Physics

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Physics is the science that deals with matter and energy and with the interactions between them. Physics, the foundation of all other sciences, is an attempt to provide a comprehensive rational explanation of the structure and workings of the universe.

An axiom among physicists—since the writings of Italian astronomer and physicist Galileo Galilei (1564–1642)—provides that the road to sure knowledge about the natural world is to carry out controlled observations (experiments) that will lead to measurable quantities. It is for this reason that experimental techniques, systems of measurements, and mathematical systems for expressing results lie at the core of research in physics.

In ancient Greece, in a natural world largely explained by mystical and supernatural forces (i.e., the whims of gods), the earliest scientists and philosophers of record dared to offer explanations of the natural world based on their observations and reasoning. Pythagoras (582–500 BC) argued about the nature of numbers, Leucippus (c. 440 BC), Democritus (c. 420 BC), and Epicurus (342–270 BC) asserted matter was composed of extremely small particles called atoms.

Many of the most cherished arguments of ancient science ultimately proved erroneous. For example, in Aristotle's (384–322 BC) physics, a moving body of any mass had to be in contact with a "mover," and for all things there had to be a "prime mover." Errant models of the universe made by Ptolemy (ca. AD 87–145) were destined to dominate the western intellectual tradition for more than a millennium. Midst these misguided concepts, however, were brilliant insights into natural phenomena. More then 1700 years before the Copernican revolution, Aristarchus of Samos (310–230 BC) proposed that Earth rotated around the sun and Eratosthenes of Cyrene (276–194 BC), while working at the great library at Alexandria, deduced a reasonable estimate of the circumference of Earth.

Until the collapse of the Roman civilization there were constant refinements to physical concepts of matter and form. Yet, for all its glory and technological achievements, the science of ancient Greece and Rome was essentially nothing more than a branch of philosophy. Experimentation would wait almost another two thousand years for injecting its vigor into science. Although there were technological advances and more progress in civilization that commonly credited, during the Dark and Medieval Ages in Europe science slumbered. In other parts of the world, however, Arab scientists preserved the classical arguments as they developed accurate astronomical instruments and compiled new works on mathematics and optics.

At the start of the Renaissance in Western Europe, the invention of the printing press and a rediscovery of classical mathematics provided a foundation for the rise of empiricism during the subsequent scientific revolution. Early in the sixteenth century Polish astronomer Nicolaus Copernicus's (1473–1543) reassertion of heliocentric theory sparked an intense interest in broad quantification of nature that eventually allowed German astronomer and mathematician Johannes Kepler (1571–1630) to develop laws of planetary motion. In addition to his fundamental astronomical discoveries, Galileo made concerted studies of the motion of bodies that subsequently inspired seventeenth century English physicist and mathematician sir Isaac Newton's (1642–1727) development of the laws of motion and gravitation in his influential 1687 work, *Philosophiae Naturalis Principia Mathematica (Mathematical Principles of natural Philosophy)*.

Following *Principia*, scientists embraced empiricism during an Age of Enlightenment. Practical advances spurred by the beginning of the Industrial Revolution resulted in technological advances and increasingly sophisticated instrumentation that allowed scientists to make exquisite and delicate calculations regarding physical phenomena. Concurrent advances in mathematics, allowed development of sophisticated and quantifiable models of nature. More tantalizingly for physicists, many of these mathematical insights ultimately pointed toward a physical reality not necessarily limited to three dimensions and not necessarily absolute in time and space.

Nineteenth century experimentation culminated in the formulation of Scottish physicist James Clerk Maxwell's (1831–1879) unification of concepts regarding electricity, magnetism, and light in his four famous equations describing electromagnetic waves.

During the first half of the twentieth century, these insights found full expression in the advancement of quantum and relativity theory. Scientists, mathematicians, and philosophers united to examine and explain the innermost workings of the universe—both on the scale of the very small subatomic world and on the grandest of cosmic scales.

By the dawn of the twentieth century more than two centuries had elapsed since the Newton's *Principia* set forth the foundations of classical physics. In 1905, in one grand and sweeping theory of special relativity German-American physicist Albert Einstein (1879–1955) provided an explanation for seemingly conflicting and counter-intuitive experimental determinations of the constancy of the speed of light, length contraction, time dilation, and mass enlargements. A scant decade later, Einstein once again revolutionized concepts of space, time and gravitywith his general theory of relativity. Prior to Einstein's revelations, German physicist Maxwell Planck (1858–1947) proposed that atoms absorb or emit electromagnetic radiation in discrete units of energy termed quanta. Although Planck's quantum concept seemed counter-intuitive to well-established Newtonian physics, quantum mechanics accurately described the relationships between energy and matter on atomic and subatomic scale and provided a unifying basis to explain the properties of the elements.

Concepts regarding the stability of matter also proved ripe for revolution. Far from the initial assumption of the indivisibility of atoms, advancements in the discovery and understanding of radioactivity culminated in renewed quest to find the most elemental and fundamental particles of nature. In 1913, Danish physicist Niels Bohr (1885–1962) published a model of the hydrogen atom that, by incorporating quantum theory, dramatically improved existing classical Copernicanlike atomic models. The quantum leaps of electrons between orbits proposed by the Bohr model accounted for Planck's observations and also explained many important properties of the photoelectric effect described by Einstein.

More mathematically complex atomic models were to follow based on the work of the French physicist Louis Victor de Broglie (1892–1987), Austrian physicist Erwin Schrödinger (1887–1961), German physicist Max Born (1882–1970), and English physicist P.A.M. Dirac (1902–1984). More than simple refinements of the Bohr model, however these scientists made fundamental advances in defining the properties of matter—especially the wave nature of subatomic particles. By 1950, the articulation of the elementary constituents of atoms grew dramatically in numbers and complexity and matter itself was ultimately to be understood as a synthesis of wave and particle properties.

The end of World War II gave formal birth to the atomic age. In one blinding flash, the Manhattan Project created the most terrifying of weapons that forever changed the course of history.

Classical and modern physics

The field of physics is commonly sub-divided into two large categories: classical and modern physics. The dividing line between these two sub-divisions can be drawn in the early 1900s, when a number of revolutionary new concepts about the nature of matter were proposed. Included among these were Einstein's theories of general and special relativity, Planck's concept of the quantum, Heisenberg's principle of indeterminacy, and the concept of the equivalence of matter and energy.

In general, classical physics can be said to deal with topics on the macroscopic scale, that is on a scale that can be studied with the largely unaided five human senses. Modern physics, in contrast, concerns the nature and behavior of particles and energy at the sub-microscopic level. As it happens, the laws of classical physics are generally inapplicable or applicable only as approximations to the laws of modern physics.

The discoveries made during the first two decades of the twentieth century required a profound re-thinking of the nature of physics. Some broadly accepted laws had to be completely re-formulated. For example, many classical laws of physics are entirely deterministic. That is, one can say that if A occurs, B is certain to follow. This cause-and-effect relationship was long regarded as one of the major pillars of physics.

The discoveries of modern physics have demanded that this relationship be re-evaluated. With the formulation of quantum mechanics, physical phenomena could no longer be explained in terms of deterministic causality, that is, as a result of at least a theoretically measurable chain causes and effects. Instead, physical phenomena were described as the result of fundamentally statistical, unreadable, indeterminist (unpredictable) processes. Physicists are now more inclined to say that if A occurs, there is an X percent chance that B will follow. Determinism in physics—at very small physical scales—has been replaced by probability.

Divisions of physics

Like other fields of science, physics is commonly sub-divided into a number of more specific fields of research. In classical physics, those fields include mechanics, thermodynamics, sound, light and optics, and electricity and magnetism. In modern physics, some major sub-divisions include atomic, nuclear, and particle physics.

Mechanics, the oldest field of physics, is concerned with the description of motion and its causes. Thermodynamics deals with the nature of heat and its connection with work.

Sound, optics, electricity, and magnetism are all divisions of physics in which the nature and propagation of waves are important. The study of sound is also related to practical applications that can be made of this form of energy, as in radio communication and human speech. Similarly, optics deals not only with the reflection, refraction, diffraction, interference, polarization, and other properties of light, but also the ways in which these principles have practical applications in the design of tools and instruments such as telescopes and microscopes.

The study of electricity and magnetism focuses not only on the properties of particles at rest, but also on the properties of those particles in motion. The field of static electricity examines the forces that exist between charged particles at rest, while current electricity deals with the movement of electrical particles.

In the area of modern physics, nuclear and atomic physics involve the study of the atomic nucleus and its parts, with special attention to changes that take place (such as nuclear decay) in the atom. Particle and high-energy physics, on the other hand, focus on the nature of the fundamental particles of which the natural world is made. In these two fields of research, very powerful, very expensive tools, such as linear accelerators and synchrotrons ("atom-smashers") are required to carry out the necessary research.

Interrelationship of physics to other sciences

One trend in all fields of science over the past century has been to explore ways in which the five basic sciences (physics, chemistry, astronomy, biology, and earth sciences) are related to each other. This has led to another group of specialized sciences in which the laws of physics are used to interpret phenomena in other fields. Astrophysics, for example, is a study of the composition of astronomical objects, such as stars, and the changes that they undergo. Physical chemistry and chemical physics, on the other hand, are fields of research that deal with the physical nature of chemical molecules. Geophysics deals with the physics and chemistry of Earth's dynamic processes. Biophysics, as another example, is concerned with the physical properties of molecules essential to living organisms.

KEY TERMS

Determinism
: The notion that a known effect can be attributed with certainty to a known cause.

Energy
: A state function that reflects an ability to do work.

Matter
: Anything that has mass and takes up space.

Mechanics
: The science that deals with energy and forces and their effects on bodies.

Sub-microscopic
: Referring to levels of matter that cannot be directly observed by the human senses, even with the best of instruments; the level of atoms and electrons.

Physics and philosophy

The development of quantum theory, especially the discovery of Planck's constant and the articulation of the Heisenburg uncertainty principle, carried profound philosophical implications regarding limits on knowledge. Modern cosmological theory (i.e., theories regarding the nature and formation of the universe) have provided us with an understanding of nucleosynthesis (the formation of elements) that has forever linked mankind to the lives of the stars: our bodies and the ground beneath our feet are literally made out of the ashes of dead stars.

Further Readings

Books

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