# 4. WORK, ENERGY AND POWER

## WORK

In common usage the term 'work' may refer to any kind of physical or mental activity. But according to scientific definition, work is done only when a force produces motion. Thus work is done on a weight that is being lifted, or on a spring that is being stretched or compressed, or on a gas that is undergoing compression in a cylinder.

When the force acting on a moving body is constant in magnitude and direction, the amount of work done is defined as the product of just two factors: the component of the force in the direction of motion, and the distance moved by the point of application of the force.

If the magnitude of the force is $F$ and the distance through which the body moves is $d$, the work

$W = Fd$.

The SI unit of work is joule (J) which is also newton-metre.

## ENERGY

Energy is defined as the capacity to do work. We see energy in many different forms like chemical energy, electrical energy, which are used in a number of ways. For example, we utilise the chemical energy locked up in sources like coal, oil, and gas when it is released in the form of heat. Light and sound also carry energy. One form of energy can be converted into another form. Energy like work is measured in joules (J).

In mechanics, energy is classified into two kinds : kinetic and potential.

**Kinetic Energy** Moving objects, such as bullets, cars and cricket balls, all have kinetic energy. Kinetic energy is the energy which is possessed by a body by virtue of its motion.

Kinetic energy (KE) = $1/2mv^2$ where m is the mass of the body and $v$ is its speed.

**Potential Energy** Potential energy is the energy stored in a body or a system by virtue of its position in a field of force or by its configuration. A force acting on a body or a system can alter its potential energy.

There are two common examples of potential energy corresponding to the two situations mentioned above. The first one is the potential energy of a body due to gravity above the surface of the earth. The second example is the potential energy of a spring when it is compressed or elongated by an external force.

Conversion of gravitational PE to KE and then on to some usefull purpose is made use of in many situations. Perhaps the most important instance of this is in hydroelectric power generation. Dams are built at high levels to store large amounts of water which will posses great amounts of gravitational PE. This water is made to rush down pipes; thus its PE is converted in to KE and it gains tremendous speed. It is then made to run the turbines of the electric generators that produce electrical energy. It is this hydroelectrical energy that is used in innumerable ways every day in our lives.

## DIFFERENT FORMS OF ENERGY

**Thermal energy** All materials are made up of tiny particles called molecules. These molecules are constantly in motion. In solids and liquids, the molecules are held close together by strong forces of attraction, and move by vibrating to and fro. In gases, the molecules have become so spaced out that they move about freely at high speed. In some cases they also spin.

Molecules have kinetic energy because they are moving. They also have potential energy because their movements keep them separated, despite the 'spring-like' attractions trying to pull them together. Thermal energy is the name given to the energy an object possesses because of the kinetic energy and potential energy of its molecules. The higher the temperature of an object the faster its molecules move, and the greater is its thermal energy.

Thermal energy is commonly known as heat energy. However, engineers prefer to keep the term heat energy for thermal energy which is the process of being transferred from one object to another.

**Chemical Energy** A stable chemical compound has less energy than its separated parts, the difference being in the specific arrangement and motion of electrons and nuclei in the compound. This difference is called chemical energy or energy of chemical binding. In a chemical reaction, energy can be absorbed or released, depending on whether the total energy of the reactants is less or more than that of the products (endothermic or exothermic reactions). Examples are respectively, hydrolysis and burning of coal.

**Electrical Energy** Electric charges and currents attract or repel each other, i.e. they exert forces on each other. Thus work needs to be done in general to move them with respect to one another. The energy associated with this work is called electrical or electromagnetic energy.

**Energy Related to Mass** While it is commonly known that differnet forms of energy are inter-convertible, it was only recently discovered that matter is equivalent to energy. Albert Einstein showed the energy (E) associated with a mass $m$ (just because of its existence) is given by the formula,

$$E = mc^2$$

Where $c$ is the speed of light in vacuum, equal approximately to 3 X $10^5$Km/s. Even a minute amount of matter can give rise to an immense quantity of energy if his conversion can be made. A collision between an electron and a positron (oppositely charged version of the electron), two bits of matter, can lead to their total annihilation and to the production of pure energy (electromagnetic radiation) of the amount given in the equation.

**Nuclear Energy** The mass-energy equation explains nuclear energy. Neutrons and protons attract each other at distances of an order $10^{-15}$m, and bind (come together) to form nuclei. The associated energy is called nuclear energy.

## CONSERVATON OF ENERGY

Energy cannot be created or destroyed. It may be transformed from one kind to the other. The total energy in a closed system remains constant. Here when we say 'energy' we must include mass also, since mass can be converted into energy.

This is the **law of conservation of energy** which has never been found to be violated. The law cannot be proved mathematically, but is an empirical one. It forms one of the fundamental principles of physics.

## POWER

A small engine can do just as much work as a larger engine, but it takes longer to do it. The larger engine can do work at a faster rate.

The rate at which work is done is called the power:

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} \text{ or } \frac{\text{energy transferred}}{\text{time taken}}$$

Power is measured in joules per second (J/s), or watts [W]. If an engine does 1 joule of useful work every second, it has a power output of 1W. If an engine does 4000J of work in 10s, it has a power output of 400W. Larger powers are also given in kilowatts or megawatts.

1 kilowatt [kW] = 1000W [1000J/s]

1 megawatt [MW] = 1000000 [1000,000J/s]

Sometimes, engine powers are given in horsepower [hp], a unit which dates from the time when steam engines first replaced horses as a power source. 1hp equals 746W, or about 3/4kW.

## Machines

A Machine is a device by which a small force applied at convenient point can be used to overcome a large force at some other point. Although the force overcome by a machine is many times greater than the input force, the energy or work output can never be greater than the input energy or work. In principle

Work input = Work output

**Efficient of a Machine** In a machine, some energy is always wasted in overcoming frictional forces. In practice, therefore, the useful work done by a machine is always less than the input work. The ratio of the useful work done by a machine and the input work is called the efficiency of the machine. Usually, this ratio is expressed as a percentage, i.e.,

$$Efficency = \frac{Useful\ work\ done\ by\ the\ machine}{Work\ done\ on\ the\ machine} \times 100$$

Thus in practice the efficiency of a machine is always less than 100 per cent.

**Simple Machines** If we were to take apart a complicated machine, such as a typewriter, we would find it made up a number of simpler elements. There are actually just six of these basic elements, which we call simple machines. These are the lever, the inclined plane, the wedge, the screw, the wheel and axle, and the pulley.

**Three Classes of Lever** A lever is the simplest and the most commonly used of all machines. A lever is a rigid bar, straight or curved, which is capable of turning freely about a fixed point, called the fulcrum F or pivot. When a force (or effort) E is applied at some convenient point on the lever, a much bigger force L (called load) is exerted at another point. The perpendicular distance between the fulcrum and the point of application of the effort is called the effort arm of the lever and the perpendicular distance between the fulcrum and the point of application of the load is called its load arm.

Levers are divided into three classes depending on the relative positions of the fulcrum F, load L and effort E.

$$V.R. = \frac{dis\tan ce\ of\ effort\ from\ fulcrum}{dis\tan ce\ of\ load\ from\ fulcrum}$$

Levers of first class: The levers which have fulcrum F between load L and effort E are said to be levers of first class. Example : crowbar, see-saw, hammer, scissors, handle of a water pump, pliers, handbrake of a bicycle, etc.

*Levers of second class:* The levers which have the load L between the fulcrum F and effort E are called levers of second class. Examples: wheel-barrow, nut-cracker, lemon squeezer, oar of a boat, a door rotating on its hinge, foot bellows, etc.

*Levers of third class:* The levers which have effort E between fulcrum F and load L are said to belong to levers of third class. Examples : fire or sugar or ice cube tongs, table knife, forces in a weight box, etc.

The mechanical advantage of every simple machine is found in the same way. We just divide the load by the effort required to move it, or we divide the effort distance by the load distance, which amounts to the same thing. In the case of levers, we can also divide the effort arm by the load arm.