Work, Energy and Power

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Work

- In everyday life, any physical or mental activity may be regarded as 'work'.
- work is said to be done only when the applied force causes some displacement of a body in its direction.
- If a constant force is applied to a body in different directions, the work done depends on the displacement of the body in the direction of the force.
- Hence, Work in Physics is defined as the product of force and displacement in the direction of the force.
- If F is the applied force, S is the displacement in the direction of applied force, and work done W is given by

Work done = Force x Displacement in the direction of force

$$W = F \,.\, S$$

Work is a scalar quantity. In the SI system, the unit of work is Nm or joule (J).

$1\ J = 1\ N \times 1\ m = 1\ kg\ m/s^2 \times 1m = 1\ kgm^2s^{-2}$

Types of Work

A) Positive work

- The work done on an object is said to be positive work when force and displacement are in the same direction.

Eg: Work done by the gravitational force on a freely falling.

B) Negative Work

- The work done is said to be negative work when force and displacement are in opposite directions.

Eg: When a body is thrown upwards, the work done by the gravitational force and displacement are opposite.

C) Zero Work

- The work done is said to be zero when force and displacement are perpendicular to each other or when either force or displacement is zero.

Eg: Work done by gravity when a person walks horizontally with some load on his head.

Energy

- The capacity (or ability) of a body to do work is called energy. Energy and work are equivalent concepts. The SI unit of energy is also joule (J).

Types of Energy

- Energy can exist in many forms, but it can be broadly classified into two categories –

1. kinetic energy
2. potential energy

a) Kinetic Energy

- The energy possessed by a body due to its motion is called kinetic energy.
- A moving vehicle, Earth revolving around the sun, and molecules moving in space all have kinetic energy.
- The kinetic energy of a moving object is directly proportional to the mass of the object and the square of its velocity. If m is the mass of the body and v is its velocity, then kinetic energy is given by

$$K = \frac{1}{2} mv^2$$

b) **Potential Energy**

- The energy possessed by a body by its position or configuration is called potential energy.
  - Eg: if we carry a brick to the top of the building, we do some amount of work against the force of gravity. The amount of energy is stored in the brick, in the form of potential energy.
  - Eg: Consider a bow and arrow. Pull the string along with the arrow in the backward direction by applying force. In doing so you change the configuration (shape) of the bow. The energy is used up in changing the shape of the bow and it is stored in the bow in the form of potential energy.
  - Water stored in a tank, a stretched rubber chord, etc. have potential energy.
- The potential energy of a body depends on the type of force acting on the body.
- Consider a mass m held at a height h above ground level in the gravitational field of Earth. If g is the acceleration due to gravity on the surface of the Earth, the potential energy of the body is given by

$$V = mgh$$

Different Forms of Energy

- Two basic types of energy namely kinetic energy and potential energy are sufficient to describe all forms of energy.
- But it is convenient to refer to a particular combination of kinetic energy and potential energy as its form. The major forms of energy include
  - mechanical energy
  - heat energy
  - light energy
  - sound energy
  - electrical energy
  - magnetic energy
  - chemical energy
  - nuclear energy.

a) Mechanical Energy

- Mechanical energy is the energy of a system due to its motion, position, or configuration. It is the sum of kinetic energy and potential energy of a system. A system can do work by utilizing its mechanical energy.
  - For example, machines use mechanical energy to do work.

b) Heat Energy

- An object possesses heat energy (thermal energy) due to the motion of molecules in it. The energy released when we burn wood, coal, oil, or gas is called heat energy.
- Steam possesses heat energy which is capable of doing work. If you cook food in a pressure cooker by placing it over a gas stove, the heat energy changes water into steam. The steam lifts the weight on the top of the lid and whistles. This lifting of weight suggests that heat is a form of energy that is capable of doing work.
- In 1765, James Watt, a young scientist, noted this phenomenon which led to the invention of the steam engine in which heat energy was used to do work.
- In thermal power stations, it is the heat energy of burning coal that is used to generate steam. The steam, in turn, runs the turbines of the generator and produces electric energy. All automobiles use heat energy by burning petrol, diesel, or CNG for doing work. The food which we consume burns slowly in our cells to produce heat energy.

c) Light energy

- Light energy is a form of electromagnetic radiation. When an excited electron in an atom or a molecule undergoes a transition from a higher energy level to a lower energy level, the difference in energy between the levels is sometimes emitted in the form of light. Light travels as waves and it is capable of travelling through vacuum.
- The plants absorb light energy and convert it into chemical energy (food) through a process called photosynthesis.

d) Sound energy

- Sound energy is produced when an object vibrates. A sound wave needs a medium to travel through such as air, water, wood, or metal. When sound waves fall on the ear membrane, they make it vibrate and we can hear the sound. When a supersonic plane breaks the sound barrier (speed of sound in air), the sound waves produced by it, shake the buildings. Similarly, the thunder of the cloud also shakes buildings. This shows that sound energy can also do work.

e) Electrical energy

- The energy produced by the movement of electrons is called electric energy. When electric energy passed through an electric motor, it sets its axle in a circular motion. This circular motion is utilized in running ceiling fans, juicers, grinders, etc. It is used for running electric moped, vehicles. It is used in factories for running heavy machines. It is also used in heating devices such as heaters, geysers, electric stoves, etc. It is also used in lighting bulbs.

f) Magnetic energy

- Magnetism is described by magnetic fields which are produced either by magnetic materials or by electric currents.
- Energy stored in a magnetic field is called magnetic energy.
- A magnet is capable of causing motion in magnetic substances.

  E.g: Iron cobalt, nickel are examples of magnetic substances.

  Magnetic energy is used in electromagnets, electric motors, electric generators, microphones, television tubes, telephones, etc. The cranes which lift heavy loads of iron or separate iron scrap from waste materials use electromagnets.

g) Chemical Energy

- Chemical energy is defined as the energy stored in the bonds between atoms or molecules in a compound. When this compound undergoes a chemical reaction, the chemical energy stored in the bonds will be released in the form of heat. The energy possessed by the fuels like coal, oil, gas, etc. is chemical energy. The chemical energy of diesel, petrol, or CNG is capable of moving vehicles. The food that we consume, possesses chemical energy which is utilized by our body to do work.

h) Nuclear energy

- The binding energy of nucleons (neutrons and protons) in the nucleus is called nuclear energy. The nucleus in an atom has an enormous amount of energy which holds the proton and neutrons together. When a heavy nucleus splits into light nuclei or two light nuclei combine to form one nucleus, it releases energy. Nuclear fission or fusion releases nuclear energy in the form of heat and light energy. In nuclear power stations, nuclear energy is used to generate electric energy. In the case of an atom bomb or hydrogen bomb, nuclear energy is used for destructive purposes

Solar Energy

- Solar energy is radiant light and heat from the Sun. Solar energy is created by nuclear fusion that takes place in the sun. The primary source of all kinds of energy on Earth is solar energy. Solar energy provides wind energy, tidal energy, and energy of sea waves. Solar energy causes the evaporation of water, which in turn leads to the water cycle. The phenomenon of photosynthesis is not possible without solar energy. It is necessary for life on Earth and can be harvested for human use in many ways. Solar cells absorb sunlight and convert solar energy into electrical energy. Solar cooker, Solar water heater, etc. utilizes heat energy present in the solar radiation.

Transformation of Energy

- Energy transformation is the process of converting one form of energy into another form.

There are various types of energy all around us and these energy sources can be converted from one form to another as explained below:

- Conversion of Potential energy into kinetic energy and vice versa
- Conversion of Light energy into heat energy.
- Conversion of Electrical energy into mechanical energy, light energy, heat energy, etc.
- Conversion of chemical energy into electrical energy.
- Conversion of mechanical energy into electrical energy, sound energy, etc.
- Conversion of Nuclear energy into light energy and heat energy.
- Conversion of Solar energy into heat energy, chemical energy, and electrical energy

Law Conservation of Energy

- *The Law of conservation of energy states that energy can neither be created nor be destroyed, but can be converted from one form to another. In other words, the total energy of an isolated system remains constant.*

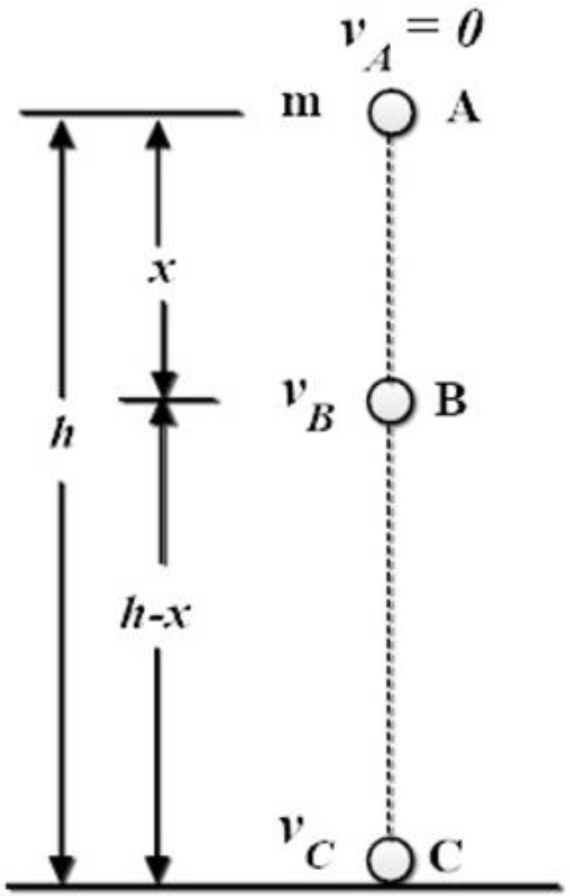
Proof

- Consider a body of mass ‘m’, initially placed at height ‘h’ above the ground level as shown in Figure.

Let the body is allowed to fall freely from its initial position A. In the case of a freely falling body, the total energy is the sum of its kinetic energy and potential energy.

As the body moves under gravity, its velocity increases and hence, kinetic energy increases.

But at the same time, the height of the body from the ground decreases, and hence, the potential energy decreases.



Total energy of a body freely falling from a height above the ground level

At Point A

Velocity at point A, $v_A = 0$

Kinetic energy at point A, $K_A = \frac{1}{2} m v_A{}^2 = 0$

The potential energy at point A, $V_A = mgh$

Total energy at point A, $E_A = K_A + V_A$

$$E_A = 0 + mgh = mgh \qquad \text{-------------} \; (1)$$

At Point B

Let B be a point at a distance x from point A. The velocity at point B, v_B can be calculated using the equation, $v^2 = u^2 + 2as$.

$$v = v_B\,; \quad u = v_A = 0; \quad a = g; \quad s = x;$$

$$v_B{}^2 = 2gx$$

Kinetic energy at point B, $K_B = \frac{1}{2} m v_B{}^2 = \frac{1}{2} m \times 2gx = mgx$

The potential energy at point A, $V_B = mg(h - x)$

Total energy at point A, $E_B = K_B + V_B$

$$E_B = mgx + mg(h - x) = mgh \qquad \text{----------} \; (2)$$

At point C

Let C be a point on the ground. The velocity at point C, v_C can be calculated using the equation, $v^2 = u^2 + 2as$.

$$v = v_C \,; \quad u = v_A = 0; \quad a = g; \quad s = h;$$

$$v_C{}^2 = 2gh$$

Kinetic energy at point C, $K_C = \frac{1}{2} m v_C{}^2 = \frac{1}{2} m \times 2gh = mgh$

The potential energy at point A, $V_C = 0$

Total energy at point A, $E_C = K_C + V_C$

$$E_C = mgh + 0 = mgh \text{ ---------- } (3)$$

It is clear from equations (1), (2), and (3) that $E_A = E_B = E_C$. Hence total energy of the freely falling body remains constant at every point on its path.