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M. S. THACKER

PLANNING COMMISSION·GOVERNMENT OF INDIA

SCIENCE AND CULTURE

I

Galsworthy, in one of the Forsyte novels, describes in detail a picture of a large whitish monkey holding the rind of a squeezed fruit in its paw. The whiskered face seems to look at the spectator with brown, heavy-lidded, almost human eyes, weighed down with a sense of sheer disappointment. The picture is presented as an allegory of life or rather, a satire on civilisation.

two

The suggestion is that man, in spite of his vaunted superior wisdom and knowledge, has cast away real values and is left loaded with the trivial and inconsequential rinds of life. Such a pessimistic view of humanity has always been voiced by a small section of philosophers in all generations but it has been gaining ground, especially after the cataclysmic disaster of the last two wars. Man, we are told, forsaking the eternal verities of life, pointed out by philosophy, religion and the humanities has chosen to run after the glittering trivialities of materialism and hence has nothing but sad disillusionment in store for him. Some even go to the extent of declaring that the culprit responsible for the present plight of humanity is science which has begun to permeate almost all walks of life. According to them, science is almost the antithesis of the humanities and the relentless pursuit of science has landed man in utter misery. While most thinkers will hesitate to subscribe to such a violent impeachment of science, there is a vague feeling on the part of many that science cannot really contribute to the values of life.

It is my endeavour in these lectures to expose the fallacy behind this feeling, to show that there is no antipathy between science and the humanities, that both have contributed to the civilisation and culture of today. Much of the misunderstanding of science and its role in moulding and shaping the minds and destinies of men is due to an incomplete appreciation of what it is. The term science seems to convey varying connotations in different circumstances. I shall attempt, first, to examine clearly all these concepts of science and to analyse the various aspects of this vast field of human knowledge. Later on, I would like to show how the very values which are associated with the humanities are nursed and tended by science and how science and humanism are really complementary to each other in various ways.

Origin and Development of Science—To understand science fully, it is essential to realise how it came to be what it is, how it has reacted in the past to the successive forms of society, and how, in its turn, it has moulded society itself. For that purpose, let me, in the first place, give in brief retrospect the origin and development of science. When did science begin? Where did it begin? The simple answer is that it began whenever and wherever man, impelled by curiosity, attempted to inquire into the phenomena of nature and later, applied the results of such inquiries to the problems of life. At first, of course, most of the solutions were *ad hoc* arrangements but later these were compared, generalised, simplified and integrated. Thus from these early efforts of man, the texture of science gradually emerged. Science seems to have evolved out of two parallel traditions which existed perhaps even before the emergence of civilisation: a technical tradition, in which practical experience and skills were handed on and developed from generation to generation and a spiritual tradition, in which human aspirations and ideas were passed on and augmented. The continuity in the development of the tools used by men of the stone age and their burial practices and cave paintings bear testimony to these two traditions even in those early ages.

In subsequent eras, the two streams remained separate for the most part, and both became further differentiated, the philosopher branching off from the priest and the scribe, and the artisans of one trade from those of another. Occasionally, however, the two streams of development tended to come together as in ancient Greece, but in general, it was not until the late Middle Ages and the early modern period that elements from the two began to fuse to give rise to the new tradition of science. The development of science thereafter became more or less autonomous, and containing both practical and theoretical elements, science produced results which had technical as well as philosophical implications. Science reacted back and influenced even its sources, and indeed it had an effect ultimately upon domains far removed from its immediate origins.

The growth of science through the ages has been by no means even or uniform. Eras of rapid advance have been alternating with ages of stagnation and even decay. The centres of scientific progress also frequently shifted, following more or less the migration of the centres of commercial activity. India, Egypt and Babylonia were the cradles of scientific progress at different periods. Greece inherited the traditions of these centres and there, for the first time, the rational basis of science was evolved. But the final decay of the City States put a stop to this flowering of science. Rome and the barbarian kingdoms of the West had little use for science and the heritage lapsed back to the East. There was a slow rebirth of science in the East, and Syria, Persia, India and China were notably the centres of the new activity. Thence, under the banner of Islam, science and the techniques developed and then invaded Europe; and there it gave rise to an almost explosive outburst of creative activity leading to modern science.

Starting from the revolutionary ideas of the Renaissance, we can trace an almost unbroken and continuous tradition of science down to our own times. In this modern period, we can, however, trace four successive waves of advance. The first, confined more or less to Italy, witnessed the attacks of Leonardo, Vesalius and Copernicus on the ideas of the ancients and their central doctrines of man and the world and opened up new horizons in the fields of mechanics, anatomy and astronomy. Soon after, the efforts of a few scientists in the Low countries, France and Britain, like Bacon, Galileo, Descartes and Newton were responsible for the evolution of a mathematical-mechanical conception of the universe. The third wave of advance started from industrial Britain and revolutionary France and threw open new vistas of knowledge such as that of electricity, unknown to the ancients. It was during this period that science began to help in a decisive way with new forms of power. machinery and chemicals, and rapid transformation of production and transport was the result. The neo-technological revolution of our own times is perhaps the greatest of all these advances in effect and extent. We are witnessing today the birth of a world science not confined to any particular geographical region or country, transforming all sectors of industries and permeating every aspect of life. Science has become all-pervasive and it is the means by which the whole of human life is being rapidly transformed. The growth of science is no longer steady and imperceptible as in the past. It advances by leaps and bounds, revolutionising the whole fabric of our civilisation.

Economic and Social Factors—This brief and perforce cursory glance at the history of science brings out very clearly one important point about scientific progress, namely that it is closely linked with economic and social factors. Greek science reflects the rise and decay of a society built on a system of slavery and dominated by considerations of money. In the Middle Ages, the feudal system had no use at all for science and it was only when the bonds of feudalism were broken by the rise of the middle classes that science could rear its head again. Thereafter, the fortunes of science became closely linked with those of capitalism. The first two periods of scientific advance in the modern age since the Renaissance witnessed the slow but gradual establishment of capitalism as the dominant economy in the important centres of Europe. The Industrial Revolution was responsible for the introduction of the factory system and the late eighteenth and the early nineteenth centuries witnessed the triumphant combination of the two forces of capitalism and science. During the last few decades, we have been witnessing a new form of socialism trying to overthrow the system of capitalism and to use in its own way the forces of science.

Incidentally, it is interesting to note how people of different ages have been reacting to science. In the late nineteenth century, there was a common and widespread belief that the applications of science would lead automatically to a steady improvement in human welfare. When Roger Bacon talked about science for the service of man, and prophesied the conquest of nature through knowledge, the idea was almost revolutionary. Science as an instrument of human welfare was confidently asserted by Francis Bacon three centuries later. The immense progressive changes which followed in the wake of the Industrial Revolution made this idea of progress through science a more or less assured and lasting truth and became almost a platitude in the Victorian era. But at present, when humanity has begun to realise that the power, science and technology can unleash, is capable of wiping out life itself from the face of earth, it is no longer possible to hug to the illusion that science is necessarily an instrument of social progress.

Since science, as a human activity, has been more or less an inseparable aspect of the process of social evolution, it is difficult to define clearly its meaning and scope. Any attempt at definition will only describe more or less inadequately one of the various aspects with which science has been associated during some period of its growth. It would be far more profitable to analyse the various aspects in which science appears in the contemporary world.

Methods of Science—One of these lies in its methods. In the first place we would be wrong in imagining that right through the ages there has been only one fixed scientific method. The method of science, which has grown with the evolution of science and society, is made up of a number of operations, both mental and manual. These in the past have yielded answers to certain general questions which are worth asking and can be answered at any stage of social development. Originally these questions were mostly in the fields of the mathematical sciences such as astronomy and physics Later, the method was extended to and modified in the fields of chemistry and biology and, in our own times, it is being applied to problems of society.

The methods of working scientists have evolved from those used in ordinary life. Whenever there is a job, we have a preliminary look at it or in other words observe the task; then we try out some method of doing it or, to put it in the scientist's language, we experiment. In observation the scientist has to be strictly objective and must be completely independent of his personal feelings and sentiments.

Classification and measurement are techniques to help the scientist in this objective observation and experiment. Classification is a method of understanding new groups of phenomena. Known materials are grouped into appropriate classes and when the scientist comes across any new material, he finds out to which group it belongs; if it does not display any of the characteristics of existing groups, he tries to probe further and finds out the reasons therefor. In the last resort, he may have even to postulate a new group for the new substance.

Measurement may be described as another method of classification, another method of grouping materials. It links science with mathematics on the one hand and mechanical practice on the other. It is by measurement that the scientist is able to indicate precisely what has to be done to reproduce certain given conditions or obtain a desired result. The early experiments of scientists were full scale trials. But with the help of measurement scientists could not only reproduce their experiments accurately but could conduct them on a small scale with the help of models. One of the most essential features of modern science is this small scale experiment. The scientist is thus enabled to conduct far more trials in the same time and far more cheaply. In one sense, all experiments of scientists belong to one of the two categories: either analysis, separating anything into its component parts, or synthesis, putting all these parts together.

To conduct these experiments, scientists have evolved a number of specialised tools—usually called the apparatus of science. Many of these, like the crucible and the forceps, are merely the tools of ordinary life used for special purposes. Sometimes the reverse happens; the scientific apparatus comes into use in ordinary life as a useful instrument. Thus the cathode ray tube has become the television set of ordinary homes in the West. All scientific apparatus can be grouped into two categories: those, like the telescope or the microscope, which extend or define more precisely our sensory perceptions of the world around us, or scientific tools, like the incubator, with which we can manipulate materials of the world under controlled conditions.

The conclusions arrived at by the scientists as a result of their various experiments and observations contribute to the growth of scientific knowledge. But the scientist does not merely string together all his observations and the results obtained by his experiments. He tries to group the results to find out the inter-relations between them and, in general, attempts to interpret them. These interpretations lead to the enunciation of scientific hypotheses, laws and theories. But this is not the end of scientific development. Practical applications arise out of these laws and theories and these in turn lead to newer experiments, newer interpretations and newer applications. All these together constitute the sum and substance of live science.

While discussing the methods of science, it is necessary to refer to the growth of what might be termed the language of science. The early scientists discovered that using ordinary words of common parlance in describing scientific observations would lead to a lot of confusion. They therefore drew on the rich treasure house of the forgotten languages of Greece and Rome. Sometimes the scientists have to use a symbolic language to express quantities. In all these cases the purpose of the specialised language, whether it consists of mathematical symbols or scientific jargon, is to establish a set of relationships which are understood in the same way by all competent people.

There is, however, a danger that scientific jargon may actually hinder rather than help scientific advance especially when it is used by pretenders to bolster up their ignorance or lack of knowledge. One effect of the specialised language evolved by scientists is that it keeps them and their ideas further away from the common mass of people. In the modern age, each branch of science has developed its own peculiar jargon, with the result that even scientists of one discipline cannot understand the language of another.

An Exclusive Profession—The aspect of science today which impresses the man in the street most is the fact of its being a sort of exclusive profession. To the ordinary man scientists are a class apart, some working in obscure and inaccessible laboratories with strange equipment and others occupied in intricate arguments and calculations. The doors of science as a career are open only to a select few after periods of long training and apprenticeship. Several peculiar characteristics mark it as something entirely different from the common avocations of society. In course of years almost an esoteric quality has grown about this profession. For one thing, most of the practitioners of science have evolved a language of their own which the ordinary man cannot understand. In general, scientists have not bothered to express their important discoveries in common language.

The evolution of science as a separate profession is of recent origin. In earlier times, science was a part-time hobby of those who were wealthy and had the necessary leisure. In the history of the earlier periods we come across a few great souls whose actions were motivated by a divine urge for scientific exploration. Such men, when they were poor, had to look round for some patron who could encourage them with liberal grants. This dependence of science on patronage has continued right through the ages. With the spread and evolution of modern commercial conditions, the role of patron played by the wealthy individual of the earlier ages was assumed by business corporations and universities.

Now-a-days the patronage has passed into the hands of governments. All over the world it has been realised that the wealth of nations in peace and their power of resistance in war are directly dependent on their industrial and scientific strength. All governments naturally try to achieve a high level of technological investment in their own borders. The result is that all over the world, the state has emerged as the controller and patron of science.

This dependence of science on patronage brings to the forefront the question of social pressure on the direction and development of science. Every scientist, as an individual in society, is naturally influenced by social and economic developments taking place around him. Apart from this indirect influence, social pressure has always been directly exerted on science. In the earlier periods, since scientists had to look around for wealthy patrons, it was more or less the monopoly of the upper or the middle classes and these groups naturally determined the direction of development of science. When a commercial corporation today engages a number of scientists disinterested love of science cannot be the main motive. The governments of today, however enlightened they may be, exert a very great influence on the direction of science, since to them science is a means by which they have to achieve some of their goals in the social and economic sphere.

In the last analysis, the duties as well as the rewards of science derive from social institutions and traditions. This social direction of science need not necessarily be evil. Thus in the seventeenth and eighteenth centuries, with the growth and expansion of overseas commerce and trade, the needs of navigation forced the scientists to set up the Royal Observatory at Greenwich and the Observatoire Royal at Paris and the determination of the longitude was the first practical question taken up by these institutions. In our own country today, government insists, and insists rightly, on a bias towards economic development in research since only such work will be of immediate benefit in the present stage of our national growth. It is only when a society begins to value science as a means only for private profit and for evolving means of destruction, that social control and direction of science become evil. But at no time in the history of man has science been pursued for its own sake except at the very incipient stage. Professor G. H. Hardy in his book, *A Mathematician's Apology*, defined pure mathematics as a subject of no practical use and added that it could not be used for promoting directly the destruction of human life or for accentuating the present inequalities in the distribution of wealth. Unfortunately events have belied the great mathematician and both the results have flowed during and since the last war from the study of pure mathematics.

Science and the State—Today the State has emerged as the supreme arbiter in science. Theoretically, therefore, the State has the power to dictate to the scientist what he should do and what he should not do. There are, of course, certain limits to the pressure that governments can exercise on scientists. If government sought to interfere with the scientist in the absolute freedom of his explorations and the integrity and independence of his speculation, it would ultimately destroy its real source of vigour or frustrate its own purpose by undermining the scientist's confidence and his will to co-operate. But one must also remember that the scientist today is far more dependent on the State than in earlier ages. Some of the tools and equipments of the modern scientist cost enormous sums; even the training of the scientist is complicated and protracted and terribly expensive. Naturally the scientist is ever dependent on the patronage, in some form or other, of the government. Usually enlightened governments take a long term view and accept the work of scientists as intrinsically valuable. The support of scientists is taken as a charge on the national exchequer and the scientists are allowed, within reasonable limits, to pursue their own lines of research. In return, the scientists have to understand their social responsibilities and must order their work in such a way as to get the best results in the interests of society.

There is also another serious limitation to the power and influence of governments in the field of science. They must remember that the great ideas of science, the new mutations, which have led human thought into truly novel channels and have ultimately had immeasurable effect on society as a whole, have been the product of great and unorthodox individuals—the Galileos, the Keplers, the Newtons, the Darwins, the Einsteins. But to the layman this truth is not so evident today. One of the reasons for this is inherent in the nature of science itself. Knowledge in this field is cumulative, and in sharp distinction to arts or letters or even to philosophy, the achievements of every man must necessarily rest intimately upon the base established by all the fellow workers before his time and can never be his alone in the same obvious manner as with the artist. Here the scientific inventor is as dependent upon the human matrix with which he works as a messenger bee on its swarm. But much too often we confuse the swarm with its messenger and imagine that it is the swarm, not the messenger, which makes the truly new discoveries. Moreover, in science when great and individual innovations are made they are brought to fruition by great efforts which are also science or something like it—yet which, in a subtle and essential way, are vastly different. These mass efforts represent the completion, not the beginning of the cycle. The distinctions between innovation and development are not easy to make. Can we distinguish, for example, between the effort that led, in the hands of a few gifted, inconspicuous individuals, scattered widely over the world, to an understanding of nuclear reactions which ultimately made atomic fission a possibility and the titanic effort that makes huge teams and great government organisations in several countries so effective in the production of nuclear weapons? We should not commit the mistake of assuming that if only sufficient money and the teams had been assembled earlier, the early phase of discovery and innovation by unorthodox individual genius might have been vastly accelerated or even avoided altogether. There is a dangerous temptation to believe that great innovation is simply proportional to the money and the manpower expended. This is confusing the end with the beginning, the means of development with the means of discovery. The essence of discovery still lies with the gifted the unorthodox genius. And governments, in spite of all their power and influence, can never order an Einstein to discover the Theory of Relativity any more than they can command a Shakespeare to write Hamlet.

Science and Society—There are two other ways in which scientists are subject to social pressure and direction. Each scientist has to carry with him his colleagues in his profession. His work is ever subject to criticism of his fellows in the various institutions and societies to which he belongs. Science has become truly international today and the research work of a scientist, published in any of the scientific journals of the world, is brought immediately to the notice of all the scientists specialising in that particular branch. The merit of his work is thus adjudged by a truly impartial body consisting of his compeers all over the world. Any vagueness in his theories or interpretations, any unwarranted conclusion drawn by him will be immediately laughed out of court. His work is subjected as it were to a double sieve, since no scientific journal publishes any research paper without proper referencing; later, after it is published, it is subject of course to the general criticism of all scientists. Only the really able can pass this rigorous test.

The scientist has also to think of the public in general. In the last resort it is the people who are the ultimate judges of the meaning and value of science. For one thing the government in almost all the countries of the world is in control of scientific progress and no government can set at naught the will of the people for long periods of time. The wishes of the people, especially their vague fears and suspicions, must be properly respected. To take a simple example from our own country, there has been a vague uneasiness in the minds of the people about the possible harmful effects of vanaspati. Bowing to public opinion, the Vanaspati Manufacturers' Association requested various scientific institutions in the country to undertake necessary experiments to find out whether there was any genuine basis for the fears of the people. This was done and the pressure of public opinion is so great that, session after session, questions are asked on the subject by members of Parliament. Moreover, the days when science was the concern of a select few are over; the ramifications of science now are so great that they touch human life and activity at almost every point. Actually one of the great responsibilities of the scientist today is to bring about a popularisation of science. This implies community of thought between scientists and non-scientists, a wider understanding of social problems on the part of the scientists and a clear appreciation of science on the part of the administrators, workers and people at large. It is absolutely necessary today to allay the very real suspicion of, and even hostility to, science which has been engendered in the minds of people by the use of science for mass scale destruction.

We have so far discussed science as an institution or a profession and we have analysed the different aspects of its methodology.

But these do not throw light on the reasons for the emergence of science as a specialised kind of social activity; nor can they explain how science has come to acquire the major functions which it has today. The origin and development of science are closely linked with the history and evolution of various forms of production. The history of civilisation may be defined as the story of the continuous attempt of man to control his organic and inorganic environment. The very names of the various stages of civilization reveal the landmarks in the struggle of man to tame the material world around him—the Stone Age, the Bronze Age and the Iron Age. And even in modern times we have had the ages of steam and electricity and ours may be aptly termed the atomic age.

Early man had to extract and fashion the materials around him to use them as tools for satisfying his prime needs. Thus the technique of production arose; it may be defined as an individually acquired and socially accepted method of doing something. But man would not be satisfied with merely following the method in a slavish manner. This urge to improve his techniques of production led to the development of sciences out of techniques. The first appearance of distinct sciences and the stages of their development make it very clear that sciences evolve and grow only when they are in close and intimate contact with the mechanism of production. We have already seen that the development of science through the ages has been anything but even. There are long fallow periods when science seems to be almost neglected in between ages of great activity; and the centres of such activity have been frequently shifting. The flourishing eras of science coincide with those of economic activity and technical advance. The track of science from Egypt and Mesopotamia to Greece, from Islamic Spain to Renaissance Italy, thence to the Netherlands and France and then to Britain of the Industrial Revolution is the same as that of commerce and industry.

Theory and Practice—Science is not a matter of thought alone, but of thought continually carried into practice and continually refreshed by practice. During the Renaissance, the demands of the techniques of mechanics, pneumatics and ballistics were responsible for the development of science; in the eighteenth century, the needs of brewing, distilling and textile chemistry forced the pace of development in science. Technical requirements provide the problems and the solution of these leads to the rise of new branches of science. In turn scientific advances are effectively fixed if they are incorporated in practical and paying trades. Some advances in optics were secured by the spectacles makers; and some in magnetism by the compass makers. Jet engines and the refrigeration industry are closely linked with developments in the theory of heat.

This close link between science and the techniques is responsible for new aspects of science arising out of practice and new developments in science giving rise to new branches of practice. The names of different categories of engineers—electrical engineers, radio engineers, chemical engineers—indicate how new branches of practice have grown out of different branches of science.

This brings me to another peculiar feature of modern science, namely the growth of a number of professions out of science. It is true that engineering as a profession is an offshoot of science. But there is a radical difference in the functional aspect of the two. The scientist's main aim is to fiind out how to do things, whereas the engineer's aim is to do them. The engineer cannot afford to rely much on abstract theory, he must follow the traditions of the past and also try out new ideas. The technical tradition ensures that the engineer cannot go wrong: but its weakness is that it is tied down by its own bonds as it were. The new ideas of engineers may give rise to steady and cumulative improvement of technique. But notable transformations can be achieved only when science enters the field. At the same time we must remember that engineering successes and more especially engineering difficulties present a fertile field of opportunity and problems for science. The complementary nature of the roles of science and engineering is one of the most important social facts of today.

The practical utilisation of science has, therefore, been a fertile and perennial source of inspiration for its growth and development. But we must at the same time recognise that the theoretical frame work, linking the practical achievements of science, is also an essential part of it. Theory has ever been playing an important part in the history of science. Biology of the nineteenth century was mainly concerned with the proving of the Darwinian theory of evolution. In the seventeenth century, the disproving of Aristotelian physics was the main topic of mechanics. The theories which individual scientists expound have a much wider bearing than the objective facts which they explain. The individual scientist is inevitably influenced by the prevailing intellectual atmosphere of his time and this influence naturally permeates and affects his theories. Very often, therefore, we find the phenomena of nature and manual acts being interpreted in social, political or religious terms. Newton's theory of inertia seems to have arisen from the prevailing rational interpretation of religion of those days. Darwin's theory of natural selection is closely linked with the then prevailing idea of the natural justice of free competition.

Sometimes the prevailing social ideas of the day lead to practically verifiable scientific advances. But sometimes these ideas become real obstacles to scientific advance. One of the greatest difficulties experienced by great scientists is not in making the necessary observations, but in breaking away from the traditionally accepted ways of interpreting the observations. When Copernicus established the movement of the earth round the sun, when Harvey explained the circulation of blood in the human system, when Planck postulated his quantum theory, the struggle lay not so much in penetrating the secrets of nature, as in overthrowing established ideas, even though these, in their own time, had helped advance of science.

A Mighty Force—I have, so far, attempted to touch upon the main features of science and to explain how many of these aspects of science have developed in course of time. The one lesson which we can draw from this brief survey is that unless we understand and appreciate the interactions of science and society we cannot even begin to appreciate what science means. The influence of science on economic and political developments has been indeed profound. Scientific ideas have also had their effect on man's philosophy and outlook. The great revolutions in man's ideas of the universe, and of his place and purpose in it, have largely been brought about by science. The new reign of simple natural law, enunciated by Galileo and Newton, influenced the return to simple Deism in religion, *laissez-faire* in economics and liberalism in politics. Was there not a close link between Darwin's theory of natural selection and the attempt to justify, under the pretence of the survival of the fittest, ruthless exploitation and race subjugation? Science has been in a subtle, barely perceptible, way exercising a deep influence on the whole pattern of human thought, culture and politics. Today, science has emerged as one of the mighty forces of the world, not because of the tremendous powers of destruction it seems to hold ready for the militarists of the world, but because it is deeply and inextricably interwoven with all aspects of human activity.

seventeen

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We have surveyed briefly the growth and development of science since the dawn of civilisation. We have seen that right through history it has been closely linked with social and economic factors and that many of the characteristic features of science can be understood and appreciated only in the light of its close affinity with man's manifold activities. We analysed also the various aspects of science and discussed the details of its methodology. We are now in a position to discuss its relationship with the humanities and to understand the points of similarity and contrast between the two.

Fundamental Unity of Knowledge—Science and the humanities are branches of human knowledge and, in the last analysis, there is a fundamental unity pervading all fields of intellectual endeavour. The firm imprint of the human personality is found in all disciplines of knowledge; and all of them reflect not only man's struggles with his environment, but also his aspirations and disappointments, his hopes and despair, his sorrow and sense of fulfilment. All knowledge is merely a mirror of humanity, a criticism of life in the truest sense of the term.

Actually, compartmentalisation of knowledge into different disciplines is a feature of later times. Science in its origin was a hardly distinguishable aspect of the lore of the priest and the mystery of the craftsman. Modern science is directly related to Greek science, which provided it not only with an outline, a method and a language, but also all the general problems to be tackled. A brief glance at the history of Greek science shows that for a long time, there was no distinction between science and philosophy. The very names of some of the great stalwarts of Greek science are enough to bear this out—the legendary figures of Thales and Pythagoras, known as the natural philosophers, and Socrates, Plato and Aristotle, whose influence on science was as deep as on philosophy and art.

This close link between the humanities and science is exemplified in the lives of many of the great scientists of the Renaissance. Were not Bacon and Descartes, to take just two examples, philosophers and scientists at the same time? The professions of the artist, the architect and the engineer were not distinct in the Renaissance. The artist might be called upon by his town or patron to cast a statue, build a cathedral, drain a swamp or besiege a town. The master craftsman had to know the properties of materials and the means of handling them. He had to instil into his work all his empirical knowledge of geometry and mechanics. Can there be a more brilliant example of a versatile genius combining mastery of all these arts and sciences than Leonardo da Vinci? The great artist, whose paintings have been at once the wonder and delight of generations, in seeking the patronage of the Duke of Milan, cites a number of military devices he can make, and at the end, as if by way of an afterthought, adds "In painting, I can do as well as another". His note books reveal how he keenly studied the operations of metal workers and engineers and how he became in reality the first great master of mechanics and hydraulics. His greatest attempt, though doomed to failure, was to achieve mechanical flight—a masterpiece of engineering research, combining observations of birds with the making of models, calculations and fullscale trials.

The fundamental unity of all knowledge is more spectacularly borne out by the philosophical interpretations which have become at present part and parcel of scientific discussions. The picture of the world presented by the men of science today, especially in physics and astronomy, is calculated to raise philosophical speculations. According to the modern physicist, matter, as we see it around us, is not to be regarded as a fundamental reality. Atoms, which form all kinds of matter, whether in the heavenly bodies, terrestrial objects or our own physical bodies, are combinations or particular arrangements of electrons, protons, and other elementary particles, held together by forces of attraction and mass and energy are interconvertible. There is no doubt about their reality or activity. The physical universe around us, therefore, according to the scientist is not what it appears to our senses, the solid substantial stuff, but is essentially immaterial in its nature.

Science and Philosophy—The motive of science is the discovery of facts about the universe itself. The why and wherefore belong to the realms of philosophy and theology. But the borders of the two naturally impinge on one another. Science, like all the intellectual efforts of man, is and must be anthropomorphic. We cannot conceive of a universe made out of nothing. All our theories and even the facts on which we build our theories are conditioned by our nature and our needs. A different mind from ours would not live in this universe at all. Science assumes an order in Nature. Dr. Whitehead, the philosopher, and Einstein, the scientist are both at one in postulating an order of Nature. The former declared, "There can be no living science unless there is a widespread conviction in the existence of an order of things and in particular of an order of Nature". The same conviction was expressed more forcibly by Einstein in these words, "The basis of all scientific work is the conviction that the world is an ordered and comprehensive reality. My religious feeling is a humble amazement at the order revealed in the small patch of reality to which our intelligence is equal". A purely mechanical conception of the universe does not satisfy the scientist any more than it does the philosophic mind. The modern mathematician's conception of the universe is a symbolic thing of which no mechanical model is possible. The scientist's philosophic concept is based not merely on theory but on a basis of fact as revealed in scientific investigation—investigation of entities that are not always capable of direct observation.

It is no use pretending that the great historic problems of philosophy have been solved and settled once for all. It is, however, clear that the higher reaches of modern science have thrown some light on these great questions. The whole texture of scientific thought has been changed within the last fifty years, widened and enriched. The trend of modern thought is away from materialism. According to Sir James Jeans the stream of knowledge is heading towards a non-mechanical reality. This view has been more emphatically stressed by Eddington and other eminent scientists. It is not my purpose to uphold or refute such views. I am only trying to emphasise the fact that since scientists have begun drawing philosophic deductions from their investigations, it is not worth while to pretend that science and philosophy walk on different sides of the street.

I have been dwelling so far on the close connection between philosophy and science. Let us now turn our attention to another aspect of the matter. It is possible to look upon science as the total of all the bits of knowledge added by individual scientists. How does a scientist achieve his aims, make discoveries and inventions ? As I mentioned earlier, the individual scientist, is spurred on in his work by two interests, the interest of his times and his own interest. Newton turned naturally to astronomy because it was the subject of his day, and finding one's way at sea had long been a practical preoccupation of the society into which he was born. Incidentally, astronomy was held in high esteem in those days, since it was used very practically for casting horoscopes. Funny as it may seem, the great Kepler was mainly interested in astrology, and astronomy was only a secondary affair with him. During the Thirty Years' War, Kepler cast the horoscope of the German general, Wallenstein and predicted a universal disaster for 1634; it proved to be the murder of Wallenstein. To return to my theme, the keen interest of the age in astronomy was responsible for Sir Issac Newton being interested in the subject. To take another example, Faraday worked all his life to link electricity with magnetism because this was the most important problem of his day, since society then was on the look out for new sources of power.

While the need of the age gives its shape to scientific progress as a whole, it does not give the individual scientist his sense of pleasure and adventure, his sense of excitement of exploration. That is due to his own inner urge, and the scientist is personally involved in his work, as the poet is in his composition, as the artist is in his painting. Paints have been used for practical purposes, just as language has been developed for prosaic communication. Yet you cannot have a man handle paints or words or symbolic concepts of physics, without immediately waking in him a sense of pleasure; and it is this aesthetic sensation which lies at the heart of all creative work.

Similarities between Art and Science—There is a great similarity between the creative acts of the mind in art and in science. Let us, for example, try to analyse the mathematician's delight in his work. His subject is primarily a language in which real parts are represented by numbers or by similar relations of order. But with the routine task of converting facts into this peculiar code, there is, in those who are experts at it a pleasure in the activity itself. They find the language richer than its bare content; the symbolism is forgotten and the logic and style of the symbols become attractive in themselves; and from these overtones grows mathematics as a literature in its own right. In this sense, pure mathematics is a form of poetry and has the same relation to practical mathematics as poetry has to prose.

This element of poetry, the delight in exploring the medium for its own sake, is a powerful ingredient in the creative process.

The example of pure mathematics which I have taken may make one feel that this creative delight is to be found only in abstract science. The same sensation is experienced by the scientist dealing with practical as well as theoretical branches of knowledge, by one propounding the kinetic theory of gases, as much as one inventing a new diesel engine. The sense of personal exploration is as urgent and as delightful to the practical scientist as to the theoretical. Very often we confuse mere routine work which involves no originality with the work of the practical scientist. Such routine work is carried out every day by all human beings, scientists, poets and ordinary men. It is such unoriginal work which keeps the world moving and it is by no means the monopoly of the practical men. A very large part of the work of every man consists of such humdrum work. The practical man, like the theoretician, may break away from what has been done before and may bring to the shaping of a new tool the same sense of pride and invention which the poet experiences in coining new expressions. It is also wrong to imagine that practical discoveries are made only by practical men. Is not the television set of today the end result of Clerk Maxwell postulating the existence of electro-magnetic waves, Heinrich Hertz proving it and J. J. Thomson discovering the electron ?

In science, as in art, mastery of nature is achieved not by force but by understanding. Both the scientist and the artist have to approach their subject matter with a deep sense of humility and a willingness to study and understand her laws. Science cannot cast any magical spell over nature. It is only in science fiction, that we come across instances of man mastering nature by outraging her laws. The science of the last four hundred years has taught us this lesson, that we can control nature only by understanding her laws. The power that we derive is only a by-product of such understanding.

There is a common fallacious impression that there is no room for the element of imagination or intuition in the way in which the scientist probes about in nature. Science is looked upon as a mere record of facts; and the scientist's business, it is assumed, is merely to collect all these facts, very much as the photographic plate records impressions of objects. Little scrutiny is necessary to expose the foolishness of such an idea. We speak of some great novelists like Balzac and Zola as realists; but at no time do we condemn them as mere collectors of facts. We know that the facts of life have been transformed in the crucible of the imagination and the result is that we have realistic novels of great literary merit. In the same manner, true insight into nature has to be combined with intuitive imagination if the scientist is to make any real discovery.

I would like to illustrate this point with a famous example which Dr. Bronowski has discussed in great detail in his famous publication, *Science and Human Values.* There is a fine painting, drawn by William Blake in 1780, of a shining youth looking outward from the sun; the picture is entitled *Glad Day.* Blake's drawing was perhaps influenced by some of the Renaissance studies, by Leonardo da Vinci and others of the Vitruvian proportions and mathematical harmonies of the human figure. We are not here concerned so much with the origin of the picture as with the suggestion that perhaps some of these Renaissance studies fired the imagination of Copernicus in his epoch-making revolutionary theory. Surely Copernicus did not postulate his theory that the earth moves round the sun after recording a number of observations. Copernicus found that the orbits of the planets would look simpler if they were looked at from the sun and not from the earth. By a leap of imagination, subconsciously influenced perhaps by the Renaissance pictures on which Blake based his *Glad Day,* he lifted himself from the earth, and put himself wildly, speculatively on the sun. Perhaps his imagination conjured up the picture of a virile youth standing in the centre of the sun and ruling all the planets around with his gestures. Anyway Blake's *Glad Day* can be looked upon as an eternal reminder to man that imagination and not any mere recording of facts, inspired Copernicus to postulate his famous theory.

A hundred years after Copernicus, Kepler announced the three laws describing the paths of the planets. The work of Newton and all subsequent developments in mechanics are based on these laws. One of Kepler's laws states that the square of the year of a planet is proportional to the cube of its average distance from the sun. The law stated in this bald manner appears matter of fact; but how was such a law discovered? Was it done by taking enough readings and squaring and cubing certain distances ? We know that Kepler's mind was full of fanciful analogies and similarities. Influenced by the idea of the music of the spheres, he tried to relate the speed of the planets to the musical intervals. He attempted to fit the five regular solids into their orbits. Kepler was feeling for his laws by way of metaphors, grouping mystically for likenesses with what he knew in every strange corner of nature. And suddenly when he hit upon his laws, he was impressed naturally by the revelation of unity in all nature. There is nothing far-fetched about all this, for did not Rutherford and Bohr in our century find a similarity in structure between the atom and of all things in the world and the whole planetary system ?

Unity in Science and Art—With a firm belief in an order of nature the scientist explores nature by trying to find out similarities. Scientific progress is achieved by this eternal search for unity in hidden likenesses. Sometimes the similarity may be as tenuous as the wildest imagination of the poet. Take for example the case of the Japanese physicist, Yukawa, who predicted the meson. He extended the idea of waves of light behaving as if they were pellets to the forces holding the nucleus of an atom together. Working on this wild analogy, Yukawa calculated in 1935 the mass of the pellet which he expected to see. Thus the meson was found and it led to a number of other mesons, the existence of which had not even been dreamt of before.

Pythagoras is reported to have defined beauty as the reduction of many to one; this may be paraphrased as unity in variety, order in seeming disorder. In a poetic image, the writer seizes and explores a hidden likeness and presents two parts of a comparison, each one shedding light and giving depth to the other. The discoveries of science, like the works of art, are explorations of such hidden similitudes and, like great poetry or art, the discovery can also be enjoyed and appreciated long after the original experience of the scientist. In the moment of appreciation we relive the experience of the creator, Yukawa, Kepler or Rutherford as the case may be, and experience the thrill of discovery.

I would like to conclude this discussion of the close similarity between the methods of science and those of art with two examples of the intuitive nature of both. The famous German chemist Kekule describes in these words the manner in which he stumbled upon the hypothesis of the ring structure of benzene on which the whole edifice of the structure of aromatic compounds is based : "I was sitting writing at my textbook; but the work did not progress; my thoughts were elsewhere. I turned my chair to the fire and dozed. Again the atoms were gambolling before my eyes. This time the smaller group kept modestly in the background. My mental eye, rendered more acute by repeated visions of the mind, could now distinguish larger structures of manifold conformation—long rows, sometimes more closely fitted together—all twisting and turning in snakelike motion. But look ! what was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightning, I awoke; and this time also I spent the rest of the night in working out the consequences of the hypothesis".

Kekule's description reminds one irresistibly of that strange experience of Coleridge which led to the birth of *Kubla Khan,* one of the brilliant gems of lyrical poetry in English. Allow me to present his experience in his own words: "In consequence of a slight indisposition an anodyne had been prescribed from the effects of which he (the author, Coleridge) fell asleep in his chair at the moment he was reading the following sentence in *Purchas's Pilgrimage*—'Here the Khan Kubla commanded a palace to be built, and a stately garden thereunto and thus ten miles of fertile ground were enclosed with a wall'. The author continued for about three hours in a profound sleep at least of the external senses, during which time he had the most vivid confidence that he could not have composed less than from two to three hundred lines; if that indeed could be called composition in which all the images rose up before him as things, with a parallel production of the corresponding expressions, without any sensation or consciousness of effort. On awakening he appeared to himself to have a distinct recollection of the whole, and taking his pen, ink and paper instantly and eagerly wrote down the lines that are here preserved". It is not necessary to comment further on these two passages; there cannot be a greater striking similarity between two experiences in which intuition played almost a romantic role in leading to a creative act.

Values of Science—One of the favourite arguments of those who are in the habit of condemning science and extolling the humanities is that the latter are closely related to certain fundamental values of man whereas the former has nothing to do with them. This is far from true. At the same time, it cannot be claimed that science has all the values usually associated with the humanities. The values of science have grown out of its practice—not because they constitute a code followed by the professional scientists, but because they are the inescapable conditions for the practice of science itself.

The foremost of these qualities, nursed by science, is independence in observation and in thought. A man must see, do and think things for himself, in the face of those who are sure that they have already been over all that ground. In science, there is no substitute for independence. All the great scientists of the world, the Galileos, the Newtons, the Rutherfords and the Einsteins, have been able to leave their imprints on the sand of time only because of their independence, their refusal to accept dogmatically what was handed down to them by their predecessors. It is a quality common not only to the great scientists, but is deeply ingrained in the practice of science itself.

As a result of the encouragement given to independent observation and thinking, science has fostered another very valuable quality, namely, originality. Science has bred the love of originality as a mark of independence. Closely linked with independence and originality is dissent, the courage to differ from accepted traditional thought. In a society, deeply influenced by science and its ramifications, these values of science have naturally been deeply prized. Independence, originality and dissent—these are the stepping stones of progress, and the civilisation of today bears the indelible stamp of these qualities. Martin Luther, the Huguenot weavers and the Quaker iron masters exemplify these very qualities as much as

Newton and Eddington. Of these qualities, originality and independence are private needs for the existence of science while dissent and freedom are its public needs. No one can be a scientist, even in private, if he does not have independence of observation and thought. But for science to be effective in public practice, certain safeguards are necessary. These are free inquiry, free thought, free speech and tolerance.

Tolerance among scientists cannot be based on mere indifference; it must be born of respect. Respect as a personal value implies the public acknowledgements of justice and due honour. To the lay man it may look as if these values—justice, honour, the respect of man for man—are far removed from the realm of science. If we see how science works, then we would appreciate the close connection between these values and science. Science confronts the work of one man with that of another and grafts one on the other, and it can never survive without justice, honour and respect between man and man. Only through these means can science flourish; and in a society in which these values are not treasured science will wither away.

I have so far dealt at length, with the close link between philosophy and science, between the methods of art and those of science. I have also dwelt upon those important values of human conduct which science cherishes and which science has been responsible for inculcating in man for the past several centuries.

Differences between Science and Humanities—I would now like to touch briefly on what appear to me to be the salient points of difference between science and the humanities. The most important difference between the two is to be found in their goals. There is a definiteness about the goals of science. A scientist can state what his particular aim is and set about trying to achieve it. Even if it relates to the realm of theory, like a cogent picture of the universe, he can, after considerable trouble and even initial mistakes and failures, attain his goal. The aim of the humanities, the perfection of man in thought, feeling and action, on the other hand, is an almost unattainable ideal. It is much easier to evolve a new synthetic product in the laboratory, to put satellites into the earth's orbit, to reach the moon, than it is to achieve humane wisdom and insight in thought, feeling and action. Since mankind is generally absorbed mainly in the struggle for subsistence, comfort, pleasure or power, the ideal goal of the humanities is far less compelling. Montaigne, the wise humanist, once declared that Socrates was a greater man than Alexander because, while the latter conquered cities, Socrates conquered himself. This conquest of the baser instincts of man, preached by all the religions of the world and the humanities, is surely an ideal which it is almost impossible to reach unless human nature undergoes a miraculous transformation. The aim of the humanities, an aim which can never be fulfilled, but which, at the same time, can never be given up, is to humanise and civilise the aggressive and sensual animal in man, to lead him to realize his distinctively human endowments, to refine and multiply his moments of vision, to free his better self from the bondage of baser feelings and passions.

Another important difference between science and the humanities lies in their scope and range. While there are more or less well defined boundaries for the various branches of science, the subject matter of literature, for example, is the whole range and texture of life, the material conditions of existence, all that man does, is and would be, as an individual being, all his desires and emotions, and all that he experiences as one of a family, a community, a nation or the human race. Even science, its social consequences, and its influence on men and their behaviour have become the subject matter of literature. In the humanities, the appeal is always to the individual, his love, his sympathy, his misery and his joys. The great writers of literature, right from the days of the glory that was Greece down to our own, have been skilfully playing various notes on these personal emotions of the individual. When the slayer of Hector and the father of Hector met, brought together by the command of Zeus, they both learnt the meaning of compassion. The same lesson is learned through suffering by King Lear and he dies, like the aged Oedipus, in the knowledge of love given and received. The mind of Hamlet swarms with ideas and feelings unknown to Orestes, but there are many affinities between them. And the religious integrity that unites Antigone with Jeanie Deans bridges the gulf between the laws that do not grow old and the God of Calvimsm. The shock of a young man's initiation into the adult world of evil links Sophocles' Neoptolemus with the central figure in Hemingway's 'The Killers'.

Man's blind groping for the ideal, his attempt to understand the relationship between himself, a small speek in a huge cosmos, and the omnipresent God, his trial to appreciate his own inner feelings and urges—these are portrayed in a vivid and telling manner by the great poets, writers and artists. While the humanities are able to act as a guidepost to man, to point out to him what he should do and what he should not, science is essentially amoral. Science is a tool in the hands of man and it is for him to determine how he is going to use it. It is true that science has been harnessed by humanity for various useful purposes. During the last four hundred years, man has mastered the sea and the sky, has harnessed the electron and drawn power from the nucleus, doubled the span of life, and halved the working hours, and enriched the leisure thus won with all the amenities of gracious living. But at the same time, man has utilised science for threatening wholesale destruction of vast areas of population by the invention of the atom bomb, the hydrogen bomb and all the other paraphernalia of what he calls, with characteristic illusion, national defence. Science, as I have pointed out earlier, cannot be blamed for its misuse in the hands of a few demoniac individuals. Scientists as a class have reacted sharply to the accusing finger pointed out at them after Nagasaki and have been busy building up quickly peaceful uses of atomic power. In itself Science is neither evil nor good.

Educational Problem—Let me now turn your attention to one of the problems which educationists all over the world have to tackle. It is also a problem of immediate interest to us in India at the present stage of our national development. Ours is essentially the age of science, and more and more of our students are gradually taking to the various technical and scientific courses. The question arises whether we should include in the courses of study for those young men studying science and technology, some of the important branches of the humanities. Our analysis of the characteristics of science and the humanities has shown that for the development of a complete personality, both science and the humanities are necessary. This is accepted on all hands as a general proposition.

But there are certain practical difficulties in the way of including some science in the studies of the humanities as in the way of adding some humanistic studies in general courses of science. One is the immense growth of modern knowledge. From ancient times until almost the end of the nineteenth century, the mass of educated men, including scientists, had a more or less uniform education, a common cultural heritage, a more or less common outlook, however much they might diverge later. But the once seamless robe of knowledge has become a thing of holes and lumps, shreds and patches. The fifty departments of a modern university are aggregates of electrons moved less by attraction than by repulsion; and the educated public is fast becoming a set of heterogeneous groups which do not speak the same language and which share only a minimum of culture.

This atomisation of knowledge should not be allowed to be an obstacle in the way of shaping our curricula in such a manner as to include some teaching of the humanities in the science courses. Let us remember that in the study of the humanities man requires only a sort of initial guide. If the general interest of the science student is aroused in literature, for example, he will naturally develop a deep and profound love of the subject and will utilise some of his leisure hours for further study of the great masters of literature.

The problem of including some science along with general humanistic studies is almost necessitated by the present day social conditions. Since science has become an important factor in all aspects of life, in commerce, trade, agriculture and all other avocations of mankind, in the office and even in the home, it would be absurd to have a course of education in which some study of science is not included. But, there is a more compelling and immediate need for general appreciation of science and its implications today, since war has become a social problem of catastrophic force and overshadowing urgency. The basis of war is power, which is a product of science. Science, therefore, is much too deeply involved in the problem of maintaining peace in a world dangerously poised near the precipice of the most colossal folly of mankind. War may be looked upon as a form of social action in which some people attempt to conserve and protect their social order to impose such an order on others. So far, in spite of the great inhumanity and utter meaningless waste of war, many societies have been able to adapt themselves to its stresses and strains and to survive the orgy of violence. But the current war weapons—nuclear, chemical and biological—seem to spell utter disaster for the whole of mankind and the chances are that man might completely wipe himself out from the face of earth.

Whether society shall continue to rely on war or abjure it for ever, willingly and voluntarily, is a social decision in which scientists have no greater or lesser rights and duties than other citizens. But, in the discussions which must lead to a decision on this point and in the development of the means for putting the decision into effect, scientists have a grave responsibility.

Science and Humanities both essential—It must, therefore, be emphasised that both science and the humanities are essential for the growth of the human personality. Our culture and civilisation are so deeply enriched by both, and our life is so inextricably bound up with both that it would be absurd for any one to scoff at either. Actually, leading scientists and great humanists have always had great respect and reverence for the contributions of these two broad divisions of intellectual endeavour. It is only the narrow specialist, blinkered by the trammels of his own small field of knowledge, who snorts with contempt at other branches of learning. The dangers of such narrow specialisation have been humorously expressed by Lionel Trilling, according to whom the modern specialist will not be able to say, "They fell in love and married" but will declare, "Their libidinal impulses being reciprocal, they activated their individual erotic drives and integrated them within the same frame of reference".

Science of Human Survival—In a recent issue of *Science*, there is a powerful and impassioned plea for the development of a science of human survival. In my opinion, such a science can be developed only by the joint efforts of great humanists and scientists, working in close collaboration and with mutual understanding and appreciation. In this age of disillusionment, when all life appears to be a dreary waste land and we seem be mere hollow men, there is as urgent and compelling a ne for the healing balm of the faith of the humanities as for t scientific temper without which we would be misfits in mode society. The pursuit of science to the exclusion of the huma ties will make mere splinters of men, fractional adults wl can never become full-fledged men and women. If man is reach the full dimensions of his intellectual, emotional a spiritual stature, he must cultivate assiduously both science a the humanities.

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