Competitive Exams: Energy & Motion

In general, the concept energy refers to "the potential for causing a change" The word is used in several different contexts. The scientific use has a precise, well-defined meaning, whilst the many non-scientific uses often do not.

In physics the energy of a system in a certain state is defined as the work needed to bring the system to that state from some reference state. Because work is defined via force involved, forms of energy are usually classified according to that force (elastic, gravitational, nuclear, electric, etc).

Energy is a conserved quantity: It is neither created nor destroyed, but only transfered from place to place or from one form to another. Ultimately, this is because the laws of nature do not change with time.

Energy is the ability to do work (work is, simplistically, a force applied through a distance), and has several different forms. However, no matter what the form, physical energy uses the same units as work: a force applied through a distance.

For example, kinetic energy is the amount of work to accelerate body, gravitational potential energy is the amount of work to elevate mass, etc. Because work is frame dependent (= can only be defined relative to certain initial state or reference state of the system), energy also becomes frame dependent.

For example, a speeding bullet has plenty of kinetic energy in the reference frame of non-moving observer, but it has zero kinetic energy in proper (co-moving) reference frame-because it takes zero work to accelerate a bullet from zero speed to zero speed. Of course, the selection of a reference state (or reference frame) is completely arbitrary-and usually is dictated to maximally simplify the problem to be dealt with:

Forms of Energy

- Kinetic energy is the energy of motion (an object which has speed can perform work on another object by colliding with it).
- Potential energy or unreleased kinetic energy. This sort of energy arises when work is done on an object to move it somewhere against an opposing force. For instance, stretching a rubber band increases the elastic potential energy stored within the band. When the band is released, this energy is converted into kinetic energy, and work is performed. Other forms of potential energy include gravitational potential energy (from moving masses apart), electrical potential energy (from moving charges against a field), and chemical potential energy (energy stored within chemical bonds).

- Thermal energy the kinetic energy associated with the various motions of microscopic particles. The average thermal energy within a sample of matter is referred to as the sample's temperature (work is required to accelerate the particles and raise the temperature).
- Light energy the energy that composes photons and is responsible for the various sorts of electromagnetic radiation (work is required to create photons).
- Nuclear energy, the energy stored within the nuclei of atoms.
- Mass is also considered as a form of energy (or in lay terms, the manifestation of energy,), because during annihilation or other mass change, the equivalent amount of energy ($E = mc^2$) is always released.

Conservation of Energy

Energy is subject to the law of conservation of energy (which is a mathematical restatement of shift symmetry of time). Thus, energy cannot be made or destroyed, it can only be converted from one form to another, that is, transformed. In practice, during any energy transformation in (macroscopic) system, some energy is converted into incoherent microscopic motion of parts of the system (which is usually called heat or thermal motion), and the entropy of the system increases. Due to mathematical impossibility to invert this process (see statistical mechanics), the efficiency of energy conversion in a macroscopic system is always less than 100%.

The first law of thermodynamics states that the total inflow of energy into a system must equal the total outflow of energy from the system, plus the change in the energy contained within the system. In other words, energy is neither created nor destroyed, only converted between forms. This law is used in all branches of physics, but frequently violated by quantum mechanics.

Force

In physics, a force is anything that causes a free body with mass to accelerate. The net (or resultant) force is the sum of all the different forces acting on a body.

The simplest way to describe force is to say that is is a 'push' or a 'pull' The push or pull on an object may cause either deformation or may change the state of motion of the object under consideration.

If we leave aside the deformation aspects, then force can be considered to produce change in the state of the motion of the object i.e.. Velocity. We have, though, experienced in real life that a 'push' or 'pull' does not always manifest in the change of motion. The reason is simple. A change in the state of motion requires a net force.

For example, if the force is great enough to overcome friction the object being pushed or pulled will move. So long as the forces on an object are balanced (i.e.. Net force is zero), the state of motion described by "velocity" will remain same.

Force is a vector quantity defined as the rate of change of momentum induced in a free body by the force, and therefore has a direction associated. The SI unit for force is the newton.

Many forces exist: Coulomb's force (the force between electrical charges), gravitational (force between masses), magnetic force, frictional forces, centrifugal, impact force, and spring force, magnetism, tension, chemical bonding and contact force to name a few.

Only four fundamental forces of nature are known: The strong nuclear force, the electromagnetic force, the weak nuclear force, and the gravitation. All other forces can be reduced to these fundamental interactions.

The modern quantum mechanical view of the first three fundamental forces (all except gravity) is that particles of matter (fermions) do not directly interact with each other but rather by exchange of virtual particles (bosons) (as, for example, virtual photons in case of interaction of electric charges). According to general relativity gravity results from the curvatures of spacetime.

Newton's Laws

Isaac Newton's laws of motion were first published in his work Philosophiae Naturalis Principia Mathematica (1687). Newton used them to prove many results concerning the motion of physical objects. In the third volume (of the text), he showed how, combined with his law of universal gravitation, the laws of motion would explain Kepler's laws of planetary motion.

Newton's second law is a mathematical definition of force, first proposed by Newton himself (thus the name).

1. "An object at rest or traveling in uniform motion will remain at rest or traveling in uniform motion unless acted upon by a net force." (inertia)
2. "The rate of change of momentum of an object is directly proportional to the force acting on the object." ($F = ma$) 3: "All forces occur in pairs, and these two forces are equal in magnitude and opposite in direction." (To every action, there is an equal and opposite reaction).

Gravity

In physics, gravitation or gravity is the tendency of objects with mass to accelerate toward each other. Gravitation is one of the four fundamental interactions in nature, the other three being the electromagnetic force, the weak nuclear force, and the strong nuclear force. Gravitation is the weakest of these interactions, but acts over great distances and is always attractive.

In classical mechanics, gravitation arises out of the force of gravity (which is often used as a synonym for gravitation). In general relativity, gravitation arises out of spacetime being curved by the presence of mass, and is not a force. In quantum gravity theories, either the graviton is the postulated carrier of the gravitational force, or time-space itself is envisioned as discrete in nature, or both.

The gravitational attraction of the Earth endows objects with weight and causes them to fall to the ground when dropped. Moreover, gravitation is the reason for the very existence of the earth, the sun and other celestial bodies; without it matter would not have coalesced into these bodies and life as we know it would not exist.

Gravitation is also responsible for keeping the earth and the other planets in their orbits around the sun, the moon in its orbit around the earth, for the formation of tides, and for various other natural phenomena that we observe.