Marx
Joyce
Abbott
Hardy
Montaigne
Machiavelli
Chesterton
Cooper
Emerson
Austen
Defoe
Melville
Haggard
Hugo
Carroll
Christie
Eliot
Grimm
Stoker
Molière
Wilde
Maupassant
Byron
Schiller
Garnett
Einstein
Fitzgerald
Engels
Smith
Goethe
Hawthorne
Kafka
Cotton
Dostoyevsky
Hall
Baum
Kipling
Doyle
Willis
Leslie
Dumas
Henry
Nietzsche
Flaubert
Turgenev
Balzac
Stockton
Vatsyayana
Crane
Burroughs
Whitman
Verne
Curtis
Tocqueville
Gogol
Vinci
Homer
Widger
Tolstoy
Busch
Darwin
Thoreau
Potter
Freud
Zola
Twain
Plato
Scott
Lawrence
Kant
Jowett
Stevenson
Dickens
Andersen
Burton
Hesse
Harte
London
Descartes
Cervantes
Poe
Aristotle
Wells
Voltaire
Hale
James
Hastings
Cooke
Bunner
Shakespeare
Chambers
Irving
Richter
Chekhov
da
Shaw
Wodehouse
Benedict
Doré
Swift
Dante
Alcott
Pushkin
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The Advance of Science in the Last Half-Century

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Imprint

This book is part of TREDITION CLASSICS

Author: Thomas Henry Huxley
Cover design: Buchgut, Berlin – Germany

Publisher: tredition GmbH, Hamburg - Germany
ISBN: 978-3-8424-7794-0

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THE ADVANCE OF SCIENCE IN THE LAST HALF-CENTURY

Recent industrial progress

The most obvious and the most distinctive features of the History of Civilisation, during the last fifty years, is the wonderful increase of industrial production by the application of machinery, the improvement of old technical processes and the invention of new ones, accompanied by an even more remarkable development of old and new means of locomotion and intercommunication. By this rapid and vast multiplication of the commodities and conveniences of existence, the general standard of comfort has been raised, the ravages of pestilence and famine have been checked, and the natural obstacles, which time and space offer to mutual intercourse, have been reduced in a manner, and to an extent, unknown to former ages. The diminution or removal of local ignorance and prejudice, the creation of common interests among the most widely separated peoples, and the strengthening of the forces of the organisation of the commonwealth against those of political or social anarchy, thus effected, have exerted an influence on the present and future fortunes of mankind the full significance of which may be divined, but cannot, as yet, be estimated at its full value.

caused by the increase of physical science

This revolution—for it is nothing less—in the political and social aspects of modern civilisation has been preceded, accompanied, and in great measure caused, by a less obvious, but no less marvellous, increase of natural knowledge, and especially of that part of it which is known as Physical Science, in consequence of the application of scientific method to the investigation of the phenomena of the material world. Not that the growth of physical science is an exclusive prerogative of the Victorian age. Its present strength and volume merely indicate the highest level of a stream which took its rise, alongside of the primal founts of Philosophy, Literature, and Art, in ancient Greece; and, after being dammed up for a thousand years, once more began to flow three centuries ago.

Greek and mediæval science.

It may be doubted if even-handed justice, as free from fulsome panegyric as from captious depreciation, has ever yet been dealt out to the sages of antiquity who, for eight centuries, from the time of Thales to that of Galen, toiled at the foundations of physical science. But, without entering into the discussion of that large question, it is certain that the labors of these early workers in the field of natural knowledge were brought to a standstill by the decay and disruption of the Roman Empire, the consequent disorganisation of society, and the diversion of men's thoughts from sublunary matters to the problems of the supernatural world suggested by Christian dogma in the Middle Ages. And, notwithstanding sporadic attempts to recall men to the investigation of nature, here and there, it was not until the fifteenth and sixteenth centuries that physical science made a new start, founding itself, at first, altogether upon that which had been done by the Greeks. Indeed, it must be admitted that the men of the Renaissance, though standing on the shoulders of the old philosophers, were a long time before they saw as much as their forerunners had done.

The first serious attempts to carry further the unfinished work of Archimedes, Hipparchus, and Ptolemy, of Aristotle and of Galen, naturally enough arose among the astronomers and the physicians. For the imperious necessity of seeking some remedy for the physical ills of life had insured the preservation of more or less of the wisdom of Hippocrates and his successors, and, by a happy conjunction of circumstances, the Jewish and the Arabian physicians and philosophers escaped many of the influences which, at that time, blighted natural knowledge in the Christian world. On the other hand, the superstitious hopes and fears which afforded countenance to astrology and to alchemy also sheltered astronomy and the germs of chemistry. Whether for this, or for some better reason, 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 school men 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.

Further advance after Renaissance.

In the early decades of the seventeenth century, the men of the Renaissance could show that they had already put out to good interest the treasure bequeathed to them by the Greeks. They had produced the astronomical system of Copernicus, with Kepler's great additions; the astronomical discoveries and the physical investigations of Galileo; the mechanics of Stevinus and the 'De Magnete' of Gilbert; the anatomy of the great French and Italian schools and the physiology of Harvey. In Italy, which had succeeded Greece in the hegemony of the scientific world, the Accademia dei Lyncei and sundry other such associations for the investigation of nature, the models of all subsequent academies and scientific societies, had been founded, while the literary skill and biting wit of Galileo had made the great scientific questions of the day not only intelligible, but attractive, to the general public.

Francis Bacon.

In our own country, 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.'

The defect of his method.

But it is not easy to discover satisfactory evidence that the 'Novum Organum' had any direct beneficial influence on the advancement of natural knowledge. No delusion is greater than the notion that method and industry can make up for lack of mother-wit, either in science or in practical life; and it is strange that, with his knowledge of mankind, Bacon should have dreamed that his, or any other, 'via inveniendi scientias' would 'level men's wits' and leave little scope for that inborn capacity which is called genius. As a matter of fact, Bacon's 'via' has proved hopelessly impracticable; while the 'anticipation of nature' by the invention of hypotheses based on incomplete inductions, which he specially condemns, has proved itself to be a most efficient, indeed an indispensable, instrument of scientific progress. Finally, that transcendental alchemy—the superinducement of new forms on matter—which Bacon declares to be the supreme aim of science, has been wholly ignored by those who have created the physical knowledge of the present day.

Even the eloquent advocacy of the Chancellor brought no unmixed good to physical science. It was natural enough that the man who, in his better moments, took 'all knowledge for his patrimony,' but, in his worse, sold that birthright for the mess of pottage of Court favor and professional success, for pomp and show, should be led to attach an undue value to the practical advantages which he foresaw, as Roger Bacon and, indeed, Seneca had foreseen, long before his time, must follow in the train of the advancement of natural knowledge. The burden of Bacon's pleadings for science is the gathering of fruit'—the importance of winning solid material advantages by the investigation of Nature and the desirableness of limiting the application of scientific methods of inquiry to that field.

Hobbes.

Descartes.

Bacon's younger contemporary, Hobbes, casting aside the prudent reserve of his predecessor in regard to those matters about which the Crown or the Church might have something to say, extended scientific methods of inquiry to the phenomena of mind and the problems of social organisation; while, at the same time, he indicated the boundary between the province of real, and that of imaginary, knowledge. The 'Principles of Philosophy' and the 'Leviathan' embody a coherent system of purely scientific thought in language which is a model of clear and vigorous English style. At the same time, in France, a man of far greater scientific capacity than either Bacon or Hobbes, René Descartes, not only in his immortal 'Discours de la Méthode' and elsewhere, went down to the foundations of scientific certainty, but, in his 'Principes de Philosophie,' indicated where the goal of physical science really lay. However, 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.

For a time the progress without fruits.

The progress of science, during the first century after Bacon's death, by means verified his sanguine prediction of the fruits which it would yield. For, though the revived and renewed study of nature had spread and grown to an extent which surpassed reasonable expectation, the practical results—the 'good to men's estate'—were, at first, by no means apparent. Sixty years after Bacon's death, Newton had crowned the long labors of the astronomers and the physicists, by coordinating the phenomena of solar motion throughout the visible universe into one vast system; but the 'Principia' helped no man to either wealth or comfort. Descartes, Newton, and Leibnitz had opened up new worlds to the mathematician, but the acquisitions of their genius enriched only man's ideal estate. Descartes had laid the foundations of rational cosmogony and of physiological psychology; Boyle had produced models of experimentation in various branches of physics and chemistry; Pascal and Torricelli had weighed the air; Malpighi and Grew, Ray and Willoughby had done work of no less importance in the biological sciences; but weaving and spinning were carried on with the old appliances; nobody could travel faster by sea or by land than at any previous time in the world's history, and King George could send a message from London to York no faster than King John might have done. Metals were worked from their ores by immemorial rule of thumb, and the centre of the iron trade of these islands was still among the oak forests of Sussex. The utmost skill of our mechanicians did not get beyond the production of a coarse watch.

The middle of the eighteenth century is illustrated by a host of great names in science—English, French, German, and Italian—especially in the fields of chemistry, geology, and biology; but this deepening and broadening of natural knowledge produced next to no immediate practical benefits. Even if, at this time, Francis Bacon could have returned to the scene of his greatness and of his littleness, he must have regarded the philosophic world which praised and disregarded his precepts with great disfavor. If ghosts are consistent, he would have said, 'These people are all wasting their time, just as Gilbert and Kepler and Galileo and my worthy physician Harvey did in my day. Where are the fruits of the restoration of science which I promised? This accumulation of bare knowledge is all very well, but *cui bono*? Not one of these people is doing what I told him specially to do, and seeking that secret of the cause of forms which will enable men to deal, at will, with matter, and superinduce new natures upon the old foundations.'

Its recent effect on life.

But, a little later, 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. Without it, the most densely populated regions of modern Europe and America must retain their primitive, sparsely inhabited, agricultural or pastoral condition; it is the foundation of our wealth and the condition of our safety from submergence by another flood of barbarous hordes; it is the bond which unites into a solid political whole, regions larger than any empire of antiquity; it secures us from the recurrence of the pestilences and famines of former times; it is the source of endless comforts and conveniences, which are not mere luxuries, but conduce to physical and moral well-being. 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.

These results often too much regarded;

What wonder, then, if these astonishing fruits of the tree of knowledge are too often regarded by both friends and enemies as the be-all and end-all of science? What wonder if some eulogise, and others revile, the new philosophy for its utilitarian ends and its merely material triumphs?

for scientific research rarely directed to practical ends

In truth, the new philosophy deserves neither the praise of its eulogists, nor the blame of its slanderers. As I have pointed out, its disciples were guided by no search after practical fruits, during the great period of its growth, and it reached adolescence without being stimulated by any rewards of that nature. 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. Werner certainly paid attention to mining, and I have not forgotten James Watt. But, though some of the most important of the improvements by which Watt converted the steam-engine, invented long before his time, into the obedient slave of man, were suggested and guided by his acquaintance with scientific principles, his skill as a practical mechanician, and the efficiency of Bolton's workmen had quite as much to do with the realisation of his projects.

but instigated by love of knowledge

In fact, the history of physical science teaches (and we cannot too carefully take the lesson to 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. In the course of this work, the physical philosopher, sometimes intentionally, much more often unintentionally, lights upon something which proves to be of practical value. Great is the rejoicing of those who are benefited thereby; and, for the moment, science is the Diana of all the craftsmen. But, even while the cries of jubilation resound and this floatsam and jetsam of the tide of investigation is being turned into the wages of workmen and the wealth of capitalists, the crest of the wave of scientific investigation is far away on its course over the illimitable ocean of the unknown.

It is in its turn assisted by industrial improvements.

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 hindered the progress of physical knowledge in the schools of Athens and of Alexandria, it has often struck me [A] 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. If science has rendered the colossal development of modern industry possible, beyond a doubt industry has done no less for modern physics and chemistry, and for a great deal of modern biology. And as the captains of industry have, at last, begun to be aware that the condition of success in that warfare, under the forms of peace, which is known as industrial competition lies in the discipline of the troops and the use of arms of precision, just as much as it does in the warfare which is called war, their demand for that discipline, which is technical education, is reacting upon science in a manner which will, assuredly, stimulate its future growth to an incalculable extent. 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.

Nevertheless, that which is true of the infancy of physical science in the Greek world, that which is true of its adolescence in the seventeenth and eighteenth centuries, remains true of its riper age in these latter days of the nineteenth century. The great steps in its progress have been made, are made, and will be made, by men who seek knowledge simply because they crave for it. They have their weaknesses, their follies, their vanities, and their rivalries, like the rest of the world; but whatever by-ends may mar their dignity and impede their usefulness, this chief end redeems them. [B] 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.

True aim and method of research.

To anyone who knows the business of investigation practically, Bacon's notion of establishing a company of investigators to work for 'fruits,' as if the pursuit of knowledge were a kind of mining operation and only required well-directed picks and shovels, seems very strange. [C] 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.

Progress from 1837 to 1887.

I am conscious that in undertaking to progress give even the briefest sketch of the progress of physical science, in all its branches, during the last half-century, I may be thought to have exhibited more courage than discretion, and perhaps more presumption than either. 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.

Nor is their any lack either of guidance, or of aids to ignorance. 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. As to subsequent events, there are numerous excellent summaries of the progress of various branches of science, especially up to 1881, which was the jubilee year of the British Association. [D] And, with respect to the biological sciences, with some parts of which my studies have familiarised me, my personal experience nearly coincides with the preceding half-century. I may hope, therefore, 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.

There is yet another prefatory remark which it seems desirable I should make. It is that I think it proper to confine myself to the work done, without saying anything about the doers of it. Meddling with questions of merit and priority is a thorny business at the best of times, and unless in case of necessity, altogether undesirable when one is dealing with contemporaries. No such necessity lies upon me, and I shall, therefore, mention no names of living men, lest, perchance, I should incur the reproof which the Israelites, who struggled with one another in the field, addressed to Moses—'Who made thee a prince and a judge over us.'

The aim of physical science

Physical science is one and indivisible. Although, for practical purposes, it is convenient to mark it out into the primary regions of Physics, Chemistry, and Biology, and to subdivide these into subordinate provinces, yet the method of investigation and the ultimate object of the physical inquirer are everywhere the same.

the discovery of the rational order of the universe

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.

It is based on postulates

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. [E] 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 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.

and uses hypotheses.

Physical science therefore 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.

Fruitful use of an hypothesis even when wrong.

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 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 is the determination of the constant relations of the phenomena thus defined, 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.

and mutual assistance of observation, experiment, and speculation.

Historically, no branch of science has followed this order of growth; but, 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.

Recognition of these truths in recent times, and consequent progress.

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 intellects. And 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.

The three great achievements. Doctrines of (1) molecular constitution of matter, (2) conservation of energy, (3) evolution.

I have said that our epoch can produce achievements in physical science of greater moment than any other has to show, advisedly; and I think that there are three great products of our time which justify the assertion. 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 was foreshadowed, more or less distinctly, in former periods of the history of science; and, so far is either from being the outcome of purely inductive reasoning, that it would be hard to overrate the influence of metaphysical, and even of theological, considerations upon the development of all three. 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, as might have been expected from the nature of the case, 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.

(1) Molecular constitution of matter.

In the early decades of this century, a number of important truths applicable, in part, to matter in general, and, in part, to particular forms of matter, had been ascertained by the physicists and chemists.

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, so far as they could be checked by observation and experiment, 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.

The two theories as to matter.

With respect to the ultimate constitution of these 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.

Reassertion by Dalton of atomic theory.

In the latter part of the eighteenth century, the chemists had arrived at several very important generalisations respecting those properties of matter with which they were especially concerned. 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; and that, so far, it varied only in its perceptibility by our senses. The course of investigation further proved that 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*), unless they were brought into contact with other kinds of matter, 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. It is obvious, that if elementary matter consists of indestructible and indivisible particles, each of which constantly preserves the same weight relatively to all the others, compounds formed by the aggregation of two, three, four, or more such