

A HISTORY OF SCIENCE
*AND ITS RELATIONS WITH
PHILOSOPHY & RELIGION*

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BY

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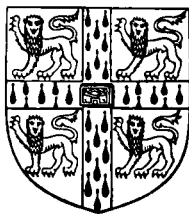
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“Natura enim non nisi parendo vincitur.”

*At first men try with magic charm
To fertilize the earth,
To keep their flocks and herds from harm
And bring new young to birth.*

*Then to capricious gods they turn
To save from fire or flood;
Their smoking sacrifices burn
On altars red with blood.*

*Next bold philosopher and sage
A settled plan decree,
And prove by thought or sacred page
What Nature ought to be.*

*But Nature smiles—a Sphinx-like smile—
Watching their little day
She waits in patience for a while—
Their plans dissolve away.*

*Then come those humbler men of heart
With no completed scheme,
Content to play a modest part,
To test, observe, and dream,*

*Till out of chaos come in sight
Clear fragments of a Whole;
Man, learning Nature's ways aright,
Obeying, can control.*

*The changing Pattern glows afar;
But yet its shifting scenes
Reveal not what the Pieces are
Nor what the Puzzle means.*

*And Nature smiles—still unconfessed
The secret thought she thinks—
Inscrutable she guards unguessed
The Riddle of the Sphinx.*

Hilfeld, Dorset

September, 1929

PREFACE

THE vast and imposing structure of modern science is perhaps the greatest triumph of the human mind. But the story of its origin, its development and its achievements is one of the least known parts of history, and has hardly yet found its way into general literature. Historians treat of war, of politics, of economics; but of the growth of those activities which have revealed the individual atom and opened to our vision the depths of space, which have revolutionized philosophic thought and given us the means of advancing our material welfare to a level beyond the dreams of former ages, most of them tell us little or nothing.

To the Greeks, philosophy and science were one, and, in the Middle Ages, both were bound up with theology. The experimental method of studying nature, developed after the Renaissance, led to a separation; for, while natural philosophy came to be based on Newtonian dynamics, the followers of Kant and Hegel led idealist philosophy away from contemporary science, which, in turn, soon learned to ignore metaphysics. But evolutionary biology and modern mathematics and physics on the one hand have deepened scientific thought, and on the other have again forced philosophers to take account of science, which has now once more a meaning for philosophy, for theology, and for religion. Meanwhile physics, which for so long sought and found mechanical models of the phenomena observed, seems at last to be in touch with concepts where such models fail, with fundamental things which, in Newton's phrase, "certainly are not mechanical".

Men of science, most of whom used naïvely to assume that they were dealing with ultimate reality, are coming to see more clearly the true nature of their work. The methods of science are primarily analytic, and lead, as far as may be, to the explanation of phenomena in mathematical form and in terms of physical concepts. But the fundamental concepts of physical science, it is now understood, are abstractions, framed by our minds so as to bring order and simplicity into an apparent chaos of phenomena. The approach to reality through science, therefore, gives only aspects of reality, pictures drawn on simplified lines, but not reality itself. Nevertheless, even philosophers are coming to see that, in a metaphysical study of reality, the methods and results of science are the best available evidence, and

that a new realism, if possible at all, must be built up by their means.

Simultaneously, a renewed interest in the history of science and its interactions with other modes of thought has grown up. The first publication in Belgium of the periodical *Isis* in 1913, and later the foundation of the History of Science Society, an international organization with its centre in America, mark an epoch in the development of the subject. Probably the philosophic and historical revivals are connected, for, while the mathematician or the experimentalist engaged on some specific problem needs only a knowledge of the work of his immediate predecessors, he who studies the deeper meaning of science in general, and its bearing on other realms of thought, must understand something of how it has come to be.

It is nearly a hundred years since Whewell wrote his books on the history and philosophy of the inductive sciences, but his careful and well-balanced judgments are still of use and value. Since Whewell's day, not only has there been a mighty growth of scientific knowledge, but many specialized studies have thrown new light on the past. The time has come for another attempt to tell the general story of science on Whewell's lines, to present, not a detailed study of any one period or subject, but a complete outline of the development of scientific thought. I believe that such a history of science has much to teach both about the inner meaning of science itself and about its bearing on philosophy and on religion.

The humanists of the Renaissance revived the study of Greek not solely for the sake of the language and literature, but also because the best knowledge of nature available was to be found in the works of the Greek philosophers. Thus a classical education then comprised all natural knowledge. That has long ceased to be true, and nowadays a culture based on the languages of two thousand years ago represents very inadequately the true Greek spirit, unless, from a simultaneous study of the methods and achievements of science in the past and the present, it looks forward joyously to an increasing knowledge of nature in the future.

The general plan of this book is based on that of a sketch of the subject by my wife and myself published by Messrs Longmans in 1912, under the name of *Science and the Human Mind*. I have also used and extended ideas which appear in some of my other writings, especially in the following: *The Recent Development of Physical Science* (Murray, 5 editions, 1904 to 1924); the chapter on "The Scientific Age" in Volume XII of the *Cambridge Modern History* (1910); the article

"Science" in the eleventh edition of the *Encyclopaedia Britannica* (1911); the collection of scientific classics in the volume of *Cambridge Readings in the Literature of Science*, 1924 and 1929; a Presidential Address to the Devonshire Association in 1927 on the Newtonian Epoch; and the chapter on "The Birth of Modern Science" in Harmsworth's *Universal History* (1928). Acknowledgment is due to the respective Publishers of these works.

It is of course quite impossible to specify all the sources from which the following chapters have been derived. But I must make mention of the help I have obtained from the historical work of Dr George Sarton, and the scientific and philosophic writings of my friends Dr A. N. Whitehead and Professor Eddington. The first volume of Dr Sarton's monumental *Introduction to the History of Science* appeared in 1927, so that I was able to use his wonderful collection of material for my account of ancient times and the early mediaeval period. His other volumes will be awaited with interest.

I am grateful for much personal help from friends who have criticized parts of the manuscript or the proof sheets. Professor D. S. Robertson read the first chapter on "Science in the Ancient World", Dr H. F. Stewart that on "The Middle Ages", Sir Ernest (afterwards Lord) Rutherford the account of "The New Era in Physics", Professor Eddington the sections on relativity and astrophysics and also the last chapter, on "Scientific Philosophy and its Outlook", while my daughter Margaret, Mrs Bruce Anderson, read the parts dealing with biology and the introductory matter. Miss Christine Elliott did most of the secretarial work; she copied and re-copied the manuscript on an average about five times, and made innumerable criticisms and suggestions. My sister and my daughter Edith shared in the tedious task of preparing the index. I offer them all my cordial thanks; to their help is due much of any value the book may possess.

I began the studies of which this volume is the outcome in an attempt to clarify my own ideas on the all-important subjects with which it deals. I have written the book chiefly for my own satisfaction and amusement, but I hope that some of my readers may find my labours useful to themselves.

W. C. D. D.-W.

Cambridge
August, 1929

PREFACE TO SECOND EDITION

THE need for a new edition of this book, coming as it does within a few months of publication, shows that the subjects with which it deals are of interest not only to men of science but also to a wider circle of readers.

No story is more fascinating than that of the development of scientific thought—man's age-long effort to understand the world in which he finds himself. Moreover, the story is of special interest now, when we see one of the historic syntheses of knowledge taking place under our eyes, and feel that we are on the eve of great events. I have a firm belief in science as a fit subject for history and a basis for literature, and, if I have done something to instil that belief into others, I am content.

I wish to thank those several reviewers and correspondents who have offered instructed criticism of specific points in the first edition. If I have not adopted all their suggestions, I have at least given to them careful consideration. In particular I must acknowledge gratefully the help I have received from my friends Sir James Jeans and Professor E. D. Adrian.

W. C. D. D.-W.

Cambridge
March, 1930

PREFACE TO THIRD EDITION

AN interval of eleven years has elapsed between the issues of the second and third editions of this book, and for some time it has been out of print, the unavoidable delay in bringing out this edition being due to the pressure of urgent work before, and still more after, the outbreak of the second world war.

Much new scientific investigation has been carried on and many striking discoveries have been made during the decade 1930-1940. Moreover, in that time, the history of science itself has become an accepted subject of study, in which systematic research has thrown new light on the past. An enormous amount of literature has appeared, but, among books dealing with the history of science in general, it may

suffice to mention the following: Sir Thomas Heath's *Greek Mathematics* (1931) and *Greek Astronomy* (1932); the two parts of the second volume of Dr G. Sarton's *Introduction to the History of Science* (1931), bringing the story down to the end of the thirteenth century; Professor A. Wolf's *History of Science, Technology and Philosophy*, dealing with the sixteenth, seventeenth and eighteenth centuries (1934 and 1938); Professor L. Hogben's *Mathematics for the Million* (1937) and *Science for the Citizen* (1940); the volume of Cambridge lectures entitled *The Background to Modern Science* (1938); and Mr H. T. Pledge's *Science since 1500*, published in 1939. The periodical numbers of the journal *Isis*, specially dedicated to the history of science, have continued to supply an almost inexhaustible mine of information. Hence it has been necessary to make extensive changes in the old text of this work, as well as to write a chapter on the output of the last ten years. The result is, in effect, a new book.

Once more their kindness has allowed me to draw on the expert knowledge of friends, to whom I offer my most sincere and cordial thanks. Professor Cornford read the old chapter on "Science in the Ancient World", and suggested many improvements. On the new material for the recent period, I have had advice in physics from Dr Aston and Dr Feather, in chemistry from Dr Mann, in geology from Dr Elles, and in zoology from Dr Pantin. My daughter Margaret wrote the section on bio-chemistry, and her husband, Dr Bruce Anderson, that on immunity. Miss Christine Elliott deciphered and typed my somewhat chaotic manuscript, and my sister, Miss Dampier, helped with the necessary additions to the index, while the Cambridge University Press carried out their part of the production with their customary courtesy and skill.

W. C. D.

Cambridge
August, 1941

PREFACE TO FOURTH EDITION

IN converting the third into the fourth edition of this book, most of the subjects treated under the heading "1930 to 1940" have been distributed among earlier chapters. Some new work, especially in England and America, done to solve definite war problems, has led incidentally to an increase in scientific knowledge. An attempt has been made to describe the more important published discoveries.

To the list of books mentioned in the last Preface should now be added Mr A. J. Berry's *Modern Chemistry*, Sir George Thomson's third edition of *The Atom*, and Professor Andrade's *The Atom and its Energy*.

Since the last edition appeared, I have to deplore the deaths of three friends who, at one stage or another, have helped me with this book: Lord Rutherford, Sir Arthur Eddington and Sir James Jeans.

W. G. D.

Cambridge
January, 1947

INTRODUCTION

THE Latin *scientia* (*scire*, to learn, to know), in its widest sense, means learning or knowledge. But the English word "science" is used as a shortened term for natural science, though the nearest German equivalent, *Wissenschaft*, still includes all systematic study, not only of what we call science, but also of history, philology or philosophy. To us, then, science may be defined as ordered knowledge of natural phenomena and the rational study of the relations between the concepts in which these phenomena are expressed.

The origin of physical science can be traced in the observation of natural occurrences, such as the apparent movements of the heavenly bodies, and in the invention of rude implements, by the help of which men strove to increase the safety and comfort of their lives. Similarly, biological science must have begun with the observation of plants and animals, and with primitive medicine and surgery.

But, at an early stage, men almost universally took a wrong path. Led by the idea that like produces like, they tried by imitating nature in rites of sympathetic magic to bring rain or sunshine, or fertility to the teeming earth. Some of them, not satisfied by the results achieved, passed to another stage, to the animistic belief that nature must be under the sway of beings, capricious like themselves, but more powerful. The Sun became the flaming chariot of Phoebus; thunder and lightning were the weapons of Zeus or Thor. Men sought to propitiate such beings, perhaps by rites which were the same as, or developed from, those which had arisen in the more primitive stage. Other men, watching the fixed stars, or the regular movements of the planets, conceived the idea of an immutable Fate controlling human destinies, which might be read in the sky. Magic, astrology and religion have clearly to be studied with the origins of science, though their exact historical relations with science and with each other are still uncertain.

Some order in empirical knowledge appears in the records of ancient Egypt and Babylon—units and rules of measurement, simple arithmetic, a calendar of the year, the recognition of the periodicity of astronomic events, even of eclipses. But the first to submit such knowledge to rational examination, to try to trace causal relations among its parts, in fact the first to create science, were the Greek nature-philosophers of Ionia. The earliest and most successful of such

attempts was the conversion of the empirical rules for land surveying, mostly derived from Egypt, into the deductive science of geometry, the beginnings of which are traditionally assigned to Thales of Miletus and Pythagoras of Samos, while the final formulation in ancient times was made by Euclid of Alexandria three hundred years later.

The nature-philosophers sought reality in matter, and slowly developed a theory of a primary element, culminating in the atomism of Leucippus and Democritus. On the other hand, the more mystical Pythagoreans of South Italy saw reality, not in matter, but in form and number. Though their own discovery that the side and diagonal of a square were incommensurable in finite units was difficult to reconcile with the idea that integral numbers are the fundamental entities of existence, that idea survived and reappeared from time to time throughout the ages.

With the rise of the Athenian School of Socrates and Plato, the Ionian nature-philosophy was superseded by metaphysics. The Greek mind became entranced with its own operations, and turned from the study of nature to look within. The Pythagorean doctrines were developed into the view that ideas or "forms" alone possess full reality, which is denied to the objects of sense. Aristotle in biology returned to observation and experiment, but in physics and astronomy he followed too closely the introspective methods of his master Plato.

The conquests of Alexander carried Hellenistic civilization to the East, and founded a new intellectual centre at Alexandria. Here, and simultaneously in Sicily and South Italy, a new method appeared. Instead of complete philosophic schemes, Aristarchus, Archimedes and Hipparchus set out specific and limited problems, and solved them by scientific processes like those of modern times. Even astronomy showed the change. To the Egyptians and Babylonians the Universe was a box, the Earth being the floor. The Ionians realized the Earth as floating free in space; the Pythagoreans as a sphere moving round a central fire. Aristarchus, considering the definite geometrical problem of the Sun, Earth and Moon, saw that it was simpler to imagine the central fire to be the Sun, and from his geometry made an estimate of its size. But this theory was unacceptable to most, and Hipparchus returned to the belief in a central Earth, with the heavenly bodies moving round it in a complex system of cycles and epicycles, a system handed on to the Middle Ages in the writings of Ptolemy.

The Romans, with all their genius as soldiers, lawyers and administrators, had little original philosophic power, and even before Rome

fell, science had ceased to advance. Meanwhile, the Early Fathers of the Church welded together Christian doctrines, Neo-Platonic philosophy, and elements derived from oriental Mystery Religions, into the first great Christian synthesis, predominantly Platonic and Augustinian. Through the Dark Ages, Greek learning was only known to the West in abstracts and commentaries, though an Arabic school arose which, deriving its original impulse from Greek sources, itself made some additions to natural knowledge.

In the thirteenth century the full works of Aristotle were rediscovered and translated into Latin, first from Arabic versions and then directly from the Greek. A new and alternative synthesis arose in the scholasticism of St Thomas Aquinas, who built up a complete, rational scheme of knowledge, in which Christian doctrines were reconciled with Aristotelian philosophy and science, a difficult task, skilfully done.

As the survival of Roman Law kept alive the ideal of order through the time of chaos and through the Middle Ages, so Scholasticism upheld the supremacy of reason, teaching that God and the Universe can be apprehended, even partially understood, by the mind of man. In this it prepared the way for science, which has to assume that nature is intelligible. The men of the Renaissance, when they founded modern science, owed this assumption to the Scholastics.

Yet the essence of the new experimental method was an appeal from a completely rational system to the tribunal of brute facts—facts which bore no relation to any philosophic synthesis then possible. Natural science may use deductive reasoning at an intermediate stage of its enquiries, and inductive theories are an essential part of its procedure, but primarily it is empirical, and its ultimate appeal is to observation and experiment; it does not, like mediaeval Scholasticism, accept a philosophic system on authority and then argue from the system what the facts ought to be. Contrary to an opinion sometimes held, mediaeval philosophy and theology made full use of reason, their results being deduced by logical methods from what were accepted as authoritative and certain premises, the scriptures as interpreted by the Church, and the works of Plato and Aristotle. Science, on the other hand, depends on experience, and uses methods somewhat like those employed in fitting together the pieces or words of a puzzle. Reason is used to solve the definite problems of the puzzle, and to form the limited syntheses and theories which alone are possible; but observation or experiment is the starting-point of the investigation and the final arbiter.

Scholasticism as interpreted by Thomas Aquinas preserved a belief in the intelligibility of nature, amid the welter of magic, astrology and superstition, mostly relics of Paganism, which enmeshed the mediaeval mind. But Thomist philosophy included the geocentric astronomy of Ptolemy, and the anthropomorphic physics of Aristotle with his many erroneous ideas—for instance, that motion implies the continual exertion of force, and again that things are essentially heavy or light and seek their natural places. Hence the Scholastics opposed the theory of Copernicus, refused to look through the telescope of Galileo, and denied that things heavy and light could fall to the ground at the same rate, even when Stevin, de Groot and Galileo had demonstrated that fact experimentally.

And an even deeper divergence lay behind these differences. To Aquinas and his contemporaries, as to Aristotle, the real world was that disclosed by the senses: a world of colour, sound and warmth; of beauty, goodness and truth, or sometimes perhaps of ugliness, evil and error. Under the analysis of Galileo, colour, sound and warmth vanished into mere sensations, and the real world appeared to be but particles of matter in motion, which apparently had nothing to do with the beautiful, the good, the true, or their opposites. The perplexities of the theory of knowledge, the difficulties which underlie the apprehension of matter in motion by a non-material and non-extended mind, appeared for the first time.

The work begun by Galileo was consummated by Newton, who showed that the hypothesis of masses moving under their mutual forces was sufficient to explain all the majestic motion of the solar system. Thus the first great physical synthesis was put together, though Newton himself pointed out that the cause of the gravitational force remained unknown. His disciples however, especially the French philosophers of the eighteenth century, ignoring his wise spirit of caution, converted Newton's science into a mechanical philosophy, in which the whole of the past and future was theoretically calculable and man became a machine.

Some clear-thinking minds realized that science did not necessarily reveal reality, while others, with practical wisdom, accepted determinism as a convenient working hypothesis for science—indeed the only hypothesis possible at the time—but treated man as a free and responsible agent in ordinary life, and continued to practise their religion unperturbed. The whole of existence is too great a thing to yield its secrets when studied in one aspect only. Another line of escape from mechanism was taken by the followers of Kant and Hegel,

who, in German idealism, built up a philosophy ultimately derived from Plato, a philosophy which became almost completely separated from contemporary science.

In spite of these reactions, Newtonian dynamics reinforced both crude materialism and the philosophy of determinism. To minds more logical than profound the inference from science to philosophy seemed inevitable, an inference strengthened with every advance in physical science. Lavoisier extended the proof of the persistence of matter to cover chemical transformations, Dalton finally established the atomic theory, and Joule proved the principle of the conservation of energy. The motion of each individual molecule, it is true, was still indeterminate, but statistically the behaviour of the myriad molecules which make up a finite quantity of matter could be calculated and predicted.

In the second half of the nineteenth century it seemed to some men that the mechanical outlook was extending to biology. Darwin gained credence for the old theory of evolution by marshalling the facts of geology and variation, and framing the hypothesis of natural selection. Man, who, a little lower than the Angels, had surveyed creation from the Earth its centre, became a mere link in the chain of organic development on a small and casual planet circling round one of a myriad stars—a puny being, the plaything of blind, irresistible forces, which bore no relation to his desires or his welfare.

Physiology, too, began to expand the field of research within which physical and chemical principles could be used to explain the functions of the living organism. In some biological problems the organism must be treated as a whole, and this fact is of philosophic importance. But science is by its nature analytical and abstract, and is forced to express as much of its knowledge as possible in terms of physics, the most fundamental and abstract of all the natural sciences. When it was found that more and more could be so expressed, confidence was gained in the method, and there arose a belief that a complete physical or mechanical explanation of all existence is theoretically possible.

Supreme importance is thus given to those physical concepts which, at any given time, are the most fundamental yet reached, though philosophers have sometimes been rather too late in adopting them. The German materialists of the nineteenth century based their philosophy on *Kraft und Stoff* just when physicists were realizing that force was but an anthropomorphic aspect of mass-acceleration, and matter was being sublimated from the hard, massy particles of Democritus

and Newton into vortex atoms or kinks in an aethereal medium. Light, explained by Young and Fresnel in terms of mechanical waves in a semi-rigid, material aether, was converted by Maxwell into electro-magnetic undulations in something unknown—a simplification to the mathematician, but a loss of intelligibility to the experimentalist.

In spite of these indications, most men of science, and especially biologists, at that time held a common-sense materialism, and believed that physical science revealed the reality of things. They did not read idealist philosophy, and in any case would not have been convinced thereby. But in 1887 Mach, speaking in language with which they were familiar, revived the old theory that science only gives information about phenomena as apprehended by the senses, and that the ultimate nature of reality is beyond the reach of our intelligence. Others upheld the view, that, while this phenomenalism is as far as the scientific evidence can carry us, yet the fact that science has put together a consistent model of natural phenomena is a valid *metaphysical* argument that some reality, corresponding to the model, lies beneath. But the different sciences are only analogous to plane diagrams from which the model can be constructed, so that, for instance, the determinism indicated by mechanics is but an effect of our procedure and of the definitions which underlie that science. Similarly, principles such as the persistence of matter and the conservation of energy are inevitable, for, in constructing a science of nature from the welter of phenomena, the mind, unconsciously and as a matter of convenience, picks out those quantities which remain constant, and builds its model round them. Then, later on, with immense labour and pains, the experimentalist rediscovers their constancy.

But few nineteenth-century men of science were interested in philosophy, even in that of Mach. Most of them assumed that they themselves were dealing with realities, and that the main lines of possible scientific enquiry had been laid down once for all. It seemed that all that remained for the physicist to do was to make measurements to an increasing order of accuracy, and invent an intelligible mechanism which would explain the nature of the luminiferous aether.

Meanwhile biology had accepted Darwinian natural selection as an adequate explanation of the origin of species and had turned to other problems. It was only with the rediscovery in 1900 of Mendel's forgotten work that the question was reopened, and Darwin's experi-

mental method once more used. While the broad facts which point to evolution in past geological ages are conclusive, some men came to doubt whether natural selection acting nowadays on small variations is a sufficient cause of new species.

Then, from 1895 onwards, there came the new revelation in physics. Atoms were resolved by J. J. Thomson into more minute corpuscles, and these in turn into electrical units, the mass of which was explained as being merely one factor in electro-magnetic momentum. It began to look as though "electricity" were to be the last and sufficient word in physical science. Rutherford explained radio-activity in terms of atomic disintegration, and pictured the atom as a positive nucleus with negative electrons circling round it. Matter, instead of being dense, closely packed stuff, became an open structure, in which the material, even as disembodied electric charges, was almost negligible in size compared with the empty spaces. Furthermore, the statistical principles of atomic disintegration were discovered. It became possible to calculate how many atoms in a milligram of radium will explode in a second, though we cannot yet tell when the life of any given atom will end.

If waves of light are electrical, they must start from electric charges in motion, and at first it seemed that in our new-found electron, moving in accordance with Newtonian dynamics, we had a satisfactory electrical theory of matter. But, if electrons swing round the nucleus of the atom as planets circle round the Sun, they should give out radiation of all wave-lengths, the energy increasing in a calculable way as the wave-length shortens. This does not happen, and, to explain the facts, Planck was led to suppose that radiation is emitted and absorbed in definite units or quanta, each quantum being a fixed amount of "action", a quantity equivalent to energy multiplied by time. This theory was greatly strengthened by its success in fields of physics other than that which saw its birth; yet it could not, like the classical theory of continuous waves, explain easily and naturally the facts of diffraction, and other phenomena due to the interference of light. We had to be content to use the classical theory for some purposes and the quantum theory for others, though they seem inconsistent with each other, a compromise unusual to the physicist, whose subject had hitherto been the most completely consistent and rationalized of all experimental sciences.

Another difficulty, the constancy of the measured velocity of light irrespective of the motion of the observer, was cleared up when Einstein pointed out that neither space nor time are absolute

quantities, but are always relative to some one who measures them. This principle of relativity, when its consequences are followed out, means a revolution not only in physical theories, but in the implicit assumptions of older physical thought. It explains matter and gravitation as the necessary consequences of something analogous to curvature in a four-dimensional continuum of space-time. The curvature even sets bounds to space, and light travelling onwards may, after millions of years, return to its starting-point.

Not only have the hard, massy particles of matter disappeared, but philosophically it will be seen that the old metaphysical concept of matter, as that which is extended in space and persistent in time, is destroyed, now that neither space nor time are absolute, but are figments of the imagination, and a particle is a mere series of events in space-time. Relativity reinforces the conclusions of atomic physics.

Rutherford's conception of the atom was developed on the lines of the quantum theory by Bohr, who explained many of the facts by supposing that the single electron in the hydrogen atom can only circulate in four definite orbits, and only radiate at the moments when it leaps suddenly from one orbit to another. This, like the quantum theory itself, is inconsistent with Newtonian dynamics, as long, at all events, as the electron is regarded as a simple particle.

For a time Bohr's atom, developed in detail by himself and others, seemed a most convincing model of atomic structure, but in 1925 it definitely failed to account for some of the finer lines in the hydrogen spectrum. In the next year a new chapter in physics was opened by the work of Heisenberg, who pointed out that any theory of electronic orbits went beyond what the facts warranted. We can only study atoms by observing what goes into them or what comes out—radiation, electrons, and sometimes radio-active particles; we cannot tell what happens at other times. Orbits are an unconscious and unjustified assumption, founded on the analogy of Newtonian dynamics. Heisenberg therefore left his theory of atomic structure in terms of differential equations, with no attempt at a physical explanation.

Then Schrödinger, taking up de Broglie's wave-mechanics, developed a new theory, on which an electron has some of the properties of a particle and some of a wave, an idea since supported by experimental evidence. Schrödinger's theory is expressed by equations which are equivalent to those of Heisenberg, so that mathematically the two theories are identical. It is impossible to frame a physical model on Heisenberg's theory, and difficult to do so on that of Schrödinger. Indeed, a principle of uncertainty has appeared, which

indicates that we cannot specify both the position and the velocity of an electron. Physical science has successively found many ultimates—gravitating particles, atoms, electrons—and in each case has gone further and invented models which explained those ultimates in terms of something yet more fundamental. But, in the quantum of “action” and in the equations of the indeterminate particle and wavelet, we see concepts which the mind finds it difficult to picture. Perhaps a new atomic model may be framed successfully once more, but possibly we are approaching fundamental things, which cannot be expressed in mechanical terms.

Meanwhile two branches of recent physics have become of special practical import. Beginning with Maxwell’s proof that electric waves are of the same nature as light, their theory has extended and their uses have multiplied till the reflection of electric signals gave us “radar”. Rutherford’s nuclear atom with Aston’s isotopic elements led to a vast development in pure science and to a method of liberating nuclear energy in an “atomic bomb” and (it is hoped) in more peaceful applications.

After a period of separation, with crude materialism on one side and somewhat hazy German idealism on the other, science and philosophy once more came into touch, first in various forms of evolutionary thought, and then, through a deeper analysis, by new developments in mathematics and physics. Recent studies of the principles of mathematics and of logic have thrown fresh light on the theory of knowledge, and led to a new realism which, turning from the general philosophic systems of the past, studies limited philosophic problems as science studies limited scientific ones, and seeks metaphysical reality beneath scientific phenomenalism.

To some modern philosophers the determinism of science seems to be due to its method of abstraction. Its concepts, the modern equivalent of Platonic ideas, are alone concerned in its abstract reasoning and theories; they have logical consequences, which are indeed inevitable and determined by the nature of the concepts. But it is a misplaced concreteness which transfers that determinism to the objects of sense. Again, “vitalism” held that in living matter physical and chemical laws are suspended by some higher agency. This idea too is discredited nowadays, but some physiologists point out that the biological organism shows a co-ordination, an integration, of its physical and chemical functions beyond the present reach of a purely mechanical explanation. Nevertheless, others contend, mechanism has to be assumed at each stage of physical or chemical investigation,

and, as Schrödinger points out, new physical and chemical laws, a present unknown, may ultimately explain vital phenomena, though it is possible that mechanism may ultimately break down in a final physical principle of uncertainty. Teleology, to be convincing, may have to take account of the whole of existence instead of only individual organisms. The universe may be completely mechanical when viewed from the abstract standpoint of mechanics, and yet completely spiritual from the aspect of mind. A ray of starlight may be traced by physics from its distant source to its effect on an optic nerve, but when consciousness apprehends its brightness and colour and feels its beauty, the sensation of sight and the knowledge of beauty certainly exist, and yet they are neither mechanical nor physical.

Physical science represents one analytical aspect of reality; it draws a chart which, as experience shows, enables us to predict and sometimes to control the workings of nature. From time to time great syntheses of knowledge are made. Suddenly bits of the puzzle fit together; different and isolated concepts are brought into harmony by some master-mind, and mighty visions flash into sight—Newton's cosmogony, Maxwell's co-ordination of light and electricity, or Einstein's reduction of gravity to a common property of space and time. All the signs point to another such synthesis, in which relativity, quantum theory and wave-mechanics may fall into the all-embracing unity of some one fundamental concept.

At such historic moments physical science seems supreme. But the clear insight into its meaning which is given by modern scientific philosophy shows that by its inherent nature and fundamental definitions it is but an abstraction, and that, with all its great and ever-growing power, it can never represent the whole of existence. Science may transcend its own natural sphere and usefully criticize some other modes of contemporary thought and some of the dogmas in which theologians have expressed their beliefs. But to see life steadily and see it whole we need not only science, but ethics, art and philosophy; we need the apprehension of a sacred mystery, the sense of communion with a Divine Power, that constitute the ultimate basis of religion.

THE ORIGINS

The Geological Record—Flint Tools—Ice Ages—Palaeolithic Times—Neolithic Times—The Bronze Age—The Iron Age—River Folk and Nomads—The Races of Europe—Magic, Religion and Science.

THE origins of science must be sought in the records of early man as given us by geologists, who study the structure and history of the earth, and by anthropologists, who observe the physical and social characters of mankind.

*The
Geological
Record*

It now seems probable that the crust of the earth solidified some thousand million years ago, 1.6 thousand million, or 1.6×10^9 years, is a recent estimate. Geologists classify the periods which followed into six: (1) Archaean, the age of igneous rocks formed from molten matter; (2) Primary or Palaeozoic, when life first appeared; (3) Secondary or Mesozoic; (4) Tertiary or Cainozoic; (5) Quaternary; (6) Recent. The sequence of these periods is shown by the relative position of their deposits in the earth's strata, but no definite measurement of their age in years can be made.

Some authorities hold that traces of man's handiwork are first seen in tertiary deposits, laid down perhaps somewhere between one and ten million years ago. They take the form of flints or other hard stones roughly chipped into tools. The oldest, called eoliths, cannot certainly be distinguished from natural products, formed by the action of moving earth or water, but the next group, named palaeoliths, are clearly of human origin. The figure shows a common palaeolithic, all-purpose tool, now known as a hand-axe. The making of the oldest tools is held by some archaeologists to show the existence of the first being worthy of the name of man. But the most important step in human development must have been the change of animal sounds into articulate speech, a step which, by the nature of the case, has left no trace save the changes in structure of skull and jaws which made speech possible.



Flint Axe.

Flint Tools

It is known that successive ice-ages, probably four, passed over Europe in early times. Some think that tools, found in East Anglia, date from before the first of these cold periods, but however that may

Ice Ages

Ice Ages be, chipped flints appear in the warmer intervals. Two methods of working them are known; either by knocking off flakes and leaving a central core to be shaped into a tool as in the figure—a method characteristic of Africa—or by using the flakes themselves, as seen particularly in Asia. Europe forms an area of interlap between the two methods, which seem to have been first developed by two distinct racial stocks.

Palaeolithic Times During the greater part of the Palaeolithic ages hand-axes continually became lighter and sharper, and other tools more varied and more delicate. It is probable that they were used by people who lived by hunting animals and gathering edible wild plants. Perhaps the oldest being of the core-culture folk in England known to us is the Piltdown man, discovered in Sussex, and next the skull found at Swanscombe in Kent.

In the final ice-age the core and flake methods were intermingled by Neanderthal men. Later the tools took on a blade-like form, leading to the cutting edge, which enabled men to carve bone into such things as harpoons and other implements.

Though fire itself had long been known, about this same time we first find traces of the deliberate kindling of fire by striking flint against ores. Fire is the earliest and most surprising chemical discovery.

Lower Palaeolithic civilizations, dating from the beginning of the Quaternary era, and ending as the last ice-age approached, must have covered an immense stretch of time, during which there appears to have been a slow but steady improvement in culture.

Middle Palaeolithic times are associated with what is called Mousterian civilization, so named from the place where it was discovered—Moustier near Les Eyzies. The race which made it, Neanderthal man, was of low type, thought not to be in the direct line of human evolution.

Upper Palaeolithic or Neo-anthropic man appeared in the land which is now France as the last ice-age drew to a close, though a mixture of reindeer with stag in the bones found shows that the climate was still cold. The associated men were higher in the scale of humanity than any earlier races. The flaking of flint was much improved, there was a definite bone industry with a making of household implements, such as eyed needles.

Neolithic Times Leaving the immense stretch of Palaeolithic time we pass to Neolithic ages with a great improvement in culture. Neolithic men seem to have invaded Western Europe from the East, bringing with them

traces of the civilizations of Egypt and Mesopotamia. They possessed domestic animals and cultivated crops. They made polished implements in flint or other hard stone, and in bone, horn or ivory. Fragments of pottery also are found, showing the deliberate creation of a new thing, a great advance on the mere adaptation of an existing material. Again, structures such as Stonehenge, where a pointer-stone marks the position of the rising sun at the summer solstice, serve not only religious uses but also astronomical functions which indicate accurate observation.

*Neolithic
Times*

Prehistoric burials are found till the end of the Neolithic period; cremation only appears later and then mostly in Central Europe, where forests supplied plentiful fuel. In Neolithic tombs stone implements are often found, suggesting a belief that such things would be useful to the dead in another world—a belief then in survival.

In some parts of the world Neolithic men discovered copper—how to smelt it and harden it by mixing it with tin, thus making the first metallurgical experiment, and passing from the stone to the bronze age. The general use of metal made possible a higher culture, with axes, daggers and their derivatives spears and swords, and the more peaceful household goods.

*The Bronze
Age*

In its turn bronze, with its comparatively rare constituents, gave place to iron, present in much greater abundance in the earth, and more effective in weapons of war and the chase. Therefore when men discovered how to extract iron from its ores, it soon displaced other metals for such uses. With the coming of the iron age we approach and soon enter periods when true history can be pieced together by the survival of written records on stone, clay, parchment or papyrus.

*The Iron
Age*

Settled life, with primitive agriculture and industrial arts, seems first to have begun in the basins of great rivers—the Nile, the Euphrates with the Tigris, and the Indus, while it is probable that in China too civilization began near its rivers. But, in contrast with these river folk, were survivals of nomads—pastoral people wandering with their flocks and herds over grass-clad steppes or deserts with occasional oases. In normal times, the unit groups of these nomads kept apart from each other, each in search of food for their beasts:

*River Folk
and Nomads*

And Lot also, which went with Abram, had flocks, and herds, and tents. And the land was not able to bear them, that they might dwell together. . . . And Abram said unto Lot . . . Is not the whole land before thee? Separate thyself, I pray thee, from me: if thou wilt take the left hand, then I will go to the right; or if thou depart to the right hand, then I will go to the left.¹

¹ Genesis xiii. 5-9.

*River Folk
and Nomads*

With these isolationist views and customs, neither civilization nor science was possible. Moreover, co-operation between the patriarchal family groups only arose for some definite purpose—a hunt of dangerous wild beasts or war with other tribes. But sometimes, owing to a prolonged drought or perhaps to a permanent change in climate, the grass failed, the steppes or oases became uninhabitable, and the nomad folk overflowed as an irresistible horde, flooding the lands of the settled peoples as barbarous conquerors. We can trace several such outrushes of Semites from Arabia, of Assyrians from the borders of Persia and of dwellers in the open grass-clad plains of Asia and Europe.

It is useless to look among nomads for much advance in the arts, still less for the origins of applied science. But the Old Testament not only gives in its earlier chapters an account of nomads, but later on deals with the legends of the settled kingdoms of the Near and Middle East—Egypt, Syria, Babylonia and Assyria—a good introduction to the more recent knowledge obtained by the excavation of buildings, sculptures and tablets, knowledge dependent on the double chance of survival and discovery.

*The Races
of Europe*

And now a few words are necessary about the races of men whose doings we shall trace. Since the late stone age, the islands of the Aegæan and the sea coasts of the Mediterranean and the Atlantic have been peopled chiefly by men short in stature with long-shaped heads and dark colouring; and to this Mediterranean race is due the prehistoric advance in civilization. Farther inland, especially among the mountains, the chief inhabitants were and are of the so-called Alpine race, a stocky people of medium height and colouring, with broad, round-shaped skulls, people who pushed into Europe from the northern east. Thirdly, centred in and spreading out from the shores of the Baltic, we find a race which may be called Nordic, tall, fair-haired and, like the Mediterraneans, with long-shaped heads.

*Magic,
Religion
and Science*

In later Palaeolithic times also we find the first examples of drawings and paintings on the walls of the caves in which men lived. Many of these are of high artistic merit, and some of them, thought to represent devils and sorcerers; throw light on primitive beliefs, as do the frequently recurring carvings indicating fertility cults and fertility magic.

More definite ideas about these beliefs can be obtained by comparing them with those of early historical times, as described by Greek and Latin authors, and with those still found among primitive people in various parts of our modern world. Sir James Frazer

collected a vast amount of such evidence in his book *The Golden Bough*. Some anthropologists regard magic as leading directly to religion on one side and to science on the other, but Frazer thinks that magic, religion and science form a sequence in that order. Another anthropologist, Rivers, holds that magic and primitive religion arise together from the vague sense of awe and mystery with which the savage looks at the world.

Again, Malinowski finds that primitive people keep distinct the simple phenomena which can be dealt with by empirical scientific observation or tradition from the mysterious, incalculable changes beyond their understanding or control. The former lead to science, the latter to magic, myth and ritual. Malinowski holds that the origin of primitive religion is to be sought in man's attitude to death, his hope of survival and his belief in an ethical providence.

But others point out that magic assumes that there are rules in nature, rules which, by the appropriate acts, can be used by man to control nature; thus, from this point of view, magic is a spurious system of natural law. Imitative magic rests on the belief that like produces like. Primitive man acts, in many forms, the drama of the year, thinking to give fertility to his crops, flocks and herds. Hence arises ritual, and (later) dogma and mythology to explain it. Many similar instances of imitation might be given. On the other hand, contagious magic holds that things once in contact have a permanent sympathetic connection: the possession of a piece of a man's clothing, and still more of a part of his body—his hair or his nails—puts him in your power; if you burn his hair, he too will shrivel up.

Such magic as this may, by coincidence, be followed by the appropriate happening, but more often it fails, and the magician is in danger from his disappointed followers, who may cease to believe in the control of nature by men, and turn to propitiate incalculable spirits of the wild—gods or demons—to give them what they want, thereby passing to some form of primitive religion.

Meanwhile the development of simple arts, the discovery and kindling of fire, the improvement of tools, leads by a less romantic but surer road to another or perhaps the only basis for science. But man needs some deeper beliefs for his questing soul, and so science did not germinate and grow on an open and healthy prairie of ignorance, but in a noisome jungle of magic and superstition, which again and again choked the seedlings of knowledge.

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