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Work

Definition and Conditions

Work is done when a force acting on a body produces displacement in it. It is a scalar quantity, meaning it has only magnitude and no direction.

Formula and Calculation

The work done by a force is given by the formula:

$$\text{Work} = \text{Force} \times \text{Displacement} \times \cos\theta$$

where θ is the angle between the force and the direction of displacement.

Types of Work

Work can be positive, negative, or zero depending on the angle between force and displacement:

- Positive work: When the force and displacement are in the same direction (angle less than 90°).
- Negative work: When the force and displacement are in opposite directions (angle greater than 90°).
- Zero work: When the displacement is zero or the force is perpendicular to displacement (angle is 90°).

Unit of Work

The SI unit of work is the joule (J). One joule is the work done when a force of one newton displaces an object by one metre in the direction of the force.

Solved Examples

Example 1: A force of 10 N acts on an object and displaces it by 5 m in the direction of the force. Calculate the work done.

Solution:

Given: Force (F) = 10 N, Displacement (d) = 5 m, $\theta = 0^\circ$ (since force and displacement are in the same direction)

Work done, $W = F \times d \times \cos\theta = 10 \times 5 \times \cos 0^\circ = 10 \times 5 \times 1 = 50 \text{ J}$

Example 2: A force of 20 N acts on an object, but the displacement is perpendicular to the force and is 3 m. Calculate the work done.

Solution:

Given: $F = 20 \text{ N}$, $d = 3 \text{ m}$, $\theta = 90^\circ$

Work done, $W = F \times d \times \cos\theta = 20 \times 3 \times \cos 90^\circ = 20 \times 3 \times 0 = 0 \text{ J}$

Practice Set

Conceptual Questions:

- **Level 1:** What is the SI unit of work?
- **Level 2:** Explain why no work is done when an object moves in a circular path under the action of a force directed towards the center.

Application-based Question:

- **Level 3:** A force of 15 N acts at an angle of 60° to the displacement of 4 m . Calculate the work done by the force.

Answer Key

Level 1: The SI unit of work is joule (J).

Level 2: When an object moves in a circular path, the force acts along the radius (towards the center), and the displacement is tangential. The angle between force and displacement is 90° , so work done is zero.

Level 3: Work done, $W = F \times d \times \cos\theta = 15 \times 4 \times \cos 60^\circ = 15 \times 4 \times 0.5 = 30 \text{ J}$.

Energy

Definition and Forms

Energy is the capacity to do work. It exists in various forms such as mechanical energy, heat energy, chemical energy, electrical energy, magnetic energy, sound energy, and light energy.

Kinetic Energy

Kinetic energy is the energy possessed by a body due to its motion. It is given by the formula:

$$\text{Kinetic Energy} = \frac{1}{2}mv^2$$

where m is the mass of the object and v is its velocity.

Potential Energy

Potential energy is the energy possessed by a body due to its position or configuration. Gravitational potential energy is given by:

$$\text{Potential Energy} = mgh$$

where m is mass, g is acceleration due to gravity, and h is height above the ground.

Law of Conservation of Energy

The law states that energy can neither be created nor destroyed; it can only be transformed from one form to another. The total mechanical energy in an ideal system remains constant.

Solved Examples

Example 1: Calculate the kinetic energy of a 2 kg object moving with a velocity of 3 m/s.

Solution:

Given: $m = 2 \text{ kg}$, $v = 3 \text{ m/s}$

$$\text{Kinetic Energy} = \frac{1}{2} \times 2 \times 3^2 = 1 \times 9 = 9 \text{ J}$$

Example 2: Find the potential energy of a 5 kg object raised to a height of 10 m. Take $g = 9.8 \text{ m/s}^2$.

Solution:

Given: $m = 5 \text{ kg}$, $h = 10 \text{ m}$, $g = 9.8 \text{ m/s}^2$

$$\text{Potential Energy} = mgh = 5 \times 9.8 \times 10 = 490 \text{ J}$$

Practice Set

Conceptual Questions:

- **Level 1:** Define kinetic energy.
- **Level 2:** State the law of conservation of energy.

Application-based Question:

- **Level 3:** An object of mass 3 kg is moving with a velocity of 4 m/s at a height of 5 m. Calculate its total mechanical energy. (Take $g = 9.8 \text{ m/s}^2$)

Answer Key

Level 1: Kinetic energy is the energy possessed by a body due to its motion.

Level 2: Energy cannot be created or destroyed; it can only be transformed from one form to another.

Level 3: Kinetic Energy = $\frac{1}{2} \times 3 \times 4^2 = 24 \text{ J}$

Potential Energy = $3 \times 9.8 \times 5 = 147 \text{ J}$

Total Mechanical Energy = $24 + 147 = 171 \text{ J}$

Power

Definition and Formula

Power is the rate at which work is done. It is a scalar quantity.

Mathematically, power is given by:

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

Units of Power

The SI unit of power is the watt (W). One watt is equal to one joule of work done per second.

Other units include kilowatt (kW) and horsepower (hp).

Average Power

Average power is calculated by dividing the total work done or energy consumed by the total time taken.

Solved Examples

Example 1: A machine does 500 J of work in 10 seconds. Calculate its power.

Solution:

$$\text{Power} = \text{Work} / \text{Time} = 500 \text{ J} / 10 \text{ s} = 50 \text{ W}$$

Example 2: A motor has a power rating of 2 kW. How much work can it do in 5 minutes?

Solution:

$$\text{Power} = 2 \text{ kW} = 2000 \text{ W}, \text{ Time} = 5 \text{ minutes} = 300 \text{ seconds}$$

$$\text{Work done} = \text{Power} \times \text{Time} = 2000 \times 300 = 600,000 \text{ J}$$

Practice Set

Conceptual Questions:

- **Level 1:** What is the SI unit of power?
- **Level 2:** Explain the difference between work and power.

Application-based Question:

- **Level 3:** A person lifts a 50 kg object to a height of 2 m in 4 seconds. Calculate the power exerted. (Take $g = 9.8 \text{ m/s}^2$)

Answer Key

Level 1: The SI unit of power is watt (W).

Level 2: Work is the product of force and displacement, while power is the rate at which work is done over time.

Level 3: Work done = $mgh = 50 \times 9.8 \times 2 = 980 \text{ J}$

Power = Work / Time = $980 / 4 = 245 \text{ W}$

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