SCIENCE.

FRIDAY, FEBRUARY 8, 1895.

CONTENTS:

MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Prof. J. McKeen Cattell, Garrison on Hudson, N. Y.
Subscriptions (five dollars annually) and advertisements should be sent to the Publisher of SCIENCE, 41 East 49th St., New York, or Lancaster, Pa.

*AN HISTORICAL SURVEY OF THE SCIENCE OF MECHANICS.**

OUR age is at once the age of excessive specialization and the age of excessive popularization of science. Every smallest field of scientific activity has its gleaners and classifiers and builders of technical terminology. The workers in each field proceed, as a rule, without much regard to the interests and objects of the workers in adjoining fields, and it may easily happen that the precise and lucid, if not romantic, literature current in one field will be well-nigh unintelligible in another. So far, indeed, has this specialization gone that the various classes of specialists have but little common ground on which to meet, and it is sometimes difficult, if not impossible, for them to dwell together in peace and harmony. In a general scientific assembly, for example, the naturalists feel great uneasiness in listening to a paper from a mathematician or physicist, while the latter are almost certain to seek relief in the open air from the depression induced in them by the wealth of terminology essential to the description of a new species. The general public, on the other hand, busy though it be with multifarious affairs, is quick to appreciate the results of science and eager to know how they have been attained. To meet this legitimate demand for information, scientific and pseudo-scientific men have given us a flood of popular literature explaining almost every discovery, principle, theory, and speculation known to scientific thought. Nay more, and worse, this popularization has gone so far that many have come to think that the royal road to learning has been found ; that it is only necessary, in fact, to acquire a little of the technical terminology, to read a few books, and to witness a few pyrotechnic experiments to come into possession of

---

*Address delivered by Professor R. S. Woodward, at a meeting of the New York Academy of Sciences, November 26, 1894.

sound knowledge. Thus we hear of university courses in science carried on by correspondence and completed in a few weeks or a few months. The professional popularizer has been developed. He expounds science from the platform and through the the press; and there is no subject so abstruse as to deter him from producing a treatise on it in sixty days. Verily, it may be said, whosoever hungers for the bread of science may find an abundance ready made; but out of this abundance few are able to select the real staff of scientific life.

As a worker in one of the narrow fields of scientific thought, I find myself in difficulties to-night in seeking to say something which may be at the same time interesting and instructive concerning a science which is more than twenty centuries old, but which has rarely if ever attracted much popular attention. How to steer clear of the rocks of obtrusive technicality, on the one hand, and of the shoals of popularization on the other, is, you will no doubt agree with me, a rather appalling task. Moreover, there are special reasons why you might expect the science of mechanics to be the driest if not the dullest of subjects for a popular discourse. One reason lies in the fact that those who, from accident or force of circumstances, find themselves obliged to pursue the study of mechanics seriously for a few months in college, are wont to celebrate the completion of such study by making this science the subject of mock funeral rites or by relegating it to the bonfires of oblivion. Another reason finds expression in a very common notion, even among highly educated people, that the mathematico-physical sciences are like so many highly perfected mills whose remorseless and monotonous grinding soon converts their operators into mere automatons destitute of every human sentiment and deaf to every human song. In explanation of this notion, at a convention of professional educators held in this city about a year ago, a distinguished college president said with appropriate solemnity:—"The line *AB* cuts the line *CD* at right angles. Who ever shed tears over such a proposition as that?" he went on; and after the applause which followed had subsided he added, "and who ever laughed at such a proposition before?"

Notwithstanding these unfavorable auspices and the profound embarrassment they entail, I have ventured to invite your attention for the hour to some of the salient features of mechanical science, and to the element of human nature which is indissolubly connected with this as with every department of orderly knowledge; believing that neither the cold facts of the science nor the hard reasoning of its expounders can be devoid of interest when recounted in our vernacular.

In our search for the beginnings of a science we look always for the person who first formulated one or more of its principles in a way intelligible to his fellow men. The law of progress admonishes us that such a person is not necessarily or generally the sole discoverer, for ideas grow by slow accretions and become susceptible of clear statement only after being entertained in many minds. But of the many who think of the laws of nature few reach the high plane of generalization, and it thus happens that the duly accredited originators of any science are usually small in number and scattered through a long lapse of time. The name which deserves first mention in the history of mechanics is that of Archimedes. He was not only the founder of the science of mechanics, but he was also the first theoretical engineer. Indeed, he may be said to have laid the foundation for mechanics and engineering so securely with the cement of sound mathematics that its stability has sufficed for the weighty superstructure reared during the succeeding twenty centuries. He knew how to weigh and to measure and how to work out the numerical relations of things; and it is a singular fact, that in an age when fancy ran riot and when men were able to put together fine phrases without troubling themselves much with the ideas which ought to accompany their words, that Archimedes should have concentrated his attention on such unpoetic things as the principle of the handspike and the crowbar, and the laws of hydrostatics. His appreciation of the doctrine of the handspike and crowbar, or of the lever as it is technically called, was worthy of its far-reaching consequences; and the saying attributed to him—"Give me a fulcrum on which to rest and I will move the earth"—is a favorite though commonly ill-understood popular expression of his most important contribution to mechanical science.

For whatever purpose we read history, we are continually reminded that the absorbing occupation of humanity has been fighting one another. The thirst for blood and butchery has always been, and we fear still is, greater than the thirst for knowledge. Thus it was in the days of Archimedes; and although devoted to those abstract studies which engender no malice toward men, he served his king and country by building engines of destruction, and perished finally at the hands of a Roman soldier in the massacre which followed the fall of Syracuse.

The slowness of the growth of ideas and the blight upon scientific thought which followed the decay of the Grecian and Roman civilizations are forcibly brought to mind by the fact that scarcely an increment to mechanical science was attained during the eighteen hundred years which elapsed between the epoch of Archimedes and the epoch of Galileo. But, as if in compensation for this long period of darkness, the torch of science relighted by Galileo has burned on with increasing intensity until now its radiance illumes almost every thought and action of our daily life. The fame of Galileo in the popular mind rests chiefly on his invention of the telescope and on his battle with the Church in the field of astronomy. But he was able to see things at short as well as at long range; and his observations on the vibrating chandelier in the cathedral at Pisa and on the laws of falling bodies must be rated as of much higher value than his discovery of the satellites of Jupiter. The peculiar merit of those observations lay in the fact that they led him to correct notions of the properties of moving masses, and of the behavior of matter under the action of force. Archimedes had dealt with matter in a state of relative rest, or with statics only. Galileo rose to the higher concept of matter in motion, and founded that branch of mechanics now known as dynamics.

It seems strange at first thought when we look back through the light of modern analysis on these advances that they should have been so slowly achieved and still more slowly accepted and utilized. We must remember, however, that the elaboration of the principles which Galileo added to our science involved the removal of much scholastic rubbish. It was essential first of all to establish the validity of precise and correct observation. He had to recognize that in studying the laws of falling bodies the most important question was not *why* they fall but *how* they fall. In doing this he set an example which has ever since been followed with success in the investigation of the phenomena of nature. Considering the times in which he lived, the amount of work he accomplished is little short of prodigious. For besides his capital contributions to mechanics and astronomy, he was the founder of our modern engineering science of the strength and resistance of materials, a science which has recently grown into a great department of mechanics under the title of the mathematical theory of elasticity. Thus, like Archimedes, he added to the practical side of science; indeed, a rude woodcut in one of his discourses, showing a beam built into a stone wall and loaded with a weight at the free end, proves that he had no scorn for common things and gives the key to a long line of subsequent researches. He was also the inventor of the thermometer, the hydrostatic balance, and the proportional dividers, all of which instruments are still in use; and for the edification of those who think the pursuit of his favorite studies leaves no room for the play of the fancy, it should be mentioned that he found time to give popular lectures on the site and dimensions of Dante's *Inferno.*

Although it is an axiom of modern philosophy that coincidence of events is no adequate evidence of their connection, yet there seems to be an innate tendency of the mind to anticipate a relation between nearly simultaneous occurrences and to attach much importance to them when they are historically allied. It is one of the curious coincidences in the history of the founders of mechanics that the year of Galileo's death is also the year of Newton's birth. Thus it might seem that Nature took care that Galileo should have a fitting successor.

During the interval of nearly a hundred years which elapsed between the epoch of Galileo and the period of Newton's activity, not a few philosophers added to the growth of mechanical science. Most conspicuous among these was Huyghens, who distinguished himself as a mathematician, astronomer, mechanician, and physicist. Of his varied and valuable contributions to these departments of knowledge, what would strike the general reader as least worthy of attention was really of the highest importance. Nothing is commoner now than the pendulum clock. The town clock and Grandfather's clock are so proverbial that few would suppose that a grand treatise could ever have been written about such a commonplace mechanism. But true it is that Huyghens, taking up Galileo's discovery of the near isochronism of the swinging chandelier, not only produced a working pendulum clock, but also a great theory of it. The introduction of this instrument for the exact measurement of time made the subsequent progress of astronomy possible, while his theory of the oscillating pendulum has been justly called the true prelude to Newton's *Principia.* The laws of vibration indeed play a wonderfully important rôle in the science of mechanics, and it may be said that he who understands the doctrine of the pendulum in all its phases has in his possession the key to the secrets of nearly every mechanical system from the common clock to the steam engine, and from the steam engine to the solar system. Well may we retain the euphonious title of *Horologium Oscillatorium* for this important memoir of Huyghens.

Chaucer—

"Dan Chaucer, the first warbler, whose sweet breath
  Preluded those melodious bursts that fill
The spacious times of great Elizabeth
  With sounds that echo still,"

has been called the Father of English literature. In a broader sense, because not limited by language, we may regard Newton as the Father of Natural Philosophy.

It was the happy lot of Newton to attain these brilliant achievements. First and greatest of these was the well nigh perfect statement of the laws of dynamics; the second was the discovery of the law of gravitation; and the third was the invention of a calculus required to develop the consequences of the other two. As we have seen, however, the laws of matter and motion were not unknown to the predecessors and contemporaries of Newton. Galileo, in fact, discovered the first two, and the third in one form or another was known to Hooke, Huyghens and others; but it was the peculiar work of Newton to state these laws so clearly and fully that the lapse of two centuries has suggested little, if any, improvement.

What, then, are these laws, you may enquire? Let me turn them into the vernacular. The first two assert that matter never starts off on a journey without solicitation; having once started it never changes its speed or direction unless forced to do so; when put to this extremity, it shows perfect impartiality to every deflecting force; and finally, it never stops unless arrested. Add to these the obvious fact that action and reaction are equal and opposite, and we have a body of doctrine which, simple as it may seem, appears to be coextensive with the material universe. It must be admitted, of course, that a mere comprehension of these laws does not suffice to make a mechanician. Between these stepping stones and the table-land from which Newton looked out on the order of nature there is a long and steep ascent; but whoso would scale the heights must go by way of these stepping stones.

The law of gravitation, though commonly considered the greatest of Newton's achievements, is, in reality, far less worthy of distinction than his foundation for mechanics. Its chief merit lay in the clear perception of the application of the law to the smallest particles of matter, for the mere notion of gravitation between finite masses was familiar to his contemporaries; in fact, according to Newton's own statement, the law of inverse squares as applicable to such masses was within the reach of any mathematician some years before the publication of the *Principia*.

A matter of the greatest importance in the history of Newton's work relates not so much to the substance as to the form of it. It is now known that the grand results brought out in his *Principia* were reached chiefly by means of his calculus, or fluxions, as he called it, a contribution to science hardly less important than either of his others. But the fashion of his day did not favor reasoning by means of infinitesimals, those mysterious increments and decrements which the learned and eloquent Bishop Berkeley a half century later called 'the ghosts of departed quantities.' The fashion, or rather prejudice, of Newton's day was strongly in favor of geometrical reasoning; and it would seem that he felt constrained to translate the results to which his calculus led him into geometrical language. It was desirable, he thought, that the system of the heavens should be founded on good geometry. Subsequent history shows that this course was an ill-judged one. The geometrical method of the *Principia* renders it cumbersome, prolix, and on the whole rather repulsive to the modern reader; and the only justification which appears at all adequate for the exclusive adoption of this method, lies in the fact that his fellow countrymen would not have readily appreciated the more elegant and vastly more comprehensive analytical method. The result was very unfavorable to the growth of mechanical science in his own country. The seed he sowed took root on the continent and has ever since grown best in French and German soil. According to Prof. Glaisher, in an address delivered by him at the celebration of the 200th anniversary of the publication of Newton's great work, "the geometrical form of the *Principia* exercised a disastrous influence over mathematical studies at Cambridge University for nearly a century and a half, by giving rise to a mistaken idea of the relative power of analytical and geometrical processes."

Readers of English mathematical text books and treatises can hardly fail to notice that the bias they show for geometrical methods, and especially for the formal, Euclidean mode of presentation, in which the procession of ideas too frequently consists of formidable groups of painfully accurate and technical paragraphs labelled Proposition, Corollary and Scholium. This formalism leads to a strained and unattractive literary style, which frequently degenerates into intolerable complexity and obscurity. It is against this sort of 'logic-chopping' that most minds rebel, against this excessive attention to the husks rather than to the kernel of the subject. Another and equally serious result of the apotheosis of pure geometry is the tendency to magnify the importance of ideal problems and the work of problem solving. The exclusive pursuit of such aimless puzzles constitutes the platitude of mathematical research, though it often happens that the devotees to this species of work are mistaken for mathematicians and natural philosophers.

It is not specially difficult in our day to understand how a mind of Newton's capacity should achieve so many important results. The simple fact is that he possessed just such powers of observation and reflection as were needed to correlate the facts his predecessors and contemporaries had collected; and the most instructive lesson of his life to us is the success which attended the industrious application of those powers. But, on the other hand, it cannot be said that the circumstances of his life were very propitious for his work, or that he availed himself to the fullest extent of his opportunities. His favorite studies were, in fact, pursued somewhat fitfully, and not always with a just appreciation of their merits. Possessing to a painful degree that modesty which is born of a knowledge of things, he shrunk from the controversy into which his discoveries drew him; and it appears probable that his *Principia* would never have been written had not his friend Halley urged him on to the marvelous feat which brought out that masterpiece in less than two years' time. The demand for works on natural philosophy in his day and the appreciation of the public for natural philosophers may be inferred from the fact that neither Newton nor the Royal Society of London, to which his great work was dedicated, was able to furnish the funds essential to print an edition of 250 copies. The entire expense of this first edition was born by Halley, who may thus be justly called the discoverer of his more famous fellow-countryman. In such hard times and under such depressing circumstances, it is not strange that Newton should have sought and obtained a position in the public service; though it seems a pity that one of the greatest of philosophers, one who said his head never ached except when studying the mechanics of the motions of the moon, should have busied himself during his declining years with the dreary details of fiscal business as master of the mint.

The period of about a hundred years which followed the epoch of the culmination of Newton's activity is remarkable for the diversity of mechanical problems to which mathematicians devoted their attention. The discoveries of Newton comprised and superseded the discoveries of Copernicus and Kepler. The sun with his planets and the planets with their satellites became grand mechanical systems under the law of gravitation. But a crowd of additional consequences of this law demanded serious study and prolonged observation. Newton had seen that the gravitation and rotation of the earth ought to make it flattened at the poles. To test this question it was essential to devise ways and means for measuring the size and shape of the earth. Out of this necessity grew the science of geodesy. Maupertius and Clairaut had to be sent to Lapland, and Bouguer and La Condamine to Peru to measure arcs of meridian before definite ideas of the figure and dimensions of our planet were attained. The precession of the equinoxes had been discovered by Hipparchus. The law of gravitation supplied a reason for this phenomenon; but to understand it fully the properties of rotating bodies had to be elaborately studied by Euler and d'Alembert. Observational astronomy began far earlier than the era of Hipparchus; but precise observational astronomy was not possible before Huyghens' invention of the pendulum clock and before Newton's law led the way to separating the motions of the earth from those proper to the stars and to light.

The earlier part of the period in question was also characterized by the variety of special processes used in the applications of mechanics. This peculiarity is due partly to the fact that the great method of investigation now known as the differential and integral calculus was not duly understood and appreciated. Newton, as we have seen, devised and used this method under the name of fluxions, but dared not bring it into prominence in his *Principia*. Independently of, though a little later than Newton, Leibnitz discovered substantially the same method. Priority of publication of the method by Leibnitz led to one of the most remarkable and bitter controversies in the history of science; proving amongst other things that scientific men are no better than other folks, and giving color to Benjamin Franklin's allegation that mathematicians are prone to be conscientiously contentious. But this war of words, in which personal and national prejudice figured shamefully enough, did not long disturb the minds of continental mathematicians. The Leibnitzian form of the calculus, by reason of its intrinsic merits, came into general use. The Bernoullis, Euler, Clairaut, and d'Alembert, who were the leading mathematicians of the time, adopted the calculus as their instrument of research and paved the way to the age of extraordinary generalizations which began near the end of the eighteenth century.

The variety of problems considered and the diversity of methods employed during this period served to call attention to the need of more comprehensive mechanical principles. Before the publication of d'Alembert's treatise on dynamics in 1743, each problem had been considered by itself, and although many important results were attained, the principles employed did not appear to have any close connection with one another. There was thus an opportunity for rival schools of mechanicians, and they fell into the habit of challenging one another with what would now be called prize problems. The first step toward a unification of principles and processes was made by d'Alembert in the treatise just mentioned. This treatise announced and illustrated a principle, since known as d'Alembert's principle, which put an end to rivalry by showing how all problems in dynamics can be referred to the laws of statics. By the aid of this principle, d'Alembert showed how to solve mechanically not only the splendid problem of the precession of the equinoxes, but also that more recondite question of the nutation of the earth's axis. The fact of nutation had been discovered a year and a half earlier by the astronomer Bradley; but d'Alembert's explanation of this fact, according to Laplace, is not less remarkable in the history of mechanics than Bradley's discovery in the annals of astronomy.

The work of the devotees to mechanics in the times of which we speak is not generally fully appreciated. Their fame is, indeed, eclipsed by that of Newton and by that of their immediate successors. But their contributions were important and substantial. Clairaut gave us the first mathematical treatise on the figure of the earth; while his colleague, Maupertius, in the famous Lapland expedition, announced the the principle of 'least action' and the 'law of repose,' both of which have proved fruitful in later times. The Bernoullis, a most distinguished family of mathematicians, of whom John the first and his three sons were then active, worked in all fields of mathematical research, and rendered especially good service in extending the theory of elasticity founded by Galileo. The industrious Euler, a pupil of John Bernoulli, and a companion of his sons, enriched analysis in every direction, gave for the first time the correct theory of rotating bodies, and wrote on almost every question in the mathematics, physics, and astronomy of his day. It is estimated that his memoirs if fully printed would fill sixty to eighty quarto volumes. Not the least noteworthy of his works are his Letters to a German Princess, giving a popular account of the principles of mechanics, optics, acoustics, and astronomy.

Notwithstanding the broad foundation for mechanics laid by Newton in his *Principia*, and notwithstanding the indefatigable labors of Clairaut, d'Alembert, the Bernoullis, and Euler, there was near the end of the eighteenth century no comprehensive treatise on the science. Its leading principles and methods were fairly well known, but scattered through many works, and presented from divers points of view. It remained for Lagrange to unite them into one harmonious system. Mechanics had not yet freed itself from the restrictions of geometry, though progress since Newton's time had been constantly toward analytical as distinguished from geometrical methods. The emancipation came with Lagrange's *Mécanique Analytique*, published one hundred and one years after the *Principia*. How completely the geometrical method was supplanted by the analytical, at the hands of Lagrange, may be inferred from a paragraph in the advertisement to his *Mécanique Analytique*. "One will find" he says, "no diagrams in this work. The methods I expose require neither geometrical construction nor geometrical reasoning, but only algebraical operations subjected to a regular and uniform procedure."

From a philosophical and historical point of view this characteristic feature of the *Mécanique Analytique* is of the greatest importance. The mere statement of the fact, however, conveys no adequate idea of the immense value of Lagrange's treatise. The value of his work consists in the exposition of a general method by which every mechanical question may be stated in a single algebraic equation. The entire history of any mechanical system, as for example, the solar system, may thus be condensed into a single sentence; and its detailed interpretation becomes simply a question of algebra. No one who has not tried to cope with the difficulties presented by almost any mechanical problem can form a just appreciation of the great utility of such a labor-saving and thought-saving device. It has been well called 'a stupendous contribution to the economy of thought.' But Lagrange did more than this for the science of mechanics. He not only perfected a unique and comprehensive method, and showed how to apply it to many of the most important and recondite problems of his day, but he was the first to draw sharply the line of demarcation between physics and metaphysics. The mechanical ideas of Descartes, Leibnitz, Maupertius, and even of Euler, had proved to be more or less hazy and unfruitful from a failure to separate those two distinct regions of thought. Lagrange put an end to this confusion, for no serious attempt has since been made to derive the laws of mechanics from a metaphysical basis.

The age which witnessed the culmination of the splendid generalization of Lagrange in his *Mécanique Analytique* was also the age in which Newton's law of gravitation received its verification, and the age in which the foundations of the modern science of mathematical physics were laid. Lagrange himself is closely identified with these two important events in the history of mechanics; but the names which outshine all others are those of Laplace and Poisson.

It was the life-work of Laplace to deduce the consequences of the law of gravitation as applied to the solar system. No problem of equal magnitude has ever been attacked and treated single-handed with such consummate skill and success as shown by Laplace in his *Mécanique Céleste*. The five volumes of this work, together with the popular exposition contained in his *Système du Monde*, constitute, I think, the greatest systematic treatise ever written. Think, for a moment, of the mental equipment essential to begin such an investigation. Copernicus and Kepler had discovered by observation the salient features of the motions of the planets about the sun. Newton showed that these features were immediately and easily derived results of the law of gravitation. But these were the salient features only. Had our planet been the sole one of the system, had it been moonless and devoid of rotation, the task of Laplace would have been easy. But instead of a single planet, there is a crowd of them, each rotating on its axis while traveling about the sun, and most of them accompanied by lunar attendants. When this array of facts is considered, the simple law of gravitation leads to great complication. The motion of our planet at any time depends not only on its position relatively to the sun, but on its position relatively to the neighboring planets. Our moon also plays an important rôle in the motions of the earth. By reason of these interactions the earth's axis of rotation, which is the principle line of reference for astronomical observations, pursues a devious course in the heavens. Add to these difficulties those arising from the facts that our planet is surrounded by an atmosphere which prevents us from observing our true relative position, and that light travels with a finite though great speed, and the magnitude of the task Laplace set for himself is in some degree apparent. A complete mastery of every branch of the mathematics and physics of his day and a capacity to enlarge the boundaries of either were the indispensable prerequisites, which, supplemented by a boundless genius for industry, enabled him to make dynamical astronomy the most perfect of the applied sciences. His conception of the magnitude and importance of the work he undertook is clearly but modestly set forth in the preface to the *Mécanique Céleste*. "Astronomy," he says, "considered in the most general manner, is a grand problem of mechanics, whose solution depends on the precision of observations and on the perfection of mathematical analysis. It is extremely desirable to avoid all empiricism in our treatment of this problem and to draw on observation for indispensable data only. The present work is destined to accomplish, as far as I am able, this interesting object. I trust that, in consideration of the difficulties of the subject, mathematicians and astronomers will receive the work with indulgence."

Not less important than the contributions of Lagrange and Laplace to pure mechanics and dynamical astronomy were the voluminous and luminous writings of Poisson during the same period. Equally at home with Lagrange and Laplace in their favorite researches, many of which he corrected and extended, he explored the additional fields of heat, light, elasticity, electricity, and magnetism. To his penetrating insight into these abstruse subjects and to the wealth of analytical resources he developed are due more than to any other single source the subsequent developments of mathematical physics, by which is meant the application of mechanics to physical questions. His discoveries and researches are scarcely less brilliant than those of his two eminent contemporaries, while he outstripped both of them in his range and grasp of mathematical and physical principles. Moreover, he was the prince of expositors of mathematical subjects. His memoirs (of which there are more than 150) must even now be classed amongst the best models of scientific exposition.

It is a striking series of facts that the three most eminent workers in our science during the period in question, a period extending, say, from 1775 to 1825, were all Frenchmen, that they were warm personal friends, and that they all resided, in their later years at least, at Paris. Still more striking is the fact that this period of extraordinary development in mechanical science was coincident with a period of most profound social agitation with Frenchmen in general and with Parisians in particular. How was it possible to pursue abstract theories of matter and motion, how was it possible to contemplate the grandeur of the celestial universe at a time when the heads of statesmen and philosophers were falling into the waste basket, not before the metaphorical axe of changing ministers, but before the whetted blade of the guillotine? Tocqueville, in his Democracy in America, has warned us against the depressing effect on abstract thought of the incessant attrition of American life. Why did not the stormy times of the French Revolution check the current of scientific progress? The answer to these questions is to be found, I think, in the fortunate circumstance that Frenchmen and the French government, whatever may have been their shortcomings in other respects, have developed a higher appreciation for science and scientific men than any other nationality. However they may have fallen out as a people on questions of religion and politics, they have maintained a high regard for scientific thought. It was his admirable devotion to celestial mechanics that saved Laplace from disgrace, or a worse fate, at the hands of his fellow-countrymen. Even the sorry figure he cut during his brief career as Minister of the Interior, into the business of which he introduced the 'spirit of the infinitesimals,' as the future emperor said, did not deprive him of favors due to a man of science.

The personal characteristics and the intimate friendship and association of Lagrange, Laplace, and Poisson are amongst the most attractive features of their lives, and worthy of a brief digression.

Lagrange was of French descent, though he was born at Turin and became famous before taking up a residence at the focus of French civilization. While yet a youth, the ample means of his family were lost in commercial speculation; and to this early lesson of adversity is due, probably, the determination of his career, for he was wont to say that had he been rich he might never have pursued mathematical studies. Like most mathematicians of distinction, he seems to have owed much less to scholastic instruction than to his own efforts and industry. At the age of eighteen he was appointed professor of mathematics at the royal school of artillery at Turin; and at nineteen he was in correspondence with Euler concerning isoperimetrical problems, which ultimately led to his perfection of that highest branch of pure mathematics, the caculus of variations. At twenty-two he was one of the founders of a society which afterwards became famous as the Turin Academy of Sciences. At the early age of thirty he was called to the post of director of the mathematical department of the Berlin Academy of Sciences as the successor of the distinguished Euler. Here he remained for twenty years' working with marvelous industry and success. About the time of the appearance of his great work on analytical mechanics in 1788, he removed to Paris at the instance of the French court, which made him a 'veteran pensioner' and received him with the most flattering honors. He lived through the stormy period of the Revolution, winning additional favors and distinctions from the French government, and closing his remarkable career at the ripe age of seventy-seven.

Little seems to be known of the ancestry and early life of Laplace. It appears, however, that he was the son of a farmer and that he had achieved some local distinction as a teacher of mathematics at the age of eighteen, when he went up to Paris with such letters of recommendation as he could get, and applied for a position in the government schools. He appealed to d'Alembert, who was then the leading mathematician at the French capital, but d'Alembert, it is said, gave no heed to either the application or the recommendations of the aspirant for office. Thereupon the unknown Laplace wrote the great geometer a letter on the principles of mechanics which brought an immediate reply. "You needed no introduction or recommendation," said d'Alembert, "you have recommended yourself; my support is your due." Through the influence of d'Alembert, Laplace was soon given a professorship of mathematics in the military school of Paris, and his scientific career was thus begun. He was not yet twenty-five years of age when he made one of the most important advances in the history of dynamical astronomy toward the solution of the grand problem of the stability of the solar system. By this step he became at once the peer of his older and eminent contemporaries, Euler, d'Alembert, and Lagrange. From this time on until his death in 1827, his indefatigable labors and penetrating insight brought to light a continuous series of brilliant discoveries. The history of dynamical astronomy, indeed, for the half century ending with 1825, is essentially the history of the work of Laplace as recorded in his *Mécanique Céleste*. A persistent and lofty enthusiasm for the system of the world is displayed in all his works; his latest writings even being no less inspiring than his earliest. His zeal recognized no bounds. "He would have completed the science of the skies," says Fourier, "had that science been capable of completion." He died at the age of seventy-eight, and his last words were worthy of the philosopher he was. "What we know is very little; what we are ignorant of is immense."

Poisson, the youngest of this famous trio, was forty-five years younger than Lagrange and thirty-two years younger than Laplace. He was born of humble parentage at Pithiviers, in 1781, his father at that time being a petty government official. While yet an infant, Poisson was confided to the care of a neighboring peasant-woman, at whose hands he received rather startling treatment for one who was destined to become famous in the annals of science. Poisson relates that his father came one day to see how his son was getting on, and was horrified to find that the peasant-nurse had gone to the fields, leaving the child suspended from the ceiling by a small cord at a height just sufficient to secure immunity from the teeth of the swine which, it seems, had free access to the house. In relating this novel incident in his early life, Poisson used to say that "a gymnastic effort carried me incessantly from one side of the vertical to the other; and it was thus, in my tenderest infancy, that I made my prelude to those studies of the pendulum that were to occupy me so much in my mature age."

As the youth grew up, receiving the bare elements of education from his father, the question was raised in his family as to what calling he should follow. It was suggested that he should become a notary, but the better judgment of the family councils decided that the business of a notary required too much intellectual capacity for the young man, and it was therefore determined to make a surgeon of him. He was apprenticed to an uncle who practiced the art of blood-letting and blistering of that day, and who set the beginner at work pricking cabbage leaves with a lancet. How he got on at surgery, Poisson himself relates best: "One day my uncle sent me," he says, "to put a blister on the arm of a sick child; the next day when I presented myself to remove the apparatus, I found the child dead. This event, very common, they say, made a profound impression upon me; and I declared at once that I would never become a physician."

He returned to his home, where, soon afterwards, an accidental circumstance revealed the true bent of his mind. His father, being still a government officer, received a copy of the *Journal de l'École Polytechnique.* The son read it, and was able, unaided, to understand some of its contents. He was encouraged to study and soon went to the school of Fontainebleau. Here he was fortunate in finding a good and sympathetic teacher in one M. Billy, who took a warm interest in, and formed a life-long attachment for, his pupil.

At the age of seventeen Poisson went to Paris to enter the *École Polytechnique.* His genius soon disclosed itself, and at the end of his first year he was excused from the requirements of the set curriculum and allowed freedom of choice in his studies. Before he had been at the school two years, or before he was twenty years of age, he published two memoirs which attracted the attention of mathematicians, and led to his speedy entrance into Parisian scientific society, whose leaders at that time were Lagrange and Laplace. They were quick to recognize and appreciate Poisson's ability, and it was doubtless through their good offices that Poisson was appointed to a professorship at the *École Polytechnique,* where he succeeded the distinguished Fourier in 1806. From this time to the end of his life in 1840, Poisson was connected with the educational system of France. As a scientific investigator his untiring patience, industry, and success have been equalled only by those of Euler, Lagrange, and Laplace. "Life," he was wont to say, "is good for two purposes only: to invent mathematics and to expound them."

One of the best estimates of the character and scope of Poisson's work may be inferred from the esteem in which he was held by Lagrange and Laplace. They treated him with the greatest consideration; and that Lagrange considered him a worthy successor in the footsteps of the most eminent of mechanicians is shown by the following incident related by Arago: "I am old," said Lagrange to Poisson one day; "during my long intervals of sleeplessness I divert myself by making numerical calculations. Keep this one; it may interest you. Huyghens was 13 years older than Newton; I am 13 years older than Laplace; d'Alembert was 32 years older than Laplace; Laplace is 32 years older than you." Arago remarks that no more delicate way could be conceived of intimating to Poisson his admission to the inner circle of the fraternity of mathematical genius.

The dazzling spendor of the achievements in dynamical astronomy during the epoch of Laplace not only diverted attention from other applications of mechanical science, but it would seem also to have led to an underestimate of the importance of such applications. Thus the work of Fourier and Poisson in the theory of heat, and that of Fresnel and Green in the theory of light, were not duly appreciated by contemporary philosophers. All eyes were turned towards the heavens. The permanence of the solar system and the dangers of encounters with comets were more important questions than those presented by phenomena close at hand. For nearly a quarter of a century after the epoch of Laplace, comparatively little progress was made in the fundamental ideas of our science, though its machinery received many important accessions, especially from Green and Gauss.

About 1850, however, the accumulating data of experimental philosophers and the reflections of a number of theorists led to the announcement of the principle of the conservation of energy, a doctine which is now held to be the highest generalization of mechanical science. This doctrine asserts that the total energy of any mechanical system is a quantity which can neither be increased nor dimished by any mutual action of the parts of the system, though it may be converted into any one of the forms of which energy is susceptible. Thus, the solar system, supposing it to be isolated from all other systems of the universe, contains a definite amount of energy, and whatever may have been or may be the vicissitudes of the sun and planets, that quantity of energy was and will be the same.

But what, in common parlance, some one may properly enquire, is energy in a mechanical sense? The answer to this question is not difficult. If we raise a weight, as, for example, an elevator car above the surface of the earth, work must be done. On the other hand, if it be elevated and its cable be cut, the car will fall back to the earth and do work of destruction in its fall. The work stored up in raising the car to a given height is called energy of position, or potential energy. The work the car can do by reason of its fall is called energy of motion, or kinetic energy. If a strict account of the expenditure is kept in this case, it is found that the sum of the energies of position and motion at any instant is constant. Similarly, it was found by Count Rumford and Joule that in boring cannon and in agitating liquids heat is produced, and that if in these cases accurate record is kept, the amount of heat developed bears a definite ratio to the amount of energy expended. Thus heat is brought into the category of energy, hot bodies being such, as we now think, by reason of the more or less furious agitation, or kinetic energy, of their ultimate particles.

The law of the conservation of energy, then, is a simple statement of Nature's balance-sheet with respect to material systems. The capital invested remains always the same, however diversified may be the investments. A part may be entered as potential energy; a part as kinetic energy; a part as heat; etc., but when properly added together, their sum is constant. Broadly speaking, it is believed that the various forms of energy may be comprised in two categories: the energy of position, or potential energy, and the energy of motion, or kinetic energy.

It is interesting to note in connection with the history of this doctrine that the ideas which led up to it go back certainly to the time of Newton and Leibnitz. The conservation of matter is, indeed, a fundamental concept of mechanics; but the earlier philosophers, from Newton and Leibnitz down, were acquainted with the conservation of momentum and energy in a variety of special cases. And it is probable that our modern science owes something to the metaphysical notions of Descartes, Maupertius and others, who held that Nature performs her operations in the most economical ways and is, on the whole, conservative.

It appears not a little remarkable that this important doctrine eluded the insight of Lagrange and Laplace. Lagrange, especially, was so near to it that he supplied nearly all the analytical machinery essential to put it into practical use. Indeed, that machinery meets a much higher demand. It not only enables us to express and interpret the properties of systems which are obviously mechanical, but it shows clearly what must be the characteristic features of a mechanical explanation of any phenomenon. Thus, in the direct application of the doctrine of energy to a mechanical system, we express the kinetic energy in terms of the masses involved, their coördinates of position, and the time from any assumed epoch; while the potential energy is expressed in terms of the masses and their relative positions, irrespectively of the time. From the expressions for these two parts of the energy, all of the properties of the system can be derived by means of the Lagrangian machinery. In the case of most phenomena it is impossible to observe more than a very limited number of the circumstances of motion; such as, for example, the coördinates of one or more of the masses at definite epochs, the rates of variation of those coördinates, etc.; but if we can express the two parts of the energy, and if the derived circumstances agree with the observed circumstances, the mechanical explanation is regarded as complete. On the other hand, a phenomenon may not be clearly or obviously mechanical, and it becomes important in many cases to learn whether it is susceptible of mechanical explanation. The criterion supplied by the Lagrangian machinery is this: If the phenomenon can be defined by two expressions or functions having the properties of kinetic and potential energy, a system of masses with appropriate positions may be found to satisfy those functions and hence explain the phenomenon mechanically.

The law of the conservation of energy, then, affords a very comprehensive view of mechanical phenomena; and when we add that this law is believed to be coextensive with the material universe, one can see why it should have played so important a rôle in the recent developments of mechanical science. Along with the growth and applition of this law has come a degree of perfection in the technical terminology of mechanics surpassing that of most other sciences. The terms mass, force, energy, power, etc., as now used in mechanics, possess a precision of meaning which, strange as it may seem, was largely wanting in them thirty to fifty years ago. Nothing illustrates this fact more forcibly than titles to some of the important papers published during the past half century. Thus, the great memoir published in 1847 by Helmholtz on what we now call the conservation of energy was entitled 'The Conservation of Force.' In 1854 Prof. Thomson, now Lord Kelvin, published an interesting and important 'Note on the possible density of the luminiferous medium, and on the mechanical value of a cubic mile of sunlight.' We should now render the 'mechanical value of a cubic mile of sunlight' as meaning the energy of a cubic mile of the ether due to the action of the sun. About thirty years ago the late Professor Tyndall published his capital work on 'Heat Considered as a Mode of Motion.' We must now translate this into Heat a Mode of Energy. There was, thus, in the writings of experts of a half century or less ago, much obscure phraseology, while the literature of less careful authors was often provokingly ambiguous. The word force, for example, in a number of treatises published since 1850, has been used to denote the three radically different things we now call stress, impulse and energy.

To the development of the law of energy, and its applications in electricity and magnetism especially, are due also an important fixation of our ideas with respect to the units and the dimensions of units which enter into mechanical quantities. Less than a quarter of a century ago our science was in a certain sense restricted by its terrestrial moorings. So strong, indeed, had been the influence of our earthly abode that only experts like Lagrange, Laplace, and Poisson would have known how to formulate a treatise suitable for instruction in any other part of the universe. Thanks to the half forgotten labors of Fourier and Gauss, however, when it became essential to state the laws of mechanics in a way readily applicable to phenomena wherever the investigator may be, the restrictions of terrestrial attraction were easily removed. By the introduction of the so-called absolute systems of units, one form of which is known as the C. G. S. system, a great step in advance was made. It is no exaggeration, in fact, to assert that one properly educated in the mechanics of our day and planet would be as well fitted to investigate mechanical phenomena on the companion of Sirius, as on our diminutive member of the solar system.

The rigorous definiteness of terminology, and the application of the C. G. S. system of units in mechanics, are humorously set forth in a little poem published over the signature *'dp dt'* about twenty years ago in the journal *Nature*. It is now known to have been written by Clerk-Maxwell. This poem purports to give an account of certain lectures on the C. G. S. system delivered to women by one *Professor Dr. Chrschtschonovitsch*. The author figures as one of the auditors, and her lamentations and criticism run as follows:

Prim Doctor of Philosophy
From academic Heidelberg!
Your sum of vital energy
Is not the millionth of an erg.
Your liveliest motion might be reckoned
At one tenth-metre* in a second.

"The air," you said, in language fine
Which scientific thought expresses—
"The air" (which with a megadyne
On each square centimetre presses)—
The air, and I may add, the ocean,
Are naught but molecules in motion."

Atoms, you told me, were discrete,
Than you they could not be discreter,
Who knows how many millions meet
Within a cubic millimetre;
They clash together as they fly,
But *you!* you dare not tell me why.

Then, when, in tuning my guitar,
The intervals would not come right,
"This string," you said, "is strained too far,
'Tis forty dynes, at least, too tight."
And then you told me, as I sang,
What over-tones were in my clang.

You gabbled on, but every phrase
Was stiff with scientific shoddy;
The only song you deigned to praise
Was "Gin a body meet a body;"
And even there, you said, collision
Was not described with due precision.

"In the invariable plane,"
You told me, "lay the impulsive couple;"
You seized my hand, you gave me pain,
By torsion of a wrist too supple.
You told me what that wrench would do;
"'Twould set me twisting round a screw."

Were every hair of every tress
Which you, no doubt, imagine mine,
Drawn towards you with its breaking stress,
A stress, say, of a megadyne,
That tension I would sooner suffer
Than meet again with such a duffer!

Our survey of the development of mechanical science is thus brought down to the present time. But no account of progress can be complete without some allusions to the grand problems which are now occupying the attention of mechanicians. It is hardly necessary to say that these are the problems presented by the phenomena of heat, light, electricity, and magnetism, or, in short, the phenomena of that unseen medium we call the ether. Just as the problems presented by the solar system were the absorbing questions in mechanics at the close of the 18th century, so are the problems presented by the ether the engrossing questions at the close of the 19th century.

In approaching this subject, whether for the present purpose of popular exposition, or for the higher purpose of investigation, one must confess to a difficulty, apparent at least, which might be raised by any hard headed reasoner. It might be asked, for example, by what right we speak of the ether as a medium, when nobody has ever seen any such thing? May we not be merely juggling with mathematical symbols

---

One-tenth metre $= 1$ metre x 10^{-10}.

which stand for no reality? In answer to such questions we should have to admit that most of our evidence is what would be called indirect, or circumstantial. Nevertheless, we could maintain that the evidence of things unseen may be very strong, and that it is nowhere stronger than in the domain of the mechanics of the ether. It seems essential, therefore, to recall, briefly, the salient features of this evidence.

In the first place, it is known that light travels through the celestial regions with a definite speed of about 186,000 miles a second. Induction from a wide variety of observations leads also to the conclusion that heat travels with the same speed, and that it and light are, in fact, only different aspects of the same phenomenon. Year in and year out our astronomical tables proceed on the assumption that eight minutes and seventeen seconds after the sun has risen above the plane of our horizon, we may perceive his light and feel the glow of his heat. The earth is traveling in its orbit around the sun at the rate of about eighteen miles in a second, a fact which, taken in connection with the speed of propagation of light, makes the apparent position of a star a little different from its real position. This is the beatiful phenomenon of aberration discovered by the astronomer Bradley more than two generations ago. The impressive feature of the phenomenon lies in the fact that it is always the same, due allowance being made for the speed and direction of the earth's motion. Thus we are forced to the conclusion that the velocity of light in the stellar spaces is the same, regardless of the source and direction of a luminous ray. The step from this conclusion to the conception that light is propagated by means of some sort of an elastic medium is easy and natural, and experience with gross matter, like water and air, leads quickly to the suggestion that vibration of such a medium must be the mode of propagation. A crowd of readily observable facts of reflection, refraction, and diffraction confirms the suggestion and dignifies it with the title hypothesis, and finally we are led to accept the undulatory theory of light, and to speak as confidently of the luminiferous ether as of any visible matter. Indeed, Lord Kelvin asserted, a few years ago, that we know more of the ether than we do of shoemaker's wax. Certian it is that the labors of Fresnel, Green, Cauchy and their successors have given us a splendid development of this mechanical theory of light. But, alas! they do not enable us to express in common parlance a very definite idea of the medium. No one, it is safe to say, would undertake with any degree of confidence to predict how a portion of the ether, a cubic foot say, would look if isolated and rendered visible. It might appear like a very tenuous and tremulous jelly. Its weight would certainly escape detection, for a bulk equal in volume with the earth would weigh somewhat less than one ounce. Arguing from the phenomena of light alone, it would be found to possess a slight rigidity, but whether it would prove compressible or incompressible we cannot say.

But the strain on the imagination in trying to visualize the ether does not end here. Quite recently it has been rendered almost certain that new and still more complex properties must be attributed to this invisible but omnipresent medium. About thirty years ago, Maxwell, taking up the brilliant experimental researches of Faraday, sought to give mechanical expression to the phenomena of electricity and magnetism. The characteristic idea of Faraday and Maxwell concerning these phenomena was that their seat lies not so much in the electrified and magnetized bodies themselves as in some kind of medium surrounding and permeating them. The result of Maxwell's labors was the publication, in 1873, of a grand but enigmatic treatise—grand, because of its thought-provoking qualities; enigmatic, because no one has yet been able to say just what Maxwell's views were The pursuit of his treatise is like a journey through a dreamland, wherein the travelers seem never to reach their destinations. But the leading idea is plain. It is that the medium is the important factor, and on the medium the attention must be riveted if we would seek a satisfactory explanation of electricity and magnetism.

Faraday died twenty years before, and Maxwell nine years before, anything like crucial experiments decided in favor of their theory. The old theories of action at a distance, without the aid of an intervening medium, but with their fluids and positive and negative subtilties, died hard, if indeed they can be said to be quite dead yet. The recent investigations of Hertz and others, however, seem to render it practically certain that the Faraday-Maxwell conception is the correct one, and that the medium in question can be no other than the medium of light and heat.

Thus the multifarious phenomena of the four sciences of heat, light, electricity, and magnetism appear destined to become unified as the mechanical properties of a universal plenum. The present concentration of activity along this line of inquiry seems fraught with results of the greatest interest. We seem to be, in fact, on the eve of discoveries no less brilliant and important than those whose record has already adorned the history of mechanics. Nevertheless, it may not be our good fortune to witness such advances. The ether may prove intractable for a century or more. It is conceivable, at any rate, that the full comprehension of this medium lies beyond the present range even of that extra sense which the late Charles Darwin attributed to mathematicians. It may be essential, in fact, to first give attention to visible and tangible substances, like shoemaker's wax, before the mind will be prepared to visualize the hidden reality.

But however this may be, mechanical science will remain worthy of the arduous labors of its devotees. The phenomena of matter and motion, though subject to few and simple laws, are infinitely varied and infinitely instructive. The knowledge of those phenomena already acquired gives assurance, as Helmholtz said in these halls a year ago, that we possess the *right method* of investigation. We may therefore expect that a diligent application of this method will yield in the future a not less inspiring body of truth than that which has come down to us from Archimedes and his successors.

R. S. WOODWARD.
COLUMBIA COLLEGE.

THE FIVE BOOKS OF HISTORY.

IN the study of the phenomena of history scientific men resort to five great classes of records. The science of geology seeks to discover the history of the earth—of the rocks of which it is composed and of the plants and animals which have lived from time to time. In this research the geologist discovers that nature's last chapter contains a story of mankind, for it is found that the bones of man and some of the works of his arts have been buried by natural agencies in the geologic formations. Sometimes these materials of history are buried in cave drift and in deposits derived from mineral waters which drop from the ceilings or ooze from the crevices of the caves. In flowing away and evaporating, such waters leave behind certain mineral constituents, especially carbonate of lime, which, consolidating and crystallizing, accumulate over the floors and walls of the caves and form pavements of calcite and aragonite. From the waters dropping down from the ceilings stalactites are formed above and stalagmites below, in marble columns of great natural beauty. Under and within such formations the bones of men and vestiges of their arts