The Physical World

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THE PHYSICAL WORLD

BY

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WITH FOUR HUNDRED TWENTY SIX
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PREFACE

For several years a need of a text book has been recognized in the field of so called "cultural" physics; a type of physics suitably adapted for those who are not going into science, but who desire to know something about physics and still not be frightened away by mathematical formulae and endless problems. During these same years there has been a growing demand also for a textbook in physical science; that is, one combining astronomy, physics, and chemistry mainly.

This textbook is an outgrowth of the attempt to meet these needs. The various units have been used in mimeographed form for several years. The book represents an attempt to guide the non-technical student into the "hows" and "wherefores" of physical science by a descriptive method in general; that is, to analyze physical science by means of accurate descriptions rather than to have the student briefly sketch through the "meat" of physics, (the accurate descriptions or the laws) and then to spend most of his time trying to find what formula will work this or that particular problem at the end of a chapter. It is granted that a certain minimum number of problems is necessary in order to show the student how the physical quantities are exactly related, because physics is an exact science. But it is the feeling of the author that well chosen and stimulating questions will succeed quite well in the analysis of physical science. After all, the students of journalism, English, the classics, are not going to spend their time making numerical solutions but, instead, they want to know something about the physical world in which they live.

For purposes of definiteness and somewhat for the feeling of completeness, the subject matter of the book has been divided into eleven units. A unit is not always strictly complete in itself, as some units depend, in a general way, on the subject matter of a preceding one. For example, in the discussion of heat, the assumption is made that the preceding unit treating of energy has been taken up.

The order of the units follows, in a general way, the usual order of the subdivisions of physics, namely; mechanics, molecular motion, heat, sound, electricity, light and modern physics, with the additional subjects on the meaning of science, astronomy, and chemistry, injected at the most logical places. There is, of course, always a question as to the logical order to be followed. Each unit, however, is complete enough to allow of any order of selection that may be adopted.

The first unit attempts to give the student a brief resumé of the history and meaning of physical science as well as to consider some of the topics and questions, which one hears in everyday discussion regarding the method and results of physical science. It also serves as an introduction to the subsequent units. The second unit, The External World,[1] serves to orient the student with the workings, size, shape, and complexity of the universe. Various physical explanations are, of course, always necessary in a discussion, and it has been the attempt of the author to bring such explanations in as briefly, and yet as completely as possible, in order not to digress too much from the main theme. Unit three, in a general way, covers those topics of mechanics which are usually covered in classical physics.

In unit four, an attempt has been made to give the student some background of the meaning of the forces that produce motion; also, an especial effort has been made to give the concept of energy (usually an elusive one for the student) a definite meaning.

Unit five represents a collection of the various phenomena which are associated with the individual molecules of a substance; namely, molecular motion, cohesive and adhesive properties of molecules. There is, also, a general discussion of various types of states of matter.

The unit concerning heat is probably the most mathematical of any. It has been designed in that manner because many of the subjects of heat lend themselves only to a numerical analysis, and further, because heat, to the student, is not so elusive as some other physical quantities, therefore, he is not so much at sea in the analysis of heat problems.

[1] Aside from the standpoint of interest and historical sequence, this unit could well be postponed until the last since some of its phraseology and methods have been discussed in intervening units.

Units seven and eight, which describe sound, magnetic and electric phenomena, are treated in conventional order. In unit nine, light is discussed first in a general way, then its dual behavior presented in such a way as to tie together certain modern physical phenomena with the analysis of light as a wave. In the treatment of geometrical optics, the author feels that the real meaning comes out of a graphical analysis and this method has been used exclusively.

Unit ten attempts to acquaint the student with the fundamental principles and ideas of chemistry through a discussion of oxidation and reduction, and the structure of the atom and formation of molecules. Unit eleven takes up the discussion of x-rays, their production, properties and use, as well as the properties of radioactive substances and their interpretation in terms of the structure of the atom.

Finally, the author acknowledges the valuable assistance of Dr. J. B. Heidler in smoothing out many rough places of English; of Dr. W. S. Gammertsfelder who gave valuable criticism and suggestions concerning the philosophy of science; of Dr. H. P. Knauss who read the manuscript and who offered valuable suggestions; and of Professor A. A. Atkinson without whose constant encouragement and help the book would not have been possible. Credit must also be given to the intangible assistance of many textbooks of physics, chemistry and astronomy whose ideas, as Professor Saunders of Harvard University says, sometimes return to the mind of an author as original.

CONTENTS

THE PHYSICAL WORLD

UNIT 1

THE ORIGIN AND MEANING OF SCIENCE

HUMANISTIC
"The accent or turn of expression will at once mark a scholar."
RUSKIN

REALISTIC
"The first and last thing required of genius is the love of truth."
GOETHE

REALISM VS. HUMANISM

The successes of physical scientists in eludicating natural phenomena started a controversy between the advocates of **realism** and **humanism.** By realism (in a general way) we mean that knowledge which may be verified by observation; and by humanism, that in which the reactions and relations come mainly from the emotions and feelings, in much the same way as masterpieces of the artist come from inspiration.

In academic circles, therefore, we have heard a vast amount of evidence pro and con in the debate, "Realism vs. Humanism—Which of the two is the best to study for developing capable thinking people into ideal citizens?" This controversy will probably continue for a long time, or at least until some scale of values for realistic and humanistic study can be established. The humanists of the last century denied to the most eminent men of science the term, **scholar,** but at the present time the sharp boundary between realism and humanism in academic studies is rapidly disappearing.

It has been pointed out by the humanists that the most eminent statesmen of the past century were classical or humanistic scholars; and yet, in these same statesmen we find just the characteristics which the advocates of realism declare could result only from realistic studies; namely, the ability to choose between a situation that is real and lasting and one of only passing importance, and the ability to eliminate themselves and their emotions in the analysis of problems. The realist would reply that the classics has always had the advantage, therefore, the more capable people have been advised to study them. He would also add that the outstanding men of science may have been equally outstanding as statesmen had they directed their attentions and efforts in that direction.

The study of realism has two quite forceful arguments in its favor:

1. The development of open-mindedness and method of critical examination rather than the attitude of dogmatism and accepting-for-grantedness.

2. A rapidly developing interest due to the desire to know something of the natural and physical world about us. This interest has developed very remarkably during the past century and has become intimately related to our everyday life.

In our discussion, so far, the difference between realism and humanism has been exaggerated. This was really the picture a century ago. As early as the Renaissance a reformed humanism, the "New Humanism," was under way, and now the humanistic studies, in the main, have adopted the methods and rules of science. The method of science, first applied to physical and mathematical thinking and practically applied to industry and the arts, is now permeating such other fields of thought as philosophy, history, sociology and literature. A striking example of this situation is the study of philology. Its method in the field of literature is identical with the theory of evolution in biology.

Hence today, the realists and humanists almost universally agree that both have advantages, and in order to develop a well-rounded education, a study of the methods and meaning of both is essential.

The Development of the Scientific Method. The Growth of Realism

According to historical records, there have been two periods (600 B. C. to 100 B. C.) and (1600 A. D. to the present) in which science (realism) developed remarkably. Between these periods we find the Dark Ages which were characterized by stagnancy, not only in science, but in all other fields of learning and human progress. The true scientific method, as we recognize it, was not fully developed until the beginning of the seventeenth century when Galileo applied the experimental method.

Since the beginning of realistic thinking we find, intermittently, sparks of the true scientific method such as the very thorough work of **Archimedes** (B. C. 287–212). Similarly, even since the development of the true scientific method by **Galileo** (1564–1642), instances may be observed when scientific thinking suffered a relapse; that is, a tendency developed to rest on the oars of accomplishment and to project too much **deductive** thinking and inference into the process, rather than to gather **new experimental** evidence and material which are indispensable in the march of scientific progress.

Greek Civilization and Science

The first era of scientific progress occurred in the Greek civilization (600 B. C. to 100 B. C.). A series of circumstances seemed to combine, accidentally, to start this very fruitful period. In the first place the Greeks at this time were high in power and relatively wealthy. Since a large slave population existed, the free Greek citizens busied themselves at trade, law and national defense, rather than with menial labors. The fact that the Greeks possessed much power and had slaves was not in itself peculiar, but in previous civilizations nothing but debauchery and corruption were bred of such systems.

The colonization of the surrounding countries, which had been carried out by the Greeks, had stimulated trade and increased wealth and leisure. Accordingly, a certain amount of security was felt in all classes. The greater percentage of the Greeks, however, still spent their time tilling the soil and performing those duties which produced the necessities and conveniences of their everyday life. Indeed, the agricultural and industrial life of the people probably was not greatly different from that of today.[1]

A rather small percentage of the Greek population, however, freed from economic stress, engaged in the intellectual life of the sophists or teachers. The geographic location of Greece, which enabled it to maintain contact with many earlier civilizations, also served as a factor in the general intellectual awakening. In addition, although the average person was quite serious about his

[1] **Encyclopedia Brittanica** Vol. 10, p. 783, 14th edition.

religion, the flexibility of the religious forms allowed a reasonable freedom of thought.[1]

With this very fertile set of conditions existing, only a spark was needed to start the fire. This spark was supplied by **Thales** of Miletus about 600 B. C. The conclusions of Thales in developing certain propositions in geometry were deduced from special cases rather than from general axioms and were, therefore, not accepted as fundamental work in geometry. Irrespective of the conclusions to be drawn concerning his work, it must be conceded that he started an era of thinking which was to go far and lead to very important consequences.

After Thales we find **Pythagoras** (about 500 B. C.), a pure mathematician. Pythagoras held to a world-perfect point of view; that is, that the universe could be expressed accurately in the symmetry of numbers and geometry. The general trend of development during the period from Thales to Aristotle (600 B. C. to 350 B. C.) centered about geometrical and astronomical knowledge. Pythagoras was largely responsible in sponsoring this development on account of his great enthusiasm for the "beauty of numbers."

During this period probably the greatest exponent of idealism, **Plato** (427–347 B. C.), came upon the scene. The "beauty of numbers" theme of Pythagoras raced rampant through the work of Plato. Plato carried his idealistic methods to the point where the behavior of nature was deduced from human needs. As a result of this idealistic theme, it was postulated that the earth was the center of the universe and that the planets moved in systems of cycles about it. This postulate was developed, in full, later by Ptolemy. Plato's entire system of ideas were developed **a priori** and thereby led to inferences far from true. The fluency and the scope of his teachings, which extended through mathematics, astronomy, physics and even human physiology, established a precedent and habit of thought which existed for nearly a thousand years. Plato was the first to realize that some fundamental pattern or scheme of things existed which was more profound than that the senses detected. He had no faith in the impressions obtained by means of the senses and constantly tried to start apart from the senses by metaphysical reasoning and thus arrive at the true pattern of things. In this respect Plato had a basic knowledge of the **nature** of science.

[1] **A History of Science,** Dampier-Whetham, p. 15.

The teachings of Plato were very influential in moulding the way of thinking of his students, one of whom, **Aristotle** (384–322 B. C.), was to develop the foundations of the scientific method.

The entire Greek culture seemed to be crystallized by Aristotle. In him we discover a man who influenced general culture probably more than any other one person in history. His influence in thinking in the fields of politics, botany, geology, zoology was felt down through the years to the sixteenth and seventeenth centuries. Evidence of this is found in the well-known question prevalent in scholastic circles through those centuries, "What does Aristotle say about it?"

Inasmuch as we are concerned directly with the **advance of science** we shall consider only the influence and method of Aristotle in that direction. First, let us look at some of the characteristics of the Greek so-called scientific method which Aristotle was largely responsible for developing. Aristotle was the first to organize and maintain a laboratory. By means of a staff of hundreds of people, he was able to bring zoological specimens and information from various parts of the world to his famous zoological gardens. He was also the first to make a systematic classification of the observations and information which he was able to obtain from various sources.

Theoretically, Aristotle stated the fundamental steps upon which the scientific method rests. He formulated the method, as he says in one of his works, "Let us understand the facts and then we may seek for the cause." This is really an elaborate process of induction and maybe analyzed into the following steps:

1. A collection of facts or evidence which have a bearing on the problem at hand.

2. A proper classification of the evidence, carefully taking into account the conditions accompanying each (sifting process).

3. The development of a theory (from all the evidence). The theory serves as a skeleton or thread to hold together all of the evidence.

4. The carry-out of deductions from the theory which would lead to the discovery of new evidence and facts which, in turn, would further substantiate the theory or introduce necessary corrections, or possible abandonment of the theory.

In actual practice Aristotle was a literal example of the phrase, "Do as I say and not as I do." The reason Aristotle did not practice the method he had originally postulated, probably may be traced back to his enthusiasm for the method of deduction since he is recognized as the father of the deductive method of reasoning. Aristotle neglected to get more than a few facts and then failed to criticize them. He also neglected to introduce any **new** ideas into his theories, and never changed any theory, always tenaciously holding to his first one. As a result, he always attempted to lay the fault of any disagreement between observation and theory on the observation rather than on any discrepancy in the theory.

Many times Aristotle allowed single observations to lead to inferences. This procedure was probably due to his characteristic impatience and haste in drawing conclusions. This characteristic led to a common practice in the Aristotelian school of arriving at conclusions hastily drawn from metaphysical reasoning rather than from careful consideration of objective fact. Typical of Aristotle's reasoning is his argument that motion in a vacuum is impossible: "In a void (vacuum) there could be no difference of up and down, for as in nothing there are no differences so there are none in a privation or negation. But a void is merely a negation of matter, therefore, in a void, bodies could not move up or down, which it is their nature to do." In a later discussion this type of argument will be compared with the genuine scientific attitude of Galileo.

Not long after Aristotle, a prominent man of science, **Archimedes,** appears in history. He is said to have lived 1700 years before his time in the type of reasoning and method of attack he applied in resolving natural phenomena. It seems very unfortunate that Archimedes should have lived at this particular time when the current culture was not ready to accept or follow the methods he practiced, and when the lack of experimental evidence available presented so great a handicap. Archimedes is best known for his work in flotation, the inclined plane, the lever and the pulley.

Science from the Greeks to the Renaissance

After the decline of Grecian civilization (200 B. C.) we find that nothing replaced or succeeded it. It was not even to be continued by the Romans with any great enthusiasm. Their point of view was that of big business, and as a result they were too much interested in conquest to do any more than apply in a practical way those discoveries which had been made by the Greeks. They did protect the culture of the Greeks to the extent of building great libraries, but were almost inactive in the production or promotion of any new scientific thought.

The Roman empire by the year 500 A. D. had come to a state of political turmoil; torn apart by the existing conditions of religious differences and economic chaos. It was an easy task for the barbarian hordes to overthrow the Roman government and to destroy and plunder the rich civilization which had been set up.

At this point science and culture must acknowledge an indebtedness to the Arabians, who seized the opportunity presented by the crumbling Roman civilization to build an empire across the Mediterranean. This empire existed from 600 to 1200 A. D., and then, none too stable, it quickly disintegrated under the pressure of the Christian crusades and the Mongolian invasions. During this interval the Arabians maintained the Greek learning and made a few important contributions such as the application of Arabic numbers to the various fields which had used Roman numerals before. They also started something in the form of chemistry on account of their interest in the mysterious reactions occurring between various substances. It should be pointed out, however, that their interest along this line was not stimulated so much by a true scientific attitude as by their interest in magical and phenomenal results.

It had become a common custom among the Arabian caliphs to establish centers of learning at certain places in their empire. The local Arabian governors in Spain made the same practice of patronizing learning and education and, as a result, an excellent university at Cordova, Spain, was established. This center of learning was destined to play an important part in the spread of Greek learning into continental Europe, where it was to grow with leaps and bounds during and following the period of the Renaissance.

Western Europe, by the tenth century, had grown into a system of feudal states, each of which had developed its own government and system of commerce. As a result of this development, a class of men, essentially merchants and traders, somewhat free of menial labor, had ample time to do some thinking for themselves. They were aided in their interest in various problems by their trade contacts with the Arabian civilization. These contacts led to the adoption of the Arabic number system in preference to the more cumbersome Roman numerals, and many other short cuts which had been devised by tde Arabians during their patronage of the Greek culture.

The age of scholasticism, which in its broadest sense extended from 800 to 1400 A. D., began during this same period. Its growth was stimulated by a mandate made by Charlemagne in 787 which established schools in connection with the abbies and monasteries. The curriculum usually consisted of two groups of studies. One was composed of geometry, astronomy, music and arithmetic and the other was composed of grammar, logic and rhetoric. Later, about 1120, through an active translation of the Greek classics from Arabic into Latin, the authentic works of Plato, Aristotle and Ptolemy were made available for the schools. The completion of these translations, which required approximately one hundred fifty years, introduced the most fruitful period of scholasticism.

The two outstanding personalities of the scholastic period were Saint Thomas Aquinas (1225–1274) and Roger Bacon (1210–1292). Saint Thomas Aquinas, under the influence of the newly translated works of the Greeks, welded together a large part of natural science with theology. Much of Aquinas reasoning was based on Aristotle's science and logic. Roger Bacon, a friar in the Franciscan order, after a study of the works of recognized historic and contemporary thinkers, became unsatisfied with the acceptance of inferences and statements which were based on authority. He recognized the importance of the experimental method and urged the people to verify their statements by observation. Bacon was also quick to recognize the importance of mathematics as a basis for the sciences. His vivid imagination enabled him to make descriptions of many practical devices, some of which were in the form of predictions like those in which he described mechanically driven ships, carriages, and flying machines. Pope Clement became interested in Bacon's work and commanded him to put his ideas into the form of a book. The three volumes which resulted from this request give us an accurate description of Bacon's contributions and attitude toward science.

The enthusiasm and mental activity which had been aroused by the introduction and interpretation of the Greek classics began to wane in the 15th century. A shift in the attitudes of the people seemed to take place. The teleological point of view, in which all types of experiences are interpreted in terms of desire and purpose, no longer gave a satisfactory answer. A certain amount of objective thinking was begun especially by those who were in a position to have the time and resources for making contact with the existing culture. The Renaissance, which followed this age of scholasticism, can be definitely traced to this development of a freedom of thought by a middle class, similar to that of the Greeks. This entire movement was also aided by the invention of the art of printing which, by the year 1500, had produced eight million volumes. The downfall of Constantinople (1453), accompanied by an exodus of Greek scholars into European countries, also served to promote this general intellectual awakening.

Rebirth of Science with the Physical Philosophy of Galileo

Although Aristotle had "preached" the true scientific method, in actual practice, he had not lived up to his own doctrine. For this reason he can not be considered as a true scientist. The critical mind of Galileo was probably awakened by the general intellectual revolution which was started in science by the work of Copernicus, Tycho Brahe, and Kepler, mainly in the field of astronomy. Galileo studied nature for its own sake; hence he felt the necessity of taking no one's word as authority when the point in question could be checked experimentally. Galileo's aptitude in devising apparatus served as an excellent auxiliary in his quest for data. Typical of his ability in this direction is the fact that he made a telescope with merely the information that one existed.

Armed with this technical skill, Galileo proceeded to run through the stop signals of his day and to blast many of the false inferences which had been handed down since the time of Aristotle. The scientific philosophy of Galileo differed from that of Aristotle in the very fundamental respect, that instead of attempting to make all observed phenomena fit into certain preconceived laws as Aristotle had done, he set about to discover the natural laws themselves. In short, the "why" of Aristotle was converted into a "how" by Galileo. Instead of arguing about the motion of the distant stars and attempting to set up laws concerning it, he set about to observe the motions of objects close at hand and to discover the relations between them. As soon as the relation between the distance covered and the time of motion was determined for objects close at hand, the motion of distant objects was classified and simplified. As an example, the **inverse square force** law, which is so valuable in astronomical problems, could not have been developed by Newton had not Galileo laid the foundation in his dissection of the problem, "What is the relation existing between the force or effort and the resulting motion?" In addition to laying the foundation of mechanics (the study of bodies, fixed and free, under the action of impressed forces), Galileo also made valuable contributions to other fields of physical science especially in optics. These will be pointed out in the particular study of the various fields.

Sir Francis Bacon (1561–1626) had severely criticized the usual dogma surrounding the so-called scientific method at this same time and insisted that **all** of the evidence must be taken into account before the formulation of a theory. This attitude which, of course, is genuinely scientific is, however, not practical. Galileo recognized the **more important** facts and proceeded to arrange them into a theory, leaving the **details** to be worked out later and incorporated in a more general theory. This attitude is recognized also as that which distinguishes the mathematician from the physicist. The mathematician insists on rigor and accuracy. The physicist, on the other hand, employs rigor and accuracy when possible, but when new paths are to be blazed he is satisfied with a rough check of the theory. Afterwards, he revises his theory to better fit the observations. Sir Francis Bacon may be called a scientific "idealist" while Galileo is best termed a "practical" scientist.

In the year of Galileo's death there was born an Englishman, **Sir Isaac Newton** (1642–1727), who was to wield a great influence on scientific thinking, which has continued to the present time. This influence grew out of an attitude which, although initiated by Galileo, was mainly developed by Newton; it is recognized as the mechanistic attitude. Perhaps the best known work of Newton is his "laws of motion" which, although they have been proved by Einstein to be only special cases, are valid for everyday problems and are used today almost in their original form.

Newton, just as Galileo, was an experimentalist with the additional trait of being able to devise mathematics to fit the particular physical problem at hand. He had an unequalled ability of accurately describing the phenomena which he observed. In fact, as we shall see later, the so-called **laws** of motion as given by Newton are nothing more than **accurate descriptions** of the relation between forces and the motion resulting from the forces. Carefully analyze his first law of motion, "All objects at rest continue to remain at rest or if in motion continue to remain in motion unless acted upon by some force." This law is nothing but an accurate description of the phenomenon. Inasmuch as the concept of force and the even greater outgrowing concept of energy permeates the whole of physical science, scarcely enough credit can be given Newton for the part he played in beginning the superstructure of physical science on so stable a foundation.

The experimental method so greatly developed by Galileo and Newton became highly successful in the production of significant discoveries, as indicated by the accompanying graph, Fig. 1(1); just

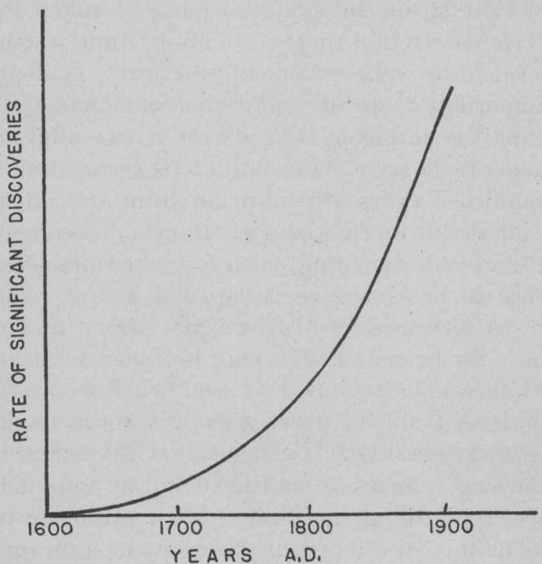

Fig. 1(1).—How the rate of significant discoveries has increased since the rebirth of the scientific method by Galileo.

how long the general trend of the relation indicated may be maintained, no one is in a position to predict.

An interesting situation existed near the end of the nineteenth century when it was rather common parlance to describe physical science as a completed science; that is, that nothing new was left to be discovered and it only remained to carry out the measurements to several more significant decimal places. Of course, nothing could have been farther from the truth as recent history has shown. The discovery of photo-electricity, x-rays, radio, and a study of electrical discharges in the decade previous to the beginning of the twentieth century heralded an unprecedented era in physical science. The new ways of thinking introduced by Plank, Einstein, Bohr,