AN OVERVIEW OF THE DEVELOPMENT OF PHYSICS

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Summary

Physics is, to a large extent, an empirical science; collecting knowledge obtained through observations and experiments. But it also aims to search for underlying order beneath the results of observations and experiments. According to Newton, physics is a mathematical description of natural phenomena that describes the underlying relationships from which behavior of observed matter can be derived. It is essential to identify a proper set of dynamical variables that are most relevant to the physical phenomena under investigation and disregard all others that are irrelevant. Newton identified, correctly, mass, acceleration, and force as the relevant quantities to formulating the laws of motion of matter.

Some of the important concepts in physics that contributed most to the development of modern physics are reviewed here, namely:

- the deterministic nature of laws of physics
- the symmetry principle
- the concept of atoms
- the concept of quanta
- the concept of order and disorder.

Newton's equation of motion is deterministic in the sense that once the initial conditions for motion of a system are given, time evolution of the system is uniquely determined. This deterministic nature turned out to be violated by the uncertainty principle of

quantum mechanics and the possible occurrence of chaotic behaviors in the system, even in the realm of classical physics.

Newton's laws of motion were not formulated in any special co-ordinate system, thus leaving all points in space and time equivalent. The space/time symmetry of laws of motion has been tested and it has become more natural to formulate laws of physics by means of the laws of symmetry. Einstein's theory of relativity was the first such attempt to derive a law of nature by imposing the most general symmetry principle with great success.

The concept of atoms played a leading role in developing modern physics. Today, atoms are no longer regarded as indivisible and structureless. An atom consists of electrons and a nucleus, a nucleus consists of protons and neutrons, and even these consist of quarks. No isolated quark exists in nature, yet quarks are a fundamental constituent of matter. Along with our growing knowledge of the fundamental particles, our understanding of the fundamental forces has evolved, and they are classified into four kinds of forces, some of which are unified into a still more fundamental force.

Quanta are the phenomena of physics that are quite outside of our daily experiences. Quantum physics is mainly concerned with microscopic phenomena, but all of physics is quantum physics. The system described by quantum physics has a distinguishing feature: values of physical quantities, such as energy, are quantized and cannot be varied continuously, but are discrete. For example, a beam of light is a train of quanta called photons. Any force has its associated field whose oscillating wave is a train of quanta of the field.

The concept of order and disorder is a key to untangle complex phenomena and to bridge the gap between the macroscopic and microscopic worlds. The degree of order in the arrangement of atoms or molecules in a macroscopic system will change from one to another as a variable, such as the temperature of the system, or the external flux in energy or matter coming into the system is varied beyond a certain critical value. The symmetry property of the system will change in such a transition and a more ordered state has less symmetry in general.

1. Introduction

The natural sciences, as distinct from the social sciences, have as their subjects nature, which is the physical properties of the material universe as revealed through human experiences. Physics is the natural science mainly concerned with matter and energy, and deals with composition, structure, interaction, and every other aspects of matter and energy.

There is no clear beginning to science or to physics. It was born from the belly of myth and magic, and the scientific world view gradually emerged from mysticism. Physics is to large extent an empirical science collecting knowledge obtained through observations and experiments. Yet a catalog of this knowledge usually adds little to our comprehension of nature. Physics is not a mere listing of human experiences, and not a directory of observations and measurements. Rather physics searches for the underlying order beneath the results of observations and experiments.

Within the body of observations, regular patterns or orders are sought after that reveal some intimate relationships among the data. An empirical law is a description of such an observed pattern or order of occurrences. Generally these empirical laws apply to a limited range of physical phenomena, so that we have laws dealing with different aspects of the material universe.

The next step is to ask what gives rise to empirical laws or to an understanding of the basis of these laws. We set up a hypothesis about the underlying mechanism and deduce some of the physical consequences of the hypothesis. If the predictions of the hypothesis fit well the diversity of physical phenomena, it means that we have constructed a theory. Experimentation is the controlled observation of a selected aspect of the physical environment. Any phenomenon is not simple and repeated observations of the same phenomenon do not usually give the same result, because of the existence of unexpected disturbances or occurrence of unavoidable errors associated with observations. Experiments are usually designed to minimize these disturbances and errors so that one can get useful relationships among the relevant physical quantities to be measured.

Physics, or science in general, can be characterized by the reproducibility of experimental results, that is, identical systems behave identically, which makes re-checking possible. Scientific theory must be formulated so as to lend itself to re-checking or even to be disproved. In many cases, only one prediction needs be proved incorrect to disprove a theory.

In physics, law is usually tentative and a fact is usually the result of human interpretation. Experimental data are the record of human perceptions and the laws are expressions of how we understand the relevant physical phenomena. Thus the human element cannot be overlooked in physics. Experimental data are not quite the same for the occurrence of the same physical phenomenon, and we make facts out of data by interpreting what we observed within the context of what we believe, often within the framework of an accepted theory. Although a way to perceive and interpret physical phenomena depends somewhat upon individuals, it is remarkable that everybody can share a common understanding of physical phenomena and laws through learning and experience. Any physical quantity must be quantified through its measurements by appropriate objective methods. And, in most cases, a physical law is presented as a mathematical relation between the measured values of physical quantities, thus eliminating as much as possible intervention of an individual mind.

The mind–body problem has puzzled philosophers for many centuries and even puzzles us now. For example, early natural philosophers, such as Aristotle, speculated about the cause of animal behavior, and much later Descartes proposed a mechanical model of human brain activity based on hydraulically-actuated statues. We know now that construction of the perceived physical world and interpretation of physical phenomena occurring there are mainly due to functions of the human brain, which consists of a very large number of nerve cells.

All scientists hope to explain natural phenomena and some of them even hope to understand the mental phenomena underlying the logical thinking that leads to the formulation of physical laws. In this context the term “explanation” has two basic meanings: generalization and reduction. Generalization refers to the classification of phenomena according to their essential features so that general laws can be formulated. Reduction refers to the description of phenomena in terms of more basic physical processes. Further study of functions of the human brain might give us some hope that someday even the complex body–mind problem will be substantially clarified.

The development of physics is probably not an easy subject to appreciate and it may appear as something hidden in a black box for most people. However, people can use without much difficulty various tools and appliances that are products of applied physics or science, and we can live with them in spite of knowing very little about the underlying physics. This separation between making use of the outcomes of physics and knowing the fundamentals of physics is common to all species of animal.

Bats are able to fly in the dark and locate the positions of obstacles or prey. Most species of bats send out ultrasonic sound waves as signals, and receive and analyze the reflected waves in order to locate objects. Some bats fly towards their prey (usually moths), emitting sounds of rapidly changing frequency, so that they can accurately locate the position of the prey. This is equivalent to the frequency modulation method used in our modern telecommunication. Some bats even measure the difference of outgoing and reflected sound waves in frequency and estimate relative speed between the bat and the prey. This is based on the so called Doppler effect in physics. Some moths can even catch supersonic sounds sent by bats and, in turn, send sound signals to disturb the sounds bats, so that they can escape from their predators. There exist many examples in which animals make use of proper physical processes to catch prey or to escape from predators. Through the long history of the evolution of life, animals must have acquired various ways to adjust themselves to natural selection by employing the appropriate physical or chemical phenomena available to them.

It can be said that human beings know physics at birth. Newly-born babies will direct their eyes towards a moving object or their face towards a source of sound. Babies try hard to sense and feel what is going on in their environment and learn how to appreciate diverse physical phenomena occurring there, just as children learn their native language entirely through listening to other’s conversation without much help from their parents.
When we hold out a mass of clay towards a baby of about one year old, it will stretch its arm and hold the mass. Then the arm sharply falls down, probably because the mass was heavier than the baby expected. After repeating the same exercise, it learns to adjust tension in the muscles of the arm so that it can hold the clay without the arm falling down. After the baby has learned to properly receive the ball of clay, we can squeeze the clay into a flatter shape before it so that the clay appears larger. If we hold out the reshaped mass of clay, then the bay’s arm sharply rises at the instant when it holds it. The baby seems to know that a larger object is heavier and tries to increase the tension in the muscles of its arm when it holds a heavier-looking object.

This kind of misjudgment about the weight of an object will have gone when the baby is about eighteen months old. A baby of that age can catch and hold a mass of clay without its arm either going up or down, even if the clay is deformed into a flatter shape before it. The baby now seems to understand that the weight of an object does not change by deformation, and it has grown up to the point that it can apply this knowledge to the weight of the clay deformed before its eyes. This is a kind of physicist's impression on the results of observation upon the adaptive behavior of babies.

We might ask how many physical and chemical processes have been used by human beings through the evolution of life. The average man takes about 2,000 kilo calories of food every day and performs a diversity of work by using that amount of energy. This energy is about equal to the electric power consumed by a 100 watt light bulb turned on for one day. Since the energy conservation law is strictly valid even for biological processes, we have to live with that small amount of energy conversion every day. Thus, it is not an exaggeration to say that human beings use all kinds of physical and chemical processes of good energy conversion efficiency, at normal body temperature, to live with that much energy.

Summarizing what has been said up to now, the study of physics or science is nothing but the discovery and formulation, in general terms, of the physical and chemical processes already occurring in the human body as seen through our conscious minds. Therefore, everybody must be able to study physics and to understand it. For example, information processing in the nervous system of our brain is mainly due to electrochemical processes, although most of them are occurring without arousal of consciousness. Therefore, the discovery of electricity might simply mean that we had achieved conscious recognition of electric processes occurring in human bodies and that the electricity was destined to be discovered.

2. Ancient Roots

Natural science or natural philosophy, which presents a unified and organized view of the universe, developed with the rise of Greek civilization. Greek culture and scientific thinking were first developed on the Ionian coast of Asia Minor around the sixth century B.C., and later in the Aegean islands and the Greek colonies in southern Italy. One of the epoch-making events was that the Greeks founded institutions, such as the Academy, the Lyceum, and the Museum. Plato (*c*.427–*c*.347 B.C.) founded the Academy on the outskirts of Athens, while his pupil Aristotle (384–322 B.C.) founded the Lyceum in Athens in 334 B.C. These institutions might be considered as the first prototype of the research institutions or universities of modern times. They lasted for almost nine centuries until they were closed in the early sixth century A.D.

Primitive humans lived on herbs and berries, and the animals and fish that they managed to catch. As the centuries passed, groups of hunters began forming settlements, and small settlements gradually enlarged into villages and towns, and finally into great cities. Division of labor was inevitable in any great city with an organized social structure, and further advance of the labor division resulted in some people becoming specialized in engaging in intellectual games, such as speculating about the origin of the universe or the underlying laws of the physical world. Social circumstances that did not force all the people to engage in routine jobs and social requirements to train some people in advanced technology or knowledge might have led to the establishment of institutions headed by some of the great philosophers. Thus, the foundation of the Academy or the Lyceum might be regarded as a natural outcome of the advanced civilization of ancient Greek cities.

The Lyceum was moved from Athens to Alexandria in Egypt after the death of Aristotle, and the Museum founded there and modeled on the Lyceum consisted of a group of institutions that had, altogether, about a hundred scholars and more than half a million works of literature. The highly-evolved culture and the establishment of these institutions resulted in leaving a fine intellectual heritage for future generations. The writings of Plato and Aristotle have survived to the present day and we can read a large number of books on ancient Greek culture.

Although many impressive achievements were made by Greek philosophers, ancient Greek science never became a self-sustaining enterprise. Perhaps the greatest heritage that Greek philosophy left to us was to demonstrate the various patterns of logical and scientific thought of human beings, such as to define, to hypothesize, to infer, and to prove. Furthermore, the Greeks showed us that to search for a unified view of everything in the universe is characteristic of humankind.

Thales of Miletus (*c*.625–*c*.545 B.C.), who is regarded as the founder of the Ionian school of natural philosophy, searched for a unifying principle underlying all phenomena. He postulated that water is the basis of all things and that everything is formed by water through the power of water itself. Democritus (*c*.460–*c*.375 B.C.), who is regarded as the father of atomic theory, speculated that atoms comprised all beings and everything else was void. Thus, even the concept of atom as the smallest and indivisible entity had its origin in Greek philosophy.

The greatest of the Greek philosophers was probably Aristotle. He described a wide range of natural phenomena and theorized that everything must happen in accordance with fundamental principles. He adopted the concept of Empedocles that all matter was made up of four primary elements: earth, air, fire, and water. He further speculated that each element had a natural place that it sought to attain. Thus fire goes upwards and earthly bodies fall to the ground, explaining the change of celestial matter on earth.

One of most remarkable heritages of Greek science is the *Elements* of Euclid (*c*.330–*c*.275 B.C.), which served as the basic textbook in mathematics for the next 2,000 years. The text consists of thirteen volumes and describes information on plane and solid geometry, as well as on the theory of numbers. It summarized the mathematical knowledge developed in ancient Greek culture and showed us the high standard of natural philosophy in Greek culture. In geometry a set of axioms are first presented. These axioms provided the starting point for geometry and they have to be accepted simply as facts of experience without further explanation being required. From the set of axioms one proceeds by logical deduction to derive useful theorems in geometry. Then one solves each individual problem by using some of these theorems. The aggregate of logical steps from the set of axioms to the solution is called “proof.” This entirely logical procedure called proof, might be the greatest heritage ancient Greek natural philosophy left to us. Aristotle is named as the father of the study of logic and his achievements might be considered as materialized in the text of Euclid.

In other areas of the world, particularly in China, we can find development of natural philosophy similar to the Greek philosophy. For example, as early as 300 B.C., a model of the universe was constructed based on the Chinese concept of yin and yang: paired opposites. A little later, Zou Yan, a member of Prince Xuan's Academy, systemized a theory of matter that contained five elements: water, metal, wood, fire, and earth. We can even find a writing at the time that contains a clear statement of the first law of motion of matter much later formulated by Newton.

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Biographical Sketch

Gyo Takeda, Professor Emeritus of Tokyo University and Tohoku University, was born in Tokyo in 1924. His speciality is the theory of particle physics and nuclear physics, and he also carries out research into neuroscience. He has served as: Associate professor, Kobe University; Professor and Director, Institute for Nuclear Studies, University of Tokyo; Professor of Physics Department and Dean of Faculty of Science, Tohoku University; and Professor, General Education, Tohoku Gakuin University.