his "Angelus Pacis" (Amsterdam, 1667), addressed to English and Dutch plenipotentiaries, which contains a plea to all nations to abandon war and establish courts of peace for international consultations and the direction of human affairs. Whether a pansophic academy would have achieved the objects that Comenius had in view may be doubted. He was in advance of his age, and, apart from the far-seeing savants who founded the Royal Society, there were few who showed enthusiasm for his projects. No one on the Continent was prepared to do more than support the printing of his books and, indeed, it is only in modern times that international organizations have begun to function.

G. W. Leibniz (1642–1716), who was of Slav origin, showed a sympathetic interest in Comenius and assimilated his ideas regarding encyclopædic compilations and scientific societies, restating them and implementing them as completely as the unsettled state of Europe allowed.

Nor were Comenius's educational endeavours to meet with immediate success. He was a realist at a time when his contemporaries still learned their natural history from Aristotle and Pliny. Problems were 'settled' by reference to the writings of the authorities even after Comenius had asked, "Do not we ourselves dwell in the garden of Nature as well as the ancients ? Why should not we use our eyes, ears and noses as well as they ? Why should we need other teachers than these our own senses ? Let the children touch, feel, see, hear and find out by experiment for themselves, draw the object, measure it and understand it".

To generations of his own countrymen Comenius has served as an inspiring example. They named the new University of Bratislava and also the Czechoslovak secondary school in Vienna after him. His energy and fortitude can serve to-day as a stimulus to us all to continue steadfastly working for those same ideals which we know to be true.

The papers read at the Cambridge tercentenary meeting are to be made available in a permanent form. Other recent works on the life and activities of Comenius are the following: "Comenius in England" by Dr. R. F. Young (Oxford University Press, 1932); "Comenius and the Red Indians of New England" by Dr. R. F. Young (1929); "Comenius" by W. M. Keatinge (McGraw Hill, 1931); and "Johannes Amos Comenius" by Dr. J Jakubec (Orbis, Prague, 1928). Prof. R. J. Kerner's "Czechoslovakia" (University of California Press, 1940) also contains references to Comenius.

SCIENTIFIC KNOWLEDGE AND ACTION*

BY SIR RICHARD GREGORY, BART., F.R.S.

IN the study of man and his activities three types of cultural development may be recognized; and they are all measured by different standards. In the fine arts the imaginative qualities of the mind appeal primarily to the emotions through stimulation of the æsthetic judgment; material culture is the province of the industrial arts; and science—the domain of reason—is systematic and formulated knowledge in all fields of human understanding—natural, moral, social and political.

Natural science, or natural philosophy, is only one division of science as thus defined, yet, in general usage, the single word 'science' signifies verifiable knowledge acquired by observation and experiment. The history of civilization from this point of view is a history of intellectual development in which science has been the chief factor in changing habits of thought from superficial observation and magical theories of causation to clear concepts, rational conclusions, and progressive principles in the advancement of man and society.

It is common in these days to think of progress in terms of material development and to leave out of consideration the contacts of science with what is known as 'polite' learning—literature, religion, and other expressions of the human spirit. The noblest works of man are not, however, represented by great industrial advances, but by the search for the truths upon which they are based, and by the influence of this effort upon personal and social ethics.

In the pursuit of natural knowledge, the common object is to solve problems of life and thought; and all additions to knowledge thus gained contribute to the world's store, whether they admit of immediate practical application or are deposited in the archives of science for safe keeping. There can be scientific knowledge without action, and action without scientific knowledge; and the two are combined in applied science for practical service. There are, however, many aspects of Nature

* From the Hinchley Memorial Lecture delivered before the Institution of Chemical Engineers on October 24.

which appeal to the human mind, in addition to those in which usefulness is the measure of achievement. Purely scientific studies may claim to represent this attitude towards knowledge for its own sake and to be responses to a stimulus more exalted than that derived solely from material aims. So long as this spirit prevails, the influence of the high ideals of truth-seeking associated with scientific research will be extended: without them, science becomes a business in which the highest attributes and needs of human nature take no part.

Concepts of natural causes and phenomena must change with increased insight and inquiry, whether the interpretations represented by them are myths or scientific theories. Science asks for no faith in theories, except as reasonable explanations based upon verifiable observations, or as suggestive schemes which may or may not be found true when tested by further knowledge. Its duty is to observe with open eye and unprejudiced mind the picture presented by Nature, and to get nearer and nearer to the view. No loss of the sense of beauty need be involved in the analysis of the details which create the picture. The scientific mind is not satisfied with distant views and is critical of itself and its conclusions. It must, however, record faithfully what it perceives, knowing that the value of the record will be measured by its approach to permanent truth. True to Nature is the highest tribute that can be paid to a scientific testimony, as it is also to reflexions of Nature expressed in art and literature.

Observations carefully made and precisely recorded may be used or explained in various ways, but they are part of the permanent structure of natural knowledge. Whether undertaken with direct practical service in mind, or purely in the spirit of interest in natural objects and processes, is unimportant in comparison with the perception they afford of natural truths. In this respect, all who contribute to the store of verifiable knowledge increase the useful and the intellectual heritages of the human race.

Man is, indeed, more than an animal needing food and shelter and other essential means of existence: he seeks also to understand the nature and meaning of these things, usually with the view of deriving advantage for himself and for others from his discoveries, but often also with the desire to satisfy his curiosity in the object and operations of Nature. The common aim is to obtain information by inquiry and experience, though the motive in one type of observer is application of the knowledge gained, while in the other it is to explore the unknown and explain the mysterious. The standard of value of one is use and of the other intellectual satisfaction; and the difference between the two is that between practical service and philosophy.

The discovery that certain natural events were repeated in orderly succession, and that their re-occurrence could be predicted, was a practical generalization from systematic observations, and revealed, therefore, a natural truth or law. If a generalization is well founded, it remains true independently of speculations as to the powers or causes which create and control the natural phenomena observed.

At all times, Nature has created wonder in the human mind as well as the desire to use and understand the proximate or ultimate causes of what is perceived by the senses. Knowledge of natural properties and effects was first acquired to supply needs of the body, and their interpretation as influences of spirits in the empyrean had mystery as its basis. The separation of the study of Nature from that of personal deities may be said to have begun with the Greeks. In the sixth century before the Christian era, Thales, Xenophanes and Pythagoras first opened up those veins of speculative philosophy which occupied afterwards so large a part of Greek intellectual energy. It is in their philosophies that the idea of an impersonal Nature was considered as a subject of study apart from mythical conceptions. They defined the scope of natural philosophy with its objective character and invariable laws, discoverable by the exercise of human intellect, and they first used the word *phusis*, signifying Nature and surviving in the words physics, physiology, physiography, and similar derivatives, to distinguish such studies from theology.

When early Greek philosophers began to speculate upon the nature of the universe and the meaning of life they introduced the spirit of liberty of thought in inquiring into all things—sacred, social or political—independent of authority, and thus established the principle of intellectual freedom essential for the advance of science, art, literature, or any other aspect of civilized culture. Many of their speculations were crude in the light of modern knowledge, but they all represented attempts to apply reason to the problems presented to human senses, and some have proved to be of fundamental significance. The particular contributions of the Greeks were not in the technical arts and crafts, or in knowledge gained by observation and experiment, but in generalized thinking about universals. Their characteristic was creative thought and theory on intellectual planes as far removed from needs of the body as mind is apart from matter. They used knowledge of natural properties and processes, acquired by observers and craftsmen before the classical period, not as useful applications of science but to construct philosophic systems which were logically sound and therefore required no other proof. It was believed that truth in Nature could be revealed by abstract thought, without the slow and laborious process of learning by experience what things or circumstances in earth or sky could be applied to useful human service. Passive contemplation has an appearance of dignity not usually associated with the active exercise of either hands or brain.

When manual work of any kind began to be regarded as a menial occupation, and meditation became the characteristic of a higher social class, a distinction was created between useful knowledge and academic or philosophic thought. Pure science has thus come to mean natural knowledge acquired for itself alone, and studies without particular useful purposes in mind. Similarly, a pure chemist is said to be one whose active interests are confined to chemistry, while a pure biologist has physical life as his field of study. The word 'pure' used in this sense is objectionable for several reasons. Chemistry and biology, like other sciences, cannot be sharply separated from the main body of natural knowledge, but often merge into one another and lead to new productive branches, so that pure biochemists come into being, and members of the families of physics and chemistry, long separated by verbal distinctions, unite to produce the fertile line of physical chemists.

In general, however, it may be said that the main distinction between pure and applied science arises from exclusive attention to theory and practice respectively. Applied science is concerned directly with theory only as a generalization or principle which relates natural causes to consequences and enables new effects to be predicted. It is based upon observation, and its aim is the production of new agents or powers for the service of man. In most scientific societies, the passport to publication in their records is obtained by observational inquiry of a practical kind or original conceptions suggested by them. In their pursuit of natural knowledge by methods of observation and experiment, independent adventurers and practical prospectors meet on common ground, whether the purpose of inquiry is knowledge itself or its application.

In one of his aphorisms, Francis Bacon said that "All knowledge should be referred to use and action". On this narrow view, the value of scientific work is measured in terms of application to human service, without consideration of the dignity of knowledge and the intellectual aspiration to attain it. It is true that the main object of Bacon's new philosophy was to enlarge the dominion of man by increasing his knowledge and control of operations of Nature; and in this sense the standard of scientific achievement is service. Whether his philosophy was limited to this outlook is, however, unimportant in comparison with his advocacy of independent observations of natural operations and events, and legitimate inferences from them, free from prejudice and to be judged only by their faithfulness to natural truth. Whatever views may be held as to the inter relationships between science and society, civilized life is shaped by the uses to which scientific discoveries are put; and the spirit and method of scientific inquiry are now accepted as essential principles in the pursuit of truth through verifiable evidence of any kind.

Theories based upon such evidence are mental models of structures and actions for use as stepping-stones to further knowledge, and they have to be modified or discarded when they fail to satisfy crucial tests of their validity. Most natural philosophers are content to base their understanding of Nature upon the solid ground of observed facts, and to leave ultimate meanings to metaphysical minds. They are constructional engineers continually building bridges to cross into new territories and using materials of which they have discovered or created properties of practical value in the execution of the design. As the traffic of science increases, such bridges have to be replaced from time to time by others of newer designs and better materials; but the purpose is, as it is in all forms of organic life, the efficient adaptation of structure to function.

Artists and poets may use their imaginations to construct scenes and cities having no factual foundation; and without deliberate intention they sometimes anticipate designs and developments which eventually come to pass. Such conceptions of truth belong, however, to mysticism rather than to realism. The anticipations of expanding applications of scientific discoveries and their social consequences, made by Mr. H. G. Wells in many of his outlooks upon life, are of a very different character. They are similar in nature to scientific theories in which new relationships are foreseen from observed reactions, and are afterwards confirmed. They represent the products of a disciplined imagination working upon existing knowledge with the wide vision and adventurous insight by which the greatest advances have been made in both pure and applied science. It is in this spirit, and by the recognition of possibilities in opportunities presented by new contributions to knowledge, that material progress is achieved in industry and in science.

In these aspects of progress, theory and practice are complementary factors of service, each being used to reconstruct the other by relating effect to cause. This is the method of Bacon's inductive philosophy; and the achievements of modern science are due to its application. It is possible, however, to arrive at generalizations about the nature of things and the structure of the universe by theoretical reasoning independently, or largely so, of observational or experimental evidence. With a few great exceptions, this was the method of approach of classical Greek philosophers towards problems of Nature ; and it takes an important place in the history of science. They gave little consideration to the practical or useful services of science represented by chemistry, mechanics and engineering, but they take a supreme place by their philosophic and mathematical contributions. Many Greek philosophers meditated upon the nature of matter and space, each conceiving theories of primary elements or substances from which everything in the universe was formed and evolved. Abstract ideas about causes were discussed as propositions to be established or rejected by logical reasoning independently of knowledge perceptible by the senses.

Following this method of interpreting Nature by thought alone, Democritus, in the fifth century B.C., conceived the theory that the universe is made up of atoms varying in size and shape and moving in a vacuum. The atoms were indivisible particles and infinite in number ; and by their motions and combinations with one another the world and all in it were produced. This atomic theory of the universe was taught a century later by Epicurus, whose philosophy was embodied by Lucretius in his great poem, "De Rerum Natura", in the first century B.C. The theory remained a philosophic conception until the beginning of the nineteenth century, when Dalton gave scientific precision to it. To Dalton, as to the Greek philosophers, an atom meant "the smallest possible quantity of any element which can combine with other substances", and the three laws formulated by him as to the structure of bodies by atoms are the foundations of modern chemical science.

These principles still hold good to explain chemical constitutions and changes, though there has been a complete revolution in conceptions of the structure of atoms themselves. In this revolution, however, theory has been used to account for observed properties and to forecast new effects from known causes. So long as the operations of the mental model thus constructed proceed according to plan it serves a useful purpose by providing points and movements of attack and defence. When opposing forces or natural obstacles reveal weaknesses in the system, adjustments have to be made to meet them. Expressed in another way, schemes of operations in the battlefield of science are not final orders to be followed without question, but working hypotheses which have continually to be modified to meet changing requirements of the front line.

In the fields of applied science, usefulness is the standard of value of both fact and theory. Natural relationships and laws represent the accumulation and collation of empirical knowledge, and nothing more is desired or claimed of them than service in action. Whether such generalizations, arrived at by theoretical and experimental research, are causally repetitional, and have no other significance, is too abstract a proposition to influence the activities of scientific workers generally in laboratory or field. When, however, the special theory of relativity, the quantum theory, the indeterminancy principle, and similar mathematical conceptions become factors which have to be taken into consideration in constructing rational schemes of structure and happenings in atoms and the universe, physical laws appear to be only convenient rule-of-thumb guides to practice and not ultimate truths.

Most scientific workers are satisfied with confirmatory experiment or observation as a test of the validity of a theory or principle. Clerk Maxwell's electromagnetic equations were of this type and were established as true by the experiments of Hertz and Lodge. Mathematical equations thus interpreted in physical phenomena often develop, however, into broader schemes and suggest that other states or conditions exist for which no objective proof may be attainable. In arriving at such equations upon purely mathematical principles, it is permissible to assume properties and relationships without reference to conscious knowledge of them. Though only a few of these revelations of the mind find contact with reality, while the rest belong to the realm of ideals, the general shape of the structure depends upon mathematical reasoning, which may be logically sound even when it does not coincide with observational knowledge.

The right of mathematicians to construct schemes of this kind, in which laws are derived from *a priori* concepts, must be conceded, however unsubstantial such flights of imagination may appear to practical minds. A physical law is not an unalterable creed, but a statement of knowledge of particular relationships of Nature derived from observation and experience. It has to be altered when cases arise which are not covered by it, and is not, therefore, a permanent statute. No scientific mind supposes that a physical law is among the eternal verities or a faith which it is sacrilege to assail.

There are other rational standards of value in Nature, in addition to those based upon scientific methods of inquiry. The inductive method is usually employed to construct theories of the nature of the universe from what has been discovered as to the constitution and distribution of the bodies in it, but such theories can obviously be nothing more than rational pictures painted in the pigments available at the time. As they must change with the expansion of theoretical and observational knowledge, they can never be more than temporary schemes which explain what is known when they are expressed, and suggest a possible past and future history from present appearances. Mathematics and philosophy are, however, not confined to known laws of Nature or to observable phenomena: though these may be used in constructing mechanical systems of the universe, they are not essential factors in mathematical conceptions, any more than they are in poetic flights of fancy. Ideas as to the origin and construction of the universe, based on logical mathematical principles, can only be refuted, therefore, by positive evidence of their untruth, and not by the apparent lack of contact with what is known when they are put forward.

Our senses determine the range of objective phenomena, but creative thought has no such limitations. It is the source of the greatest human achievements, whether expressed in music and poetry or in scientific discovery and invention. Its exercise is determined not by what is known but by what is unknown; and whether a pursuit is worth while must be measured by originality of intention and result rather than by direct intellectual or practical service. Here, then, is the common standard by which all scientific inquiries, and all expressions of human feelings, may be judged. It makes no distinction between pure and applied science, so long as the object is increase of knowledge and the endeavour is the discovery of truth.

When this is borne in mind, the pursuit of knowledge for its own sake becomes just as estimable an occupation as that in which the purpose is use or action. It is generally acknowledged that inquiries undertaken to solve purely scientific problems, and without thought of their proximate or ultimate usefulness, have been the starting points of most of the great achievements of modern science; but such problems need not be excluded in planning scientific work for the benefit of the community. Science has transformed so many aspects of modern civilization that structures of society designed in earlier times have been shaken to their foundations by it. Its sources and resources, if they are wisely used, give almost unlimited powers to construct a world in which life can be made worth living to all peoples of the earth.

Systems of planning with these objects in view have to provide not only for the full use of existing knowledge but also for efficient means of extending it. Most scientific inquiries are best advanced when groups of workers concentrate attention upon them, whether intellectual interest or industrial application is the motive. It is, however, as impossible as it is undesirable to attempt to limit creative thought to a particular pattern, or to apply the criterion of usefulness to its exercise. This is as true of science as it is of other activities in which hand and brain combine to express themselves in new products. Men of science, like musical composers and other artists, may follow their occupations as a means of living, but their most original achievements are those which depend for their expression upon inborn light rather than external influences. In every walk in life, both interest and pleasure are required for contented effort, but they are not always to be hired in the market place. They are at their best when they are exercised in perfect freedom, whether in craftsmanship or in the expression of human consciousness.

STRUCTURE OF LIQUID METALS

BY DR. A. LATIN

RESEARCH DEPARTMENT, MESSRS. THOMAS BOLTON AND SONS, LTD.

THE view that the arrangement of atoms or molecules in a liquid is not entirely random may now be considered well established. In other words, the liquid possesses certain characteristics to which the term 'structure' can be properly applied. This does not mean that a liquid possesses anything so definite as a 'lattice structure', and any reference to a 'liquid lattice' may be very misleading, if not, indeed, devoid of meaning. It would perhaps be allowable to refer to the 'ghost of a lattice. Before going on to consider liquid metals themselves, it will be as well to deal first with the general question of the structure of liquids.

There are perhaps two main types of conception of liquid structure that have proved of value. These may be termed (1) group and (2) statistical conceptions. In some ways, indeed, these con-