UNIT 1: INTRODUCTION

SCIENCE: Is it possible to define what we mean by science? Perhaps not, for science is one of the major activities of our minds, in this sense resembling art, religion or philosophy. None of these can be understood unless we consider them in relation to their past history. Science may perhaps be regarded as a mood in which we consider our world. No man is always in the same mood, and no man of science remains permanently in the scientific mood. In estimating the value of the judgments of men of science outside their own scientific department it is well to remember this, for these judgments are sometimes to be rated very low.

As soon as we attempt to discuss science as a whole, a host of difficulties appear. The Latin word *Scientia* meant nothing more definite than "knowledge", but the modern usage covers only certain kinds of knowledge. The area of these is now so vast that no man can have a grasp of more than a minute fraction of them. Moreover, even the kinds of knowledge regarded as "scientific" are extremely divers. They extend from subatomic reactions to mental process; from mathematical laws of thermodynamics to the economics of rare relations; from the births and deaths of stars to the migration of birds; from the study of ultramicroscopic viruses to that of extragalactic nebular; from the rise and dissolution of culture and of crystals to the rise and dissolution of atoms and of universe. They include both knowledge of the workings of living bodies and knowledge of the laws of thought, together with that of the nature of their disturbances. Can these innumerable and endlessly diverse topics be brought under any one formula?

These very different activities and disciplines all involve systematic and unbiased observations; the due examination of the records of these by trained minds leads to classification; from such classification general rules or "laws" are deduced; these laws may be applied to further observations; failures in correspondence between new obserGvations and accepted laws may result in alternations of the laws;; and these alterations lead to yet further observations; and so on. This chain of activities is usually held to constitute the "method' of science.

Admittedly this chain is not followed invariably. It may be short-circuited by some sort of mental process of which we know little; but even in such cases the final appeal is to observation, often in that specialized form known as experiment. Further, science is, of its nature, always developing and not a mere body of knowledge. To summarize, science is search for judgments to which universal assent may be obtained – universal, that is, on the part of those who understand the judgments and their bases. It is a search that never ends and is never satisfied.

It is always dangerous to infer the semantic value or range of meaning of a wore on its etymological basis. Nevertheless, it cannot be disregarded, that in English, as in other languages with vocabularies even more largely Latin-derived, the complex ,adjectival form of the word *science,* namely *science (i.e.,* "knowledge making") has been steadily displacing simpler, shorter and more natural formations, such as *sciential, scientific* and their variants, since the beginning of the 17th century. The acceptance of our usage of *scientific* follows closely the growing prestige of what has come to be called "science" (earlier it was known as "natural philosophy"). This correlation of concept and adjective becomes intelligible if we consider the spread of the awareness that science is the making of knowledge and is not knowledge as such. Science has thus become constantly more nearly equated with "research" and has come to connote a process and not a static body of doctrine. This situation is evident enough and can be illustrated by many examples showing that when the process of making knowledge ceases, science subsides into static or recessive tradition. But it is highly important that this should not be taken to mean that science excludes tradition. The reverse is the case, for science necessarily involves a developing tradition. Not a few persons active in advancing science have persuaded themselves that they had no need of tradition that is of the history of their subject. Some have at times refrained from studying the work even of their contemporaries and have prided themselves thereon. These men have all deceived themselves, for the man of science cannot forsake his tradition however he strive. Doubtless atomic physic for example, may be advanced without exact knowledge of the careers achievements and mental processes of Max Planck and Albert Einstein. Moreover there are episcopes of research wherein the researcher is wise to confine himself temporarily to his own thoughts. But those thoughts have been shaped by the scientic tradition. To forget that tradition for a moment does not change the fact that the man of science inherits an age-old way of thinking and that his research is but part of an ever-growing body of knowledge based on tradition. Only by extending knowledge previously won can he build new knowledge. He can no more free himself from the millenuuial tradition of science than from the language that he speaks or from the civilization in which he has been reared. *"L'histoire de la science,"* said Auguste Comte, *"c'est la science meme"* ("The history of science is science itself").

Despite their philosophical importance controversy on the nature of knowledge, on the question of whether our knowledge real or whether there is another and deeper reality to which we cannot reach and the even more pressing debate as to how or whether science can give certude are of no aid in defining, delimiting or understanding the nature of science (see KNOWLEDGE, THEORY OF). Science can treat the outer world solely on its own level, that is, the level of *phenomena* ("things that appear," "appearances"). These can appear only to the senses that we possess. It may be that our senses yield results that are ultimately contradictory or at least, that our minds find no rest in them, or which sation of harmony. But the quieting of our minds on such things is ultimately a task of philosophy or religion or both. Science, as such, can have only an indirect share in this.

Evidently, in the study of phenomena our sense often deceives us. But science seeks ever to correct, aid, extend and supplement our senses by technological devices. With these the sphericity of the earth, the discontinuity of matter and of forces, the movements of atoms, the bending of light by the sun's mass and even the mutual convertibility of mass and energy may be demonstrated to our senses. It is also true that science frequently leaves phenomena altogether, to mount into an atmosphere of abstract symbols usually of a mathematical kind. But science takes such fight only to descend again to the prediction or demonstration of phenomena. Phenomena must ultimately be sensed, and mathematical considerations, however recondite, and scientific instruments, however intricate, are but delicate, remote and specialized ways of sense-experience, though sense-experience may for some (and perhaps eventually for all) be ultimately reducible to seal readings.

UNIT 2: THE METHOD OF SCIENCE

The Method of Science: The first modern philosopher of science, Francis Bacon (*q.v,; 1561-1626)* , set forth in his *Advancement of Learning* the belief that in any field of knowledge the facts might be collected, according to an accepted and prearranged plan, and then passed through an automatic logic process from which correct judgments would inevitably emerge. This method cannot be applied in practice, when we seek to explore any field of knowledge, we must somehow choose form among the phenomena – often called facts. The question then arises as to how the man of science can best choose the phenomena to be observed and recorded.

The history of science shows that only those with knowledge of how their predecessors have succeeded or failed have chosen profitably. In other words the process of choosing phenomena is an act of judgment on the part of a learned or experienced chooser, a scientist; and the most learned is often modestly unconscious of the depth of his own learning.

But is not this also the case with the choosing of words by that word-chooser whom we call a poet or the choosing of colours by that colour –chooser whom we call an artist? The choice of scientist, of poet, of artist is necessarily controlled by his knowledge of his special field, his 'subject", as we are wont to call it. Perhaps it would be more true to say that the choice is controlled by his experience of the scientific, of the poetic or of the artistic mood. The scientist, like the poet and the artist, exercises his judgment to select those things, which bear to each other certain relations which he has himself conceived or which he seeks. He may find something, which he ahs not conceived or does not seek. This discovery may lead him to further search and so to further discovery. And yet no experience of the scientific mood, however profound, no acquaintance with the history of his science, however complete, no reasoning, however deft, will make a man a scientific discoverer. Nor, for that matter, will any knowledge of metre, or of colour, or of the nature and history of verse or perspective make a poet or an artist. Successful scientific men, like poets and artists, may be directed by training and are always molded by tradition. But they must also possess that incommunicable power of judgment, as necessary in science as in the arts. Thus in the end science, lime the other great human activities, comes up against the impenetrable mystery of mind.

We therefore return to phenomena. The scientific man, in practicing his art of discovery, has to exercise a series of quite different mental activities. These may be classified as, first, collecting observations; second, forming an hypothesis that links the observations; third testing the truth or falsehood of the hypothesis; and fourth, using the hypothesis in examination of further observations or re-examination of those already considered. When the hypothesis answers suitably to repeated or sufficiently delicate tests; our scientist has made a "discovery". It is true that the four processes of choosing of drawing an hypothesis, of testing it and demonstrating its validity and, lastly, of using it to guide further observational activity are often inadequately distinguished by the scientist in his own thinking. Often, too, the exposition of his discovery helps him, more or less unconsciously, to new acts of judgment, these to a new selection of facts, and so on in endless complexity. But essentially the processes are separable, and the power to wield one of them may be developed while the others are in relative abeyance. It would be easy to selectmen of science more skilled in some of these processes and less in others. But for due display of nature's ways all these powers must be at work.

On this matter, scientific articles (and especially textbooks) commonly give a false impression. They are composed to convince the reader of the truth of certain views or to put him in possession of certain knowledge. In doing this, such works normally obscure the process by which the views were reached. That process, as we have seen, usually consists of a series of improved judgment or working hypotheses interspersed with a provisional series of observations. Many such judgments are normally found untenable and much observation is irrelevant, ill-chosen, badly made or needing further test. An article or book is necessarily and rightly silent on these side issues and false starts; otherwise it would be diffuse beyond all toleration. Nevertheless, these omissions conceal the tracks of the investigator. For this reason, among others, science can never be learned from books, but only by contact with phenomena.

The relationship between the process of discovery and that of demonstration is often missed or glossed over, even by men of science. During the Middle Ages it was almost consistently avoided. On this point Francis Bacon remained in darkness. He rightly emphasized the importance of systematic fact collection but failed to perceive how deeply the act of judgment must be involved in it. No important discovery has ever been made along Baconian lines, though some discoverers have thought that they were following them. Some of the founders of the Royal society, in the middle decades of the 17^{th} century, regarded themselves as followers of Bacon. Investigation, however, has repeatedly revealed that each great discoverer has worked out his own line of research in a way suited to that line and to his own way of thinking, with little reference to any theory of the nature of science itself.

Study of the philosophy and history of science illumines our view of world and makes it more with investigation. It absorbs the reader and raises the status of the man of science. But such study will never be a direct instrument of discovery. The characteristic of the modern scientific scene that separates it from the mediaeval outlook is less possession of a method the constant devotion to and even obsession with observation as the demonstrative test. This point is often missed by those who seek scientific elements among mediaeval activities. Such elements existed; but, with little devotion to observation, they bore little fruit.

From all this it is apparent that the scientific process can be yet further reduced to two main activities: discovery and demonstration. As regards discovery, there is hardly any faculty or power that has not from time to time, been used by scientific men in their inquiry into nature's ways. But how his ideas reach the man of science is of relative insignificance. They may come in a dream or in an illuminating flash, or follow painful calculation, or be suggested by an analogy (often a false one). In all this the unconscious mind cannot be disregarded. In the end these things are matters of temperament. But it is in the processes of demonstration that we discern the man's efforts as scientific. Discovery is an art, demonstration makes the science. In the series of processes involving investigation, these two kinds of activity are inevitably mingled, but they can often be disentangled by study of accounts that men of science have given of their own experience.

Scientific knowledge is a developing thing. As with other developing things, its structure and functions can be understood only through its history, which is of its nature, "progressive". The "idea of progress" has many implications, mathematical, philosophical, biological, social, spiritual, with which we are not here concerned, but there can be no true science that dose not extend its range. Science, of course, may perish, but in so far as it is alive, it can build only on the science that has gone before. There were indeed periods of history and episodes of civilizations in which science progress was retarded, or in which its records were corrupted or forgotten or destroyed. These periods and episodes have their special interest because of the fragments of the great tradition that survived them, but examination of them cannot reveal the processes of development of science.

UNIT 3: ANCIENT SCIENCE

The traceable history of progressive science divides naturally into two moan periods. One is the active Greek period from about 600 B. C. to about A. D. 200. The other is the active modern period from about 1450 onward, in the full flood of which we live. Since of Greek science only is the full course known – even in outline – it is related here as the sole possible exemplar of our own. This is not to foretell disaster; but appréciation of the history of Greek science may help to avert danger form our own. The Greek achievement can be examined in its entirety with steady and unbiased vision.

The Age of Anonymous Science: When then did science begin? Something remotely resembling it is discernible very early, long before the Greeks. With very slowly increasing skill men of the Old Stone Age fashioned weapons or tools – the tow were at first undifferentiated. Perhaps 400,000 years ago these began to assume a symmetrical form involving some mental image of the object before it was wrought. This form implied an adaptation of means to ends based primarily on trail and error a crude form of experiment used even by lower animals. Again and again in the succeeding millennia men have made such adaptations. When they became conscious that trial and error is a way to solve problems, men took a great step on the road to science some 30,000 years ago they succeeded in portraying animals in positions of movement and in the chase. A further passage to exact observation and record of nature occurred when men ceased to be food gatherers and began to become food growers some 13,000 years ago. There then arose the need to choose the right time to sow and to reap. Apart from day and night, the obvious way to reckon lapse of time is by charges in the moon. Months or moon cycles cannot be made to correspond to any exact faction of the solar year or sun cycle. But in the earlier agricultural stages the one set was given some temporary approximation to the other.

As men gathered in aggregates, forming cities, and began to be civilized, more moriri divisions of time were needed. It became necessary to number the days in the year and in its seasons. This soon became a task for specialists, men who could enjoy the new social surplus. Moreover, the settled agricultural life needed more tools, at first of stone. Thus a professional technology developed.

The age of store passed into that of metals. The treatment of rights in land demanded some sort of survey. Tradition has it that the annual Nie flood rendered necessary an annual remeasurement of the fields of Egypt. Thus geometry (literally "earth measurement") was born. The cutting-up of animals for food and the examination of their entrails for divination yielded, especially in Mesopotamia, some knowledge of bodily structure. These activities are among the sources of what we now call metallurgy, mathematics and anatomy.

As society became yet more complex, commerce increased. The stewards and pries of palaces and temples needed records. Thus systems of numerical notation were invented. Ultimately writing developed from pictographs. The ancient world presents numerous examples of such inventions, fathered by necessity and mothered by experience. All have some claim to be considered in a history of science. Early civilizations united men into larger and ultimately into imperial units. But those who share our Judaeo Graeco-Roman culture, when they examine the records of the earliest civilization, are impressed by the failure to stress human individuality.

Investigation of the ancient empires, notably of the Babylonian, has revealed a far more extensive and systematic accumulation of astronomical and mathematical information than was formerly suspected. Science can therefore no longer be called a Greek product. Cumulative records began in the 4^{th} millennium B.C. in the river valleys of both Egypt and Mesopotamia and perhaps elsewhere. Nevertheless our records of these are still so discontinuous that, while it would be possible to write an account of what we empires is still impossible. It is, however, important to recall that to the Babylonians we owe exact measurement of the lunar and solar cycles, the tracing of the paths of the planets, the division of the circle into 360 degrees and the designation of constellations, notably those of the zodiac.

Science First Conscious of Itself (c. 600-c. 300 B.C) – The figure traditionally associated with the beginning of science among the Greek is Thales of Miletus (*q.v*) in Asia minor, who flourished in the first half of the 6^{th} century B.C. The Greek alphabet is thought to have firs emerged (from the phoenician) in Miletus about 200 years before Thales. He was a merchant, son of a Greek father and of a Phoenician mother, and had visited Mesopotamia and Egypt. He made certain geometrical discoveries, though the elements of the latter came them from Mesopotamia; those of the former, according, to their own traditions from Egypt. The Egyptians, however, had not generally reached beyond an empirical use of certain special relations of such figures as triangles and rectangles, pyramids and spheres[1] Thales or his Greek contemporaries succeeded in generalizing such special cases and, moreover made other discoveries familiar in what is now regarded as very elementary mathematics.

The 6th century B.C. Greek-speaking people had founded colonies in the west, namely in southern Italy and in Sicily. The intellectual activity in these settlements was significant for science, especially that of the "Phythagoreans." Born about 582 B.C., their founder Phythagoras (*q.v)* established a brotherhood or sect the influence of which has been very persistent. The Pythagoreans developed what seems now a peculiar teaching on numbers. These were held to have a real and separate existence. The use by the Greeks, as by the Phoenicians and Hebrews, of letters to express numbers encouraged this conception, which has often given mystical and magical application. But the Pythagoreans gave to the word *mathematics*-which first meant simply "learning" – its special relationship to number. Aristotle in his *Metaphysics* tells that they saw in numbers many resemblances to "the things that exist and are coming into being," almost all things being numerically expressible – in particular the attributes and ratios of the musical scale: This conception seems very fanciful now, but fancies of this type have repeatedly been of value to science. The human mind, it seems, is somehow

attuned to the processes of nature or, as some would say, has attuned itself, perhaps under the guidance of Pythagoreans and others. Certainly we live in a world the major phenomena of which are susceptible of mathematical expression. And it has many times happened that the theoretical developments of mathematicians have been found to bear a relation to observations.

Why and how this should be so mysteries. Yet consciousness that there is a correspondence between the working of our minds and the working of nature is a conclusion most important for the development of science. We owe this idea to the Pythagoreans. Their conception of the "harmony of the spheres" – on which Aristotle touches – proceeded from the observation that the pitch of musical notes depends on a simple numerical ratio in the length of the chords struck. It was not unnatural that, having made this great discovery, they should have suggested that this ration might correspond to the distances of the heavenly bodies from their common centre.

A Pythagorean of the 5th century B.C. launched another doctrine, which has had repercussions to our time and is still embedded in our language. He supposed that love and strife held away over all things, even material things. In matter itself, in which he distinguished the four elements, water was opposed to fire but allied to earth, while air was opposed to earth but allied to fire. By arranging these elements in pairs, four primary qualities were evolved; namely heat (air and fire), dryness (fire and earth), cold (earth and water) and moisture (water and air). The conception was later extended to the living body. This was held to be composed of four "humours", blood, phieg, yellow bile (or choer) and black bile (or melancholy), characteristic of the four "temperaments", of which we still speak (sanguine, phlegmatic, choleric melancholic). This was the first attempt to trace the rules of the external world to the working of man's body.

By the middle of the 5th century both eastern and western schools of Greek thought were becoming overshadowed by the Athenian. In Athns the systematic accumulation of knowledge was rendering old-fashioned those who "took all knowledge to be their province". Something like specialization thus began to appear and has characterized science ever since. It resulted immediately in the recognition of mathematics and of medicines as independent disciplines both bore the name Hippocrates and came form Islands of the eastern Aegean.

Hipppocrates of Chips, the mathematician (*f.c. 450 B.C.)*, was the first to compose a work on the elements of geometry. One of his discoveries was that the lune bounded by an arc of 90^0 and by a semicircle on its chord has an area equal to that of a triangle having the chord for base and the center of the arc for apex. Thus the area of the lune, a figure bounded by curves, can be equaled with a figure bounded by straight lines. Of course, this is not equivalent to squaring the circle nor even an approach thereto, but it is the first known introduction of the circle into geometric construction and thus had a great future.

The name of Hippocrates of Cos (*q.v*) the physician (*a.c 400 B.C*), has been attached on many works. Probably none is his, but the earliest of them are significant for the expression, with religious intensity, of a faith in the constant sequence of cause and effect. Thus in the work called *The Divine Disease* (*sc.*, epilepsy), we find. As for this disease called divine, surely it has its nature and causes, as have other diseases. It arises –like them-from things that enter and quit the body, such as cold, the sun and the winds, things ever changing and never at rest. Such things are divine or not- as **you will**, for the distinction matters not-and there is no need to make such division anywhere in nature, for all are alike divine or all are alike human. All have their antecedent causes, which can be found by those who seek them. (Slightly paraphrased).

The intellectual history of the 4th century B.C is filled by the gigantic figures of Plato and Aristotle. They are considered here only in their relation to science.

Plator regards mathematics as yielding that type of certitude to with other studies should conform. Mathematics fro him relies for its material upon something of the nature of his "ideas" (*see FORM)*. Many of his thoughts assume a mathematical guise, and he tended to respect a science in the degree to which it had progressed to a mathematical stage. Following his Pythagorean teachers, he regarded the motions of the heavenly bodies as being examples of perfect geometric forms. For astronomy-especially on this theoretic side – Plato had a high regard, and by his followers mathematics became identified with astronomy. We think of astronomy as a field for the application of mathematics; to the Platonists it was rather field for its exemplification.

Plato regarded the mathematical form of the universe a evidence of the rational mind of its creator. "God", he is said to have said, "ever goemetrizes". To deny the existence of mind as a separate entity was he held to assume the universe to be the result of accident. To suggest such a universe was a denial of the validity of philosophy. It is not inconsistent with this view that Plato respected Hippocrates the physician, who "was the first who separated science from philosophy". But the trend of Platonism in general and of ancient Platonism in particular was usually away from observational activity. There have been many evident exceptions, and Platonism has often been helpful to science both in stressing its quantitative aspect and in opposing an entrenched static Aristotelianism. It was from Pythagorean teachers that Plato derived the so-called "Platonic bodies", the five regular polyhedra which have equal sides and equal angels (see SOLIDS, GEOMETRIC). Many countries later mathematicians proved that the possible number of regular bodies is only five. Moreover, it was from a consideration of these bodies that Kepler developed the first unitary scheme of the universe (A.D. 1596).

Aristotle devoted his incomparable genius to systematizing and organizing the whole area of knowledge. His earliest an, from the modern scientific point of view, his best efforts were on biological topics. The whole of his science and indeed the whole cast of his mind was deeply influence by his first-hand observations on living things. In his *parts of Animals,* he sets forth his view of the relation between biology and "physics", the latter being for him a general description of the universe. He says:

Of the things constricted by nature some are ungenerated, imperishable, eternal; others subject to generation and decay. The former are excellent beyond compare and divine, but less accessible to knowledge. The evidence that might throw light on them and on the problems which we long to solve respecting them sis furnished but scantily by our senses. On the other hand, we know much of the perishable plants and animals among which we dwell. We may collect information concerning all their various kinds, if we but take the pains. (Somewhat paraphrased).

Living things are for Aristotle the type of existence, and existence as a whole present; according to him, evidence of design. He attempted to analyze the nature of generation, of heredity and of sex. He treated many other topics now discussed by naturalists. There is a profundity in his biological thought, which gives it a permanent value. He was a first-class observing naturalist in the modern sense.

Aristotle, like Plato, had Pythagorean tendencies, which he exhibits in his physical scheme. He emphasized the "perfection" of the circle and the sphere, on which therefore the world is modeled for him the heavens are a series of concentric spheres arranged round our earth as a central body. These sphere he described, however, as crystalline, mechanizing them from the schemes of certain of his older Athenian mathematical contemporaries.

The mechanical scheme of the universe set out by Aristotle and his successors suggests a series of geared wheels and may have come to the minds of the Greeks through some such complex apparatus. This view of Aristotle was the basis of the theory of the universe that held men's minds for 2,000 years. We may thus summarize it.

1. Matter is continuous.
2. All mundance thins are made up of four "elements", which in their turn manifest the four "qualities".
3. Stars and planets move with uniform circular velocity, embedded in crystalline spheres, centred round the earth. Each sphere is subject to the influence of those beyond.
4. Circular, changeless, eternal movement is perfect order. It contrasts with the rectilinear movement, which prevails on our changing and imperfect earth.
5. The universe is limited in space and with an outmost sphere. It is unlimited in time, being subject as a whole neither to creation nor to destruction.