THE FIRST CENTURY OF THE REPUBLIC.

[Fourteenth Paper.]

THE PROGRESS OF THE EXACT SCIENCES.—I.

IN any review of the progress of science during the first century of the republic, the period which lies between the declaration of independence and the close of the eighteenth century may, without danger of any important omission, be passed over in silence. There were men, it is true, in the colonies and in the newly emancipated States whose native abilities and distinguished attainments as astronomers or physicists won for them a reputation which in their time reached to other lands, and which has since come down to us; but these, though they were masters, were not originators, and their names are but incidentally connected with the history of science. Of this class David Rittenhouse is an honorable example. His scientific activity is illustrated in his numerous communications to the American Philosophical Society, of which he was a member, and in the presidency of which he succeeded Franklin—communications which display not only a powerful but also a remarkably versatile mind; and his singular ingenuity and extraordinary mechanical skill are attested by his orreries, still to be seen in the College of New Jersey and the University of Pennsylvania, which, according to the account given in the Transactions of the Philosophical Society, show the movements of the heavenly bodies for a period of five thousand years, and their positions in each year, month, day, and hour, with such accuracy as not in all this time to differ sensibly from those given by the astronomical tables.

Toward the close of the century the celebrated Priestley, whose discoveries entitle him to a high place among the original investigators of his day, made our country his home; but as the successes to which his fame is due were achieved before he left his native country, and as his later years were mainly occupied with the profitless task of defending a now long exploded theory, which his own discoveries had already rendered indefensible, and which his contemporaries were every where even then abandoning, he can not be counted as having materially contributed to the advancement of science in America. Another illustrious name belongs to this time, which should have been ours, but which was lost to us by influences not wholly unlike those which gained us Priestley. Benjamin Thompson, afterward Count of Rumford, was an American who early in life abandoned a home and a country which his fellow-citizens had made intolerable. Received into the service of a foreign prince, his force of character, activity of intellect, and singularly practical turn of mind at once commanded appreciation, and secured to him a position which enabled him to achieve a noble reputation not only as an efficient administrative officer and a zealous philanthropist, but also as an original and sagacious scientific investigator. To Rumford belongs the immortal honor of having boldly announced, before the close of the eighteenth century, a truth which the world was not very ready to receive till near the middle of the nineteenth, a truth which lies at the foundation of the mechanical theory of heat, and through that theory leads to the grandest generalization in the history of science—the truth that heat is a mode of motion. Now that this truth has come to be as universally admitted as it was then questioned, America may be justly proud that its discovery was made by one of her own sons.*

That the government of the United States, though it has as yet made no systematic and permanent provision for promoting scientific investigation, has not been wanting in liberality when solicited to lend its occasional aid to special objects of scientific interest, will be evident when we call to mind the Wilkes exploring expedition of 1838, the Lynch Dead Sea exploration of 1848, the solar parallax expedition under Gilliss in 1849, the expedition of the *Polaris* in 1871, and the more recent provision for the dispatch of parties to distant parts of the world to observe the transit of Venus of 1874. But besides these instances, in which the advancement of science for its own sake has been the exclusive aim of Congressional appropriations, many other examples may be mentioned in which legislation has been indirectly favorable to the same end. The Coast Survey is, from the necessity of things, a scientific institution and a school for training scientific men. The same is true of the public survey of the great lakes, of the boundary commissions, of the exploring expeditions in the heart of the continent, of the Naval Observatory, of the Nautical Almanac Office, and of the special commissions from time to time created for investigating experimentally certain questions regarded as practical, which have nevertheless important scientific relations, such as the heat

* Bacon and Locke, it is true, spoke of heat as motion; but with them the view was a pure hypothesis; with Rumford it was a demonstrated certainty. Speaking of the paper in which it was communicated to the Royal Society, Professor Tyndall says: "Rumford in this memoir annihilated the material theory of heat. Nothing on the subject more powerful has since been written."

developed in the combustion of coal, the tenacity, rigidity, and other useful qualities of different descriptions of iron and steel, the causes producing the explosions of steam-boilers, and others of like character.

Though we can attempt no history of scientific associations or organizations, there is one exception which may properly be made to this rule. The Smithsonian Institution is an organization unique in its character, which for the past thirty years has held a peculiar relation to the science of the country, of which it has been, also, one of the most powerful promoters. In the language of the will of its founder, an English gentleman of wealth who had never visited this country, it has for its large and liberal object "the increase and diffusion of knowledge among men." The fund from which it derives its revenue is bequeathed in trust to the United States of America, and its affairs are administered by a Board of Regents appointed principally by the Senate. During the infancy of the institution there was at one time danger that, instead of being made an instrumentality for the increase of knowledge by the encouragement of original research, it would become merely a depository of objects of interest in natural history or archæology, and of books of general literature, exhausting itself thus in the creation of a museum and a library. To this it was proposed to add a show of diffusing knowledge by means of popular lectures delivered annually in Washington during the winter. Such lectures were, in fact, given down to about 1860; but the danger menaced by the other part of the project was averted by the earnest zeal and conclusive logic with which the purposes of the founder were set forth and defended by the able secretary of the institution, Professor Joseph Henry. Thus for a long period of years the institution has employed all its available income in defraying, in whole or in part, the expense of original investigations, and in publishing the results of these, and of any others independently made which, after careful examination by expert judges, have appeared to be substantially valuable contributions to knowledge. Under the title of *Smithsonian Contributions to Knowledge* there have now been published nineteen large quarto volumes, embracing elaborate monographs on a large variety of subjects in exact science, in natural history, in ethnology, and in linguistics, including among them the important astronomical researches of Walker, Newcomb, and Stockwell, the ingenious discussions of rotary motion by General Barnard, the elaborate investigations of terrestrial magnetism by Bache, the grammar and vocabulary of the Dakota language by Riggs, and the explorations of the North American earth mounds by Squier and Davis.

In addition to its usefulness in provoking scientific research, of which it would be difficult to measure the value, the institution has also fulfilled, and is now fulfilling, a most important function in acting as the organ of a widely extended system of scientific exchanges between our own and foreign countries. Its correspondents and agents are scattered every where throughout the civilized world. Plants, minerals, books, specimens in natural history, objects of archæological interest—every thing, in short, which belongs to the material, or is serviceable for the illustration, of science is through its instrumentality expeditiously forwarded to the remotest destination, without any expense, except that which attends the local delivery, to sender or receiver. No such agency any where else exists. The degree to which it is promotive of scientific activity, not only by stimulating individual effort, but by bringing distant individuals into frequent communication with each other, and inducing systematic co-operation, need hardly be insisted on.

In the pure mathematics our country has an honorable, if not a very extensive, record. In this honorable record no name stands higher than that of Nathaniel Bowditch, whose voluminous and lucid commentary on the *Mécanique Celeste* of Laplace not only eclipsed the multitude of his previous admirable performances, but drew from analysts and physical astronomers of the highest eminence abroad most enthusiastic expressions of commendation. Professor Benjamin Peirce, of Harvard University, a pupil and friend of Bowditch, still in the vigor of life, stands hardly second to his master in the originality and value of his contributions to mathematical literature. His *Analytic Mechanics*, which is professedly an attempt to consolidate the latest researches and the most exalted forms of thought of the great geometers into a consistent and uniform treatise, is more than it professes to be. It is rather an attempt—successfully accomplished—to carry back the fundamental principles of the science to a more profound and central origin, and thence to shorten the path to the most fruitful forms of research. The most remarkable and most original of Professor Peirce's publications is the description of a new mathematical method, called by him "Linear Associative Algebra." This method seems to be a step in the direction of quaternions, but a larger one. It therefore oversteps the power of human conception to grasp its essence, while its visible machinery is algebraic, and in the modes of its use it has analogies both with algebra and with quaternions. The method is of too recent origin to have been largely developed in its capabilities or tested in its applications.

Of other eminent mathematicians whose labors deserve a more extended notice our limits allow but a mere mention. The algebra of Professor Theodore Strong, the memoir on "Musical Temperament" by Professor A. M. Fisher, the essay of Professor A. D. Stanley on the "Calculus of Variations," Professor Patterson's "Calculus of Operations," Professor Newton's memoirs on questions of higher geometry and on transcendental curves, General Alvord's "Tangencies of Circles and Spheres," General Barnard's "Theory of the Gyroscope and Problems in Rotary Motion," Professor Ferrel's "Converging Series," and his investigation of the movements of the atmosphere, are all valuable contributions to mathematical science; and this list might easily be greatly enlarged.

ASTRONOMY.

There are several distinct departments of astronomical science which are often pursued independently of each other. The elder Herschel occupied himself chiefly with discovery; Tycho Brahe, with the accurate determination of the places of known objects; and the same is true in general of the practical astronomers of the present day. Our gifted countryman, Mitchell, was especially interested in devising new methods of observation and record; our esteemed fellow-citizen, Mr. Rutherfurd, with the application of photography to astronomy. Some astronomers, like Newton, Lagrange, and Laplace at an earlier period, or like Adams, Leverrier, Peirce, Newcomb, and Stockwell in our own time, have engaged in the theoretic investigation of the laws of celestial motion, and of the action of the heavenly bodies on each other. Others—and the number is large, including at present De la Rue, Huggins, Lockyer, Faye, and Secchi abroad, and Young, H. Draper, and Langley among ourselves—have been busied in the fascinating study of solar and stellar physics. Finally, comets and shooting-stars, and the recently detected connection between these two seemingly very different classes of bodies, have been a subject of long-continued study, fruitful of interesting results, to a series of observers, among whom are most prominent at present Professor Schiaparelli, of Milan, and Professor Newton, of our own country.

In connection with *discovery*, an interesting chapter might be written on the history of the agencies to which discoveries are mainly due, that is, of observatories—a history which the limitation of our space necessarily excludes. Half a century ago such a thing as an astronomical observatory was unknown in the United States. At present the number is considerably greater than the necessity. Though the work of the observatory is the basis on which the theory of the existing universe must rest, it is not a work which needs to be indefinitely repeated. With the very superior instruments which the skill of recent times has furnished, a few observatories, judiciously distributed over the earth's surface, are all that the physical astronomer requires. There are at present in the United States not fewer than thirty astronomical observatories, probably more. If so many had been needed, they would still in many cases have been founded in vain, since no suitable provision has accompanied their erection for maintaining them subsequently in use. Some of them, connected with the colleges of the country, have, perhaps, been made sufficiently useful for purposes of instruction to justify their erection; but it is perfectly clear that the founders in general have been laboring under the delusion that an observatory when once brought into existence will somehow work itself. It has accordingly happened that, except in the case of the Naval Observatory, at Washington, that of Harvard University, and, in its earlier period, that of the Cincinnati Observatory, the responsibility for the use of the instruments, provided at great expense in these various establishments, has fallen upon men overburdened with heavy duties as instructors, occupying the greater part of their time by day, and rendering continuous systematic observation by night physically impossible. Notwithstanding these disadvantages, several of the gentlemen here referred to have found time in the midst of their distractions to render so signal services to astronomical science as to connect their names permanently with the history of its progress. There exists, however, no adequate provision, and in general no provision at all, for the training of observers and the support of observations; and hence much of this costly apparatus has been hitherto comparatively useless for the purposes of practical astronomy. Still less has there been a provision for what is now the most urgent necessity of the science—the encouragement and maintenance of a class of astronomers of a superior order of scientific culture, devoted to the study and reconstruction of theory. This is a consideration to which the benefactors of this noblest of sciences, who have provided it with so many instruments of magnificent proportions as monuments of their liberality speaking to the eye, would do wisely in the future to turn their attention.

Some of the most interesting of the astronomical discoveries of the century have been due to the keen-sightedness of American observers. The great telescope of the Cambridge Observatory was mounted in the summer of 1847. On the 16th day of September, 1848, it was the means of rendering for the first time visible to human eyes the eighth satellite of the planet Saturn—the eighth in the order of discovery, though the seventh in the order of distance from the planet. Five satellites of this planet had been discovered in the seventeenth century; two more, very close to the ring, were seen in 1789 by Sir William Herschel, who, as illustrated in this example and in several others, seems to have been endowed with an almost preternatural keenness of vision; but his observations were not confirmed until his son, more than forty years after (1836), rediscovered one of them, and caught a single doubtful glimpse of the other. Ten years later (1846) Mr. Lassell, of Liverpool, recovered the remaining one. The new satellite discovered by the Messrs. Bond is fainter than either of these two extremely difficult objects, though more distant from the planet than any other, except that known as Iapetus. Between this satellite and Titan, the next interior, a wide gap had been noticed to exist, Titan revolving around the primary in a little less than sixteen days, and Iapetus in more than seventy-nine. Bond's satellite, which has received the name Hyperion, has a period of a little over twenty-one days, so that it is comparatively near to Titan, and leaves still a large seemingly unoccupied space between itself and Iapetus. It is remarkable that Hyperion was noticed by Mr. Lassell on the 18th of September, only two days after its discovery by Bond.

The most wonderful object in the universe, as well to the physical astronomer as to the observer who surveys the heavens only for the gratification of his curiosity, is the double or multiple ring surrounding the planet Saturn. The ring is certainly double, a wide space, through which in one or two instances fixed stars have been seen, separating the inner, broader, and brighter from the outer, narrower, and less bright. Some very good observers have occasionally noticed what appeared to be lines of division in the breadth of both these rings, and these appearances, together with the deductions of theory as to the conditions necessary to the stability of the system, have led to the general belief that the rings are not rigid solids. Until the year 1850, however, only two rings had been suspected to exist, unless by occasional and temporary subdivision. But on the 11th of November in that year there was noticed by the Messrs. Bond a shadowy appearance interior to the broad ring, which led them to suspect the existence of a third and almost nebulous ring, having a breadth about two-thirds as great as that of the narrow or outer ring. Subsequent observations confirmed them in this belief; and the same appearances were later noticed by Dawes and Lassell in England. An interesting question hereupon arose as to whether this dusky ring was of recent formation, or had been noticed but not understood before. It was ascertained that Galle had mentioned appearances of a similar kind in a memoir published in 1838; and Father Secchi testified that such had been noticed in the observatory at Rome as early as 1828. Mr. Otto Struve also adduced evidences from the observations of J. Cassini in 1715, and those of Halley in 1720 and 1723, that the obscure ring had been noticed by those observers, and assumed by them to be a belt upon the planet itself. Mr. Struve created some excitement in the astronomical world by stating that on a comparison of the measurements of the apparent distance between the inner edge of the broad bright ring and the planet's disk made by his father in 1826 and by himself in 1851, together with an examination of similar measurements by Huyghens, Cassini, Bradley, Herschel, Encke, and Galle, he was satisfied that the inner edge of the bright ring is gradually approaching the planet, while the total breadth of the two rings is constantly increasing. This proposition was too startling to meet with ready acceptance by astronomers generally, and up to the present time the question remains where Struve left it, with, however, an apparently growing disposition to accept his conclusions. If it is true that the ring is slowly subsiding toward the planet, the hypothesis is not without plausibility that Bond's dusky ring may be composed of loosely scattered fragments, which, from causes possible to assign, have been accelerated in their descent beyond the general mass.

The astronomical discovery next in interest deserving mention, as an American contribution to science during the century, was remarkably enough made in the immediate neighborhood of the observatory which the successes of the Messrs. Bond had already made famous. Mr. Alvan Clark had just completed the great telescope of eighteen and a half inches designed for the University of Mississippi, and now at Chicago, when on the night of January 31, 1862, his son, Mr. Alvan G. Clark, directing the instrument toward Sirius, the brightest of the fixed stars, detected almost in contact with it a minute point of light which he recognized immediately as a companion star. Curiously enough, a well-founded suspicion had long been entertained that this star is double. Minute as are the annual proper motions of the fixed stars in the heavens, they are in general uniform and well ascertained. But the motion of Sirius was long ago discovered by Bessel to be affected by an irregularity such as would be produced by the action of some other body revolving with it around a common centre. The orbit of the imaginary attendant star had, in fact, been inferred by Peters, of Altona, and Safford, then of the Cambridge Observatory. No scrutiny with instruments then existing had, however, been successful in detecting this attendant, when the newly finished glass of Mr. Clark made it visible without effort. After its discovery it was seen with the Harvard equatorial and others of less power; but the 9½-inch Munich glass of the Naval Observatory has never shown it. This admirable discovery, or more properly the construction of a glass capable of making a discovery so difficult, was rewarded by the Academy of Sciences of France by the presentation to Mr. Clark of the Lalande Medal—a prize annually decreed to the author of the most interesting discovery of the year.

Several comets have been discovered by American astronomers, among which may be mentioned, the first of 1846, discovered February 26, 1846, by William C. Bond, of which the elliptic elements were determined by Peirce, giving a period of ninety-five years. The comet known by the name of Miss Maria Mitchell was first seen by her on October 1, 1847, at her private observatory in Nantucket. Two days later it was also seen by De Vico at Rome, and Mr. H. P. Tuttle at Cambridge. The comet 1862, III., which was discovered by Mr. Tuttle July 18, 1862, and by Mr. Thomas Simons, of Albany, on the same evening, but later, belongs to the August stream of meteoroids. An interesting fact in regard to Miss Mitchell's comet is that, four days after its discovery, it passed centrally over a fixed star of the fifth magnitude without in the slightest degree obscuring it. For a brief time the star was, in fact, so truly in the centre of the nebulosity that it appeared like the proper nucleus of the comet.

Of the swarm of minute planets which occupy the place between Mars and Jupiter, where the law of Bode indicates a member of the solar system to be missing, about one-third have been discovered by American observers. It is remarkable that all of this numerous group, now amounting to no fewer than 146, belong to the nineteenth century, the first to be detected having been discovered on the evening of the first day of the century, January 1, 1801, by Piazzi, at Palermo. Three others were discovered within the seven years next succeeding, after which nearly forty years elapsed without adding to the number. Up to the close of 1850 the total number known amounted to thirteen only. Within the twenty-five years which have since elapsed there have been discovered 133 more, or about five per annum. It is to be observed that discovery in recent years has been greatly facilitated by the Berlin star maps and other celestial charts, in which every star down to the ninth magnitude is set down. When an object is seen which is not in the map, therefore, the probability is great that it is an asteroid, and the question will be settled by a second observation on the following night, or even a few hours later on the same night. The first American astronomer to detect an asteroid previously unknown was Mr. James Ferguson, of the Naval Observatory, by whom the thirty-first of the series, now known as Euphrosyne, was found on September 1, 1854. Two others were subsequently discovered by him, making three in all. Besides these, there have been discovered one by Searle, two by Tuttle, sixteen by Watson, and twenty-two by Peters, making a total of forty-four, all discovered within a period of about twenty years.

Practical Astronomy.—The automatic registration of time observations by means of electro-magnetism is an improvement in practical astronomy due to American ingenuity. The merit of its first suggestion has been somewhat in dispute, but the earliest experimental demonstration of its feasibility was certainly made by Professor John Locke, of Cincinnati, who in 1848 introduced a clock provided with a suitable mechanism into the circuit of the electric telegraph between Cincinnati and Pittsburg. The distance is four hundred miles, and the experiment was continued for two hours, during which the beats were regularly registered at every station throughout the whole line. The application to astronomical observations immediately followed. In recognition of the value of this invention, Congress awarded to Dr. Locke the sum of ten thousand dollars, and ordered a clock of the same description to be constructed for the Naval Observatory. As a recording instrument, the ordinary telegraphic register of Professor Morse was at first employed. More convenient forms of apparatus were subsequently devised by Professor Mitchell, Mr. Joseph Saxton, of the Coast Survey, and Messrs. W. C. and George P. Bond, who introduced the regulator which has since been so almost universally employed in these instruments, known as Bond's spring governor. More recently (1871) a printing chronograph has been invented by Professor George W. Hough, of the Dudley Observatory, which records to the nearest tenth of a second, and saves to the observer who employs it the labor and time required for deciphering and recording in figures the indications of the register in common use. The electro-magnetic method of recording transits was adopted without delay in the observatories of the United States, and soon after found its way into those of Great Britain and the continent of Europe, where it was known as the American method. Of its great value in promoting accuracy it is not necessary to speak; but only those who have had experience in observation can adequately appreciate the degree to which it has lightened the labor of the observer. Previously to its introduction the clock divided with the object viewed the observer's attention, and the necessity for unceasing vigilance was exhausting in the extreme. If nothing else had been gained by it but this, the benefit would be incalculable.

The introduction of the electric chronograph into observatories furnished a very simple means of determining differences of longitude between any two places connected by a telegraphic wire. These determinations are made by comparing the exact times of transit of a given celestial object over the meridians of both places, a single clock giving the times for both, or by transmitting time signals alternately in opposite directions compared with the clocks at both ends. The earliest observations of this kind were made in January, 1849, between Washington and Cambridge, Massachusetts. The method has since been brought into very extensive use throughout the world. In 1867, and again in 1871 and in 1872, it was employed to determine the difference of longitude between Greenwich and Washington, by means, in the first instance, of the Anglo-American cable, and, in the second and third, of the French, from Brest to St. Pierre, and Danbury, Massachusetts.

In observing for longitude, the velocity of propagation of electric impulses in the wires of the circuit becomes a matter requiring attention, and thus the telegraph has become the means of throwing light upon this interesting question in physics.

Improvement of Instruments.—Until about 1850 the observatories of the United States were furnished with instruments of foreign manufacture exclusively. Since that time the telescopes of American opticians have rivaled, if they have not surpassed, in excellence those of the most celebrated constructors of the Old World. The 12½-inch equatorial of the Michigan University is one of many admirable instruments produced by Mr. Henry Fitz, of New York, an ingenious artisan, who was removed by a premature death just as his reputation had been firmly established, and as he was preparing for a bolder attempt than any of those in which he had been previously so successful —the construction of an objective of twenty-four inches aperture. Mr. Charles A. Spencer, of Canastota, New York, in the year 1848 suddenly acquired an extraordinary celebrity for superior skill in constructing objectives for microscopes. Having proved himself to be without a superior in this field, he turned his attention to the construction of telescopes with a success no less signal. One of the most remarkable examples on record of a career commenced without previous preparation, rather late in life, in a most difficult art, and leading in the end to the highest eminence, is to be found in the history of Mr. Alvan Clark, whose latest achievement has been the construction of the grand 26-inch objective erected in 1873 in the Naval Observatory at Washington. Mr. Clark's superior merit as an optician was recognized by the very skillful observer, Rev. W. R. Dawes, of Haddenham, England, some years before it was generally known to his own countrymen; but the work by which he first attained the assured celebrity which he now enjoys was the construction, in 1860 and 1861, of the magnificent telescope of 18½ inches aperture, for the observatory of the University of Mississippi, then under the direction of the writer of this article, which the troubles of the times diverted from its destination, and which was subsequently erected at the observatory of Chicago.

Some of the most successful constructors of astronomical instruments in our country are to be found among the astronomers themselves. Mr. Lewis M. Rutherfurd, of New York, is the originator of a department of practical astronomy requiring the use of instruments specially adapted to its purposes; and as the most expeditious and satisfactory mode of providing these instruments, he resolved to construct them himself. His idea was to make photography subservient to the uses of astronomy, and especially of uranography. Considering how rare are the occasions in which atmospheric conditions are altogether favorable to the observation of difficult objects in the heavens, and how large is the necessary consumption of time in making measurements of position and distance between the objects observed, it occurred to him that if these favorable opportunities should be seized to make exact photographic maps of the groups under examination, measurements of these maps might take the place of direct measurements of the stars, and that thus a single evening might be made productive of results as numerous and valuable as those obtained in many months in the ordinary course of observation. His first attempts at a practical realization of this idea were made with a reflecting telescope, for the reason that a parabolic speculum is free from aberration both of color and figure. The Cassegrainian form was adopted, as best suited to the purpose; but the tremors produced by passing street vehicles were so largely magnified by the double reflection in this instrument that he was soon compelled to abandon it for the refractor. A little experience, however, taught him that the refracting telescopes in common use, whatever their degree of excellence for purely optical purposes, would not furnish him celestial photographs exhibiting the stars with the degree of sharpness which his plan required. Though the luminous rays are well concentrated, the actinic rays are scattered, giving indistinct images of the larger stars, and failing to exhibit minute ones at all. He therefore undertook the construction of an objective corrected for actinic effect, without regard to color. The whole of the work, theoretic and practical, was done by himself, and about the year 1863 he completed an actin-aplanatic objective of eleven and a quarter inches aperture, which gave results entirely satisfactory. With this he speedily obtained many sharply defined maps of star groups upon glass, and it remained only to effect the intended measurements upon these maps. Here was presented a new mechanical problem of peculiar difficulty. No known micrometric apparatus was adapted either in form or in dimensions to effect these measurements. Mr. Rutherfurd met the difficulty with his characteristic ingenuity, and with his own hands constructed an instrument in which, by means of an observing microscope directed toward the plate, and having motion in two directions at right angles to each other, the co-ordinates of position of the objects observed may be measured with a delicacy which leaves nothing to be desired. In the original form of this instrument a micrometer screw was depended on to give these dimensions, and an immense amount of labor was expended in the construction of such a screw and in determining its error. The investigation resulted, however, in demonstrating that the error of the screw is not constant, no matter how faultless the workmanship or how excellent the material. Discarding the screw, therefore, for purposes of measurement, Mr. Rutherfurd introduces into the instrument, as at present constructed, two auxiliary microscopes traveling with the observing microscope, one in each direction, and reading the distances traveled upon fixed scales ruled on glass. In a paper read before the National Academy of Sciences in 1866 Mr. Rutherfurd gave an account of his method; and at the same meeting a discussion of measurements made at his observatory upon photographs of the Pleiades was presented by Dr. B. A. Gould, who reached the conclusion that the micrometric measurements of a single such plate, with the customary corrections for refraction, etc., would give results about as accurate as those obtained by Bessel with thirteen years' labor—the time employed by him in mapping this group.

Another American astronomer, whose ingenuity in the construction of instruments is no less remarkable than his skill in the use of them, Dr. Henry Draper, has devoted himself to the improvement of reflecting telescopes. The use of silvered glass for astronomical specula had been suggested by Foucault, as being a material lighter and less brittle than speculum metal, and as reflecting a larger proportion of the light; and he had practically illustrated the value of this suggestion by actually grinding and silvering one or two such specula with his own hands. With no light to guide him but the knowledge of these facts, Dr. Draper undertook an investigation of the best mode of proceeding in the construction of such specula, recording the results of his experiments as he went on; and having at length attained a triumphant success, he published his method among the *Smithsonian Contributions*, in an elaborate memoir, which has become a standard authority on the subject, and is continually quoted as such at the present day. The telescope described in this memoir is of fifteen and a half inches aperture, and it was for a long time the largest in the country; but it is now surpassed by one of twenty-eight inches, also constructed by Dr. Draper, and mounted in his observatory equatorially under a dome. With both these telescopes Dr. Draper has taken splendid photographs of the moon, one representing the satellite in the third quarter, which has borne an enlargement to fifty inches in diameter; and also the spectroscopic photographs of Alpha Lyræ, mentioned later in this article.

Physical Astronomy.—No incident in the history of astronomy has ever excited more universal interest than the detection, in August, 1846, by a method purely mathematical, of a planet which had been previously lurking unseen upon the confines of the system ever since the creation. This marvelous achievement, of which the history is too well known to need repetition here, was simultaneously accomplished by two foreign astronomers, and does not belong to American science. But it is a curious fact that the planet thus discovered fell immediately after into the hands of American astronomers, and that they have made it practically their own ever since. Owing to the exceedingly slow motion of the body, the elements of its orbit could not be determined from the observations of a few months. Assuming the orbit to be circular, several European astronomers reached early and concurrently the conclusion that its mean distance from the sun is less than the discoverers had supposed by between five and six hundred millions of miles. But the first approximately correct theory of its motions was wrought out by Professor Sears C. Walker, of the Naval Observatory at Washington, in February, 1847. When Herschel discovered the planet Uranus in 1781, Lexell was enabled to determine its orbit by means of observations made of the same body (supposed then to be a fixed star) by Bradley and Mayer nearly thirty years before; and the number of such previous accidental observations of this body which have since been discovered amounts to no less than nineteen. It was naturally hoped that the examination of star catalogues of earlier years would furnish some similar help to the solution of the problem presented by Neptune. Of these catalogues, however, most were for one reason or another useless in this inquiry. One only offered a possibility that the newly discovered body might have been by good fortune recorded in it. This was the *Histoire Céleste* of Lacaille, embracing 50,000 stars; and Mr. Walker soon discovered that Lacaille had swept over the probable path of the planet on two days nearly following each other—the 8th and 10th of May, 1795. Having, therefore, from the observations made at Washington, combined with those received from Europe, computed as well as he could the place of the body for these dates, varying the elements so as to include the entire region within which it could possibly have been at that time, he selected from Lalande all the stars within one degree of the computed path. There were nine of these, but among the nine one only seemed likely to be the planet. The question then presented itself, Is this star still in the place in which Lalande saw it? Two days after this question had been raised by Mr. Walker, the telescope of the Washington Observatory was directed to the spot, and found it vacant. Assuming, therefore, this missing star to have been the planet, Mr. Walker computed an elliptic orbit which represented with gratifying precision all the modern observations. The elliptic elements first obtained were, however, only approximate. In order to their more exact determination it was necessary that the theory of the perturbations should be revised. Here Professor Peirce, of Harvard University, lent his powerful assistance, and with the perturbations furnished by him, and revised normal places, Walker computed an ephemeris of the planet which he published in the *Smithsonian Contributions*. The only attempt at a theory of Neptune made abroad was by Kowalski, of Kasan, Russia, in 1855; but this, though formed on a much larger number of recent observations, did not represent the motions of the body more exactly than that of Walker.

The ephemerides founded on these early theories were affected more or less with error. Toward 1865 the errors were increasing with rapidity, and it was evident that without a new determination of the orbit, they would reach, before the end of the century, the serious amount of 5′ of longitude. Professor Simon Newcomb, of the Naval Observatory, Washington, now addressed himself to the laborious task of reconstructing the theory from the foundation. His results are published in the *Smithsonian Contributions*, and embrace (1) a determination of the elements of the orbit from observations extending through an arc of 40°; (2) an inquiry whether the mass of Uranus can be determined from the motion of Neptune; (3) an examination of the question whether these motions indicate the action of an extra-Neptunian planet; (4) tables and formulæ for finding the place of Neptune at any time, but more particularly between the years 1600 and 2000.

In the computation of the tables the elements adopted are not the mean elements, but their values at the present time as affected by secular inequalities and inequalities of long period, particularly that of 4300 years arising out of the near approach of the mean motion of Uranus to twice and a half that of Neptune, these being adapted to give the place of the planet with the highest degree of accuracy during the period for which the tables are specially designed, *i. e.*, till the year 2000. The work is one involving an enormous amount of labor. As to the mass of Uranus, Professor Newcomb concludes that no trustworthy value can be deduced from the motions of Neptune, nor, had this body been unknown, could even its existence have been detected from all the observations of the exterior planet hitherto made. It results, almost of course, that no evidence yet appears of the existence of any still more distant planet remaining yet undiscovered.

Soon after the publication of Professor Walker's "Elements of Neptune," Professor Peirce, in a communication to the American Academy of Arts and Sciences, after demonstrating that this planet, with the mass deduced from Bond's observations of Lassell's satellite, and with the orbit assigned by Walker, would fully reconcile all the modern observations and all the ancient accidental ones better than the hypothetical planet of Leverrier or Adams (Flamsteed's observation of 1690 being discordant with Adams to the extent of 50″ and with Leverrier to 20″, but harmonizing with the computation from the Walker and Peirce theory within a single second), ventured upon the bold assertion that the planet actually discovered by Galle, searching under Leverrier's direction, was not the planet predicted or expected, but a very different body, which occupied that place at that time only by a happy accident. Leverrier had fixed the distance of his planet from the sun at 36.154 times the earth's distance, and Professor Peirce demonstrated that at the distance 35.3 (at which a planet would have a periodical time equal to twice and a half that of Uranus) so important a change takes place in the character of the perturbations as to make it impossible to extend to the space within that distance any investigations relating to the space beyond. The observed distance is slightly over 30; and it appears that a second similar peculiarity occurs at 30.4, where a planet would have a period just double that of Uranus. The perturbations produced by it on this latter would, therefore, for a twofold reason, be of very different character from those resulting from the supposed planet at the distance of 36. Though these criticisms of Professor Peirce are well founded, and have never been satisfactorily answered, yet they can not materially affect our estimate of the merit of Adams and Leverrier. A planet such as that indicated by their analysis would have produced very nearly the actually observed irregularities of motion of Uranus, and must have been occupying very nearly the place in the heavens of that which was actually found. Any planet capable of doing this must have been in this neighborhood at the time of the discovery, and it was the merit of the analysis that it indicated the quarter in which the disturbing body was to be looked for—a merit which remains, though the actual planet differs from the planet predicted in mass, distance, and period.

Besides his "Theory of Neptune," Professor Newcomb has made numerous very valuable contributions to physical astronomy. His "Investigation of the Orbit of Uranus," published in the *Smithsonian Contributions* in 1873, is a work of great labor, commenced as early as 1859, but necessarily deferred till after the completion of the "Theory of Neptune."

In 1871 he published in Liouville's *Journal*, Paris, a "Theory of the Perturbations of the Moon produced by the Action of the Planets." Of this very able and very original investigation it is sufficient to cite the opinion expressed by Professor Cayley, president of the Royal Astronomical Society of London, who pronounces it, "from the boldness of the conception and the beauty of the results, a very remarkable memoir, constituting an important addition to theoretical dynamics."

Another very interesting memoir by Professor Newcomb embraces an investigation of the secular variations and mutual relations of the orbits of the asteroids, for the purpose of testing the question, from a theoretic point of view, whether the theory of Olbers, that these bodies are the fragments of a single shattered planet, is tenable or not. Twenty-five asteroids are included in the comparison, and the conclusion is unfavorable to the hypothesis in question.

In the Washington observations for 1865 there appeared an investigation by Professor Newcomb of the value of the solar parallax, reached by a discussion of the observations made in 1862 at six observatories in the northern hemisphere and two in the southern, and a combination of these with other results furnished by micrometrical measures of Mars by Professor Hall, the parallactic equation of the moon, the lunar equation of the earth, and finally the transit of Venus of 1769 recomputed by Professor Powalky. The inference is that the true parallax is 8.85″, with a probable error of 0.013″. Apparently the conclusion from the transit of 1874 will not be far from 8.87″, a result very near to that previously obtained by Professor Newcomb.

The great geometers who succeeded Newton in applying the principle of gravitation to the explanation of planetary motions assume that those minute inequalities, of which the effects only become sensible after long intervals, and produce considerable changes only after many centuries, or, perhaps, myriads of centuries, are developed uniformly with the time—a supposition which answered the immediate purpose, though it is by no means true. Yet a knowledge of the laws which govern these inequalities is important to the settlement of a number of interesting questions, especially such as concern the stability of the system, and the vicissitudes of heat and cold to which our own planet has been manifestly subjected in the distant past. Lagrange pointed out the mathematical criterion by which the general question of stability might be determined. Its application required a knowledge of the masses of the planets. These were not accurately known, but by substituting approximate values for them he was able to announce that none of the variations of the planetary elements could go on increasing forever. Laplace went further than this, and proved that, provided the direction of revolution is the same for all the planets, the stability of the system is independent of the masses. In this case he showed that the sum of the products of the several masses by the squares of the eccentricities and the square roots of the mean distances is constant, and that if the eccentricities are small, the variations will be small, so that the system will not only be stable, but will undergo no large departures from its mean condition. This is the state of things in our solar system. The actual condition of physical astronomy at present has seemed to demand a more complete investigation of this intricate subject, and such an investigation has been recently undertaken and successfully accomplished by Mr. J. N. Stockwell, of Cleveland, Ohio, whose elaborate memoir relating to it has been published among the *Smithsonian Contributions to Knowledge*. The object of the investigation has been to determine the numerical values of the secular changes of the elements of all the planetary orbits. The elements considered are four: the eccentricities and inclinations of the orbits, and the longitudes of the nodes and of the perihelia. The fluctuations of value are largest in the case of Mercury, and smallest in the case of Neptune. We are concerned chiefly with what relates to our own planet, and more especially with the fluctuations in the eccentricity of its orbit. This eccentricity may vary between the limits zero and

0.0694, involving a difference between the aphelion and perihelion distance of the earth from the sun of 13,000,000 miles, and also a difference between the duration of the summer and the winter half year of thirty-two days. It can hardly now be doubted that to these changes of eccentricity have been due the remarkable vicissitudes of climate to which, as geology informs us, the earth has been subjected. At present the winter of the southern hemisphere occurs in aphelion, and is longer than the summer by eight days. The consequence is that the south pole is capped with massive ice, which occupies an area of probably more than 2000 miles in diameter. When the eccentricity is maximum, the hemisphere which has the winter in aphelion is probably ice-bound nearly or quite down to the tropic.

The stability of the Saturnian system and the mechanical condition of the material of Saturn's rings form the subject of an important memoir read by Professor B. Peirce at the meeting of the American Association for the Advancement of Science held at Cincinnati in 1851. The conclusion arrived at is that the rings could not possibly be stable unless sustained by the mutual attraction between them and the inner satellites; and consequently that, in the absence of such satellites, they could have no existence. Also, that inasmuch as no solid material known is sufficiently tenacious to resist without rupture the immense divellent forces to which a solid ring under such circumstances must be subjected, therefore the rings must be fluid, and not solid. Laplace had recognized the difficulty attendant on the hypothesis of a continuous solid ring of such breadth, and had therefore assumed that the rings, though apparently presenting continuous plane surfaces, are nevertheless divided into many concentric and comparatively narrow rings. He also perceived that such rings would necessarily be in a condition of unstable equilibrium with the planet in case their centres of gravity should coincide, as would seem from their appearance to be most probable, with their centres of figure; and he accordingly supposed that there exist irregularities in the disposition of their substance imperceptible to us, which, by displacing the centres of gravity, give them the necessary stability. He failed to show that these two hypotheses can both be true and at the same time consistent with the optical phenomena, and, in fact, left the theory of this system incomplete. In 1857 Mr. J. Clerk Maxwell, in a prize essay presented to the University of Cambridge, in England, investigated these hypotheses of Laplace, and showed conclusively that they are untenable. On the hypothesis of fluidity he investigated the tidal movements which must take place in the rings, and rejected equally this supposition. But his analysis did not extend to the movement of the rings in mass, and therefore it is not in conflict with the view of Professor Peirce. If this be discarded, there remains no other but to suppose the rings to be made up of innumerable small discrete solid masses so near together that, in a zone having the generally admitted thickness of one or two hundred miles, they present to a distant observer the appearance of a continuous solid. This view is that which is held by Mr. R. A. Proctor.

Few of our American astronomers have contributed more abundantly to the literature of the science than Professor Stephen Alexander, of Princeton. In 1843 Professor Alexander presented to the American Philosophical Society an elaborate memoir upon the physical phenomena attending eclipses, transits, and occultations, which excited much interest in the astronomical world. In 1874 there was published among the *Smithsonian Contributions* a paper by the same astronomer, entitled, "Exposition of certain Harmonies of the Solar System." The design is to show inductively a tendency in nature to the arrayment of the planets according to a law of distances from the sun's centre, in which the distance of each succeeding planet is five-ninths of that of the last preceding, and to explain the actual departures from this law in the existing solar system by the supposition that in one or two instances two planets (called, therefore, half-planets) have been formed in the place of one. The earth and Venus constitute a pair of this kind. This ingenious speculation may be classed among the curiosities of astronomy, as it does not appear practicable to test its probability by mathematical analysis.

In the year 1849 Professor Daniel Kirkwood, then of Delaware College, Newark, now of the State University of Indiana, announced a remarkable law connecting the masses and distances of the planets of the solar system and their periods of rotation on their axes. To understand this, let it be premised that between any two planets succeeding each other in order as numbered from the sun outward, there is, when the bodies are in conjunction at their mean distances, a point of equal attraction, that is to say, a point in which a body free to move would be held *in equilibrio* by the opposing attractions of the two planets. Suppose these neutral points to be found for all the planets of the system, and the distance between the two neutral points above and below each planet to be called the diameter of the sphere of attraction of that planet, then, according to this law, it will be true that the cubes of these diameters for any two planets will be to each other as the squares of their respective numbers of rotations during one sidereal revolution of each. This law was subjected to a close examination by Professor Sears C. Walker in 1850, with a favorable conclusion. It is to be observed, however, that the uncertainty existing as to the masses of several of the planets, and as to the periods of rotation of some of them, gives to this conclusion the character of a probable rather than of a certain result. In order to extend the analogy throughout the system, Mr. Walker interpolates a planet in the region of the asteroids between Mars and Jupiter, which he places very nearly at the distance given by Bode's law. He finds also that if there exists a planet nearer the sun than Mercury, its distance must be one-fifth that of the earth, or about 18,000,000 miles. For the doubtful masses, Mr. Walker finds that the values demanded by the law are within the limits, often pretty wide, of those actually employed by different authorities in the investigations of physical astronomy and in the construction of tables. It will only be after a higher degree of perfection shall be attained in the theory of every planet than has yet been reached, that the accuracy of Kirkwood's analogy can be conclusively tested.

The physical condition of the sun is a subject which has occupied very much of late years the attention of the scientific world. Ever since the invention of the telescope the solar spots have been observed with careful and curious interest, and these, together with the varying features of the photosphere itself, when minutely examined, led early to a general though hardly universal acquiescence in the opinion expressed by Wilson in the Philosophical Transactions of 1774, and adopted by Sir William Herschel, that the luminous surface which we see is not the surface of a solid. The question what is beneath this surface remained a subject of controversy; and on any hypothesis of the state of the sun's mass, the essential nature of the spots and the causes producing them were matters equally unsettled. The vastly improved instruments of recent years, the employment of photography in aid of observation, and above all, the application of the spectroscope to the study of the chromosphere and the photosphere, have shed a flood of light upon this difficult subject, which is likely soon to harmonize all opinions, though it can hardly be said to have done so yet.

Immediately after the erection of the great Munich achromatic at the Harvard Observatory, this splendid instrument was employed by Mr. W. C. Bond in a continuous series of observations of the solar spots continued for a period of more than two years, maps of the spots being carefully drawn at every observation. The results are published in full in the Annals of the Harvard Observatory, and furnish a valuable means of studying the varying aspects of the spots, their growth, decline, and duration. More recently many foreign observers have devoted themselves to the investigation; among whom may be mentioned Mr. De La Rue, Mr. Balfour Stewart, and Mr. Loewy in England, who have given special attention to the laws governing the variations of the total area of sun spot and its distribution over the solar disk; Mr. Faye, in France, and Father Secchi, in Rome, who have engaged not only in observations, but in speculations on theory. The British observers arrived at the conclusion that the maxima and minima of spot development are periodic, the period coinciding with the synodical revolution of the planet Venus, to the influence of which body they therefore ascribe it. They attribute a similar and perhaps as powerful an effect to Jupiter; but in this case the irregularities are less, on account of the greater distance of the disturbing body. Professor Loomis, of New Haven, investigated the question of the period of maximum, in a paper published in 1870, arriving at the conclusion, somewhat different from that above mentioned, that the period is determined by Jupiter, and is about ten years; the magnitude of the maximum fluctuating, and dependent on Venus, with irregularities unaccounted for still outstanding. As to the sun's physical constitution, Professor Sterry Hunt is the author of a theory which is essentially a part of his theory of chemical geology, according to which the solar sphere consists wholly of matter in a gaseous condition, all the elements being mingled but not combined, their affinities being held in check by the intensity of the heat. The partial cooling of the surface by radiation depresses the temperature to the point at which combination is possible, and thus are formed vast volumes of finely divided solid or liquid matter, which, suspended in the surrounding gases, become intensely luminous, and form the source of the solar light. This view is sustained also by Mr. Faye and by Mr. Balfour Stewart, but is dissented from by Father Secchi, who inclines to believe the luminous envelope to form a kind of liquid or viscous shell. Recent observations by Professor S. P. Langley, with the admirable thirteen-inch objective of the Alleghany Observatory, have furnished probably the most conclusive evidence on this subject which has yet been obtained, and are entirely favorable to the theory of Professor Hunt. Professor Langley's papers have been published in the *American Journal of Science* for 1874 and 1875, and are full of interest not only as to the phenomena of the spots, but as to the minute features of the sun's general superficies. Accompanying his latest paper is a magnificent engraved illustration from a drawing of a typical solar spot observed in December,

1873. It represents what is commonly called the penumbra as being formed of long-drawn luminous filaments which in their curvature give evidence of gyratory movements, indicating that the spots are formed by tremendous vortices spirally ascending or descending. Professor Langley remarks of the apparently black centre or nucleus of the spot, that he has found it by direct experiment, when all extraneous light is excluded, to be not only intrinsically bright, but insupportably intense to the naked eye.

One of the most interesting contributions to the knowledge of the solar physics was the discovery in 1871 by Professor C. A. Young of that comparatively limited but well-defined solar envelope called the chromosphere, where the lines which in the ordinary solar spectrum are black become reversed, and assume the brilliant tints which characterize the spectra of the elements to which they belong, as seen in experiments artificially instituted.

A very ingenious device recently suggested by Professor A. M. Mayer, of Hoboken, for the study of the laws of the distribution of heat upon the sun's surface is the latest addition which has fallen under our notice to the means of investigating the physical condition of that body. The double iodide of copper and mercury becomes discolored when raised to a certain ascertained temperature. Let a thin paper, blackened on one surface and coated with the iodide on the other, receive the solar image on the blackened side, the aperture of the object-glass being reduced to such an extent that no discoloration of the salt may occur. Then let the aperture be gradually enlarged. Presently a spot will appear, which marks in the image the point of maximum temperature in the solar disk. By successive additional enlargements of aperture the spot on the paper will be correspondingly enlarged, and its borders will indicate the isothermal lines of the solar disk.

Comets.—In 1843 Professor Alexander, of Princeton, presented to the American Philosophical Society an investigation of the orbit of the great comet of that year, according to which it appeared that the body must almost have touched the sun, this result being explained on the hypothesis that the centre of gravity of the comet was not coincident with its centre of figure. In 1850 he published in the *Astronomical Journal* a memoir on the classification and special points of resemblance of certain periodic comets, and the probability of a common origin in the case of some of them. Three classes were distinguished. The possible rupture by the planet Mars of a large comet—that of 1315 and 1316—to furnish three of the third class was suggested as an example. This hypothesis was very lightly treated by Humboldt in his *Cosmos*, but it has found unexpected corroboration in the observations of our own time.

In regard to cometary physics some very important speculations, or, perhaps, more properly discoveries, are due to American physicists and astronomers. The nature of the appendages called tails and the causes producing them have been in all ages subjects of perplexing discussion, and have given rise to a variety of hypotheses, many of which are more or less wild. This character can not be attributed to the theory presented in 1859 by Professor W. A. Norton, of Yale College, in which the formation of comets' tails is assumed to be due to electrical repulsion, exerted both by the nucleus and by the sun, upon the attenuated matter sublimed from the mass by the solar heat. The particles, under the action of these forces, pass off in hyperbolic orbits. An application was made of this theory to the case of the remarkable comet of 1858, known as Donati's, by Professor Peirce. This comet had been continuously observed and mapped through all its varying and wonderful aspects, during the entire five months of its visibility, by Mr. George P. Bond, whose monograph on the subject, published in the Annals of the Harvard Observatory, with its numerous and beautifully executed illustrations, will always make it an authority of the highest character on the subject of cometary changes. Professor Peirce's analysis led to results entirely in harmony with the hypothesis, explaining not only the phenomena in general, but the special aspects, including the simultaneous exhibition of one or more rectilinear tails, along with the principal tail, which was curved in the form of a sabre. He applied a similar analysis to the great comet of 1843, with results equally satisfactory. Here also the investigation explained the existence of two tails, one of which did not reach the comet's head. The theory of electrical repulsion as applied to comets was proposed by some foreign astronomers, perhaps independently, at about the same time with the appearance of Professor Norton's memoir. It is frequently spoken of abroad as Professor Zöllner's view.

Auroras.—The aurora borealis has formed the subject of a pretty voluminous literature, both at home and abroad, during the last half century. All the scientific journals teem with articles on the subject, and the transactions of societies contain numerous elaborate memoirs relating to it. We can mention but a few of these publications, and those only briefly. In the first volume of Transactions of the Connecticut Academy there appeared the results of seventeen years' study of auroras by Edward C. Herrick, of New Haven, an observer unsurpassed for accuracy of observation and soundness of judgment. This paper will ever be a high authority in regard to the facts. Professor Loomis, of New Haven, examined a few years since the question of the periodicity of the aurora, and of its relation to the maxima and minima of solar disturbance as indicated by the spots, with reference to the possibility that both phenomena are dependent on a common cause. He found the periods nearly equal, but the auroral period less regular than the other, and the coincidences in general only approximate. This question was at the same time occupying Professor Lovering, of Harvard University, who has investigated it, so far as records go, to exhaustion. The tenth volume of the Transactions of the American Academy contains a catalogue by him of every aurora to be found in accessible records from the year 502 B.C. down to A.D. 1868. The total number is about 12,000; and this immense catalogue is carefully analyzed with a view to determine the daily, the yearly, and the secular periodicity, if such exists. The results, which are not only tabulated, but expressed in curves, do not exhibit all the regularity which might be anticipated, but they show, nevertheless, evidences of a periodicity, subject manifestly to large disturbances from unknown causes.

Meteoric Astronomy.—To American astronomers is due the credit of having first correctly interpreted the phenomena presented by the frequent intruders from the regions of space into our atmosphere called shooting-stars. In regard to the nature of these bodies the most widely various hypotheses had from the earliest times been held by different speculators, none of them supported by proofs, or resting on any systematic observation. Some of the earliest conjectures regarding them seem to have been soundest. Anaxagoras, whose general views of the structure of the universe were so much in advance of his time, supposed that there are non-luminous bodies revolving about the earth, from which meteors may proceed, though this idea is marred by the supposition that such bodies may have been thrown off from the earth itself by centrifugal force. Diogenes of Apollonia, whose own writings are not extant, but who wrote on cosmology, is said to have held that, besides the visible planets, there are other planets which are invisible. These sagacious conjectures, however, were overborne by the later authority of Aristotle, who inculcated the doctrine that shooting-stars are terrestrial meteors originating in the atmosphere itself—a doctrine generally received as the most probable down to the present century.

On the morning of November 13, 1833, there occurred one of the most wonderful displays of celestial pyrotechnics that was probably ever witnessed. As observed in the Eastern United States, it commenced about midnight and continued for some hours, increasing in magnificence until it was lost in the light of the rising sun. It was visible probably over the greater part of North America, and was actually observed at various points from the West India Islands to Greenland, and westwardly to the one-hundredth degree of longitude. From the numerous descriptions of this sublime spectacle with which, immediately after its occurrence, the journals of the day were crowded, it seems to have presented the appearance of a literal shower of fire, the meteors falling on all sides in prodigious numbers, and many of them exhibiting a splendor truly dazzling. An important fact in regard to these meteors noticed by many observers was the apparent divergence of their paths from a single radiant point. All accounts agreed in fixing this radiant in the constellation Leo, and in the statement that it continued to maintain its position unchanged as the constellation advanced with the diurnal motion of the heavens. This fact offered very conclusive evidence that the source of the meteors was foreign to the earth, and that their paths, though seemingly divergent, were actually parallel to each other and to a line drawn from the spectator to the radiant, the divergency being merely an effect of perspective. To Professor Denison Olmsted, of New Haven, belongs the credit of having first pointed out the legitimate conclusions to be drawn from these phenomena, which he did in a paper published in the *American Journal of Science* in March, 1834. Having first demonstrated the cosmical origin of the meteors, Professor Olmsted proceeded, with the aid of such imperfect data as at that time existed, including observations of a similar star-shower observed on the Eastern Continent in 1832, and of a much earlier one witnessed by Humboldt and Bonpland in Cumana, South America, in 1799, to devise upon this basis a theory adequate to account for the facts. The conclusion reached by him was that the meteors must be portions of a nebulous body drawn into the earth's atmosphere at a point of near approach, and inflamed by the heat generated by the resistance of the atmosphere to their motion. Professor Olmsted did not explain the meaning attached by him to the term nebulous. If he meant by it a gas, or a finely comminuted and uniformly diffused solid matter, his theory is inadmissible. But if he meant a congeries of loosely scattered discrete bodies, the phenomena are in harmony with his view; and to this extent the more recent and more exact investigations of Professor Newton, of Yale College, and Professor Schiaparelli, of Milan, have confirmed his conclusions. But in assigning to the supposed nebulous body a period of 182 days, and in his speculations as to the density of the constituent parts of the nebula, he was less happy. He supposed the specific gravity to be very small, whereas the researches of Newton and others conclusively prove that these bodies must have the average density of our harder rocks; and the numerous specimens in cabinets of the fragmentary portions of them which have forced their way through the atmospheric shield by which our planet is protected against their destructive impact are many of them largely or wholly composed of metal. The intense interest excited in all classes of persons by the meteoric display of 1833 turned the attention of a multitude of observers in this and other countries to the study of these phenomena—a study which was pursued both by the careful examination of records for the discovery of past examples of similar occurrences, and by the direct and continuous observation of the heavens themselves. The scientific journals of the period bear striking witness to the activity of these investigators. One of the most successful among them was Mr. E. C. Herrick, of New Haven, at that time, or later, librarian of Yale College, who presently announced the discovery of three or four additional periods of periodical shooting-star abundance or star showers, viz., in January, August, April, and December. In regard to the August period, Quetelet, of Brussels, was afterward found to have anticipated him, but his discovery of the others was original. Since that time observation in many quarters has been so persistent and so fruitful of results as to justify the statement that there are not fewer than fifty different days in the year on which there is a tendency to a meteoric display above the average.

As from the examination of records, ancient and modern, the number of observed returns of the November shower was increased, two very important deductions followed—first, the congeries of bodies furnishing the meteors must extend along its own orbit to a distance equal in longitude to about one-sixteenth or one-seventeenth of an entire circumference; and secondly, there must be a continuous advance or procession of the node, or intersection of the orbit with that of the earth, causing a retardation of the display by about a day at each return. The significancy of the accumulated data was first shown by Professor Newton in 1864, who, from a comparison of observations covering a period of 931 years, determined the length of the cycle to be 33.25 years, the annual mean procession of the node 1.711′, the inclination of the orbit about 17°, and the length of the part of the cycle within which showers might be expected 2.25 years. From these definitely ascertained results he deduced the highly important conclusion that the periodic time of the group of bodies from which the meteors proceed must be one of the five following, and no other, viz., 179.915 days, 185.413 days, 354.586 days, 376.575 days, or 33.25 years. It remained only, by applying the principles of physical astronomy, to compute the amount of annual procession of the node for each of these five orbits, and, by comparing the results with the observed procession, to determine which of the five orbits is the true one. This computation Professor Newton suggested as the *experimentum crucis*; but delaying to apply it himself, the honor was snatched from him by Mr. Adams, of Cambridge, England, who demonstrated that the only orbit of the five which fulfills the conditions is that which belongs to the period of 33.25 years.

Professor Newton followed up his success with the November meteors by investigations hardly less remarkable of the numerous irregularly occurring bodies of this class called sporadic. From a very large number of determinations of the altitudes of these bodies above the earth, he formed a table arranging the observations in groups between limits of altitude regularly increasing, by which it appeared that few are seen at heights greater than 180 kilometers and few below 30 kilometers, the mean altitude on the whole being 95.55 kilometers. He then, by a course of very ingenious reasoning and analysis, proceeded to demonstrate that the number of meteors which traverse some part of the earth's atmosphere daily, and are large enough to be visible to the naked eye (sun, moon, and clouds permitting), amounts to more than seven and a half millions. Including those fainter bodies of this class which escape the unaided eye, but may be detected by the telescope, this number must be greatly increased. Taking as a basis of calculation the number of telescopic meteors observed by Winnecke between July 24 and August 3, 1854, with an ordinary comet-seeker of 53′ aperture, the total number per day would seem to be more than 400,000,000—a number which higher optical power would, of course, correspondingly increase. The following are some of the more interesting conclusions reached in this investigation: 1. It is impossible to suppose that these sporadic meteors proceed from a group or ring at the same mean distance from the sun as the earth. 2. The mean velocity of these meteoroids considerably exceeds that of the earth in its orbit, and hence the orbits are not approximately circular, but resemble the orbits of comets. 3. The number of meteoroids in the space through which the earth is moving is such that in each volume of the size of the earth there are as many as 13,000 small bodies, each one of which is capable of furnishing a shooting-star visible, under favorable circumstances, to the naked eye.

The further contributions to the theory

of shooting-stars in which American astronomers have participated are those which connect these bodies with the comets. Near the end of December, 1845, Mr. Herrick and Mr. Bradley, of New Haven, watching the Biela comet with the Clark telescope in the observatory of Yale College, observed a small companion comet beside the principal one. The same was seen two weeks later by Lieutenant Maury and Professor Hubbard at the Naval Observatory at Washington, and two days later than this was noticed in Europe. Professor Hubbard thereafter made this body a special study. At the time of the observations above mentioned the comet was receding, and each day the pair presented some novel phase. At one time an arch of light connected the two; the principal one had two nuclei, and each had two tails. The smaller grew till it equaled the larger in brilliancy, then faded gradually, until, when the comet was last seen in March, it was no longer visible. In 1852 the comet was very distant, but it was still double, the two companions being a million and a quarter miles apart. Since September of that year this remarkable object has never been again seen. At the return in 1859, it was in conjunction, or nearly so, with the sun, and was necessarily invisible. In 1866 every thing favored its visibility, and hundreds of observers swept the heavens in search of it without success. Another return was due in the autumn of 1872. The body was not seen, but countless fragments broken from its mass came pouring into the earth's atmosphere on the night of the 27th of November, producing a star shower which for an hour or two almost rivaled in brilliancy that of the 13th of the same month in 1833. A German astronomer, Professor Klinkerfues, at once conceived the notion that, if this were the comet's following, the main body might be seen in its retreat, though we had not seen it in its approach. But if so, it must be seen in the southern hemisphere. He telegraphed Mr. Pogson, at Madras: "Biela touched earth November 27. Search near Theta Centauri." Mr. Pogson looked, and found the comet. The question is unsettled whether this was one of the two parts into which the comet was divided in 1845. Professor Newton thinks it was more probably a fragment thrown off long—perhaps centuries—before.

The comet of 1862, III., was discovered on the 18th July, 1862, by Mr. H. P. Tuttle, of Cambridge, Massachusetts. It has been proved by Professor Schiaparelli that this comet is only a large member of the August stream of meteoroids. The comet of 1866, I., discovered by Tempel, December 19, 1865, is shown also by Schiaparelli to be a member of the November stream. This comet Professor Newton has identified with one which appeared in 1366. From the evidence furnished in these instances, and for other reasons, Professor Newton and Professor Weiss regard all these meteoroids as sufficiently proved to be made up of countless fragments detached from solid cometary masses, which comets until thus entirely broken up are only large members of the swarms with which they move in company. The cause of the fracture is supposed by Professor A. W. Wright, of Iowa, to be the intense heat of the sun as the body approaches its perihelion. Professor Wright has recently obtained a gas from the Iowa meteorite which has the same spectrum as that of the comets. The comet's tail, therefore, is a gaseous emanation not to be confounded with these meteoroid masses.

Comets and meteoroids having thus been demonstrated to be generally identical, the question of the origin of all these bodies has become one of great interest. A theory on this subject, put forth in 1866 by Professor Schiaparelli, of Milan, assumed that matter is disseminated throughout space in all possible grades of division—embracing, in the first place, immense suns or stars of different magnitudes; secondly, groups of smaller or comparatively minute stars, such as those into which many of the nebulæ are resolved; then bodies so small as to be invisible except when they approach our sun, appearing then as comets; and finally, "cosmical clouds," made up of elements conformable in weight to such as we may handle or transport upon the earth. The elements of these cosmical clouds he supposes to be so distant from each other that their mutual attraction is insufficient to counteract the effect of the sun's unequal action upon their different members, so that when drawn into our system from the regions of space, they lose wholly their globular form, and enter as streams, "which may possibly consume years, centuries, and even myriads of years in passing the perihelion, forming in space a river whose transverse dimensions are very small with respect to its length." This was the essential part of a theory which won for its author the Copley medal from the Royal Society—a theory of which the only part not pure hypothesis is the demonstration that the mean velocity of the meteoroids exceeds that of the earth, and this fact had already been demonstrated by Professor Newton some years before. The rest, viz., all that relates to the different mechanical conditions of matter in space, is mere conjecture, and it is doubtful whether it continues still to be held by Professor Schiaparelli himself. A more probable theory of the origin of comets is suggested by a very significant observation of the sun made by Professor Young, of Dartmouth College, on the 7th of September, 1871. An explosion was seen to take place at that time, by which a volume of exploded matter was driven to a height of 200,000 miles, with a velocity, between the altitudes of 100,000 and 200,000 miles, of 166 miles per second. The visible clouds consisted of hydrogen. The resistance of the solar atmosphere prevented their complete separation from the sun, but should solid masses be projected with an equal velocity, they must be driven off never to return. Professor Young's observation, therefore, suggests an origin of comets which harmonizes with the views of Weiss and Newton as to the source of meteoric streams; and it is in further confirmation of these views that hydrogen was found by Graham in abundance occluded in meteoric masses, and that the gas of the Iowa meteor gave to Professor Wright a cometary spectrum.

METEOROLOGY.

As early as 1743 Dr. Franklin made the important discovery that the atmospheric disturbances known as northeast storms on the Atlantic coast of North America begin actually in the southwest. The first fact which drew his attention to this seeming physical paradox was the occurrence of an eclipse of the moon on the 21st of October in the year just mentioned, which a northeaster prevented him from observing at Philadelphia, although it was seen to its close by his brother, at Boston, before the storm began. This storm did great damage along the coast, and, from the accounts subsequently obtained, it appeared that its effects were felt progressively from Carolina to Massachusetts. Other storms of the same kind were observed to advance in the same manner, whence Franklin inferred the existence of a law, and proceeded to inquire the cause. This he presumed to be the rarefaction of the air by the tropical heats of the far south, producing upward currents, with diminished pressure and a consequent flow of air toward the region of rarefaction. This inference of Dr. Franklin was the first step toward a proper understanding of the law of storms in the temperate zones.

The views then held by Dr. Franklin as to the mechanical action of the air in water-spouts, and as to the identity of the phenomena with tornadoes on the land, were very nearly those at present entertained. He failed, however, to recognize the important agency of the heat set free by condensation in the whirling column in maintaining and promoting the violence of the action, and he supposed that the height of the column of water raised was limited to that which the static pressure only of the atmosphere is capable of sustaining in a vacuum. For a long period after these observations, meteorological science made very little advance either in this country or abroad. The year 1814 was marked by the publication of the well-known essay on dew by William Charles Wells, which has become a classic in meteorological science, and has been pronounced by Sir John Herschel a model of experimental inquiry. Dr. Wells was a native of Charleston, South Carolina, and though his life was principally spent abroad, he belongs in a certain sense to the science of America. In the year 1827 Mr. William C. Redfield, of New York, published the first of a series of papers in which he announced and maintained a theory of the storms of the Atlantic coast, or, as he called them, Atlantic hurricanes, which gave rise to much controversy, but which has since in substance been received as a true statement of the law governing the great progressive storms of the northern hemisphere. Mr. Redfield held—and aimed by a laborious comparison of observations upon the winds, made at numerous and widely distant points on land and at sea during these storms, to prove—that the storm is a vast whirlwind, circular in figure, its motion of gyration being to an observer within it from right to left. While such was supposed to be the internal movement, the whole storm was shown to have a motion of translation along a curved path, convex toward the west, and having usually its vertex in about latitude 37° or 38°, entering upon the continent between Georgia and Texas, and passing off on the coast of New England or of British America. The motion of progress is, therefore, the reverse of that of rotation, and the storm moves on its path in the same manner in which a wheel might be supposed to roll along a curved track. The birth-place of these storms was supposed by Mr. Redfield to be the West India Islands and the Caribbean Sea, and, like Franklin, he supposed them to be caused by uprising currents produced by local tropical heats. As for their progress, he supposed them to be borne along first by the trades, and then by the counter-trades, or prevailing west winds of the higher temperate zone.

To the theory of Mr. Redfield was opposed a rival theory, identified with the name of its originator, Mr. James P. Espy, of Pennsylvania, who published in 1841 an essay entitled, "The Philosophy of Storms." As to the origin of storms the two theories were in harmony; but Mr. Espy supposed the air currents within the storm to follow the direction of radii of the circle from the circumference to the centre, instead of being coincident in direction with the circumference itself. Long-continued and extended observation has shown that in this he was in error; and it is, in fact, capable of *a priori* demonstration that no two opposite atmospheric currents, drawn toward the same point by a local diminished pressure, can approach in straight lines or meet each other directly. From the configuration of the earth, and from its motion of rotation, of which the atmosphere partakes, such currents must necessarily deviate toward the right, producing as a result a motion of gyration. It is evident, however, that Mr. Redfield was not wholly correct. The true motion of the winds within the storm is neither rectilinear nor circular, but spiral, converging to the centre. Mr. Espy made an important contribution to the physics of storms in pointing out the source of the energy which maintains them in action after the merely local cause which originally produced them has ceased to have effect. This is the immense liberation of the heat of elasticity which takes place in consequence of the condensation of the aqueous vapor contained in the ascending air. As the air ascends, it expands from diminished pressure; expansion reduces its temperature below the dew-point; condensation occurs, and the heat released causes further expansion. Thus the process continues till the moisture of the air is exhausted. The storm would soon cease if it were not in this manner continually fed by fresh supplies of uncondensed vapor drawn in with the air from surrounding regions. No such storm can endure upon deserts like those of Northern Africa. Mr. Espy's merits were acknowledged by the French Academy of Science in a formal report. Professor Loomis, of Yale College, has made many valuable contributions to meteorological science in the study of particular storms, and more recently in a careful analysis of the weather maps which have for the last few years been issued daily from the Signal-office of the United States War Department. He has especially shown that while all our great storms are cyclonic, and to that extent conformable to Mr. Redfield's theory, they are not by any means, as Mr. Redfield had supposed, circular. They are rather irregularly elliptical, having their longer diameter generally north and south, inclining most frequently to the northeast and southwest direction, and they have often large sinuosities of outline.

The weather maps of the Signal-office just mentioned, and the system of widely extended telegraphic communication of observations from all points of our national territory to a single central office at Washington, by means of which the material is gathered for their preparation, have furnished admirable means for studying the laws which govern atmospheric changes on this continent. The system originated in 1869, at Cincinnati, with Professor Cleveland Abbe, who now conducts it, under General Myer, chief signal officer. The telegraphic prognostications of the weather daily transmitted for publication from the central office to all the chief cities of the Union have proved to be a very important public benefit. Something similar to this was attempted about twenty years ago by Mr. Espy, who then held an official appointment as meteorologist under the government, but the means at his command were more limited, and his organization less complete. The Smithsonian Institution, ever since its establishment, has been active in promoting meteorological observation, and has maintained constant communication with several hundred observers in all parts of the United States. Previously to the war the secretary, Professor Henry, had planned and had partially put into operation a system of weather bulletins and storm warnings like the present, which, in consequence of the disturbed state of public affairs, was necessarily abandoned after the commencement of hostilities; and for a number of years there was maintained at the institution a large meteorological wall map of the continent exposed to public view, on which were daily exhibited emblems showing the aspect of the weather and the direction of the wind at each of a large number of points of observation distributed widely throughout the country, as communicated by telegraph.

SOUND.

The science of acoustics has been greatly advanced by the labors of the physicists and physiologists of the present century. The mathematical theory of sound, the mode of its generation and propagation, the principles of music, and the laws of harmony had been well established by previous investigators. But the experimental study of the particular phenomena of vibration, of the physiology of audition, of the elementary tones which enter into the ordinary notes of music, of the physical causes of *timbre* or quality in sounds, and of whatever else in acoustics is incapable of being deduced abstractly from definitions or first principles, had received comparatively little attention, or had been pursued with little success. The recent progress of experimental acoustics has been wonderfully promoted by the ingenuity of the methods employed in the study of vibration; some of them graphic, in which the vibrations record themselves, and others optical, in which they present a visible picture of their phases to the eye. The methods strictly acoustic have, moreover, been greatly improved in the hands of modern investigators; as in the case of the *sirene* of Cagniard de la Tour, which has been converted by Helmholtz into an instrument of largely increased capabilities. The vibrating lens of Lissajous, and the revolving mirrors and manometric flames of Kœnig, have furnished admirable means of illustrating the composition and resolution of harmonic vibrations. Professor Tyndall's singing tubes and sensitive flames have shown in a striking manner the power of one vibration to excite or repress another. Recent comparatively simple forms of apparatus contrived by German experimenters have shown that the velocity of propagation of sound in air or other gases can be determined in the space of a few feet with as much accuracy as has been heretofore attained in the most elaborate and protracted observations made in the open air between signal stations separated from each other by some miles.

No single investigator has contributed more largely to the advancement of acoustic science than Professor Helmholtz, of Berlin. In his great work on tone sensation he has given the whole philosophy of composite waves and the theory of audition as founded on the capacity of the ear to resolve these waves into their component elements. He has shown that within a certain portion of the structure of the ear there are found a multitude of microscopic stretched cords, each of which is fitted to respond to a particular vibration, just as in a piano a single string will vibrate when its own note is sounded, while all the rest remain silent. He has also contrived hearing tubes or shells, called by him resonators, which possess this same property of separating an elementary tone out of an ordinary composite musical note, and by means of a series of these he succeeds in discovering all the elements of which such notes are composed. Every such elementary tone when separately heard has precisely the same quality, whether derived from a reed, a stringed, or a wind instrument; and thus it appears that the quality or *timbre* of a musical instrument is an effect of difference of composition, and not of difference of elementary sound.

In the United States the number of investigators who have occupied themselves with this interesting branch of science is small. Professor W. B. Rogers, now of Boston, gave some attention as early as 1850 to the curious phenomena of singing tubes, that is, of tubes which utter a musical note on the introduction within them of a small gas flame. The vibration was imputed by Professor Rogers to a periodical explosive combustion of the gas, extinguishing the flame, which is immediately re-illuminated. For the purpose of demonstrating this latter fact, he employed as his gas jet a tube bent twice at right angles, which, by means of a pulley, he caused to revolve rapidly around its lower limb. When this is revolved it produces an apparent ring of flame so long as the tube is silent; but the moment the sound begins, the ring breaks into a crown of minute flames resembling a string of pearls.

Professor Henry, in the discharge of his duties as chairman of the Light-house Board, has made many experiments on sound, with a view to improve the system of fog-signals. Some of the facts observed by him are interesting contributions to science. One of these is the remarkable property manifested by powerful sounds to propagate themselves laterally, or in directions divergent from that to which they are originally confined. A steam-whistle, for example, blown at the focus of a large parabolic mirror will at moderate distances be better heard in front and in the prolonged axis of the mirror than behind it; but when the distance amounts to several miles, it is heard as well behind as before. In like manner, if a source of sound be near a building, an observer at a distance on the other side of the building may hear it distinctly, and yet may entirely lose it as he approaches the building. Another remarkable observation is as to the effect of winds on the audibility of sounds. At any considerable distance a wind blowing from the observer toward the source diminishes the loudness. This is explained by the consideration that the lower strata of the air are retarded in their movements by the friction of the earth, and consequently that the fronts of the sound waves become inclined to the earth's surface. But as the direction of sound propagation is normal to the wave fronts, it happens that a sound proceeding against the wind is deflected upward so that its force passes above the heads of distant listeners.

The only elaborate continuous series of investigations in acoustics which has been undertaken in this country has been conducted by Professor A. M. Mayer, of Hoboken. The processes of Professor Mayer, which are themselves extremely ingenious, have led to many results of interest and value. It is a proposition deducible from theory, and was so announced by Döppler more than thirty years ago, that the undulations generated by a vibratory body in motion will be effectively shortened in the direction toward which the body moves, and lengthened in the opposite direction. This is true as well in optics as in acoustics, and it is upon the assumption of its truth that Mr. Huggins has founded his inferences as to the absolute velocities with which the fixed stars are approaching the earth or receding from it. It has first been experimentally proved in the researches of Professor Mayer.

The double *sirene* of Helmholtz affords a convenient means of studying the effect of partial or complete interference between sound waves which differ in phase at the point of origin, but there has been hitherto no instrumental means devised for determining the amount of difference of phase which exists between two waves originating in a common phase at the same origin, but brought by different and unequal paths to the point of interference. This want Professor Mayer has supplied, and in doing so has at the same time provided the most exact mode hitherto devised of measuring the wave length corresponding to any pitch, and of ascertaining the velocity of sound in the air or in any gaseous medium. The determinations are made by means of the serrated flames in Kœnig's revolving mirrors, and their precision is secured by what is called a flame micrometer—as ingenious in conception as it is exact in its indications.

The analysis of a composite note which Helmholtz accomplished by the use of his resonators, combined with Kœnig's manometric flames and revolving mirrors, was effected by Professor Mayer directly by connecting the arms of a number of steel tuning-forks by means of tightly stretched silk fibres with a membrane forming part of a reed pipe. On causing the pipe to speak, every fork whose tone forms a part of the note immediately sounded.

Professor Mayer has also presented very strong evidence to confirm the opinion which many naturalists have entertained, that the antennæ of insects constitute for them the organs of hearing, or organs, at least, through which they receive impressions for their guidance from the vibrations of the atmosphere; he has investigated and delineated the curves which represent the resultant sound wave of a composite note, and has devised the means of optically representing the movements by which a single molecule of an elastic vibrating medium must be animated under the influence of such complex impulses. The most interesting of his contributions to this department of science is found in his determination of the law which connects the pitch of a sound with the duration of its residual sensation, and in the deductions which flow from this law. It appears experimentally that if a sound of any pitch is suddenly arrested there follows a momentary dissonance, but that if the interruption is regular and periodic the dissonance diminishes with a diminution of the intervals till it finally disappears; also, that a more rapid succession of the impulses is necessary to this disappearance in proportion as the pitch is higher. Professor Mayer finds that for a tone produced by forty vibrations a second, the residual sensation lasts one-eleventh of a second, while for one of 40,000 vibrations per second, it lasts only one-five-hundredth of a second. This difference of duration of the residual sensation is the reason that trills upon the upper notes are pleasing, while those on the lower are not. The application of these principles to the study of harmony and to the means of producing the most agreeable effects in musical composition is important. F. A. P. BARNARD.

NEW YORK. [TO BE CONTINUED.]

GARTH:*

A Novel.

BY JULIAN HAWTHORNE.

CHAPTER IX.

IT is not my purpose to ask the reader's company across the threshold of the room where the dead body lies; let Garth pass in alone, and out of our sight. We have followed him closely enough thus far, and now, perhaps, it will be as well to pause and take a new departure; and, forbearing to make a direct inspection of the events of the next few years, to rejoin that square-visaged, dark-browed young gentleman in farmer's attire, whom we left, many pages ago, at his morning easel on the shore of the quiet lake. Here again is the level translucence of the silent surface, the golden islet at the cove's mouth, the broad glory of the October woods, the Persian pomp of distant Wabeno—every thing as it was before, save that the shadows of the trees on the eastern shore are less lengthened than at first. It now lacks but an hour or so of noon, and the artist is putting the finishing touches to his study. The stillness of the early morning, broken only by a few scattered bird notes, has melted into a voicelessness yet more profound, as though Nature were hushing herself beneath the overriding sun. When Garth sent forth a snatch of mellow whistling, or tapped his easel musingly with the handle of his paint-brush, the sound would go titillating articulately across the lake, and sometimes come tiptoeing back to its source, as an infant's spirit might revisit its earthly cradle. Had Garth been in the humor to shout aloud, or boisterously laugh, the whole wide basin would have been racked with noisy echoes. But he seldom raised his voice above a moderate conversational tone, and as a mode of soliloquy he preferred whistling to any other. It was a sort of musical accompaniment to thought, and threaded the whimsical incongruities of fancy on a strand of melody. Moreover, there was a delicate satisfaction in the nice evolution of such tuneful trifles, which bore analogy to the pleasure of a happy stroke of the brush, and enhanced it.

By-and-by Garth glanced up at the sun, and told himself that it must be eleven o'clock: too late to paint any more. Indeed, for the last half hour he had been