The Advance of Science in the Last Half-Century

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The Advance of Science in the Last Half-Century (1889) by Thomas Henry Huxley and edited by Thomas Humphrey Wood, is a reprint of his work first published in *The Reign of Queen Victoria: a Survey of Fifty Years of Progress* (1887) Vol. 2, edited by Thomas Ward.

Quotes

- The founders of the schools of the Middle Ages included astronomy, along with geometry, arithmetic, and music, as one of the four branches of advanced education; and, in this respect, it is only just to them to observe that they were far in advance of those who sit in their seats. **The schoolmen considered no one to be properly educated unless he were acquainted with, at any rate, one branch of physical science. We have not, even yet, reached that stage of enlightenment.**

- Francis Bacon had essayed to sum up the past of physical science, and to indicate the path which it must follow if its great destinies were to be fulfilled. And though the attempt was just such a magnificent failure as might have been expected from a man of great endowments, who was so singularly devoid of scientific insight that he could not understand the value of the work already achieved by the true instaurators of physical science; yet the majestic eloquence and the fervid vaticinations of one who was conspicuous alike by the greatness of his rise and the depth of his fall, drew the attention of all the world to the 'new birth of Time.'

- **Descartes was an eminent mathematician, and it would seem that the bent of his mind led him to overestimate the value of deductive reasoning from general principles, as much as Bacon had underestimated it.**

- The progress of physical science has been effected neither by Baconians nor by Cartesians, as such but by **men like Galileo and Harvey, Boyle and Newton,** who **would have done their work just as well if neither Bacon nor Descartes had ever propounded their views respecting the manner in which scientific investigation should be pursued.**

- That **growth of knowledge** beyond imaginable utilitarian ends, which is the condition precedent of its practical utility, **began to produce some effect upon practical life; and the operation of that part of nature we call human upon the rest began to create**, not 'new natures,' in Bacon's sense, but **a new Nature, the existence of which is dependent upon men's efforts, which is subservient to their wants, and which would disappear if man's shaping and guiding hand were withdrawn. Every mechanical artifice, every chemically pure substance employed in manufacture**, every abnormally fertile race of plants, or rapidly growing and fattening breed of animals, **is a part of the new Nature created by science.** ...During the last fifty years, this new birth of time, this new Nature begotten by science upon fact, has pressed itself daily and hourly upon our attention, and has worked miracles which have modified the whole fashion of our lives.

- The bare enumeration of the names of the men who were the great lights of science in the latter part of the eighteenth and the first decade of the nineteenth century, of Herschel, of Laplace, of Young, of Fresnel, of Oersted, of Cavendish, of Lavoisier, of Davy, of Lamarck, of Cuvier, of Jussieu, of Decandolle, of Werner, and of Hutton, suffices to indicate the strength of physical science in the age immediately preceding that of which I have to treat. But **of which of these great men can it be said that their labors were directed to practical ends? I do not call to mind even an invention of practical utility which we owe to any of them, except the safety lamp of Davy.**

- **The history of physical science teaches** (and we cannot too carefully take the lesson heart) **that the *practical* advantages, attainable through its agency, never have been, and never will be, sufficiently attractive to men inspired by the inborn genius of the interpreter of nature**, to give them courage to undergo the toils and make the sacrifices which that calling requires from its votaries. **That which stirs their pulses is the love of knowledge and the joy of the discovery** of the causes of things sung by the old poets **—the supreme delight of extending the realm of law and order ever farther towards the unattainable goals of the infinitely great and the infinitely small, between which our little race of life is run.**

- Far be it from me to depreciate the value of the gifts of science to practical life, or to cast a doubt upon the propriety of the course of action of those who follow science in the hope of finding wealth alongside truth, or even wealth alone. Such a profession is as respectable as any other. And quite as little do I desire to ignore the fact that, **if industry owes a heavy debt to science, it has largely repaid the loan by the important aid which it has, in its turn, rendered to the advancement of science.**

- In considering the causes which considering hindered the progress of physical knowledge in the schools of Athens and of Alexandria, it has often struck me that **where the Greeks did wonders was in just those branches** of science, such as geometry, astronomy, and anatomy, **which are susceptible of very considerable development without any, or any but the simplest, appliances.**

- **It is a curious speculation to think what would have become of modern physical science if glass and alcohol had not been easily obtainable; and if the gradual perfection of mechanical skill for industrial ends had not enabled investigators to obtain, at comparatively little cost, microscopes, telescopes, and all the exquisitely delicate apparatus for determining weight and measure and** for estimating the lapse of **time** with exactness, which they now command.

- **It has become obvious that the interests of science and of industry are identical**; that science cannot make a step forward without, sooner or later, opening up new channels for industry; and, on the other hand, that every advance of industry facilitates those experimental investigations, upon which the growth of science depends.

- **We may hope that, at last, the weary misunderstanding between the practical men who professed to despise science, and the high and dry philosophers who professed to despise practical results, is at an end.**

- **The great steps in its** [science's] **progress have been made, are made, and will be made, by men who seek knowledge simply because they crave for it.**

- **Nothing great in science has ever been done by men, whatever their powers, in whom the divine afflatus of the truth-seeker was wanting. Men of moderate capacity have done great things because it animated them; and men of great natural gifts have failed, absolutely or relatively, because they lacked this one thing needful.**

- **In science, as in art**, and, as I believe, in every other sphere of human activity, **there may be wisdom in a multitude of counsellors, but it is only in one or two of them. And, in scientific inquiry**, at any rate, **it is to that one or two that we must look for light and guidance.**

- Newton said that he made his discoveries by 'intending' his mind on the subject; no doubt truly. But to equal his success one must have the mind which he 'intended.' Forty lesser men might have intended their minds till they cracked, without any like result. It would be idle either to affirm or to deny that the last half-century has produced men of science of the calibre of Newton. It is sufficient that it can show a few capacities of the first rank, competent not only to deal profitably with the inheritance bequeathed by their scientific forefathers, but to pass on to their successors physical truths of a higher order than any yet reached by the human race. And if they have succeeded as Newton succeeded, it is because they have sought truth as he sought it, with no other object than the finding it.

- So far as physical science is concerned, the days of Admirable Crichtons have long been over, and the most indefatigable of hard workers may think he has done well if he has mastered one of its minor subdivisions. Nevertheless, **it is possible for anyone, who has familiarised himself with the operations of science in one department, to comprehend the significance, and even to form a general estimate of the value, of the achievements of specialists in other departments.**

- By a happy chance, the first edition of Whewell's 'History of the Inductive Sciences' was published in 1837, and it affords a very useful view of the state of things at the commencement of the Victorian epoch.

- I may hope... that my chance of escaping serious errors is as good as that of anyone else, who might have been persuaded to undertake the somewhat perilous enterprise in which I find myself engaged.

- **Physical science is one and indivisible. ...the method of investigation and the ultimate object of the physical inquirer are everywhere the same. The object is the discovery of the rational order which pervades the universe; the method consists of observation and experiment** (which is observation under artificial conditions) **for the determination of the facts of nature; of inductive and deductive reasoning for the discovery of their mutual relations and connection.**

- The various branches of physical science differ in the extent to which, at any given moment of their history, observation on the one hand, or ratiocination on the other, is their more obvious feature, but in no other way; and **nothing can be more incorrect than the assumption one sometimes meets with, that physics has one method, chemistry another, and biology a third.**

- **All physical science starts from certain postulates.** One of them is the objective existence of a material world. It is assumed that the phenomena which are comprehended under this name have a 'substratum' of extended, impenetrable, mobile substance which exhibits the quality known as inertia and is termed matter. Another postulate is the universality of the law of causation; that nothing happens without a cause (that is a necessary precedent condition), and that the state of the physical universe, at any given moment, is the consequence of its state at any preceding moment. Another is that any of the rules, or so called 'laws of nature,' by which the relation of phenomena is truly defined, is true for all time.

- **The validity of these postulates** [of science] **is a problem of metaphysics**; they are neither self-evident nor are they, strictly speaking, demonstrable. The justification of their employment, as axioms of physical philosophy, lies in the circumstance that expectations logically based upon them are verified, or at any rate, not contradicted, whenever they can be tested by experience.

- **Physical science... rests on verified or uncontradicted hypotheses; and, such being the case, it is not surprising that a great condition of its progress has been the invention of verifiable hypotheses.**

- **It is a favorite popular delusion that the scientific inquirer is under a sort of moral obligation to abstain from going beyond that generalisation of observed facts which is absurdly called 'Baconian' induction. But** anyone who is practically acquainted with scientific work is aware that **those who refuse to go beyond fact, rarely get as far as fact**; and anyone who has studied the history of science knows that almost every great step therein has been made by the 'anticipation of Nature,' that is, by the invention of hypotheses, which, though verifiable, often had very little foundation to start with; and, not unfrequently, in spite of a long career of usefulness, turned out to be wholly erroneous in the long run.

- The geocentric system of astronomy, with its eccentrics and its epicycles, was an hypothesis utterly at variance with fact, which nevertheless did great things for the advancement of astronomical knowledge.

- Kepler was the wildest of guessers.

- Newton's corpuscular theory of light was of much temporary use in optics, though nobody now believes in it; and the undulatory theory, which has superseded the corpuscular theory and has proved one of the most fertile of instruments of research, is based on the hypothesis of the existence of an 'ether,' the properties of which are defined in propositions, some of which, to ordinary apprehension, seem physical antinomies.

- It sounds paradoxical to say that the attainment of scientific truth has been effected, to a great extent, by the help of scientific errors. But the subject-matter of physical science is furnished by observation, which cannot extend beyond the limits of our faculties; while, even within those limits, we cannot be certain that any observation is absolutely exact and exhaustive. Hence it follows that **any given generalisation from observation may be true, within the limits of our powers of observation at a given time, and yet turn out to be untrue, when those powers of observation are directly or indirectly enlarged.** Or, to put the matter in another way, **a doctrine which is untrue absolutely, may, to a very great extent, be susceptible of an interpretation in accordance with the truth.**

- At a certain period in the history of astronomical science, the assumption that the planets move in circles was true enough to serve the purpose of correlating such observations as were then possible; after Kepler, the assumption that they move in ellipses became true enough in regard to the state of observational astronomy at that time. **We say still that the orbits of the planets are ellipses, because, for all ordinary purposes, that is a sufficiently near approximation to the truth; but, as a matter of fact, the centre of gravity of a planet describes neither an ellipse or any other simple curve, but an immensely complicated undulating line.**

- **It may fairly be doubted whether any generalisation, or hypothesis, based upon physical data is absolutely true, in the sense that a mathematical proposition is so; but, if its errors can become apparent only outside the limits of practicable observation, it may be just as usefully adopted for one of the symbols of that algebra by which we interpret nature, as if it were absolutely true.**

- The development of every branch of physical knowledge presents three stages which, in their logical relation, are successive.

- The first [stage of physical knowledge] is the determination of the sensible character and order of the phenomena. This is *Natural History*, in the original sense of the term, and here nothing but observation and experiment avail us.

- The second [stage of physical knowledge] is the determination of the constant relations of the phenomena thus defined [above] and their expression in rules or laws. The third is the explication of these particular laws by deduction from the most general laws of matter and motion. The last two stages constitute *Natural Philosophy* in its original sense. In this region the invention of verifiable hypotheses is not only permissible but is one of the conditions of progress.

- From the dawn of exact knowledge to the present day, observation, experiment, and speculation have gone hand in hand; and, **whenever science has halted or strayed from the right path, it has been, either because its votaries have been content with mere unverified or unverifiable speculation** (and this is the commonest case, because observation and experiment are hard work, while speculation is amusing); **or it has been, because the accumulation of details of observation has for a time excluded speculation.**

- **The progress of physical science**, since the revival of learning, **is largely due to the fact that men have gradually learned** to lay aside the consideration of unverifiable hypotheses; **to guide observation and experiment by verifiable hypotheses; and to consider the latter, not as ideal truths,** the real entities of an intelligible world behind phenomena, **but as a symbolical language, by the aid of which nature can be interpreted in terms apprehensible by our intellect.**

- **If physical science, during the last fifty years, has attained dimensions beyond all former precedent**, and can exhibit achievements of greater importance than any former such period can show, **it is because able men**, animated by the true scientific spirit, carefully trained in the method of science, and having at their disposal immensely improved appliances, **have devoted themselves to the enlargement of the boundaries of natural knowledge in greater number** than during any previous half-century of the world's history.

- **I think that there are three great products of our time... One of these is that doctrine concerning the constitution of matter which, for want of a better name, I will call 'molecular;' the second is the doctrine of conservation of energy; the third is the doctrine of evolution.**

- Each of these [above doctrines] was foreshadowed more or less distinctly in former periods of the history of science... The peculiar merit of our epoch is that it has shown how these hypotheses connect a vast number of seemingly independent partial generalisations; that it has given them that precision of expression which is necessary for their exact verification; and that it has practically proved their value as guides to the discovery of new truth.

- All three doctrines are intimately connected, and each is applicable to the whole physical cosmos. But... the first two grew mainly out of the consideration of physico-chemical phenomena; while the third, in great measure, owes its rehabilitation, if not its origin, to the study of biological phenomena.

- **The laws of motion** of visible and tangible, or *molar*, matter had been worked out to a great degree of refinement and embodied in the branches of science known as Mechanics, Hydrostatics, and Pneumatics. These laws **had been shown to hold good... throughout the universe on the assumption that all such masses of matter possessed inertia and were susceptible of acquiring motion, in two ways, firstly by impact, or impulse from without; and, secondly, by the operation of certain hypothetical causes of motion termed 'forces,'** which were usually supposed to be resident in the particles of the masses themselves, and to operate at a distance, in such a way as to tend to draw any two such masses together, or to separate them more widely.

- With respect to the ultimate constitution of... masses, the same two antagonistic opinions which had existed since the time of Democritus and of Aristotle were still face to face. According to the one, matter was discontinuous and consisted of minute indivisible particles or atoms, separated by a universal vacuum; according to the other, it was continuous, and the finest distinguishable, or imaginable, particles were scattered through the attenuated general substance of the plenum. A rough analogy to the latter case would be afforded by granules of ice diffused through water; to the former, such granules diffused through absolutely empty space.

- **In the latter part of the eighteenth century, the chemists had arrived at several very important generalisations**... However plainly ponderable matter seemed to be originated and destroyed in their operations, they proved that, as mass or body, it remained indestructible and ingenerable... **a certain number of the chemically separable kinds of matter were unalterable by any known means** (except in so far as they might be made to change their state from solid to fluid, or *vice versâ*)... **and** that **the properties of these several kinds of matter were always the same**, whatever their origin. All other bodies were found to consist of two or more of these, which thus took the place of the four 'elements' of the ancient philosophers. **Further, it was proved that, in forming chemical compounds, bodies always unite in a definite proportion by weight**, or in simple multiples of that proportion, and that, if any one body were taken as a standard, every other could have a number assigned to it as its proportional combining weight. **It was on this foundation of fact that Dalton based his re-establishment of the old atomic hypothesis on a new empirical foundation.**

- The gradual reception of the undulatory theory of light necessitated the assumption of the existence of an 'ether' filling all space. But whether this ether was to be regarded as a strictly material and continuous substance was an undecided point, and hence the revived atomism escaped strangling in its birth. For it is clear, that if the ether is admitted to be a continuous material substance, Democritic atomism is at an end and Cartesian continuity takes its place.

- The real value of the new atomic hypothesis... did not lie in the two points which Democritus and his followers would have considered essential—namely, the indivisibility of the 'atoms' and the presence of an interatomic vacuum—but in the assumption that, to the extent to which our means of analysis take us, material bodies consist of definite minute masses, each of which, so far as physical and chemical processes of division go, may be regarded as a unit—having a practically permanent individuality. ...that smallest material particle which under any given circumstances acts as a whole.

- The doctrine of specific heat originated in the eighteenth century. It means that the same mass of a body, under the same circumstances, always requires the same quantity of heat to raise it to a given temperature, but that equal masses of different bodies require different quantities.

- Ultimately, it was found that the quantities of heat required to raise equal masses of the more perfect gases, through equal ranges of temperature, were inversely proportional to their combining weights. Thus a definite relation was established between the hypothetical units and heat. The phenomena of electrolytic decomposition showed that there was a like close relation between these units and electricity. The quantity of electricity generated by the combination of any two units is sufficient to separate any other two which are susceptible of such decomposition. The phenomena of isomorphism showed a relation between the units and crystalline forms; certain units are thus able to replace others in a crystalline body without altering its form and others are not.

- **The laws of the effect of pressure and heat on gaseous bodies, the fact that they combine in definite proportions by volume, and that such proportion bears a simple relation to their combining weights, all harmonised with the Daltonian hypothesis and led to the bold speculation known as the law of Avogadro—that all gaseous bodies, under the same physical conditions, contain the same number of units. In the form in which it was first enunciated, this hypothesis was incorrect—perhaps it is not exactly true in any form; but it is hardly too much to say that chemistry and molecular physics would never have advanced to their present condition unless it had been assumed to be true.**

- Another immense service rendered by Dalton, as a corollary of the new atomic doctrine, was the creation of a system of symbolic notation, which not only made the nature of chemical compounds and processes easily intelligible and easy of recollection, but, by its very form, suggested new lines of inquiry. **The atomic notation was as serviceable to chemistry as the binomial nomenclature and the classificatory schematism of Linnæus were to zoölogy and botany.**

- The class of neutral salts... includes a great number of bodies in many ways similar, in which the basic molecules, or the acid molecules, may be replaced by other basic and other acid molecules without altering the neutrality of the salt; just as a cube of bricks remains a cube, so long as any brick that is taken out is replaced by another of the same shape and dimensions, whatever its weight or other properties may be. Facts of this kind gave rise to the conception of 'types' of molecular structure, just as the recognition of the unity in diversity of the structure of the species of plants and animals gave rise to the notion of biological 'types.'

- The notation of chemistry enabled these ideas to be represented with precision; and they acquired an immense importance, when the improvement of methods of analysis, which took place about the beginning of our period enabled the composition of the so called 'organic' bodies to be determined with rapidity and precision. A large proportion of these compounds contain not more than three or four elements, of which carbon is the chief; but their number is very great, and the diversity of their physical and chemical properties is astonishing. The ascertainment of the proportion of each element in these compounds affords little or no help towards accounting for their diversities; widely different bodies being often very similar, or even identical, in that respect. And in the last case, that **of isomeric compounds, the appeal to diversity of arrangement of the identical component units was the only obvious way out of the difficulty.**

- Here, again, hypothesis proved to be of great value; not only was the search for evidence of diversity of molecular structure successful, but the study of the process of taking to pieces led to the discovery of the way to put together; and vast numbers of compounds, some of them previously known only as products of the living economy, have thus been artificially constructed.

- **It is largely because the chemical theory and practice of our epoch have passed into this deductive and synthetic stage, that they are entitled to the name of the 'New Chemistry' which they commonly receive.**

- This new chemistry has grown up by the help of hypotheses, such as those of Dalton and of Avogadro, and that singular conception of 'bonds' invented to colligate the facts of 'valency' or 'atomicity,' the first of which took some time to make its way; while the second fell into oblivion, for many years after it was propounded, for lack of empirical justification. As for the third it may be doubted if anyone regards it as more than a temporary contrivance.

- Combining them [chemical hypotheses] with the mechanical theory of heat and the doctrine of the conservation of energy, which are also products of our time, physicists have arrived at an entirely new conception of the nature of gaseous bodies and of the relation of the physico-chemical units of matter to the different forms of energy. The conduct of gases under varying pressure and temperature, their diffusibility, their relation to radiant heat and to light, the evolution of heat when bodies combine, the absorption of heat when they are dissociated, and a host of other molecular phenomena, have been shown to be deducible from the dynamical and statical principles which apply to molar motion and rest; and **the tendency of physico-chemical science is clearly towards the reduction of the problems of the world of the infinitely little, as it already has reduced those of the infinitely great world, to questions of mechanics.**

- The primitive atomic theory, which has served as the scaffolding for the edifice of modern physics and chemistry, has been quietly dismissed. **I cannot discover that any contemporary physicist or chemist believes in the real indivisibility of atoms, or in an interatomic matterless vacuum.** Atoms appear to be used as mere names for physico-chemical units which have not yet been subdivided, and 'molecules' for physico-chemical units which are aggregates of the former. And these individualised particles are supposed to move in an endless ocean of a vastly more subtle matter—the ether.

- **If this ether is a continuous substance... we have got back from the hypothesis of Dalton to that of Descartes. But there is much reason to believe that science is going to make a still further journey, and, in form, if not altogether in substance, to return to the point of view of Aristotle.**

- The greater number of the so-called 'elementary' bodies, now known, had been discovered before the commencement of our epoch; and it had become apparent that they were by no means equally similar or dissimilar, but that some of them, at any rate, constituted groups, the several members of which were as much like one another as they were unlike the rest. Chlorine, iodine, bromine, and fluorine thus formed a very distinct group; sulphur and selenium another; boron and silicon another; potassium, sodium and lithium another; and so on. In some cases, the atomic weights of such allied bodies... could be arranged in series, with like differences between the several terms. In fact, the elements afforded indications that they were susceptible of a classification in natural groups, such as those into which animals and plants fall.

- Recently this subject [periodicity of the chemical elements] has been taken up afresh with a result which may be stated... so that it is said to express a *periodic law* of recurrent similarities. ...This is a conception with which biologists are very familiar, animal and plant groups constantly appearing as series of parallel modifications of similar and yet different primary forms. In the living world, facts of this kind are now understood to mean evolution from a common prototype. It is difficult to imagine that in the not-living world they are devoid of significance. **Is it not possible, nay probable, that they may mean the evolution of our 'elements' from a primary undifferentiated form of matter?** Fifty years ago, such a suggestion would have been scouted as a revival of the dreams of the alchemists. At present, it may be said to be the burning question of physico-chemical science.

- **The** so called '**vortex-ring' hypothesis** is a very serious and remarkable attempt to deal with material units from a point of view which is consistent with the doctrine of evolution. It **supposes the ether to be a uniform substance, and that the 'elementary' units are, broadly speaking, permanent whirlpools, or vortices, of this ether, the properties of which depend on their actual and potential modes of motion.** It is curious and highly interesting to remark that **this hypothesis reminds us not only of the speculations of Descartes, but of those of Aristotle.**

- The resemblance of the 'vortex rings' to the 'tourbillons' of Descartes is little more than nominal; but the correspondence between the modern and the ancient notion of a distinction between primary and derivative matter is, to a certain extent, real. For this ethereal 'Urstoff' of the modern corresponds very closely with the *πρώτη ὕλη* of Aristotle, the *materia prima* of his mediæval followers; while matter, differentiated into our elements, is the equivalent of the first stage of progress towards the *έσχάτη ὕλη*, or finished matter, of the ancient philosophy.

- If the material units of the existing order of nature are specialised portions of a relatively homogeneous *materia prima*—which were originated under conditions that have long ceased to exist and which remain unchanged and unchangeable under all conditions, whether natural or artificial, hitherto known to us—it follows that the speculation that they may be indefinitely altered, or that new units may be generated under conditions yet to be discovered, is perfectly legitimate.

- **Theoretically, at any rate, the transmutability of the elements is a verifiable scientific hypothesis; and such inquiries as those which have been set afoot, into the possible dissociative action of the great heat of the sun upon our elements, are not only legitimate, but are likely to yield results which**, whether affirmative or negative, **will be of great importance.**

- **The idea that atoms are absolutely ingenerable and immutable 'manufactured articles' stands on the same sort of foundation as the idea that biological species are 'manufactured articles' stood thirty years ago**; and the supposed constancy of the elementary atoms, during the enormous lapse of time measured by the existence of our universe, is of no more weight against the possibility of change in them, in the infinity of antecedent time, than the constancy of species in Egypt, since the days of Rameses or Cheops, is evidence of their immutability during all past epochs of the earth's history.

- It seems safe to prophesy that **the hypothesis of the evolution of the elements from a primitive matter will, in future, play no less a part in the history of science than the atomic hypothesis**, which, to begin with, had no greater, if so great, an empirical foundation.

- **The connotation of these terms, in the mind of the modern, is almost infinitely different from that which they possessed in the mind of the ancient philosopher.** In antiquity, they meant little more than vague speculation; at the present day, they indicate definite physical conceptions, susceptible of mathematical treatment, and giving rise to innumerable deductions, the value of which can be experimentally tested. The old notions produced little more than floods of dialectics; the new are powerful aids towards the increase of solid knowledge.

- **In the old philosophy, a curious conjunction of ethical and physical prejudices had led to the notion that there was something ethically bad and physically obstructive about matter. Aristotle attributes all irregularities and apparent dysteleologies in nature to the disobedience, or sluggish yielding, of matter to the shaping and guiding influence of those reasons and causes which were hypostatised in his ideal 'Forms.'**
    - *also see Teleology*

- Given a cause of motion of a certain value, the amount of motion, measured by distance travelled in a certain time, which it will produce in a given quantity of matter, say a cubic inch, is not always the same, but depends on what that matter is—a cubic inch of iron will go faster than a cubic inch of gold. Hence, it appears, that since equal amounts of motion have, *ex hypothesi*, been produced, **the amount of motion in a body does not depend on its speed alone, but on some property of the body. To this the name of 'mass' has been given. And since it seems reasonable to suppose that a large quantity of matter, moving slowly, possesses as much motion as a small quantity moving faster, 'mass' has been held to express 'quantity of matter.'** It is further demonstrable that, at any given time and place, the relative mass of any two bodies is expressed by the ratio of their weights.

- **When** all these great truths respecting molar motion, or the movements of visible and tangible masses, had been shown to hold good not only of terrestrial bodies, but of all those which constitute the visible universe, and **the movements of the macrocosm had** thus **been expressed by a general mechanical theory, there remained a vast number of phenomena, such as those of light, heat, electricity, magnetism, and those of**

the physical and chemical changes, which do not involve molar motion, **Newton's corpuscular theory of light was an attempt to deal with one great series of these phenomena on mechanical principles, and it maintained its ground until, at the beginning of the nineteenth century, the undulatory theory proved itself to be a much better working hypothesis.**

- **Heat up to that time** [early nineteenth century] **and indeed much later, was regarded as an imponderable substance, *caloric*; as a thing which was absorbed by bodies when they were warmed, and was given out as they cooled; and which, moreover, was capable of entering into a sort of chemical combination with them, and so becoming latent.** Rumford and Davy had given a great blow to this view of heat by proving that the quantity of heat which two portions of the same body could be made to give out, by rubbing them together, was practically illimitable. This result brought philosophers face to face with the contradiction of supposing that a finite body contain an infinite quantity of another body...

- **It was not until 1843, that clear and unquestionable experimental proof was given of the fact that there is a definite relation between mechanical work and heat**; that so much work always gives rise, under the same conditions, to so much heat, and so much heat to so much mechanical work. Thus originated **the mechanical theory of heat**, which **became the starting-point of the modern doctrine of the conservation of energy.**

- Molar **motion had appeared to be destroyed by friction. It was proved that no destruction took place, but that an exact equivalent of the energy of the lost molar motion appears as that of the *molecular* motion, or motion of the smallest particles of a body, which constitutes heat.**

- Before 1843... the doctrine of conservation of energy had been approached. Bacon's chief contribution to positive science is the happy guess... that heat may be a mode of motion; Descartes affirmed the quantity of motion in the world to be constant; Newton nearly gave expression to the complete theorem; while Rumford's and Davy's experiments suggested, though they did not prove, the equivalency of mechanical and thermal energy.

- **The discovery of voltaic electricity, and the marvellous development of knowledge, in that field, effected by such men as Davy, Faraday, Oersted, Ampere, and Melloni, had brought to light a number of facts which tended to show that the so-called 'forces' at work in light, heat, electricity, and magnetism, in chemical and in mechanical operations, were intimately, and in various cases, quantitatively related. It was demonstrated that any one could be obtained at the expense of any other**; and apparatus was devised which exhibited the evolution of all these kinds of action from one source of energy. Hence **the idea of the 'correlation of forces'** which **was the immediate forerunner of the doctrine of the conservation of energy.**
  - *also see James Prescott Joule & Julius Robert von Mayer*

- Even the second edition of the 'History of the Inductive Sciences,' which was published in 1846, contains no allusion either to the general view of the 'Correlation of Forces' published in England in 1842, or to the publication in 1843 of the first of the series of experiments by which the mechanical equivalent of heat was correctly ascertained. Such a failure on the part of a contemporary, of great acquirements and remarkable intellectual powers, to read the signs of the times, is a lesson and a warning worthy of being deeply pondered by anyone who attempts to prognosticate the course of scientific progress.

- **In so far as matter may be conceived to exist in a purely passive state, it is, imaginably, older than motion.**

- Let it be conceived that the [or a] particle acquires a tendency to move, and that nevertheless it does not move. It is then in a condition totally different from that in which it was at first. A cause competent to produce motion is operating upon it, but for some reason or other, is unable to give rise to motion. If the obstacle is removed, the energy which was there, but could not manifest itself, at once gives rise to motion. While the restraint lasts, the energy of the particle is merely potential; and the case supposed illustrates what is meant by *potential energy*. **In this contrast of the potential with the actual, modern physics is turning**

to account the most familiar of Aristotelian distinctions—that between *δύναμιζ* [potential] **and *ἐνέϱγεια*** [action, effect, entelechy, power or energy].
  - *also see potentiality and actuality, entelechy*

- If a stone is picked up and held, say, six feet above the ground, it has *potential energy*, because, if let go, it will immediately begin to move towards the earth; and this energy may be said to be *energy of position*, because it depends upon the relative position of the earth and the stone. The stone is solicited to move but cannot, so long as the muscular strength of the holder prevents the solicitation from taking effect. The stone, therefore, has potential energy, which becomes kinetic if it is let go, and the amount of that kinetic energy which will be developed before it strikes the earth depends on its position—on the fact that it is, say, six feet off the earth, neither more nor less. Moreover, it can be proved that the raiser of the stone had to exert as much energy in order to place it in its position, as it will develop in falling. Hence the energy which was exerted, and apparently exhausted, in raising the stone, is potentially in the stone, in its raised position, and will manifest itself when the stone is set free. Thus the energy, withdrawn from the general stock to raise the stone, is returned when it falls, and there is no change in the total amount. Energy as a whole is conserved.

- In the currently accepted language of science, the cause of motion... when bodies tend to move towards or away from one or another, without any discernible impact of other bodies, is termed a 'force,' which is called 'attractive' in the one case, and 'repulsive' in the other. And such **attractive or repulsive forces are often spoken of as if they were real things, capable of exerting a pull, or a push, upon the particles of matter concerned. Thus the potential energy of the stone is commonly said to be due to the 'force' of gravity which is continually operating upon it.**

- The bob of a pendulum swings first to one side and then to the other of the centre of the arc which it describes. Suppose it to have just reached the summit of its right-hand half-swing. It is said that the 'attractive forces' of the bob for the earth, and of the earth for the bob, set the former in motion; and as these 'forces' are continually in operation, they confer an accelerated velocity on the bob; until, when it reaches the centre of its swing, it is, so to speak, fully charged with kinetic energy. If, at this moment, the whole material universe, except the bob, were abolished, it would move for ever in the direction of a tangent to the middle of the arc described. As a matter of fact, it is compelled to travel through its left-hand half-swing, and thus virtually to go up hill. Consequently, the 'attractive forces' of the bob and the earth are now acting against it, and constitute a resistance which the charge of kinetic energy has to overcome. But, as this charge represents the operation of the attractive forces during the passage of the bob through the right-hand half-swing down to the centre of the arc, so it must needs be used up by the passage of the bob upwards from the centre of the arc to the summit of the left-hand half-swing. Hence, at this point, the bob comes to a momentary rest. The last fraction of kinetic energy is just neutralised by the action of the attractive forces, and the bob has only potential energy equal to that with which it started. So that the sum of the phenomena may be stated thus: At the summit of either half-arc of its swing, the bob has a certain amount of potential energy; as it descends it gradually exchanges this for kinetic energy, until at the centre it possesses an equivalent amount of kinetic energy; from this point onwards, it gradually loses kinetic energy as it ascends, until, at the summit of the other half-arc, it has acquired an exactly similar amount of potential energy. Thus, on the whole transaction, nothing is either lost or gained; the quantity of energy is always the same, but it passes from one form into the other.

- To all appearance, the phenomena exhibited by the pendulum are not to be accounted for by impact: in fact, it is usually assumed that corresponding phenomena would take place if the earth and the pendulum were situated in an absolute vacuum, and at any conceivable distance from one another. If this be so, it follows that **there must be two totally different kinds of causes of motion: the one impact—a *vera causa*** [true cause], **of which, to all appearance, we have constant experience; the other, attractive or repulsive 'force'—a metaphysical entity which is physically inconceivable.**

- **Newton expressly repudiated the notion of the existence of attractive forces, in the sense in which that term is ordinarily understood; and he refused to put forward any hypothesis as to the physical cause of the so-called 'attraction of gravitation.'**

- As a general rule, his [Newton's] successors have been content to accept the doctrine of attractive and repulsive forces, without troubling themselves about the philosophical difficulties which it involves. But this has not always been the case; and **the attempt of Le Sage, in the last century, to show that the phenomena of attraction and repulsion are susceptible of explanation by his hypothesis of bombardment by ultra-mundane particles, whether tenable or not, has the great merit of being an attempt to get rid of the dual conception of the causes of motion which has hitherto prevailed.** On this hypothesis, the hammering of the ultra-mundane corpuscles on the bob confers its kinetic energy, on the one hand, and takes it away on the other; and the state of potential energy means the condition of the bob during the instant at which the energy, conferred by the hammering during the one half-arc, has just been exhausted by the hammering during the other half-arc.

- **It seems safe to look forward to the time when the conception of attractive and repulsive forces, having served its purpose as a useful piece of scientific scaffolding, will be replaced by the deduction of the phenomena known as attraction and repulsion, from the general laws of motion.**

- The doctrine of the conservation of energy which I have endeavored to illustrate is thus defined by the late Clerk Maxwell: 'The total energy of any body or system of bodies is a quantity which can neither be increased nor diminished by any mutual action of such bodies, though it may be transformed into any one of the forms of which energy is susceptible.'

- Energy, like matter, is indestructible and ingenerable in nature.

- **The phenomenal world, so far as it is material, expresses the evolution and involution of energy, its passage from the kinetic to the potential condition and back again.**

- Wherever motion of matter takes place, that motion is effected at the expense of part of the total store of energy.

- As the phenomena exhibited by living beings, in so far as they are material, are all molar or molecular motions, these are included under the general law [of the conservation of energy].

- **That a particular molecular motion does give rise to a state of consciousness is experimentally certain; but the how and why of the process are just as inexplicable as in the case of the communication of kinetic energy by impact.**

- When dealing with the doctrine of the ultimate constitution of matter, we found a certain resemblance between the oldest speculations and the newest doctrines of physical philosophers. But there is no such resemblance between the ancient and modern views of motion and its causes, except in so far as the conception of attractive and repulsive forces may be regarded as the modified descendant of the Aristotelian conception of forms.

- The essential and fundamental difference between ancient and modern physical science lies in the ascertainment of the true laws of statics and dynamics in the course of the last three centuries; and in the invention of mathematical methods of dealing with all the consequences of these laws. **The ultimate aim of modern physical science is the deduction of the phenomena exhibited by material bodies from physico-mathematical first principles. Whether the human intellect is strong enough to attain the goal set before it may be a question, but thither will it surely strive.**

- **The emanistic theories which played so great a part in Neoplatonic philosophy and Gnostic theology are forms of evolution.** In the seventeenth century, Descartes propounded a scheme of evolution, as an hypothesis of what might have been the mode of origin of the world, while professing to accept the ecclesiastical scheme of creation, as an account of that which actually was its manner of coming into existence. In the eighteenth century, Kant put forth a remarkable speculation as to the origin of the solar system, closely similar to that subsequently adopted by Laplace and destined to become famous under the title of the 'nebular hypothesis.'

- The careful observations and the acute reasonings of the Italian geologists of the seventeenth and eighteenth centuries; the speculations of Leibnitz in the 'Protogæa' and of Buffon in his 'Théorie de la Terre;' the sober and profound reasonings of Hutton, in the latter part of the eighteenth century; all these tended to show that **the fabric of the earth itself implied the continuance of processes of natural causation for a period of time as great, in relation to human history, as the distances of the heavenly bodies from us are, in relation to terrestrial standards of measurement. The abyss of time began to loom as large as the abyss of space. And this revelation to sight and touch, of a link here and a link there of a practically infinite chain of natural causes and effects, prepared the way, as perhaps nothing else has done, for the modern form of the ancient theory of evolution.**

- In the beginning of the eighteenth century, De Maillet made the first serious attempt to apply the doctrine [of evolution] to the living world. In the latter part of it, Erasmus Darwin, Goethe, Treviranus, and Lamarck took up the work more vigorously and with better qualifications. The question of special creation, or evolution, lay at the bottom of the fierce disputes which broke out in the French Academy between Cuvier and St.-Hilaire; and, for a time, the supporters of biological evolution were silenced, if not answered, by the alliance of the greatest naturalist of the age [Cuvier] with their ecclesiastical opponents. **Catastrophism, a short-sighted teleology, and a still more short-sighted orthodoxy, joined forces to crush evolution.**

- Lyell and Poulett Scrope, in this country, resumed the work of the Italians and of Hutton; and the former, aided by a marvellous power of clear exposition, placed upon an irrefragable basis the truth that natural causes are competent to account for all events, which can be proved to have occurred, in the course of the secular changes which have taken place during the deposition of the stratified rocks.

- **The publication of 'The Principles of Geology,' in 1830, constituted an epoch in geological science. But it also constituted an epoch in the modern history of the doctrines of evolution, by raising in the mind of every intelligent reader this question: If natural causation is competent to account for the not-living part of our globe, why should it not account for the living part?** By keeping this question before the public for some thirty years, Lyell, though the keenest and most formidable of the opponents of the transmutation theory, as it was formulated by Lamarck, was of the greatest possible service in facilitating the reception of the sounder doctrines of a later day.

- **Agassiz... was doomed to help the cause he hated.** Agassiz not only maintained the fact of the progressive advance in organisation of the inhabitants of the earth at each successive geological epoch, but he insisted upon the analogy of the steps of this progression with those by which the embryo advances to the adult condition, among the highest forms of each group. In fact, in endeavoring to support these views he went a good way beyond the limits of any cautious interpretation of the facts then known.

- Although little acquainted with biological science, Whewell seems to have taken particular pains with that part of his work which deals with the history of geological and biological speculation; and several chapters of his seventeenth and eighteenth books, which comprise the history of physiology, of comparative anatomy, and of the palsetiological sciences, vividly reproduce the controversies of the early days of the Victorian epoch. But here, as in the case of the doctrine of the conservation of energy, the historian of the inductive sciences has no prophetic insight; not even a suspicion of that which the near future was to bring forth.

- Those who still repeat the once favorible objection that Darwin's 'Origin of Species' is nothing but a new version of the 'Philosophie zoologique' will find that so late as 1844, Whewell had not the slightest suspicion of Darwin's main theorem, even as a logical possibility. In fact, **the publication of that theorem by Darwin and Wallace, in 1859, took all the biological world by surprise.**

- **Neither those who were inclined towards the 'progressive transmutation' or 'development' doctrine, as it was then called, nor those who were opposed to it, had the slightest suspicion that the tendency to variation in living beings, which all admitted as a matter of fact; the selective influence of conditions, which no one could deny to be a matter of fact, when his attention was drawn to the evidence; and the occurrence of great geological changes which also was matter of fact; could be used as the only necessary postulates of a theory of the evolution of plants and animals which, even if not, at once,**

competent to explain all the known facts of biological science, could not be shown to be inconsistent with any.

- **So far as biology is concerned, the publication of the 'Origin of Species,' for the first time, put the doctrine of evolution, in its application to living things, upon a sound scientific foundation. It became an instrument of investigation, and in no hands did it prove more brilliantly profitable than in those of Darwin himself.** His publications on the effects of domestication in plants and animals, on the influence of cross-fertilisation, on flowers as organs for effecting such fertilisation, on insectivorous plants, on the motions of plants, pointed out the routes of exploration which have since been followed by hosts of inquirers, to the great profit of science.

- **It is only within the present epoch, that physiology and chemistry have reached the point at which they could offer a scientific foundation to agriculture; and it is only within the present epoch, that zoology and physiology have yielded any very great aid to pathology and hygiene.** But within that time, they have already rendered highly important services by the exploration of the phenomena of parasitism. Not only have the history of the animal parasites, such as the tapeworms and the trichina, which infest men and animals, with deadly results, been cleared up by means of experimental investigations... but the terrible agency of the parasitic fungi and of the infinitesimally minute microbes, which work far greater havoc among plants and animals, has been brought to light.

- The 'particulate' or 'germ' theory of disease... has obtained a firm foundation, in so far as it has been proved to be true in respect of sundry epidemic disorders. Moreover, it has theoretically justified prophylactic measures, such as vaccination, which formerly rested on a merely empirical basis; and it has been extended to other diseases with excellent results. ...**the progress of experimental physiology and pathology will, indubitably, in course of time place medicine and hygiene upon a rational basis.**

- **Two centuries ago England was devastated by the plague; cleanliness and common sense were enough to free us from its ravages.** One century since, small-pox was almost as great a scourge; science, though working empirically, and almost in the dark, has reduced that evil to relative insignificance. ...sooner or later it will deal in the same way with diphtheria, typhoid and scarlet fever.

- There is no reasonable ground for believing that the oldest remains yet obtained carry us even near the beginnings of life. The impressive warnings of Lyell against hasty speculations, based upon negative evidence, have been fully justified; time after time, highly organised types have been discovered in formations of an age in which the existence of such forms of life had been confidently declared to be impossible.

- **Certain forms persist with very little change, from the oldest to the newest fossiliferous formations; and thus show that progressive development is a contingent, and not a necessary result, of the nature of living matter.**

- **Geology is, as it were, the biology of our planet as a whole**. In so far as it comprises the surface configuration and the inner structure of the earth, it answers to morphology; in so far as it studies changes of condition and their causes, it corresponds with physiology; in so far as it deals with the causes which have effected the progress of the earth from its earliest to its present state, it forms part of the general doctrine of evolution.

- It should never be forgotten that **what we call 'catastrophes,' are, in relation to the earth**, changes, the equivalents of which would be well represented by the development of **a few pimples, or the scratch of a pin on a man's head.**

- **There is no study better fitted than that of geology to impress upon men of general culture that conviction of the unbroken sequence of the order of natural phenomena, throughout the duration of the universe, which is the great, and perhaps the most important, effect of the increase of natural knowledge.**

External links

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