## 1.1 Energy

In physics, *energy* is a conserved extensive property of a physical system, which cannot be observed directly but can be calculated from its state. Energy is of central importance in physics. It is impossible to give a comprehensive definition of energy because of the many forms it may take, but the most common definition is that it is the capacity of a system to perform *work.*

The definition of work in physics is the movement of a force through a distance, and energy is measured in the same units as work. If a person pushes an object $x$ meters against an opposing force of $F$ newtons, $Fx$ joules (newton-meters) of work has been done on the object; the person's body has lost $Fx$ joules of energy, and the object has gained $Fx$ joules of energy. The SI unit of energy is the joule (J) (equivalent to a newton-meter or a watt-second); the CGS unit is the erg, and the Imperial unit is the foot pound. Other energy units such as the electron volt, calorie, BTU, and kilowatt-hour (1 kWh = 3600 kJ) are used in specific areas of science and commerce.

One reason for the importance of energy in physics is that it is a conserved quantity: the law of conservation of energy states that energy can neither be created nor destroyed, but it can be changed into different forms. The sum of all the forms of energy inside a volume of space can only change by the amount of energy leaving or entering the volume. Another reason for its importance is the number of different forms that energy can take. Two major categories of energy are *kinetic* and *potential.*

Kinetic energy is energy of motion, carried by a moving mass such as a thrown baseball. Potential energy is energy possessed by an object due to its position in a force field, such as a gravitational, electric or magnetic field. For example, lifting an object against gravity stores gravitational potential energy in it, which is converted to kinetic energy if it falls. Specific forms of energy include the radiant energy of electromagnetic waves such as light, elastic energy due to the stretching or deformation of solid objects, chemical energy such as is released when a fuel burns, and thermal energy, the microscopic kinetic and potential energies of the random motions of the particles making up matter.

## 1.2 Energy Transformation

The concept of energy and its transformations is vital in explaining and predicting most natural phenomena. One form of energy can often be readily transformed into another; for instance, a battery, from chemical energy to electric energy; a dam: gravitational potential energy to kinetic energy of moving water (and the blades of a turbine) and ultimately to electric energy through an electric generator.

There are strict limits to how efficiently energy can be converted into other forms of energy via work, and heat as described by Carnot's theorem and the second law of thermodynamics. These limits are especially evident when an engine is used to perform work. Some energy transformations can be quite efficient.

The direction of transformations in energy (what kind of energy is transformed to what other kind) is often described by entropy (equal energy spread among all available degrees of freedom) considerations, as in practice all energy transformations are permitted on a small scale, but certain larger transformations are not permitted because it is statistically unlikely that energy or matter will randomly move into more concentrated forms or smaller spaces.

Energy transformations in the universe over time are characterized by various kinds of potential energy that has been available since the Big Bang, later being "released" (transformed to more active types of energy such as kinetic or radiant energy), when a triggering mechanism is available. Familiar examples of such processes include nuclear decay, in which energy is released that was originally "stored" in heavy isotopes (such as uranium and thorium), by nucleon synthesis, a process ultimately using the gravitational potential energy released from the gravitational collapse of supernovae, to store energy in the creation of these heavy elements before they were incorporated into the solar system and the Earth. This energy is triggered and released in nuclear fission bombs or in civil nuclear power generation.

Similarly, in the case of a chemical explosion, chemical potential energy is transformed to kinetic energy and thermal energy in a very short time. Yet another example is that of a pendulum. At its highest points the kinetic energy is zero and the gravitational potential energy is at maximum. At its lowest point the kinetic energy is at maximum and is equal to the decrease of potential energy. If one (unrealistically) assumes that there is no friction or other losses, the conversion of energy between these processes would be perfect, and the pendulum would continue swinging forever.

## 1.3 Reversible and Non-Reversible Transformations:

Transformation of energy into useful work is a core topic of thermodynamics. In nature transformations of energy can be fundamentally classed into two kinds: those that are thermodynamically reversible, and those that are thermodynamically irreversible. A reversible process in thermodynamics is one in which no energy is dissipated (spread) into empty energy states available in a volume, from which it cannot be recovered into more concentrated forms (fewer quantum states), without degradation of even more energy.

A reversible process is one in which this sort of dissipation does not happen. For example conversion of energy from one type of potential field to another is reversible, as in the pendulum system described above. In processes where heat is generated, quantum states of lower energy present as possible excitations in fields between atoms, act as a reservoir for part of the energy from which it cannot be recovered, in order to be converted with 100% efficiency into other forms of energy. In this case, the energy must partly stay as heat, and cannot be completely recovered as usable energy, except at the price of an increase in some other kind of heat-like increase in disorder in quantum states, in the universe (such as an expansion of matter, or a randomization in a crystal).

## 1.4 Applications of the Concept of Energy

Energy is subject to a strict global conservation law; that is, whenever one measures (or calculates) the total energy of a system of particles whose interactions do not depend explicitly on time, it is found that the total energy of the system always remains constant.

- The total energy of a system can be subdivided and classified in various ways. For example, it is sometimes convenient to distinguish potential energy (which is a function of coordinates only) from kinetic energy (which is a function of coordinate time derivatives only). It may also be convenient to distinguish gravitational energy, electric energy, thermal energy, and other forms. These classifications overlap; for instance, thermal energy usually consists partly of kinetic and partly of potential energy.
- The transfer of energy can take various forms; familiar examples include work, heat flow, and advection, as discussed below.
- The word "energy" is also used outside of physics in many ways, which can lead to ambiguity and inconsistency. The vernacular terminology is not consistent with technical terminology. For example, while energy is always conserved (in the sense that the total energy does not change despite energy transformations), energy can be converted into a form, e.g., thermal energy, that cannot be utilized to perform work. When one talks about "conserving energy by driving less," one talks about conserving fossil fuels and preventing useful energy from being lost as heat. This usage of "conserve" differs from that of the law of conservation of energy