# Physics

- **Physics** is a part of natural philosophy and a natural science that involves the study of matter and its motion through space and time, along with related concepts such as energy and force. More broadly, it is the general analysis of nature, conducted in order to understand how the universe behaves.
- Physics is one of the oldest academic disciplines, perhaps the oldest through its inclusion of astronomy. Over the last two millennia, physics was a part of natural philosophy along with chemistry, certain branches of mathematics, and biology, but during the Scientific Revolution in the 17th century, the natural sciences emerged as unique research programs in their own right. Physics intersects with many interdisciplinary areas of research, such as biophysics and quantum chemistry, and the boundaries of physics are not rigidly defined. New ideas in physics often explain the fundamental mechanisms of other sciences, while opening new avenues of research in areas such as mathematics and philosophy.
- Physics also makes significant contributions through advances in new technologies that arise from theoretical breakthroughs. For example, advances in the understanding of electromagnetism or nuclear physics led directly to the development of new products which have dramatically transformed modern-day society, such as television, computers, domestic appliances, and nuclear weapons; advances in thermodynamics led to the development of industrialization; and advances in mechanics inspired the development of calculus.

# Classical mechanics

- In physics, classical mechanics is one of the two major sub-fields of mechanics, which is concerned with the set of physical laws describing the motion of bodies under the action of a system of forces. The study of the motion of bodies is an ancient one, making classical mechanics one of the oldest and largest subjects in science, engineering and technology.
- Classical mechanics describes the motion of macroscopic objects, from projectiles to parts of machinery, as well as astronomical objects, such as spacecraft, planets, stars, and galaxies. Besides this, many specializations within the subject deal with gases, liquids, solids, and other specific sub-topics.

# Classical mechanics (2)

- Classical mechanics provides extremely accurate results as long as the domain of study is restricted to large objects and the speeds involved do not approach the speed of light. When the objects being dealt with become sufficiently small, it becomes necessary to introduce the other major sub-field of mechanics, quantum mechanics, which reconciles the macroscopic laws of physics with the atomic nature of matter and handles the wave–particle duality of atoms and molecules. In the case of high velocity objects approaching the speed of light, classical mechanics is enhanced by special relativity. General relativity unifies special relativity with Newton's law of universal gravitation, allowing physicists to handle gravitation at a deeper level.

# Classical mechanics (3)

- The initial stage in the development of classical mechanics is often referred to as Newtonian mechanics, and is associated with the physical concepts employed by and the mathematical methods invented by Newton himself, in parallel with Leibniz【莱布尼兹】, and others.
- Later, more abstract and general methods were developed, leading to reformulations of classical mechanics known as Lagrangian mechanics and Hamiltonian mechanics. These advances were largely made in the 18th and 19th centuries, and they extend substantially beyond Newton's work, particularly through their use of analytical mechanics. Ultimately, the mathematics developed for these were central to the creation of quantum mechanics.

# Thermodynamics

- **Thermodynamics** is a branch of natural science concerned with heat and its relation to energy and work. It defines macroscopic variables (such as temperature, internal energy, entropy, and pressure) that characterize materials and radiation, and explains how they are related and by what laws they change with time. Thermodynamics describes the average behavior of very large numbers of microscopic constituents, and its laws can be derived from statistical mechanics.
- Thermodynamics applies to a wide variety of topics in science and engineering—such as engines, phase transitions, chemical reactions, transport phenomena, and even black holes. Results of thermodynamic calculations are essential for other fields of physics and for chemistry, chemical engineering, aerospace engineering, mechanical engineering, cell biology, biomedical engineering, and materials science—and useful in other fields such as economics.

# Thermodynamics(2)

- Much of the empirical content of thermodynamics is contained in the four laws.
- The first law asserts the existence of a quantity called the internal energy of a system, which is distinguishable from the kinetic energy of bulk movement of the system and from its potential energy with respect to its surroundings. The first law distinguishes transfers of energy between closed systems as heat and as work.
- The second law concerns two quantities called temperature and entropy. Entropy expresses the limitations, arising from what is known as irreversibility, on the amount of thermodynamic work that can be delivered to an external system by a thermodynamic process. Temperature, whose properties are also partially described by the zeroth law of thermodynamics, quantifies the direction of energy flow as heat between two systems in thermal contact and quantifies the common-sense notions of "hot" and "cold".

# Thermodynamics(3)

- Initially, the thermodynamics of heat engines concerned mainly the thermal properties of their 'working materials', such as steam. This concern was then linked to the study of energy transfers in chemical processes, for example to the investigation, published in 1840, of the heats of chemical reactions by Germain Hess, which was not originally explicitly concerned with the relation between energy exchanges by heat and work. Chemical thermodynamics studies the role of entropy in chemical reactions. Also, statistical thermodynamics, or statistical mechanics, gave explanations of macroscopic thermodynamics by statistical predictions of the collective motion of particles based on the mechanics of their microscopic behavior.

# Thermodynamics(4)

- Thermodynamic equilibrium is one of the most important concepts for thermodynamics. The temperature of a system in thermodynamic equilibrium is well defined, and is perhaps the most characteristic quantity of thermodynamics. As the systems and processes of interest are taken further from thermodynamic equilibrium, their exact thermodynamical study becomes more difficult. Relatively simple approximate calculations, however, using the variables of equilibrium thermodynamics, are of much practical value in engineering. In many important practical cases, such as heat engines or refrigerators, the systems consist of many subsystems at different temperatures and pressures. In practice, thermodynamic calculations deal effectively with these complicated dynamic systems provided the equilibrium thermodynamic variables are nearly enough well-defined.

# Electromagnetism

- The electromagnetic force is one of the four fundamental interactions in nature, the other three being the strong interaction, the weak interaction, and gravitation. This force is described by electromagnetic fields, and has innumerable physical instances including the interaction of electrically charged particles and the interaction of uncharged magnetic force fields with electrical conductors.
- The science of electromagnetic phenomena is defined in terms of the electromagnetic force, sometimes called the Lorentz force, which includes both electricity and magnetism as elements of one phenomenon.
- The electromagnetic force is the interaction responsible for almost all the phenomena encountered in daily life, with the exception of gravity. Ordinary matter takes its form as a result of intermolecular forces between individual molecules in matter. Electrons are bound by electromagnetic wave mechanics into orbitals around atomic nuclei to form atoms, which are the building blocks of molecules. This governs the processes involved in chemistry, which arise from interactions between the electrons of neighboring atoms, which are in turn determined by the interaction between electromagnetic force and the momentum of the electrons.
- There are numerous mathematical descriptions of the electromagnetic field. In classical electrodynamics, electric fields are described as electric potential and electric current in Ohm's law, magnetic fields are associated with electromagnetic induction and magnetism, and Maxwell's equations describe how electric and magnetic fields are generated and altered by each other and by charges and currents.
- The theoretical implications of electromagnetism, in particular the establishment of the speed of light based on properties of the "medium" of propagation (permeability and permittivity), led to the development of special relativity by Albert Einstein in 1905.

# Optics

- Optics is the branch of physics which involves the behaviour and properties of light, including its interactions with matter and the construction of instruments that use or detect it. Optics usually describes the behaviour of visible, ultraviolet, and infrared light. Because light is an electromagnetic wave, other forms of electromagnetic radiation such as X-rays, microwaves, and radio waves exhibit similar properties.
- Most optical phenomena can be accounted for using the classical electromagnetic description of light. Complete electromagnetic descriptions of light are, however, often difficult to apply in practice. Practical optics is usually done using simplified models. The most common of these, geometric optics, treats light as a collection of rays that travel in straight lines and bend when they pass through or reflect from surfaces. Physical optics is a more comprehensive model of light, which includes wave effects such as diffraction and interference that cannot be accounted for in geometric optics. Historically, the ray-based model of light was developed first, followed by the wave model of light. Progress in electromagnetic theory in the 19th century led to the discovery that light waves were in fact electromagnetic radiation.

# Atomic physics

- **Atomic physics** is the field of physics that studies atoms as an isolated system of electrons and an atomic nucleus. It is primarily concerned with the arrangement of electrons around the nucleus and the processes by which these arrangements change. This includes ions as well as neutral atoms and, unless otherwise stated, for the purposes of this discussion it should be assumed that the term *atom* includes ions.
- The term *atomic physics* is often associated with nuclear power and nuclear bombs, due to the synonymous use of *atomic* and *nuclear* in standard English. However, physicists distinguish between atomic physics — which deals with the atom as a system consisting of a nucleus and electrons — and nuclear physics, which considers atomic nuclei alone.

# Statistical mechanics

- Statistical mechanics or **statistical thermodynamics** is a branch of physics that applies probability theory, which contains mathematical tools for dealing with large populations, to the study of the *thermodynamic* behavior of systems composed of a *large* number of particles. Statistical mechanics provides a framework for relating the microscopic properties of individual atoms and molecules to the macroscopic bulk properties of materials that can be observed in everyday life, thereby explaining thermodynamics as a result of the classical- and quantum-mechanical descriptions of statistics and mechanics at the microscopic level.
- Statistical mechanics provides a molecular-level interpretation of macroscopic thermodynamic quantities such as work, heat, free energy, and entropy. It enables the thermodynamic properties of bulk materials to be related to the spectroscopic data of individual molecules. This ability to make macroscopic predictions based on microscopic properties is the main advantage of statistical mechanics over classical thermodynamics. Both theories are governed by the second law of thermodynamics through the medium of entropy. However, entropy in thermodynamics can only be known empirically, whereas in statistical mechanics, it is a function of the distribution of the system on its microstates.
- The essential problem in statistical thermodynamics is to calculate the distribution of a given amount of energy $E$ over $N$ identical systems. The goal of statistical thermodynamics is to understand and to interpret the measurable macroscopic properties of materials in terms of the properties of their constituent particles and the interactions between them. This is done by connecting thermodynamic functions to quantum-mechanical equations. Two central quantities in statistical thermodynamics are the Boltzmann factor and the partition function.

# Quantum mechanics

- Quantum mechanics (QM – also known as **quantum physics**, or **quantum theory**) is a branch of physics which deals with physical phenomena at microscopic scales, where the action is on the order of the Planck constant. Quantum mechanics departs from classical mechanics primarily at the *quantum realm* of atomic and subatomic length scales. Quantum mechanics provides a mathematical description of much of the dual *particle-like* and *wave-like* behavior and interactions of energy and matter. Quantum mechanics is the non-relativistic limit of Quantum Field Theory (QFT), a theory that was developed later that combined Quantum Mechanics with Relativity Theory.
- The name *quantum mechanics* derives from the observation that some physical quantities can change only in *discrete* amounts (Latin *quanta*), and not in a continuous way. For example, the angular momentum of an electron bound to an atom or molecule is quantized. In the context of quantum mechanics, the wave–particle duality of energy and matter and the uncertainty principle provide a unified view of the behavior of photons, electrons, and other atomic-scale objects.
- The mathematical formulations of quantum mechanics are abstract. A mathematical function known as the wavefunction provides information about the probability amplitude of position, momentum, and other physical properties of a particle. Mathematical manipulations of the wavefunction usually involve the bra-ket notation, which requires an understanding of complex numbers and linear functions. The wavefunction treats the object as a quantum harmonic oscillator, and the mathematics is akin to that describing acoustic resonance. Many of the results of quantum mechanics are not easily visualized in terms of classical mechanics—for instance, the ground state in a quantum mechanical model is a non-zero energy state that is the lowest permitted energy state of a system, as opposed to a more "traditional" system that is thought of as simply being at rest, with zero kinetic energy.

# Quantum mechanics(2)

- The earliest versions of quantum mechanics were formulated in the first decade of the 20th century. At around the same time, the atomic theory and the corpuscular theory of light first came to be widely accepted as scientific fact; these latter theories can be viewed as quantum theories of matter and electromagnetic radiation, respectively. Early quantum theory was significantly reformulated in the mid-1920s by Heisenberg, Born and Jordan, who created matrix mechanics; de Broglie and Schrödinger (Wave Mechanics); and Pauli and Bose (statistics of subatomic particles). And the Copenhagen interpretation of Niels Bohr became widely accepted. By 1930, quantum mechanics had been further unified and formalized by the work of Hilbert, Dirac and John von Neumann, with a greater emphasis placed on measurement in quantum mechanics, the statistical nature of our knowledge of reality, and philosophical speculation about the role of the observer. Quantum mechanics has since branched out into almost every aspect of 20th century physics and other disciplines, such as quantum chemistry, quantum electronics, quantum optics, and quantum information science. Much 19th century physics has been re-evaluated as the "classical limit" of quantum mechanics, and its more advanced developments in terms of quantum field theory, string theory, and speculative quantum gravity theories.
- Quantum mechanics is essential to understanding the behavior of systems at atomic length scales and smaller. In addition, if classical mechanics truly governed the workings of an atom, electrons would really 'orbit' the nucleus. Since bodies in circular motion accelerate, they must emit radiation and collide with the nucleus in the process. This clearly contradicts the existence of stable atoms.
- Quantum mechanics was initially developed to provide a better explanation and description of the atom, especially the differences in the spectra of light emitted by different isotopes of the same element, as well as subatomic particles. In short, the quantum-mechanical atomic model has succeeded spectacularly in the realm where classical mechanics and electromagnetism falter.
- Broadly speaking, quantum mechanics incorporates four classes of phenomena for which classical physics cannot account: The quantization of certain physical properties; Wave–particle duality; The Uncertainty principle; Quantum entanglement

# Special relativity

- In physics, **special relativity** is a fundamental theory concerning space and time, developed by Albert Einstein in 1905 as a modification of Galilean relativity. The theory was able to explain some pressing theoretical and experimental issues in the physics of the time involving light and electrodynamics.
- Einstein postulated that the speed of light in free space is the same for all observers, regardless of their motion relative to the light source. This postulate stemmed from the assumption that Maxwell's equations of electromagnetism, which predict a specific speed of light in a vacuum, hold in any inertial frame of reference. This prediction contradicted the laws of classical mechanics, which had been accepted for centuries, by arguing that time and space are not fixed and in fact change to maintain a constant speed of light regardless of the relative motions of sources and observers. Einstein's approach was based on thought experiments, calculations, and the principle of relativity, which is the notion that all physical laws should appear the same to all inertial observers.

# Special relativity (2)

- The predictions of special relativity are almost identical to those of Galilean relativity for most everyday phenomena, in which speeds are much lower than the speed of light, but it makes different, non-obvious predictions for objects moving at very high speeds. These predictions have been experimentally tested on numerous occasions since the theory's inception. The major predictions of special relativity are:
  - Relativity of simultaneity: Observers who are in motion with respect to each other may disagree on whether two events occurred at the same time or one occurred before the other.
  - Time dilation (An observer watching two identical clocks, one moving and one at rest, will measure the moving clock to tick more slowly)
  - Length contraction (Along the direction of motion, a rod moving with respect to an observer will be measured to be shorter than an identical rod at rest), and
  - The equivalence of mass and energy (written as $E = mc^2$).

# Special relativity (3)

- Special relativity predicts a non-linear velocity addition formula which prevents speeds greater than that of light from being observed. In 1908, Hermann Minkowski reformulated the theory based on different postulates of a more geometrical nature. This approach considers space and time as being different components of a single entity, the spacetime. Likewise, energy and momentum are the components of the four-momentum, and the electric and magnetic field are the components of the electromagnetic tensor.
- As Galilean relativity is now considered an approximation of special relativity valid for low speeds, special relativity is considered an approximation of the theory of general relativity valid for weak gravitational fields. General relativity postulates that physical laws should appear the same to *all* observers (an accelerating frame of reference being equivalent to one in which a gravitational field acts), and that gravitation is the effect of the curvature of spacetime caused by energy (including mass).