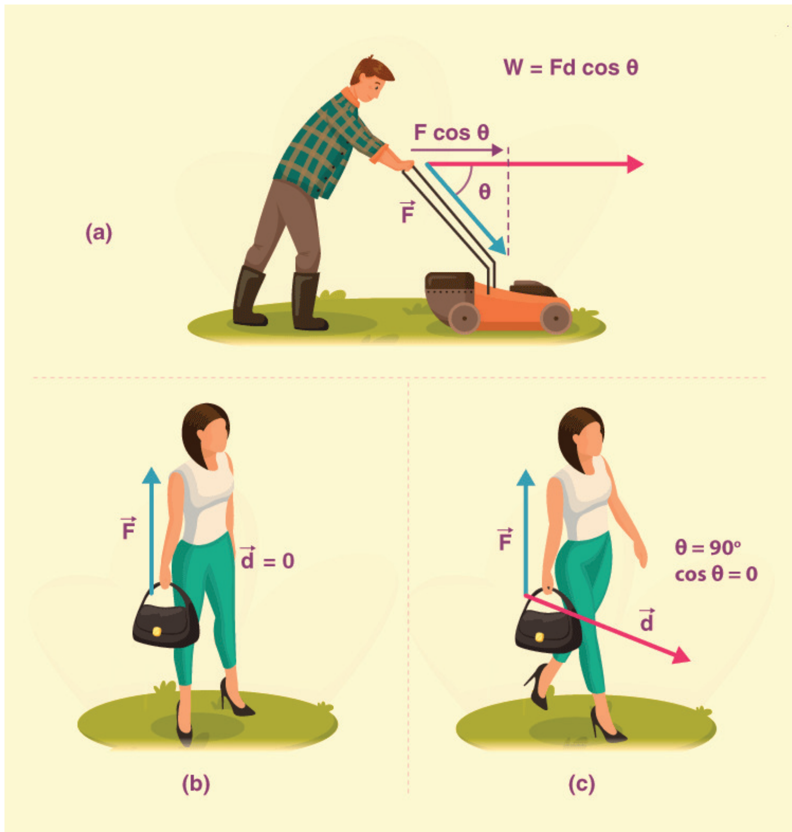
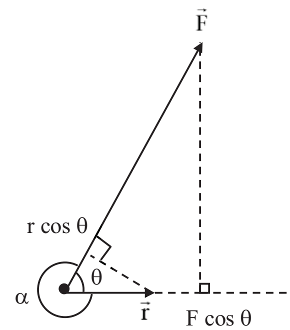
Work, Energy and Power



Work, Power and Energy

In everyday language and in ordinary sense, the term 'work' is used to denote any type of activity that requires the exertion of muscular or mental effort. In physics, the term 'work' has a precise meaning and an explicit definition. Similarly, the terms 'energy and power' are used in everyday life with different shades of meaning. The aim of this chapter is to understand these three physical quantities and to co-relate them.

Work



- **Definition of work:** It is the dot product of force $\vec{F}$ and the displacement $\vec{r}$

  $W = \vec{F}.\vec{r}$

  $= F.r\cos\theta = r.F\cos\theta$

  $= r.F\cos\theta$
- Work depends not only on the magnitudes of the displacement and the force but also on the angle between them.
- $W = 0$ if $\vec{F} \perp \vec{r}$ i.e. $\theta = 90°$

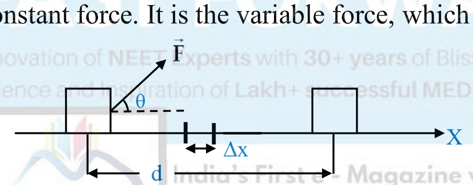
  $W =$ Fr if $\vec{F}$ is parallel to $\vec{r}$ i.e. $\theta = 0°$

  $W = -$Fr if $\vec{F}$ is antiparallel to $\vec{r}$ i.e. $\theta = 180°$
- Work is a scalar
- The dimensional formula for work is $[M^1L^2T^{-2}]$
- The SI unit of work is the joule (J)

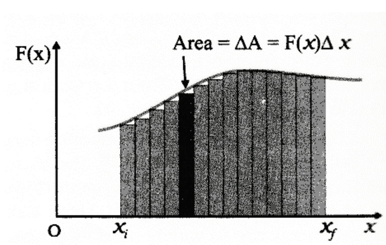
  1 J = 1 N m

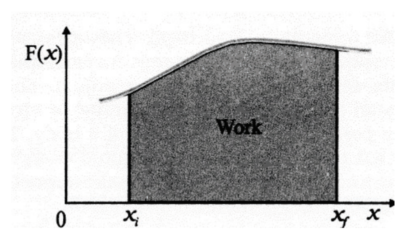
Work done by a variable force

Rarely we come across a constant force. It is the variable force, which is more commonly encountered.



An object undergoes a displacement d under the influence of the force F = F(x)





Work done is $W = \lim_{\Delta x \to 0} \sum_{x_i}^{x_f} F(x)\Delta x = \int_{x_i}^{x_f} F(x)\,dx$

For a varying force the work done can be expressed as a definite integral of force over displacement.

Nature of work done in various situations

Work done is given by $W = \vec{F} \cdot \vec{s}$

Therefore, work done will be positive, negative or zero depending on whether the angle between $\vec{F}$ or $\vec{s}$ is acute, obtuse or is 90°. Also, the work done is zero, when either $\vec{F}$ or $\vec{s}$ or both $\vec{F}$ and $\vec{s}$ are zero.

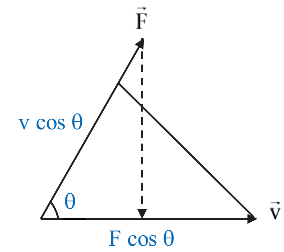
Power

It is the time rate of doing work

- Average power $P_{av} = \dfrac{\Delta W}{\Delta t}$, where $\Delta W \rightarrow$ work done in time Δt
- Instantaneous power, $P = \lim\limits_{\Delta t \to 0} \dfrac{\Delta W}{\Delta t} = \dfrac{dW}{dt}$
- The SI unit of power is watt. $1\ W = 1\ J\ s^{-1}$
- The dimensional formula for power is $[ML^2T^{-3}]$
- $P = \vec{F}.\vec{v} = Fv\cos\theta$, where $\theta \rightarrow$ angle between $\vec{F}$ and $\vec{v}$
- The FPS unit is the horse power (hp). This unit is still in use.

  The power of an engine is usually quoted in hp.

  1 hp = 746 W = 0.746 kW



Energy

A body capable of doing work is said to have 'energy'. Hence the term energy is defined as the capacity of a body to do work.

[When work is done on a body, it gains energy. When work is done by a body, it loses energy.]

The following points are important about energy.

- Energy is a scalar quantity.
- The unit of energy is same as that of work. In SI, the unit of energy is joule (J)
- Dimensional formula for energy is $[M\ L^2\ T^{-2}]$
- Energy manifests in different forms like mechanical energy, electrical energy, heat energy, sound energy, light energy, etc.
- The energy associated with the motion and position/configuration of a body or a physical system is called mechanical energy.

  The mechanical energy is of two types viz.,

  1. Kinetic energy 2. Potential energy

Kinetic energy

The energy possessed by a body by virtue of its motion is called kinetic energy.

Example: Energy possessed by a bullet fired from a gun.

Kinetic energy is given by $\dfrac{1}{2}mv^2$ where m is the mass of a body and v is its velocity.

Kinetic energy – momentum relation is $K = \dfrac{p^2}{2m}$

Both the kinetic energy K and linear momentum $\vec{p}$ of a particle depend on its velocity $\vec{v}$ and hence related to each other.

☞	Energy is a scalar quantity but momentum $\vec{p}$ is a vector quantity. But $\vec{p}\cdot\vec{p} = p^2$ is a scalar quantity.

Work and kinetic energy (Work energy theorem)

Statement

"*The change in kinetic energy of a particle is equal to the work done on it by the net force*".

$$K_f - K_i = W$$

where K_i and K_f are initial and final kinetic energies of the object.

- From the work energy theorem one can note the following points.

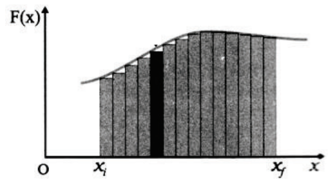
When work done on the object is positive, its kinetic energy increases.

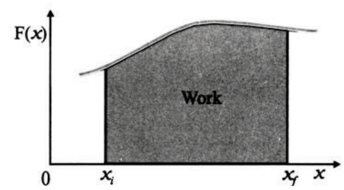
When work done on the object is negative, its kinetic energy decreases.

Work energy theorem for a variable force

For a variable force $\vec{F}$ acting on an object moving along x-axis and if K_i and K_f are the initial and final kinetic energies corresponding to x_i and x_f positions then, $K_f - K_i = W$.

$$W = \int_{x_i}^{x_f} F\,dx$$





Work energy theorem is an integral from of Newton's second law

Conservative and non-conservative force

	Conservative Force	Non-Conservative Force
1.	Work done is independent of path	Work done depends on the path
2.	Work done over a closed path is zero.	Work done over a closed path is non-zero
3.	Mechanical energy of the system (KE + PE) is always conserved	Mechanical energy of the system is not conserved
4.	PE can be defined. **Eg :** Gravitational force, Electrostatic force	PE can not be defined. **Eg :** Friction, viscous force, Air drag

Potential Energy

It is the energy possessed by a body by virtue of its position or configuration (shape or size).

OR

Potential energy of a system (configuration) may be defined as the amount of work done in bringing the bodies constituting the system to their present locations after having been removed to positions infinite distance apart.

Ex: The potential energy of water in dams is used to run turbines in order to produce electric energy from the generators.

The potential energy of a body may be the **positive** or **negative**.

1. If the force between the two bodies is repulsive in nature (such as between two like charges), then work has to be done by an external agent to bring the two bodies from infinity to their respective locations. Such a system is said to possess **positive potential energy**.
2. In case if the force between the two bodies constituting the system is attractive (such as between two unlike electric charges or between two masses) the two bodies will move at the expense of their own energy. Such a system is said to possess **negative potential energy**.