which this boy delighted held but a poor place in the respect of the aristocratic South. Self-absorbed, eccentric, and disapproved of as seeking a career in which even success meant failure, he early learned the strength of his own unaided personality and with the knowledge he acquired self-reliance; for, after due deliberation, his father decided against sending so strangely unconventional a son to college—a decision which strikes us as the more remarkable in that Charles F. Mayer was himself a graduate and a trustee of Dickinson College and his house was a center for all that was intellectual and cultured in the Baltimore of those days.

Thus in an atmosphere of opposition or indifference, which certainly developed character, even if it left its mark of sadness through many a year, the boy developed into that little-to-be envied individual—the self-made man. The first lecture upon Physics which he ever heard was one he gave himself when Assistant Professor of that science in the University of Maryland, at the age of twenty-one. Into broad fields of study and research his love of truth had led him, for he was a born experimenter and his mind, for so keen an enthusiast, was remarkably analytical; but in special departments, such as mathematics, his knowledge remained hardly adequate for the bold tasks of his life-work and, in common with other self-made men, his equipment, although highly efficient in many essentials, was somewhat weak in others.

Inevitable as this "one-sidedness" is in those who train themselves, yet in his case it seemed accentuated by the very intensity of his character, for in him the cautious, philosophic southern German seemed to struggle against the impulsiveness of the Celt and the generous altruism of the Huguenot. His indeed was a nature difficult of analysis, for there was often war within him, as if between ancestral strains whose ideals clashed one against the other. Yet to just such unbalanced characters the world owes most that is significant in the history of its progress.

At the early age of sixteen he broke from the tradition of his caste, and we find him in "overalls" laboring as a machinist in the workshop of a local engineering firm. One is under the impression that these days of new-found freedom were among the happiest of his life. He delighted in accurate craftsmanship, and soon acquired remarkable skill in turning and in chipping to a true surface the valve-seats of engines. After two years of this excellent experience, we find him acquiring a considerable local practice as an analytical chemist and serving as expert to various manufacturing and mining corporations, and, among other things, he found that the red lead then commonly used in glazing pottery was highly poisonous.

It was then, when only nineteen years of age, that he published his first scientific paper, which attracted sufficient attention to cause its republication in Germany. It was upon a new carbonic acid apparatus and appeared in the American Journal of Science, volume 19, 1855. Two years later this was followed by another in the same journal upon the use of fine rods of drawn glass in estimating minute weights down to 1/1000 milligram. For the following ten years he published no more papers, but devoted his energies to perfecting his education and to the exacting duties of a teacher. In 1857 he gave lectures upon Physics and Chemistry in the school of science and arts of the University of Maryland, succeeding Dr. John H. Alexander, who went to Europe in the endeavor to bring about an international coinage. But Baltimore was becoming too narrow a field for the young man's endeavors, and in 1858 he secured the appointment to the newly founded Charles professorship of Natural Sciences in Westminster College, Fulton, Missouri. He has left an interesting account of the long, tedious railway journey across the plains when the nights were weirdly lighted by the comet of that year. Out in this little frontier college of 150 students he soon established courses in physics, chemistry, and zoölogy, which, to judge by his prospectus, must have been unique; for at a time when dry, textbook instruction was the rule he declared that no adequate book on physics existed in the English language, and based his teaching upon lectures illustrated by numerous experiments. His skill as a manipulator of instruments was extraordinary, and it has been said that never were his class-room experiments known to fail. In his youthful enthusiasm he was obliged to resort to many makeshifts to illustrate the principles of science, and once the bursting of a defective retort seriously injured his left hand by flooding it with fused chlorate of potash.

But the dark shadow of civil conflict was then brooding over the land, and many of the bright young men for whose intellectual welfare he labored so earnestly were soon to fall in final sleep upon many a bloody battlefield. The young professor also caught the contagion of the war, for in one of his letters he declares his intention of returning at once to serve in the artillery under the "old colonial flag of Maryland." Upon his return, however, he found the family councils set decidedly against him. His father, an abolitionist, who had freed his own slaves, was Union in sentiment, as was also his uncle, Brantz Mayer, then serving as Brigadier General of Maryland Volunteers, and afterward as an officer in the regular army, while one of his brothers had already entered the United States Navy as a commissioned officer.

Moreover, Maryland refused to secede and there was no "colonial flag" to serve. It seems difficult at this late day, when so many issues once vital have passed into the oblivion of forgetfulness, to grasp the logic of his view; but as one whose country declined to call him, he left Maryland in 1863, crossed the ocean and enrolled as a student in the University of Paris. Here Regnault, that prince of experimenters, was in his prime, and his lectures produced a deep and lasting impression upon the young American student, although he took courses in physiology and chemistry as well as in physics. The superficial glory of the third Empire was at its height and the activity and brilliancy of Paris charmed and fascinated him, causing him in after years often to long to return to this beautiful city, where these years of his fullest joy were spent. But these potentially fruitful student days were of brief duration, for in 1865 he returned to America without having taken a degree and became Professor of Physics and Chemistry in the Pennsylvania College of Gettysburg.

This college was a small one and had suffered seriously through the incidents of the Civil War, and apparently the labor of reconstruction and teaching prevented his indulging in research, for his only writings of this period were a translation of Delaunay's "Essay on the Velocity of Light" and an article upon "God in Nature," in which he maintains that the inspired character of the Bible is evident through its essential unity—a conclusion to which he could not have subscribed in later life, when he had lost faith in the tenets of any orthodox religion. The truth was that in these years he was busily engaged in perfecting his education and also in the preparation of his "Lecture Notes on Physics," which were published in the Journal of the Franklin Institute of Philadelphia in 1868 and appeared also as a separate book. That his services to the Pennsylvania College were not unappreciated is attested by the fact that in 1866 this institution conferred upon him the degree of Ph. D., this being the only collegiate degree he ever received.

His energy and ability began to attract attention, and in 1867 he was called to the Professorship of Physics and Astronomy in the newly established Lehigh University. At this university, for the first time in his life, he became master of a well-equipped laboratory, and under the stimulus of favorable surroundings he plunged enthusiastically into experimental researches, especially in the fields of electro-magnetism and astronomy, in recognition of which he was elected a member of the American Philosophical Society of Philadelphia, which brought him into intimate association with such men as Cope, Leidy, and Dr. Henry Morton. At this time, also, Mr. Robert H. Sayre, one of the trustees of Lehigh University, provided the means to erect and equip an astronomical observatory, and through the use of its six-inch equatorial Mayer observed and described a peculiar elliptical marking upon Jupiter and made studies of aurora; but the equipment of the observatory was too meager to permit of the prosecution of any really important work.

In the field of electro-magnetism he describes at this time a method for determining the relative electrical conductivity of various metals, the plan being theoretically interesting, but without practical value; also during a visit to Trenton and Niagara Falls he found that on misty days the water was heated by the arrest of motion after the descent, as one would expect in accordance with the first law of thermodynamics. If the atmosphere were dry, however, the evaporation more than offset this heating effect. He also devised a method whereby the directions of magnetic lines of force could be fixed, the plan being to form them of iron filings upon a glass plate coated with shellac and then melt the shellac, causing the filings to adhere to the plate. Professor Coffin, Superintendent of the United States Nautical Almanac, organized an expedition to study the solar eclipse of August 7, 1869, and Mayer was chief of the section which took photographs of the sun during the eclipse, at Burlington, Iowa. By means of an ingenious mechanism, supplemented by a well-devised system of manipulation, he succeeded in taking 41 perfect photographs of the eclipse, four being of totality, the exposures being about .002 second. This, with the old-fashioned wet plates, was considered to be a remarkable achievement and his published report attracted much interest.

He gives a graphic description of the eclipse: "A minute or two before totality the sky grew ashen, or rather leaden, in hue, and Venus and Mercury came out, shining beautifully on a ground of bluish gray. I thought I saw a flashing, twirling motion in the corona or in the last rays of the sun. Moths and insects in profusion passed between me and the sun, while a flock of birds, with troubled, irregular flight, seemed seeking cover from the unnatural gloom which surrounded them. A low moaning wind now sprung up, and the whole atmosphere seemed filled with a leaden-colored vapor, and I experienced an indescribable feeling of oppression when I tapped the trigger; and from that instant until the sun reappeared I had nothing but an instrumental consciousness, for I was nothing but a part of the telescope."

As is often the case in newly organized educational institutions, a certain degree of friction soon manifested itself between the governing body and the faculty of the college; and Mayer's life at Lehigh was not wholly free from the somewhat harassing effects of this period of adjustment, and this rendered doubly welcome the offer by President Henry Morton, in 1871, of the chair of Physics in the newly established Stevens Institute of Technology at Hoboken, New Jersey. This position, as senior professor of the faculty, he was destined to retain throughout the remaining twenty-five years of his life, and it is for the researches accomplished during the first nine years of this period that he is chiefly known and recalled.

At Stevens Institute he became director of one of the best endowed and adequately equipped laboratories of the period, and it was here that he commenced the series of experiments upon sound which made him clearly the leader in this field among American men of science. This was a period of activity so intense that it could not last for long. Throughout the days and far into the morning hours he worked, and yet found time to enjoy the social cheer of the Century Association in New York, of which he was a newly elected member. Apart from his work in research, he wrote three books of popular interest: "The Earth a Great Magnet," "Sound," and "Light," the last being in collaboration with Charles Barnard.

In the "Earth, a Great Magnet," he presents an excellent résumé of the subject of terrestrial magnetism, illustrated by many striking experiments, some of which were performed with the great electro-magnet of the Stevens Institute Laboratory, then believed to be the largest in the world. In this work he describes a new form of projection galvanometer, which was a decided improvement over previous forms and has been widely used in physical laboratories.

His book called "Sound," published by Appleton, is intended for beginners, and as such it remains today one of the best in the English language, abounding as it does in simple but ingenious experiments, in the devising of which its author was unsurpassed. Mayer also wrote a remarkable and well-illustrated series of articles in the "Scientific American Supplement," upon the "Minute Measurements of Modern Science," in which he maintained that "every instrument of precision contains within itself its own means of adjustment."

Several of the more important articles in Johnson's and in Appleton's Encyclopedias, such as those upon sound, the microscope, and the spectrum, are from his pen, and in the "American Journal of Science" and in the "Popular Science Monthly" he wrote articles of general interest upon the history of Young's discovery of his theory of colors, "Flying Machines and Penaud's Artificial Bird," "Marey's New Results in Animal Movements," "Edison's Talking Machine," and on "Manometric Flames," by Dr. R. Koenig, of Paris.

But the reputation of a man of science must rest, in the last analysis, not upon his skill as a popularizer of the knowledge of his day, but upon the significance of that little which he has himself discovered and given to the world; and, judged by this higher standard, the efforts of this most active period of Mayer's life, between 1871 and 1880, were more than commonly successful. It is for his discoveries in acoustics that he is best known, the results being presented in ten articles, published in the "American Journal of Science" between 1872 and 1896.

Helmholtz had discovered that a certain number of beats per second between two tones produce in the ear a maximum dissonant sensation, while a greater number will gradually blend into a smooth, continuous sound; and he also found that the sensation produced by sounds of low pitch remain longer upon the ear after the actual sound has ceased than do sounds of high pitch. Helmholtz even attempted to give a quantitative expression to this law, but failed, owing to the extreme difficulty and patience involved in the research. In 1874, and again with improved apparatus in 1894, Mayer approached this subject from the quantitative side. Moreover, his results were supported, in 1875, by the observations of Madame Emma Seiler, who had assisted Helmholtz in his studies of sound and who was noted for her acute musical perception; and in later years Rudolph Koenig also confirmed Mayer's results, which may thus be considered to be well established and have been accepted by Lord Rayleigh in his standard treatise upon sound.

Mayer's earlier method consisted in interrupting the responses of a resonator by means of a perforated rotating disk which periodically permitted and shut off its sound. Later he improved the arrangement by permitting the resonator to respond continuously, while the revolving disk merely interrupted the sound which came from it. He was thus enabled to measure the time during which the after-sensation of a sound does not appear to diminish in intensity, and he found that if we call this time D, the formula for N vibrations per second becomes:

$$D = \left(\frac{33000}{N + 30} + 18 \right) 0.0001$$

This represented the law for his own ear, but the constants differ for different ears, although the form of the equation remains that of the hyperbola for sounds between 64 and 1,024 vibrations per second. This formula has commonly been referred to as "Mayer's law." Its establishment cost its discoverer many months of patient effort, the strain of which was so severe that the hearing of one of his ears was permanently injured.

The establishment of this law led to further studies, and he soon found that the greatest dissonance between two tones is produced by about 4/10 the number of beats required to give a continuous sensation. Moreover, the smallest consonant intervals between two tones, or the smallest number of beats between the two tones which produce a resultant blended tone, follow Mayer's law with a sufficient degree of accuracy for tones between 128 and 2,806 vibrations per second. The law does not apply to Sol_1 of 96 vibrations per second, and Koenig found that there are no consonant intervals for tones of 64 vibrations per second or less.

The most interesting deduction from this law was Mayer's discovery that a sound of low pitch can, if intense, obliterate the sensation due to one of high pitch, but high-pitched sounds, no matter how intense, cannot obliterate those of low pitch. He also found, in 1894, that one can hear beats between two tones, both of which are too high in pitch to be heard; but in this he was anticipated by Koenig, who used tuning-forks, while Mayer used "bird-call" whistles.

A study that attracted much attention and gave rise to some amusement among the public was his observation of the supposed auditory organs of the mosquito. He found that certain of the fibrils of the plumose antennæ of the male mosquito were set into most vigorous vibration by tuning-forks of Ut_3 or Ut_4, ranging from 256 to 512 vibrations per second, while other tones between 128 and 1,024 vibrations per second were less effective in causing the fibrils to vibrate. In any case the fibrils vibrate most actively when they lie perpendicular to the direction whence comes the sound, and this probably enables the male mosquito to direct his course toward the female, for when both antennæ are equally affected his body points in the direction of the source of sound. As long ago as 1855 Dr. Christopher Johnson, in the Quarterly Journal of the Microscopical Society of London, had formed the opinion, based upon anatomical facts, that the fibrils of the antennæ are the auditory organs of the mosquito, and he drew the inference that the fibrils of the male responded to the sounds produced by the female, although he appears not to have observed the vibration of the antennæ. The studies of Johnson and of Mayer suggest, but do not prove, that the fibrils of the antennæ are auditory organs, for neither investigator observed the behavior of the free male mosquito in the presence of the sounds to which its fibrils covibrate.

In his study of human audition Mayer found that if the base of a tuning-fork, such as Ut_3, be pressed against the zygomatic process close to the ear, one hears not only the proper tone of the fork, but also its higher octave, and this led him to conclude that when simple vibrations impinge on the ear the tympanic and basilar membranes vibrate twice, while the hair-cell cords in the organ of Corti vibrate only once. Also, these hair-cell cords are supposed to be the covibrating bodies in the ear whose movements lead to the perception of the pitch of sound.

In January, 1876, Mayer found that the pressure on the closed end of an acting resonator is greater than at the open end; hence the resonator tends to be repelled. Thus four such resonators attached to the ends of a pivoted cross may be made to rotate. Dvořák, of Angram, Austria, had invented the same apparatus in 1875; thus this "sound mill" was devised independently by the two investigators, Dvořák's invention taking precedence over Mayer's.

In other researches upon sound, Mayer gave an experimental demonstration of Doppler's principle, showing the influence of motion upon the apparent pitch of sound, his method being closely similar to those previously adopted by Koenig and by Radau. Using Koenig's manometric flame, he devised an experimental method for detecting the phases of vibration and of measuring the wave length and exploring the form of the wave surface in the air surrounding a sounding body, and this led to the invention of an acoustic pyrometer for measuring high temperatures, which has proven of practical value in certain researches, its readings within certain limits being comparable in accuracy to those obtained from the air thermometer.

Mayer was thus the first to accurately and quantitatively determine the effect of temperature upon the rate of vibration of tuning-forks and the wave lengths to which they give rise. He also experimentally determined the relative intensities of sounds, and measured the capacities of various substances and gases to reflect and to transmit sound. He illustrated by ingenious experiments Fourier's theorem as applied to the decomposition of the vibrations of a composite sonorous wave into its elementary constituents, and also to an illustration of Helmholtz's hypothesis of audition. By stretching a number of silk fibers, one end of each of which was attached to the prong of a tuning-fork, while the other end was made fast to a loose inelastic leather membrane mounted in a frame near a reed pipe, he succeeded in one and the same experiment in demonstrating both the analysis and synthesis of a composite sound.

He also determined that the energy per second given forth by an Ut_3 fork of 256 vibrations per second was sufficient to lift one gram through a height of 10 centimeters, or about one-millionth of Joule's unit. This result was attained by measuring the relative intensities of the sound when its movements were partially damped by means of India rubber, thus causing the rubber to rise in temperature. Concerning this demonstration, Prof. Le Conte Stevens has remarked: "The difficulties attendant upon such an experiment are very great and no one but an experimentalist of exceptional skill and patience would be apt to undertake it."

His last research in acoustics, published in 1896, was upon the modulus of elasticity of aluminum as determined by its sonorous properties. In prosecuting this study, he went to Paris and enjoyed the advantages of working with the great "tonometer" of his friend, Rudolph Koenig, for nowhere else in the world could one find apparatus for determining the pitch of pure sounds with sufficient accuracy for the requirements of this research. He found unexpected variations in the modulus of elasticity of aluminum, and thus for sonorous purposes it is inferior to steel. The method is well adapted to determine the *variation* rather than the absolute value of the modulus of elasticity.

Mayer's experimental researches in the determination of the forms of acoustic wave surfaces led to the invention of an instrument which he called the topophone and which was designed to determine the direction of the source of sound. The apparatus consisted of two resonators, mounted at the ends of a rigid rod, the axis of each resonator being perpendicular to that of the rod, and the length of the rod being less than that of a wave length of the sound to which the resonators were in tune. The openings at the backs of these resonators were connected with rubber tubes, which were joined to a single tube in such a manner that one of the branches was longer by one-half the wave length of the sound than the other. Thus when the receiving openings of both resonators faced the source of the sound, interference was produced and the response reduced to a minimum. By means of this apparatus, the source of a sound from 100 to 1,000 feet away could be determined to within about 1.5° angular measure, while even an inexperienced person could determine the direction of a fog-horn within 10° when from 4 to 6 miles away from the source of sound.

This instrument was designed to enable ships to determine the direction of fog sirens, but as the tones of sirens are complex and no two give the same fundamental note, it would be necessary to adjust the resonators to each special case, although this could perhaps have been done and would indeed have provided a means of discovering not only the direction of the fog-horn, but the identity of the siren itself; yet Mayer never perfected his apparatus and it has been of no practical value.

In fact, despite the fact that he was a mechanician of rare skill and had few equals as an experimentalist, his interests were in theoretical and not in applied science. In England or in Germany his discoveries would have met with greater public appreciation than in America, where science, especially in his day, was esteemed in proportion as it filled a want or led immediately to the rise of material progress. He was a man of ideas rather than of action—a thinker, not an organizer—and all the wonderful energy of his enthusiastic, almost boyish nature seemed but to minister to the graces of his mind. A versatile conversationalist and charming story-teller, he combined in rare coördination the thoroughness of the Teuton with the fine appreciation of the Huguenot and the humor of the Celt.

Whatever he was engaged upon was done with his whole heart; everything that interested him became a "hobby," to the exclusion of all else for the time; and so true was this that even science could not claim his constant interest, for during the best and most vigorous years of his life, between 1881 and 1889, he was so enthusiastic over shooting and fishing that he all but neglected research and published only three short papers.

It was during this period that he became deeply interested in the discoveries relating to the condition of early man in the Stone Age in Europe, and he acquired a respectable collection of their implements. A piece of elk horn from the caverns of France interested him greatly, for upon it was a rude but effective drawing representing prehistoric hunters engaged in the chase of the reindeer. Several of these animals are shown in active flight, while one lies upon its back with its legs held stiffly upward. One day, however, an explanation of the matter came clearly to him, when his guide in Canada described the Indian custom of propping a slain deer upward with blocks of snow so that its legs might project above the drifts, and thus the quarry could be found upon the return of the hunters.

But to return to the researches of his most active years, between 1871 and 1880, while his major effort was in the theoretical side of acoustics, yet he conducted some interesting experimental studies upon magnetism, electricity, heat, and light.

We have already mentioned his remarkable general treatise upon "The Earth, a Great Magnet," but the most beautiful experiment he ever performed in the domain of magnetism was upon floating magnets. He magnetized a number of needles and mounted them upon corks, so they could be partially immersed within water, with their south poles upward. Then, when the north pole of a powerful steel magnet was held vertically above them, the mutually repellant floating needles were made to approach and arrange themselves in definite figures, which suggested the manner in which atoms of molecules may be grouped in the formation of definite compounds.

Thus, three needles must set themselves at the vertices of an equilateral triangle; four must arrange themselves at the corners of a square; five may either form a square with one in the center, or set themselves into a pentagon, and six may form a pentagon with one in the center, or arrange themselves three on a side in the form of an equilateral triangle. Where there are two or more forms of arrangement, some of these are more stable than others, and only the most stable form the nuclei, or central figures, of the higher combinations made from nine or more needles, for Mayer discovered that the configurations of the floating magnets may be divided into primary, secondary, tertiary, etc., classes, and the stable configurations of a lower class form the nuclei to the succeeding ones.

Thus the configuration of nine magnets begins the secondaries by having two needles for its nucleus, with seven forming a polygon around them. The other secondaries of from 9 to 19 magnets have the stable primaries from 2 to 8 for nuclei, and the tertiaries have the stable secondaries for nuclei, etc.

The experiment appears to furnish an optical analogy of molecular structure, expansion on solidification, and isomerism, and Sir William Thomson (afterward Lord Kelvin) was greatly delighted with it, and expressed his pleasure in an article in "Nature" of May 2, 1878, in which he states that Mayer's experiment had given a perfect mechanical illustration of the kinetic equilibrium of groups of columnar vortices revolving in circles around their common center of gravity, and had thus thrown light upon some problems respecting the constitution of matter.

Mayer's improvement in the laboratory form of the reflecting galvanometer we have already referred to, as also to his method of fixing and photographing the spectra of the magnetic lines of force. He also studied the effects of magnetization in changing the dimensions of iron and steel bars, using for this purpose the very sensitive reflecting comparator invented by Joseph Saxton; and he discovered that if a certain elongation is obtained by a strong electric current, this elongation tends to maintain itself, even when the current is greatly reduced by the gradual interposition of a high resistance, and remains far greater than would have been the case had the weakened current alone produced the elongation. This condition might be called "magnetic set" were it not for the fact that this term has been used by Joule and others to describe a different phenomenon.

His determinations of the coefficients of elongation and contraction of iron when magnetized were published in two papers in the American Journal of Science in 1873. In 1872 he made use of Meusel's double iodide of mercury and copper to trace the progress and to determine the boundary of a wave of conducted heat. The color of this substance is brilliant carmine, but it turns to a chocolate brown upon being heated to about 70° C., and then regains its original color upon cooling. He applied this test to the determination of the elliptical contour of the isothermal of conduction in the principal section of a quartz crystal, finding that the major axis was to the minor as 1 to 1.33, and this result is probably more accurate than the previous determination of Sénarmont, who concluded that it was as 1 to 1.31.

In 1874 Mayer described a new and simple method for investigating the oscillatory nature of the electric discharge, using for this purpose a thin, flat disk of lamp-blacked paper, which was rotated rapidly at a known rate between the discharging points of an induction coil. He found that under these conditions the discharge lasts about one-twenty-fourth of a second and consists of showers of flashes and sparks, separated by intervals of quiescence. (A figure of this apparatus is given in volume 3, part 2, of the Memoir of the National Academy of Sciences.)

It may seem remarkable that, living at a time when unparalleled progress was being made in the application of electricity to the service of civilization, he should have all but neglected this branch of physics. The truth is that in common with his great master, Joseph Henry, the practical application of scientific principles to useful ends largely failed to interest him. Thus, despite the great advantages he enjoyed as director of the excellent laboratory of the Stevens Institute and the cordial interest and respect which his achievements in pure science attracted, he was somewhat out of his true element in a school of engineering. Nevertheless his almost unrivaled energy and ingenuity as an experimenter won wide recognition. In 1872 he was elected a member of the National Academy of Sciences, and in 1873 he was an associate editor of the American Journal of Science. The American Academy of Arts and Sciences of Boston also chose him to membership, as did the American

Philosophical Society, the New York Academy of Sciences, and others in the United States.

In 1873 he visited England and was most kindly received by such eminent men of science as Tyndall, Wheatstone, De la Rue, Strutt (afterward Lord Rayleigh), Spottiswoode, Ellis, Bosanquet, and Lord Ross, and with these and others he formed enduring friendships. It seemed appropriate that when the Century Association in New York gave its farewell dinner to Professor Tyndall at the conclusion of his famous lecture tour of America, on February 4, 1873, Mayer was chosen to issue the invitations and to arrange the seating of the guests, among whom were included the intellectual, social, and official leaders of the nation.

Once again, in 1894, he visited England and attended the Oxford meeting of the British Association for the Advancement of Science, before which he read two papers. In the long years between these visits most of his old friends had departed, and his own youth had fled, and owing to his having for ten years been more interested in sport than in science his name was no longer very familiar to the rising generation of investigators.

This relatively unproductive period of his life, between 1881 and 1889, was ushered in by a study of the velocity of shot, upon which subject he read a paper before the American Association for the Advancement of Science in 1880. In this research he used a chronoscope, consisting of a rotating cylinder covered with a smoked paper, upon which a tuning-fork made a tracing of its vibrations. A spark from an induction coil perforated the paper at the instant the hammer descended, and also when the shot struck the metal plate that served as a target. His results were a confirmation and extension of those previously obtained in 1875 by Prof. J. M. Rice, of the United States Naval Academy.

Mayer decided, as a result of his experiments, that a ten, or even an eight, gauge gun if of about eight pounds in weight would be the best fowling-piece for upland shooting. As a boy he had been fascinated by shooting and fishing, and now in his middle age the old love of sport returned, and all his mind seemed bent upon perfecting methods and apparatus; for it was as an experimenter and a craftsman that he delighted in sport, not as an explorer, a lover of the beautiful in nature, or the wild woods, for indeed these things appealed but little to him. Thus it was characteristic of him that, having decided upon the best type of shot-gun, he should proceed to devise the best form of canoe paddle and the best minnow-casting rod; and as a proof of the superiority of the last named, he won the first prize at the Amateur Minnow-casting Tournament of the National Rod and Reel Association in 1884, using a rod of his own invention. He was an excellent shot and noted for his skill in casting the fly and handling a canoe, and as the memory of his achievements in science faded his reputation as a sportsman grew among the members of the fishing and shooting clubs of America.

Thus it was that the Century Publishing Company invited him to edit the superb volume upon "Sport with Gun and Rod in American Woods and Waters," which was published in 1883. To this volume he contributed scholarly articles upon *"The Prehistoric Hunter," "On the Invention of the Fishing Reel," "Bob White, the Game Bird of America," "The Shot-Gun," "A Day with the Rails,"* and *"The Blow-Gun."* This was his crowning work as a contributor to the literature of sport; but he was also known for many devices of an ingenious character designated to facilitate the comfort or convenience of anglers, and as the inventor of the very successful orange and black trout and bass fly, which he called "The Lord Baltimore."

In 1880 Mayer, when only forty-four years of age, had reached the acme of his scientific fame. In August of this year he read before the American Association for the Advancement of Science his charmingly appreciative memoir of the friend of his youth and manhood—Joseph Henry—a tribute of love and respect to the master whose memory he always cherished and of whom he delighted to speak in terms of gratitude and devotion.

One thinks that his neglect of science for the following nine years was in no small degree due to a sense of intellectual loneliness due to the death of this dear friend and confidant. Moreover, there came upon him, as with crushing force, the realization of the inappreciation of his countrymen for achievements in pure science, and this deepened the sadness of his intellectual isolation. As a boy he had struggled in vain to win the approbation and esteem of those around him, and the dearest things of all are always those beyond our reach. Thus in a spirit of Epicurean philosophy he turned from his life-work and sank into the amusements afforded by sport. There were intellectual shocks also which men of his generation were called upon to withstand which it is difficult for us in this happier day to appreciate. Darwinism had broken the anchorage of many a faith, and many a ship had drifted aimlessly over the vast ocean of agnosticism. Moreover, acoustics had well-nigh become a finished subject, and Koenig and Mayer may perhaps be regarded as the last great experimentalists upon sound, supplementing the paramount work of Helmholtz and providing the basis upon which Rayleigh developed his mathematical theories. Practical inventions, such as the telephone and the phonograph, had diverted nearly all interest from the purely scientific aspect of the subject, and both Koenig and Mayer died saddened by the thought that they had outlived contemporaneous interest in their field of study.

There was yet another factor which contributed to distract Mayer's attention from science. In 1876 he purchased a country place in Maplewood, upon the slopes of the Orange Mountains, in New Jersey; thus for two hours in every day he was obliged to endure the noise and dust of railway travel in order to reach his laboratory and return to his home; and research becomes difficult when one's time is subject to the autocratic dictates of a time-table. Indeed, it was only in 1891, after he left his country place and returned to Hoboken, that he resumed full activity as an investigator. The very charms of his beautiful country home, with its astronomical observatory and its amateur machine shop, upon the lathes of which he delighted to spend hours in turning, were distractions tending to draw him away from the college laboratory in the Stevens Institute.

Thus it was that between 1881 and 1889 he published only three papers, two appearing in the Memoirs of the National Academy of Sciences, namely, one upon a method of measuring precisely the vibratory periods of tuning-forks and determining the laws of their vibration with a view to the calibration of chronoscopes for measuring the velocities of projectiles; and the other, published in 1886 in the American Journal of Science, was upon a well-spherometer of his own invention, capable of measuring the radius of curvature of small lenses with an error of not more than 1/125,000 of an inch. In 1890 there appeared three papers, in which he described ingenious devices for illustrating principles of physics before college classes. These are on a pendulum electrometer for making measurements of static electricity in absolute units, a spring balance electrometer for measuring specific inductive capacities and potentials, and an article in the American Journal of Science on a simple method for demonstrating the truth of Ohm's law. He also read a theoretical paper before the National Academy of Sciences upon electrical potential as measured by work. In this fruitful year, 1890, he also published the results of still another research upon the determination of the coefficient of cubical expansion of a solid from the observation of the temperature at which water in a vessel made of this solid has the same apparent volume as it has at 0° C., and on the coefficient of cubical expansion of a substance determined by means of a hydrometer made of this substance. This led to the conclusion that the coefficient of cubical expansion for glass is .000025; steel, .000033; copper, .00005; brass, .000056, and zinc, .00009. The accuracy of the method depends upon the exact determination of the absolute expansion of water when heated from 0° C.

In the following year this latter research was supplemented by a study of the physical properties of vulcanite, the coefficient of linear expansion of which was found to be .0000636 between 0° and 18° C., in close agreement with Kohlrausch, while its specific heat was .33125 and its index of refraction was 1.568. As found by Bell, vulcanite readily transmits the rays of dark heat, and Mayer determined that a plate of this substance one-half millimeter in thickness transmits 24 per cent of the sun's heat rays and can be made into a lens to focus heat without light, in which respect it is superior to obsidian. In another investigation upon the illuminating power of flat petroleum flames in various azimuths, he found that the edge of the flame of a petroleum lamp gives about 37 per cent less light than the flat surface, whereas a flat coal-gas flame gives practically one and the same intensity of light in every azimuth.

After sound and magnetism he was most interested in light, and in 1882 he invented a heliostat, which in place of the usual plane mirror carried a bi-convex lens, which focussed the sun's rays upon a totally reflecting prism, thus giving a condensed beam which could be used to throw upon a screen images of objects magnified about 3,800 diameters. An account of this instrument was published in the American Journal of Science in 1897, after the death of its inventor. Between 1893 and 1895 the subject of contrast-color engaged his attention, and he devised a rotating disk photometer for determining the relative intensities of lights of different colors, which gave results comparable in accuracy with the photometer of Bunsen. Also, by means of a glass tube blackened on the outside, he attempted to analyze contrast-colors and decided that the phenomenon is physiological, not psychological or a matter of judgment. He found that complementary contrast-colors are shown by the two halves of an electric spark, the duration of which was probably less than one-millionth of a second, and this leads him to support Hering's rather than the Young-Helmholtz hypothesis of color sensation.

Working in the laboratory of his intimate friend, Professor Rood, at Columbia College, he conducted a research upon the then newly discovered Röntgen rays, finding that the X-rays cannot be polarized by transmission through crystals of herapathite, although this is by far the most powerful substance known for the polarization of ordinary light. He also determined the relative transmission of these rays through aluminum, glass, green tourmaline, herapathite, and platinum in thickness of one-tenth millimeter and one millimeter.

His last research, published in April, 1897, in the American Journal of Science, only three months before his death, was upon the equilibrium of the forces acting in the flotation of disks and rings of metal, leading to measures of surface tension. The experiments called for much mechanical skill, delicacy of touch, and dexterity of manipulation, and it seemed fitting that this last investigation of his should be one in which his distinctive excellence should be so conspicuously displayed. He found, in common with others, that chemically clean metals can be floated upon water, and that the phenomenon is due not to grease or oil, but to a film of air adherent to their surfaces. Experiments with floating disks gave .0791 as the value of the constant of the surface tension of water, while this constant obtained from observation on floating rings was .0809; and, as the mean of the twenty-eight previous determinations by various physicists is .0772, it is evident that Mayer's beautifully simple and direct method is comparable with those of Plateau and Quincke.

As a sequel to this research, he had devised a method for directly measuring the surface tension of films, when the symptoms of an illness from which he had suffered for some months became so acute that he was forced to desist, and he died on July 13, 1897, at his country place in Maplewood, New Jersey.

Biographical notices of him appeared in the American Journal of Science for August, 1897; in the Physical Review, volume 5, 1897; a more complete account of his life and work, by Prof. W. Le Conte Stevens, in Science, volume 6, pages 261-269, 1897, and a contemporaneous biographical sketch was published in the Popular Science Monthly, volume 10, pages 230-233.

His friend, Prof. A. W. Wright, says of him: "Professor Mayer's scientific work was marked by strongly characteristic traits. He possessed great ingenuity and skill in construction and a remarkable degree of delicacy and precision as an experimenter, which enabled him to obtain results that will have a high and permanent value in science. Beyond his scientific accomplishments, he was a man of wide and refined culture, with a genial presence and social qualities which made him a delightful companion and endeared him to his friends."

In the more extended notice of Mayer referred to above, Prof. W. Le Conte Stevens remarks: "His restless ingenuity was ever ready for any demand, and his mechanical aptitude was so directed by a delicate esthetic sense that he could never be satisfied with any objective proof which was not neat and simple, as well as adequate. . . . He was conscious of his skill and naturally took keen pleasure in exercising it successfully. That in so doing he gave pleasure and help to others is manifested by the extent to which his methods have served as models."

He was twice married and was survived by his wife and one son.

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