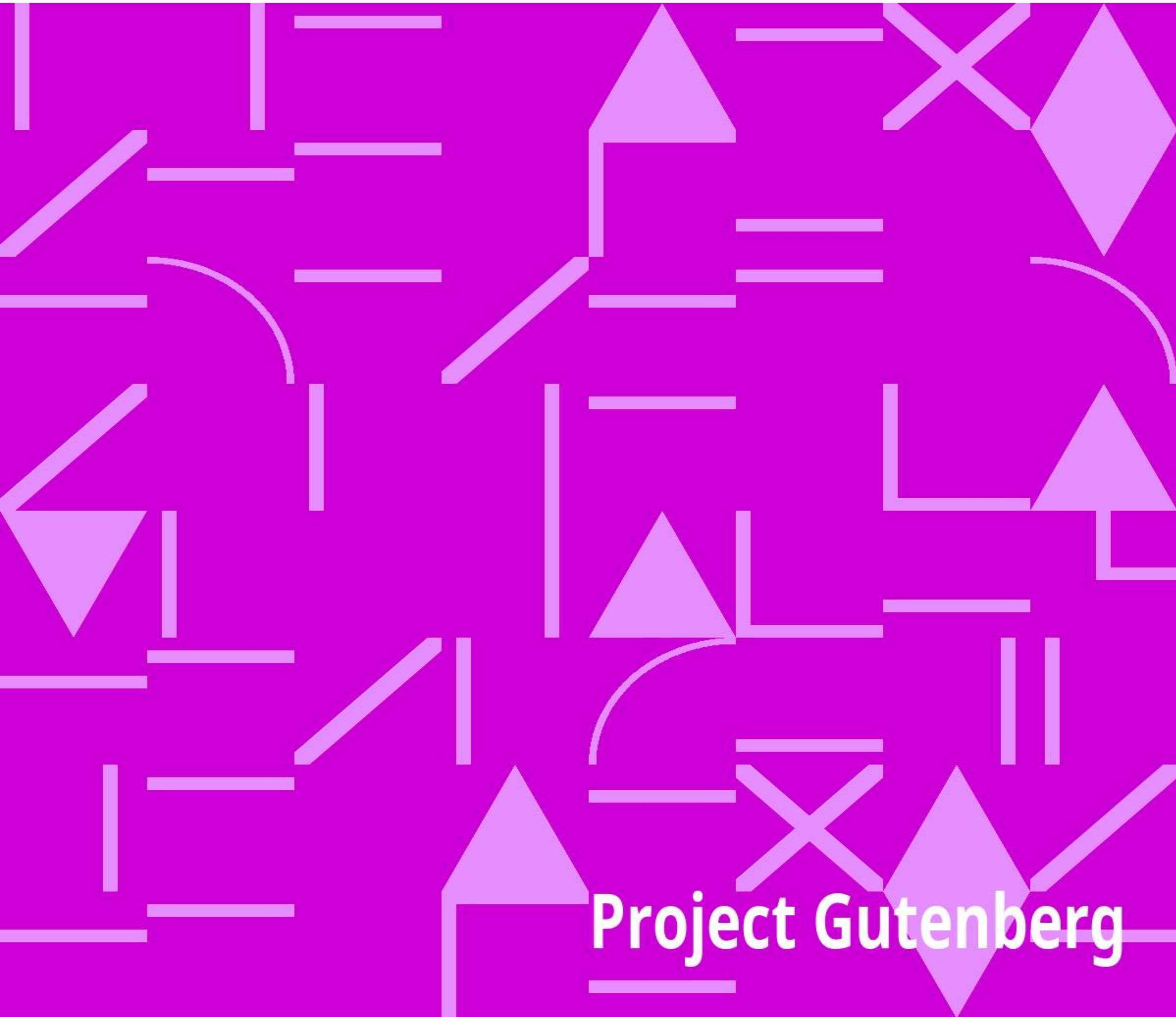
The Advance of Science in the Last Half-Century

Thomas Henry Huxley



Title: The Advance of Science in the Last Half-Century

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Release Date: March 4, 2005 [EBook #15253]

Language: English

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THE ADVANCE OF SCIENCE

IN THE LAST HALF-CENTURY

BY

T.H. HUXLEY, F.R.S.

NEW YORK

D. APPLETON AND COMPANY

1889

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 motherwit, 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 particles must exemplify the rule of combination in definite proportions deduced from observation.

In the meanwhile, 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 hypothesis; it predicates the existence of units of matter.

The real value of the new atomic hypothesis, however, 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. Just as a man is the unit of sociology, without reference to the actual fact of his divisibility, so such a minute mass is the unit of physico-chemical science—that smallest material particle which under any given circumstances acts as a whole.[F]

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.

Again, 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.

In biology a like theory of molecularstructure.

Side by side with these advances arose in another, which also has a close parallel in the history of biological science. If the unit of a compound is made up by the aggregation of elementary units, the notion that these must have some sort of definite arrangement inevitably suggests itself; and such phenomena as double decomposition pointed, not only to the existence of a molecular architecture, but to the possibility of modifying a molecular fabric without destroying it, by taking out some of the component units and replacing them by others. The class of neutral salts, for example, 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.[G] 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. Chemical work, at the present day, is, to a large extent, synthetic or creative—that is to say, the chemist determines, theoretically, that certain non-existent compounds ought to be producible, and he proceeds to produce them.

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. But 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.

But some of these hypotheses have done yet further service. Combining them 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.[H]

In the meanwhile, 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, therefore, 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.

Elementary bodies

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 were nearly the same, or 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.

fall into different series.

Recently this subject has been taken up afresh, with a result which may be stated roughly in the following terms: If the sixty-five or sixty-eight recognised 'elements' are arranged in the order of their atomic weights—from hydrogen, the lightest, as unity, to uranium, the heaviest, as 240—the series does not exhibit one continuous progressive modification in the physical and chemical characters of its several terms, but breaks up into a number of sections, in each of which the several terms present analogies with the corresponding terms of the other series.

Thus the whole series does not run:

a, b, d, e, f, g, h, i, k, &c.,

but

a, b, c, d, A, B, C, D, α, β, γ, δ, &c.;

so that it is said to express a *periodic law* of recurrent similarities. Or the relation may be expressed in another way. In each section of the series, the atomic weight is greater than in the preceding section, so that if w is the atomic weight of any element in the first segment, $w+x$ will represent the atomic weight of any element in the next, and $w+x+y$ the atomic weight of any element in the next, and so on. Therefore the sections may be represented as parallel series, the corresponding terms of which have analogous properties; each successive series starting with a body the atomic weight of which is greater than that of any in the preceding series, in the following fashion:

$$\begin{array}{ccc} d & D & \delta \\ c & C & \gamma \\ b & B & \beta \\ \underline{a} & \underline{A} & \underline{\alpha} \\ w & w + x & w + x + y \end{array}$$

The possibility of a primary form of matter.

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.

In fact, 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 πρωτη υλη 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 εσχατη υλη, 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 old and the new atomic theory.

It may perhaps occur to the reader that the boasted progress of physical science does not come to much, if our present conceptions of the fundamental nature of matter are expressible in terms employed, more than two thousand years ago, by the old 'master of those that know.' Such a criticism, however, would involve forgetfulness of the fact, that 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.

(2) Conservation of energy.

Everyday observation shows that, of the bodies which compose the material world, some are in motion and some are, or appear to be, at rest. Of the bodies in motion, some, like the sun and stars, exhibit a constant movement, regular in amount and direction, for which no external cause appears. Others, as stones and smoke, seem also to move of themselves when external impediments are taken away. But these appear to tend to move in opposite directions: the bodies we call heavy, such as stones, downwards, and the bodies we call light, at least such as smoke and steam, upwards. And, as we further notice that the earth, below our feet, is made up of heavy matter, while the air, above our heads, is extremely light matter, it is easy to regard this fact as evidence that the lower region is the place to which heavy things tend—their proper place, in short—while the upper region is the proper place of light things; and to generalise the facts observed by saying that bodies, which are free to move, tend towards their proper places. All these seem to be natural motions, dependent on the inherent faculties, or tendencies, of bodies themselves. But there are other motions which are artificial or violent, as when a stone is thrown from the hand, or is knocked by another stone in motion. In such cases as these, for example, when a stone is cast from the hand, the distance travelled by the stone appears to depend partly on its weight and partly upon the exertion of the thrower. So that, the weight of the stone remaining the same, it looks as if the motive power communicated to it were measured by the distance to which the stone travels—as if, in other words, the power needed to send it a hundred yards was twice as great as that needed to send it fifty yards. These, apparently obvious, conclusions from the everyday appearances of rest and motion fairly represent the state of opinion upon the subject which prevailed among the ancient Greeks, and remained dominant until the age of Galileo. The publication of the 'Principia' of Newton, in 1686-7, marks the epoch at which the progress of mechanical physics had effected a complete revolution of thought on these subjects. By this time, it had been made clear that the old generalisations were either incomplete or totally erroneous; that a body, once set in motion, will continue to move in a straight line for any conceivable time or distance, unless it is interfered with; that any change of motion is proportional to the 'force' which causes it, and takes place in the direction in which that 'force' is exerted; and that, when a body in motion acts as a cause of motion on another, the latter gains as much as the former loses, and *vice versâ*. It is to be noted, however, that while, in contradistinction to the ancient idea of the inherent tendency to motion of bodies, the absence of any such spontaneous power of motion was accepted as a physical axiom by the moderns, the old conception virtually maintained itself is a new shape. For, in spite of Newton's well-known warning against the 'absurdity' of supposing that one body can act on another at a distance through a vacuum, the ultimate particles of matter were generally assumed to be the seats of perennial causes of motion termed 'attractive and repulsive forces,' in virtue of which, any two such particles, without any external impression of motion, or intermediate material agent, were supposed to tend to approach or remove from one another; and this view of the duality of the causes of motion is very widely held at the present day.

Another important result of investigation, attained in the seventeenth century, was the proof and quantitative estimation of physical inertia. 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.' In modern science, the conception of the inertia, or resistance to change, of matter is complex. In part, it contains a corollary from the law of causation: A body cannot change its state in respect of rest or motion without a sufficient cause. But, in part, it contains generalisations from experience. One of these is that there is no such sufficient cause resident in any body, and that therefore it will rest, or continue in motion, so long as no external cause of change acts upon it. The other is that the effect which the impact of a body in motion produces upon the body on which it impinges depends, other things being alike, on the relation of a certain quality of each which is called 'mass.' 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.

Mechanical theory of heat.

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, and indeed much later, was regarded as an imponderable substance, *caloric*; as a thing which was absorbed by bodies when they were wanned, 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 could contain an infinite quantity of another body; but 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. The loss of the masses is the gain of their particles.

Earlier approaches towards doctrine of conservation.

Before 1843, however, the doctrine of conservation of energy had been approached Bacon's chief contribution to positive science is the happy guess (for the context shows that it was little more) 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. Again, the discovery of voltaic electricity, and the marvellous development of knowledge, in that field, effected by such men as Davy, Faraday, Oersted, Ampère, 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.

It is a remarkable evidence of the greatness of the progress in this direction which has been effected in our time, that 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.[I] 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.

What this doctrine is.

I have pointed out that the growth of clear and definite views respecting the constitution of matter has led to the conclusion that, so far as natural agencies are concerned, it is ingenerable and indestructible. In so far as matter may be conceived to exist in a purely passive state, it is, imaginably, older than motion. But, as it must be assumed to be susceptible of motion, a particle of bare matter at rest must be endowed with the potentiality of motion. Such a particle, however, by the supposition, can have no energy, for there is no cause why it should move. Suppose now that it receives an impulse, it will begin to move with a velocity inversely proportional to its mass, on the one hand, and directly proportional to the strength of the impulse, on the other, and will possess *kinetic energy*, in virtue of which it will not only continue to move for ever if unimpeded, but if it impinges on another such particle, it will impart more or less of its motion, to the latter. Let it be conceived that the 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 δυναμις and ενεργεια.

That kinetic energy appears to be imparted by impact is a fact of daily and hourly experience: we see bodies set in motion by bodies, already in motion, which seem to come in contact with them. It is a truth which could have been learned by nothing but experience, and which cannot be explained, but must be taken as an ultimate fact about which, explicable or inexplicable, there can be no doubt. Strictly speaking, we have no direct apprehension of any other cause of motion. But experience furnishes innumerable examples of the production of kinetic energy in a body previously at rest, when no impact is discernible as the cause of that energy. In all such cases, the presence of a second body is a necessary condition; and the amount of kinetic energy, which its presence enables the first to gain, is strictly dependent on the relative positions of the two. Hence the phrase *energy of position*, which is frequently used as equivalent to potential energy. 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.

Taking this as a very broad and general statement of the essential facts of the case, the raising of the stone is intelligible enough, as a case of the communication of motion from one body to another. But the potential energy of the raised stone is not so easily intelligible. To all appearance, there is nothing either pushing or pulling it towards the earth, or the earth towards it; and yet it is quite certain that the stone tends to move towards the earth and the earth towards the stone, in the way defined by the law of gravitation.

In the currently accepted language of science, the cause of motion, in all such cases as this, 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.

Another illustration may make the case plainer. 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*, 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 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.' It follows that 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.

Hence, 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. A living body is a machine by which energy is transformed in the same sense as a steam-engine is so, and all its movements, molar and molecular, are to be accounted for by the energy which is supplied to it. The phenomena of consciousness which arise, along with certain transformations of energy, cannot be interpolated in the series of these transformations, inasmuch as they are not motions to which the doctrine of the conservation of energy applies. And, for the same reason, they do not necessitate the using up of energy; a sensation has no mass and cannot be conceived to be susceptible of movement. 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. In fact, it is hardly too much to say that 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.

(3) Evolution.

The third great scientific event of our time, the rehabilitation of the doctrine of evolution, is part of the same tendency of increasing knowledge to unify itself, which has led to the doctrine of the conservation of energy. And this tendency, again, is mainly a product of the increasing strength conferred by physical investigation on the belief in the universal validity of that orderly relation of facts, which we express by the so-called 'Laws of Nature.'

Early stages of this theory

The growth of a plant from its seed, of an animal from its egg, the apparent origin of innumerable living things from mud, or from the putrefying remains of former organisms, had furnished the earlier scientific thinkers with abundant analogies suggestive of the conception of a corresponding method of cosmic evolution from a formless 'chaos' to an ordered world which might either continue for ever or undergo dissolution into its elements before starting on a new course of evolution. It is therefore no wonder that, from the days of the Ionian school onwards, the view that the universe was the result of such a process should have maintained itself as a leading dogma of philosophy. 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 'Protogaea' 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 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 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. And, in like fashion, another vehement opponent of the transmutation of species, the elder 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.

Darwin

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 palætiological 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. And those who still repeat the once favorite 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.

Darwin found the biological world a more than sufficient field for even his great powers, and left the cosmical part of the doctrine to others. Not much has been added to the nebular hypothesis, since the time of Laplace, except that the attempt to show (against that hypothesis) that all nebulæ are star clusters, has been met by the spectroscopic proof of the gaseous condition of some of them. Moreover, physicists of the present generation appear now to accept the secular cooling of the earth, which is one of the corollaries of that hypothesis. In fact, attempts have been made, by the help of deductions from the data of physics, to lay down an approximate limit to the number of millions of years which have elapsed since the earth was habitable by living beings. If the conclusions thus reached should stand the test of further investigation, they will undoubtedly be very valuable. But, whether true or false, they can have no influence upon the doctrine of evolution in its application to living organisms. The occurrence of successive forms of life upon our globe is an historical fact, which cannot be disputed; and the relation of these successive forms, as stages of evolution of the same type, is established in various cases. The biologist has no means of determining the time over which the process of evolution has extended, but accepts the computation of the physical geologist and the physicist, whatever that may be.

and philosophy

Evolution as a philosophical doctrine applicable to all phenomena, whether physical or mental, whether manifested by material atoms or by men in society, has been dealt with systematically in the 'Synthetic Philosophy' of Mr. Herbert Spencer. Comment on that great undertaking would not be in place here. I mention it because, so far as I know, it is the first attempt to deal, on scientific principles, with modern scientific facts and speculations. For the 'Philosophic positive' of M. Comte, with which Mr. Spencer's system of philosophy is sometimes compared, though it professes a similar object, is unfortunately permeated by a thoroughly unscientific spirit, and its author had no adequate acquaintance with the physical sciences even of his own time.

The doctrine of evolution, so far as the present physical cosmos is concerned, postulates the fixity of the rules of operation of the causes of motion in the material universe. If all kinds of matter are modifications of one kind, and if all modes of motion are derived from the same energy, the orderly evolution of physical nature out of one substratum and one energy implies that the rules of action of that energy should be fixed and definite. In the past history of the universe, back to that point, there can be no room for chance or disorder. But it is possible to raise the question whether this universe of simplest matter and definitely operating energy, which forms our hypothetical starting point, may not itself be a product of evolution from a universe of such matter, in which the manifestations of energy were not definite—in which, for example, our laws of motion held good for some units and not for others, or for the same units at one time and not at another—and which would therefore be a real epicurean chance-world?

For myself, I must confess that I find the air of this region of speculation too rarefied for my constitution, and I am disposed to take refuge in 'ignoramus et ignorabimus.'

Other achievements in physical science.

The execution of my further task, the indication of the most important achievements in the several branches of physical science during the last fifty years, is embarrassed by the abundance of the objects of choice; and by the difficulty which everyone, but a specialist in each department, must find in drawing a due distinction between discoveries which strike the imagination by their novelty, or by their practical influence, and those unobtrusive but pregnant observations and experiments in which the germs of the great things of the future really lie. Moreover, my limits restrict me to little more than a bare chronicle of the events which I have to notice.

Physics and chemistry.

In physics and chemistry, the old boundaries of which sciences are rapidly becoming effaced, one can hardly go wrong in ascribing a primary value to the investigations into the relation between the solid, liquid, and gaseous states of matter on the one hand, and degrees of pressure and of heat on the other. Almost all, even the most refractory, solids have been vaporised by the intense heat of the electric arc; and the most refractory gases have been forced to assume the liquid, and even the solid, forms by the combination of high pressure with intense cold. It has further been shown that there is no discontinuity between these states—that a gas passes into the liquid state through a condition which is neither one nor the other, and that a liquid body becomes solid, or a solid liquid, by the intermediation of a condition in which it is neither truly solid nor truly liquid.

Theoretical and experimental investigations have concurred in the establishment of the view that a gas is a body, the particles of which are in incessant rectilinear motion at high velocities, colliding with one another and bounding back when they strike the walls of the containing vessel; and, on this theory, the already ascertained relations of gaseous bodies to heat and pressure have been shown to be deducible from mechanical principles. Immense improvements have been effected, in the means of exhausting a given space of its gaseous contents; and experimentation on the phenomena which attend the electric discharge and the action of radiant heat, within the extremely rarefied media thus produced, has yielded a great number of remarkable results, some of which have been made familiar to the public by the Gieseler tubes and the radiometer. Already, these investigations have afforded an unexpected insight into the constitution of matter and its relations with thermal and electric energy, and they open up a vast field for future inquiry into some of the deepest problems of physics. Other important steps, in the same direction, have been effected by investigations into the absorption of radiant heat proceeding from different sources by solid, fluid, and gaseous bodies. And it is a curious example of the interconnection of the various branches of physical science, that some of the results thus obtained have proved of great importance in meteorology.

The spectroscope.

The existence of numerous dark lines, constant in their number and position in the various regions of the solar spectrum, was made out by Fraunhofer in the early part of the present century, but more than forty years elapsed before their causes were ascertained and their importance recognised. Spectroscopy, which then took its rise, is probably that employment of physical knowledge, already won, as a means of further acquisition, which most impresses the imagination. For it has suddenly and immensely enlarged our power of overcoming the obstacles which almost infinite minuteness on the one hand, and almost infinite distance on the other, have hitherto opposed to the recognition of the presence and the condition of matter. One eighteen-millionth of a grain of sodium in the flame of a spirit-lamp may be detected by this instrument; and, at the same time, it gives trust-worthy indications of the material constitution not only of the sun, but of the farthest of those fixed stars and nebulæ which afford sufficient light to affect the eye, or the photographic plate, of the inquirer.

Electricity.

The mathematical and experimental elucidation of the phenomena of electricity, and the study of the relations of this form of energy with chemical and thermal action, had made extensive progress before 1837. But the determination of the influence of magnetism on light, the discovery of diamagnetism, of the influence of crystalline structure on magnetism, and the completion of the mathematical theory of electricity, all belong to the present epoch. To it also appertain the practical execution and the working out of the results of the great international system of observations on terrestrial magnetism, suggested by Humboldt in 1836; and the invention of instruments of infinite delicacy and precision for the quantitative determination of electrical phenomena. The voltaic battery has received vast improvements; while the invention of magneto-electric engines and of improved means of producing ordinary electricity has provided sources of electrical energy vastly superior to any before extant in power, and far more convenient for use.

It is perhaps this branch of physical science which may claim the palm for its practical fruits, no less than for the aid which it has furnished to the investigation of other parts of the field of physical science. The idea of the practicability of establishing a communication between distant points, by means of electricity, could hardly fail to have simmered in the minds of ingenious men since, well nigh a century ago, experimental proof was given that electric disturbances could be propagated through a wire twelve thousand feet long. Various methods of carrying the suggestion into practice had been carried out with some degree of success; but the system of electric telegraphy, which, at the present time, brings all parts of the civilised world within a few minutes of one another, originated only about the commencement of the epoch under consideration. In its influence on the course of human affairs, this invention takes its place beside that of gunpowder, which tended to abolish the physical inequalities of fighting men; of printing, which tended to destroy the effect of inequalities in wealth among learning men; of steam transport, which has done the like for travelling men. All these gifts of science are aids in the process of levelling up; of removing the ignorant and baneful prejudices of nation against nation, province against province, and class against class; of assuring that social order which is the foundation of progress, which has redeemed Europe from barbarism, and against which one is glad to think that those who, in our time, are employing themselves in fanning the embers of ancient wrong, in setting class against class, and in trying to tear asunder the existing bonds of unity, are undertaking a futile struggle. The telephone is only second in practical importance to the electric telegraph. Invented, as it were, only the other day, it has already taken its place as an appliance of daily life. Sixty years ago, the extraction of metals from their solutions, by the electric current, was simply a highly interesting scientific fact. At the present day, the galvano-plastic art is a great industry; and, in combination with photography, promises to be of endless service in the arts. Electric lighting is another great gift of science to civilisation, the practical effects of which have not yet been fully developed, largely on account of its cost. But those whose memories go back to the tinder-box period, and recollect the cost of the first lucifer matches, will not despair of the results of the application of science and ingenuity to the cheap production of anything for which there is a large demand.

The influence of the progress of electrical knowledge and invention upon that of investigation in other fields of science is highly remarkable. The combination of electrical with mechanical contrivances has produced instruments by which, not only may extremely small intervals of time be exactly measured, but the varying rapidity of movements, which take place in such intervals and appear to the ordinary sense instantaneous, is recorded. The duration of the winking of an eye is a proverbial expression for an instantaneous action; but, by the help of the revolving cylinder and the electrical marking-apparatus, it is possible to obtain a graphic record of such an action, in which, if it endures a second, that second shall be subdivided into a hundred, or a thousand, equal parts, and the state of the action at each hundredth, or thousandth, of a second exhibited. In fact, these instruments may be said to be time-microscopes. Such appliances have not only effected a revolution in physiology, by the power of analysing the phenomena of muscular and nervous activity which they have conferred, but they have furnished new methods of measuring the rate of movement of projectiles to the artillerist. Again, the microphone, which renders the minutest movements audible, and which enables a listener to hear the footfall of a fly, has equipped the sense of hearing with the means of entering almost as deeply into the penetralia of nature, as does the sense of sight.

Photography as an instrument of science.

That light exerts a remarkable influence in bringing about certain chemical combinations and decompositions was well known fifty years ago, and various more or less successful attempts to produce permanent pictures, by the help of that knowledge, had already been made. It was not till 1839, however, that practical success was obtained; but the 'daguerreotypes' were both cumbrous and costly, and photography would never have attained its present important development had not the progress of invention substituted paper and glass for the silvered plates then in use. It is not my affair to dwell upon the practical application of the photography of the present day, but it is germane to my purpose to remark that it has furnished a most valuable accessory to the methods of recording motions and lapse of time already in existence. In the hands of the astronomer and the meteorologist, it has yielded means of registering terrestrial, solar, planetary, and stellar phenomena, independent of the sources of error attendant on ordinary observation; in the hands of the physicist, not only does it record spectroscopic phenomena with unsurpassable ease and precision, but it has revealed the existence of rays having powerful chemical energy, or beyond the visible limits of either end of the spectrum; while, to the naturalist, it furnishes the means by which the forms of many highly complicated objects may be represented, without that possibility of error which is inherent in the work of the draughtsman. In fact, in many cases, the stern impartiality of photography is an objection to its employment: it makes no distinction between the important and the unimportant; and hence photographs of dissections, for example, are rarely so useful as the work of a draughtsman who is at once accurate and intelligent.

Astronomy,

The determination of the existence of a new planet, Neptune, far beyond the previously known bounds of the solar system, by mathematical deduction from the facts of perturbation; and the immediate confirmation of that determination, in the year 1846, by observers who turned their telescopes into the part of the heavens indicated as its place, constitute a remarkable testimony of nature to the validity of the principles of the astronomy of our time. In addition, so many new asteroids have been added to those which were already known to circulate in the place which theoretically should be occupied by a planet, between Mars and Jupiter, that their number now amounts to between two and three hundred. I have already alluded to the extension of our knowledge of the nature of the heavenly bodies by the employment of spectroscopy. It has not only thrown wonderful light upon the physical and chemical constitution of the sun, fixed stars, and nebulæ, and comets, but it holds out a prospect of obtaining definite evidence as to the nature of our so-called elementary bodies.

its relation to geology.

The application of the generalisations of thermotics to the problem of the duration of the earth, and of deductions from tidal phenomena to the determination of the length of the day and of the time of revolution of the moon, in past epochs of the history of the universe; and the demonstration of the competency of the great secular changes, known under the general name of the precession of the equinoxes, to cause corresponding modifications in the climate of the two hemispheres of our globe, have brought astronomy into intimate relation with geology. Geology, in fact, proves that, in the course of the past history of the earth, the climatic conditions of the same region have been widely different, and seeks the explanation of this important truth from the sister sciences. The facts that, in the middle of the Tertiary epoch, evergreen trees abounded within the arctic circle; and that, in the long subsequent Quaternary epoch, an arctic climate, with its accompaniment of gigantic glaciers, obtained in the northern hemisphere, as far south as Switzerland and Central France, are as well established as any truths of science. But, whether the explanation of these extreme variations in the mean temperature of a great part of the northern hemisphere is to be sought in the concomitant changes in the distribution of land and water surfaces of which geology affords evidence, or in astronomical conditions, such as those to which I have referred, is a question which must await its answer from the science of the future.

Biological sciences.

The 'cell theory.'

Turning now to the great steps in that progress which the biological sciences have made since 1837, we are met, on the threshold of our epoch, with perhaps the greatest of all—namely, the promulgation by Schwann, in 1839, of the generalisation known as the 'cell theory,' the application and extension of which by a host of subsequent investigators has revolutionised morphology, development, and physiology. Thanks to the immense series of labors thus inaugurated, the following fundamental truths have been established.

Fundamental truths established.

All living bodies contain substances of closely similar physical and chemical composition, which constitute the physical basis of life, known as protoplasm. So far as our present knowledge goes, this takes its origin only from pre-existing protoplasm.

All complex living bodies consist, at one period of their existence, of an aggregate of minute portions of such substance, of similar structure, called cells, each cell having its own life independent of the others, though influenced by them.

All the morphological characters of animals and plants are the results of the mode of multiplication, growth, and structural metamorphosis of these cells, considered as morphological units.

All the physiological activities of animals and plants—assimilation, secretion, excretion, motion, generation—are the expression of the activities of the cells considered as physiological units. Each individual, among the higher animals and plants, is a synthesis of millions of subordinate individualities. Its individuality, therefore, is that of a 'civitas' in the ancient sense, or that of the Leviathan of Hobbes.

There is no absolute line of demarcation between animals and plants. The intimate structure, and the modes of change, in the cells of the two are fundamentally the same. Moreover, the higher forms are evolved from lower, in the course of their development, by analogous processes of differentiation, coalescence, and reduction in both the vegetable and the animal worlds.

At the present time, the cell theory, in consequence of recent investigations into the structure and metamorphosis of the 'nucleus,' is undergoing a new development of great significance, which, among other things, foreshadows the possibility of the establishment of a physical theory of heredity, on a safer foundation than those which Buffon and Darwin have devised.

Spontaneous generation disproved.

The popular belief in abiogenesis, or the so-called 'spontaneous' generation of the lower forms of life, which was accepted by all the philosophers of antiquity, held its ground down to the middle of the seventeenth century. Notwithstanding the frequent citation of the phrase, wrongfully attributed to Harvey, 'Omne vivum ex ovo,' that great physiologist believed in spontaneous generation as firmly as Aristotle did. And it was only in the latter part of the seventeenth century, that Redi, by simple and well-devised experiments, demonstrated that, in a great number of cases of supposed spontaneous generation, the animals which made their appearance owed their origin to the ordinary process of reproduction, and thus shook the ancient doctrine to its foundations. In the middle of the eighteenth century, it was revived, in a new form, by Needham and Buffon; but the experiments of Spallanzani enforced the conclusions of Redi, and compelled the advocates of the occurrence of spontaneous generation to seek evidence for their hypothesis only among the parasites and the lowest and minutest organisms. It is just fifty years since Schwann and others proved that, even with respect to them, the supposed evidence of abiogenesis was untrustworthy.

During the present epoch, the question, whether living matter can be produced in any other way than by the physiological activity of other living matter, has been discussed afresh with great vigor; and the problem has been investigated by experimental methods of a precision and refinement unknown to previous investigators. The result is that the evidence in favor of abiogenesis has utterly broken down, in every case which has been properly tested. So far as the lowest and minutest organisms are concerned, it has been proved that they never make their appearance, if those precautions by which their germs are certainly excluded are taken. And, in regard to parasites, every case which seemed to make for their generation from the substance of the animal, or plant, which they infest has been proved to have a totally different significance. Whether not-living matter may pass, or ever has, under any conditions, passed into living matter, without the agency of pre-existing living matter, necessarily remains an open question; all that can be said is that it does not undergo this metamorphosis under any known conditions. Those who take a monistic view of the physical world may fairly hold abiogenesis as a pious opinion, supported by analogy and defended by our ignorance. But, as matters stand, it is equally justifiable to regard the physical world as a sort of dual monarchy. The kingdoms of living matter and of not-living matter are under one system of laws, and there is a perfect freedom of exchange and transit from one to the other. But no claim to biological nationality is valid except birth.

Morphology.

In the department of anatomy and development, a host of accurate and patient inquirers, aided by novel methods of preparation, which enable the anatomist to exhaust the details of visible structure and to reproduce them with geometrical precision, have investigated every important group of living animals and plants, no less than the fossil relics of former faunæ and floræ. An enormous addition has thus been made to our knowledge, especially of the lower forms of life, and it may be said that morphology, however inexhaustible in detail, is complete in its broad features. Classification, which is merely a convenient summary expression of morphological facts, has undergone a corresponding improvement. The breaks which formerly separated our groups from one another, as animals from plants, vertebrates from invertebrates, cryptogams from phanerogams, have either been filled up, or shown to have no theoretical significance. The question of the position of man, as an animal, has given rise to much disputation, with the result of proving that there is no anatomical or developmental character by which he is more widely distinguished from the group of animals most nearly allied to him, than they are from one another. In fact, in this particular, the classification of Linnæus has been proved to be more in accordance with the facts than those of most of his successors.

Anthropology.

The study of man, as a genus and species of the animal world, conducted with reference to no other considerations than those which would be admitted by the investigator of any other form of animal life, has given rise to a special branch of biology, known, as Anthropology, which has grown with great rapidity. Numerous societies devoted to this portion of science have sprung up, and the energy of its devotees has produced a copious literature. The physical characters of the various races of men have been studied with a minuteness and accuracy heretofore unknown; and demonstrative evidence of the existence of human contemporaries of the extinct animals of the latest geological epoch has been obtained, physical science has thus been brought into the closest relation with history and with archæology; and the striking investigations which, during our time, have put beyond doubt the vast antiquity of Babylonian and Egyptian civilisation, are in perfect harmony with the conclusions of anthropology as to the antiquity of the human species.

Classification is a logical process which consists in putting together those things which are like and keeping asunder those which are unlike; and a morphological classification, of course, takes notes only of morphological likeness and unlikeness. So long, therefore, as our morphological knowledge was almost wholly confined to anatomy, the characters of groups were solely anatomical; but as the phenomena of embryology were explored, the likeness and unlikeness of individual development had to be taken into account; and, at present, the study of ancestral evolution introduces a new element of likeness and unlikeness which is not only eminently deserving of recognition, but must ultimately predominate over all others. A classification which shall represent the process of ancestral evolution is, in fact, the end which the labors of the philosophical taxonomist must keep in view. But it is an end which cannot be attained until the progress of palæontology has given us far more insight than we yet possess, into the historical facts of the case. Much of the speculative 'phylogeny,' which abounds among my present contemporaries, reminds me very forcibly of the speculative morphology, unchecked by a knowledge of development, which was rife in my youth. As hypothesis, suggesting inquiry in this or that direction, it is often extremely useful; but, when the product of such speculation is placed on a level with those generalisations of morphological truths which are represented by the definitions of natural groups, it tends to confuse fancy with fact and to create mere confusion. We are in danger of drifting into a new 'Natur-Philosophie' worse than the old, because there is less excuse for it. Boyle did great service to science by his 'Sceptical Chemist,' and I am inclined to think that, at the present day, a 'Sceptical Biologist' might exert an equally beneficent influence.

Physiology.

Whoso wishes to gain a clear conception of the progress of physiology, since 1837, will do well to compare Müller's 'Physiology,' which appeared in 1835, and Drapiez's edition of Richard's 'Nouveaux Eléments de Botanique,' published in 1837, with any of the present handbooks of animals and vegetable physiology. Müller's work was a masterpiece, unsurpassed since the time of Haller, and Richard's book enjoyed a great reputation at the time; but their successors transport one into a new world. That which characterises the new physiology is that it is permeated by, and indeed based upon, conceptions which, though not wholly absent, are but dawning on the minds of the older writers.

Modern physiology sets forth as its chief ends: Firstly, the ascertainment of the facts and conditions of cell-life in general. Secondly, in composite organisms, the analysis of the functions of organs into those of the cells of which they are composed. Thirdly, the explication of the processes by which this local cell-life is directly, or indirectly, controlled and brought into relation with the life of the rest of the cells which compose the organism. Fourthly, the investigation of the phenomena of life in general, on the assumption that the physical and chemical processes which take place in the living body are of the same order as those which take place out of it; and that whatever energy is exerted in producing such phenomena is derived from the common stock of energy in the universe. In the fifth place, modern physiology investigates the relation between physical and psychical phenomena, on the assumption that molecular changes in definite portions of nervous matter stand in the relation of necessary antecedents to definite mental states and operations. The work which has been done in each of the directions here indicated is vast, and the accumulation of solid knowledge, which has been effected, is correspondingly great. For the first time in the history of science, physiologists are now in the position to say that they have arrived at clear and distinct, though by no means complete, conceptions of the manner in which the great functions of assimilation, respiration, secretion, distribution of nutriment, removal of waste products, motion, sensation, and reproduction are performed; while the operation of the nervous system, as a regulative apparatus, which influences the origination and the transmission of manifestations of activity, either within itself or in other organs, has been largely elucidated.

Practical value of physiological discovery.

I have pointed out, in an earlier part of this chapter, that the history of all branches of science proves that they must attain a considerable stage of development before they yield practical 'fruits;' and this is eminently true of physiology. 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, and efficient modes of prevention deduced from the data so obtained; 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, as it is called, long since suggested, 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. Further, just as the discovery of the cause of scabies proved the absurdity of many of the old prescriptions for the prevention and treatment of that disease; so the discovery of the cause of splenic fever, and other such maladies, has given a new direction to prophylactic and curative measures against the worst scourges of humanity. Unless the fanaticism of philozoic sentiment overpowers the voice of philanthropy, and the love of dogs and cats supersedes that of one's neighbor, 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. At the present time, science, working in the light of clear knowledge, has attacked splenic fever and has beaten it; it is attacking hydrophobia with no mean promise of success; sooner or later it will deal, in the same way, with diphtheria, typhoid and scarlet fever. To one who has seen half a street swept clear of its children, or has lost his own by these horrible pestilences, passing one's offspring through the fire to Moloch seems humanity, compared with the proposal to deprive them of half their chances of health and life because of the discomfort to dogs and cats, rabbits and frogs, which may be involved in the search for means of guarding them.

Scientific exploration.

An immense extension has been effected in our knowledge of the distribution of plants and animals; and the elucidation of the causes which have brought about that distribution has been greatly advanced. The establishment of meteorological observations by all civilised nations, has furnished a solid foundation to climatology; while a growing sense of the importance of the influence of the 'struggle for existence' affords a wholesome check to the tendency to overrate the influence of climate on distribution. Expeditions, such as that of the Challenger,' equipped, not for geographical exploration and discovery, but for the purpose of throwing light on problems of physical and biological science, have been sent out by our own and other Governments, and have obtained stores of information of the greatest value. For the first time, we are in possession of something like precise knowledge of the physical features of the deep seas, and of the living population of the floor of the ocean. The careful and exhaustive study of the phenomena presented by the accumulations of snow and ice, in polar and mountainous regions, which has taken place in our time, has not only revealed to the geologist an agent of denudation and transport, which has slowly and quietly produced effects, formerly confidently referred to diluvial catastrophes, but it has suggested new methods of accounting for various puzzling facts of distribution.

Palæontology.

Palæontology, which treats of the extinct forms of life and their succession and distribution upon our globe, a branch of science which could hardly be said to exist a century ago, has undergone a wonderful development in our epoch. In some groups of animals and plants, the extinct representatives, already known, are more numerous and important than the living. There can be no doubt that the existing Fauna and Flora is but the last term of a long series of equally numerous contemporary species, which have succeeded one another, by the slow and gradual substitution of species for species, in the vast interval of time which has elapsed between the deposition of the earliest fossiliferous strata and the present day. 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. The western territories of the United States alone have yielded a world of extinct animal forms, undreamed of fifty years ago. And, wherever sufficiently numerous series of the remains of any given group, which has endured for a long space of time, are carefully examined, their morphological relations are never in discordance with the requirements of the doctrine of evolution, and often afford convincing evidence of it. At the same time, it has been shown that 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.

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. An interesting contrast between the geology of the present day and that of half a century ago, is presented by the complete emancipation of the modern geologist from the controlling and perverting influence of theology, all-powerful at the earlier date. As the geologist of my young days wrote, he had one eye upon fact, and the other on Genesis; at present, he wisely keeps both eyes on fact, and ignores the pentateuchal mythology altogether. The publication of the 'Principles of Geology' brought upon its illustrious author a period of social ostracism; the instruction given to our children is based upon those principles. Whewell had the courage to attack Lyell's fundamental assumption (which surely is a dictate of common sense) that we ought to exhaust known causes before seeking for the explanation of geological phenomena in causes of which we have no experience. But geology has advanced to its present state by working from Lyell's[J] axiom; and, to this day, the record of the stratified rocks affords no proof that the intensity or the rapidity of the causes of change has ever varied, between wider limits, than those between which the operations of nature have taken place in the youngest geological epochs.

An incalculable benefit has accrued to geological science from the accurate and detailed surveys, which have now been executed by skilled geologists employed by the Governments of all parts of the civilised world. In geology, the study of large maps is as important as it is said to be in politics; and sections, on a true scale, are even more important, in so far as they are essential to the apprehension of the extraordinary insignificance of geological perturbations in relation to the whole mass of our planet. 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. Vast regions of the earth's surface remain geologically unknown; but the area already fairly explored is many times greater than it was in 1837; and, in many parts of Europe and the United States, the structure of the superficial crust of the earth has been investigated with great minuteness.

The parallel between Biology and Geology, which I have drawn, is further illustrated by the modern growth of that branch of the science known as Petrology, which answers to Histology, and has made the microscope as essential an instrument to the geological as to the biological investigator.

The evidence of the importance of causes now in operation has been wonderfully enlarged by the study of glacial phenomena; by that of earthquakes and volcanoes; and by that of the efficacy of heat and cold, wind, rain, and rivers as agents of denudation and transport. On the other hand, the exploration of coral reefs and of the deposits now taking place at the bottom of the great oceans, has proved that, in animal and plant life, we have agents of reconstruction of a potency hitherto unsuspected.

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.

THE END.

FOOTNOTES:

[A] There are excellent remarks to the same effect in Zeller's *Philosophie der Griechen*, Theil II. Abth. ii p. 407, and in Eucken's *Die Methode der Aristotelischen, Forschung*, pp. 136 *et seq*.

[B] Fresnel, after a brilliant career of discovery in some of the most difficult regions of physico-mathematical science, died at thirty-nine years of age. The following passage of a letter from him to Young (written in November 1824), quoted by Whewell, so aptly illustrates the spirit which animates the scientific inquirer that I may cite it:

> 'For a long time that sensibility, or that vanity, which people call love of glory is munch blunted in me. I labor much less to catch the suffrages of the public than to obtain an inward approval which has always been the mental reward of my efforts. Without doubt I have often wanted the spur of vanity to excite me to pursue my researches in moments of disgust and discouragement. But all the compliments which I have received from M.M. Arago, De Laplace, or Biot, never gave me so much pleasure as the discovery of a theoretical truth or the confirmation of a calculation by experiment.'

[C] 'Mémorable exemple de l'impuissance des recherches collectives appliquées à la découverte des vérités nouvelles!' says one of the most distinguished of living French *savants* of the corporate chemical work of the old Académie des Sciences. (See Berthelot, *Science et Philosophie*, p. 201.)

[D] I am particularly indebted to my friend and colleague Professor Rücker, F.R.S., for the many acute criticisms and suggestions on my remarks respecting the ultimate problems of physics, with which he has favored me, and by which I have greatly profited.

[E] I am aware that this proposition may be challenged. It may be said, for example, that, on the hypothesis of Boscovich, matter has no extension, being reduced to mathematical points serving as centres of 'forces.' But as the 'forces' of the various centres are conceived to limit one another's action in such a manner that an area around each centre has an individuality of its own extension comes back in the form of that area. Again, a very eminent mathematician and physicist—the late Clerk Maxwell—has declared that impenetrability is not essential to our notions of matter, and that two atoms may conceivably occupy the same space. I am loth to dispute any dictum of a philosopher as remarkable for the subtlety of his intellect as for his vast knowledge; but the assertion that one and the same point or area of space can have different (conceivably opposite) attributes appears to me to violate the principle of contradiction, which is the foundation not only of physical science, but of logic in general. It means that A can be not-A.

[F] 'Molecule' would be the more appropriate name for such a particle. Unfortunately, chemists employ this term in a special sense, as a name for an aggregation of their smallest particles, for which they retain the designation of 'atoms.'

[G] 'At present more organic analyses are made in a single day than were accomplished before Liebig's time in a whole year.'—Hofmann, *Faraday Lecture*, p. 46.

[H] In the preface to his *Mécanique Chimique* M. Berthelot declares his object to be 'ramener la chimie tout entirère ... aux mêmes principes mécaniques qui régissent déjà les diverses branches de la physique.'

[I] This is the more curious, as Ampère's hypothesis that vibrations of molecules, causing and caused by vibrations of the ether, constitute heat, is discussed. See vol. ii. p. 587, 2nd ed. In the *Philosophy of the Inductive Sciences*, 2nd ed., 1847, p. 239, Whewell remarks, *à propos* of Bacon's definition of heat, 'that it is an expansive, restrained motion, modified in certain ways, and exerted in the smaller particles of the body;' that 'although the exact nature of heat is still an obscure and controverted matter, the science of heat now consists of many important truths; and that to none of these truths is there any approximation in Bacon's essay.' In point of fact, Bacon's statement, however much open to criticism, does contain a distinct approximation to the most important of all the truths respecting heat which had been discovered when Whewell wrote.

[J] Perhaps I ought rather to say Button's axiom. For that great naturalist and writer embodied the principles of sound geology in a pithy phrase of the *Théoris de la Terre*: 'Pour juger de ce qui est arrivé, et même de ce qui arrivera, nous n'avons qu'à examiner ce qui arrive.'

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