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Work and Power

Definition of Work

Work is said to be done when a force causes displacement of a body in the direction of the applied force. Mathematically, work done W is given by the dot product of force \vec{F} and displacement \vec{s} :

$$W = \vec{F} \cdot \vec{s} = Fs \cos \theta$$

where θ is the angle between the force and displacement vectors.

Properties of Work

- Work is a scalar quantity.
- Work done is positive when $0 \leq \theta < \frac{\pi}{2}$.
- Work done is negative when $\frac{\pi}{2} < \theta \leq \frac{3\pi}{2}$.
- Work done is zero when force is perpendicular to displacement ($\theta = 90^\circ$).
- SI unit of work is joule (J), where 1 joule = 1 newton meter (N·m).
- CGS unit of work is erg, where 1 joule = 10^7 erg.
- Work done does not depend on the time taken to do the work.

Internal Work or Zero Work

Internal work refers to the work done by muscles when strained without causing displacement. For example, a person standing still carrying a heavy load does zero external work but experiences internal work due to muscle strain.

Dimensions of Work

Work has dimensions $[ML^2T^{-2}]$.

Definition of Power

Power is the rate at which work is done. It measures how quickly work is performed.

Mathematically,

$$P = \frac{\text{Work done}}{\text{Time taken}} = \frac{W}{t}$$

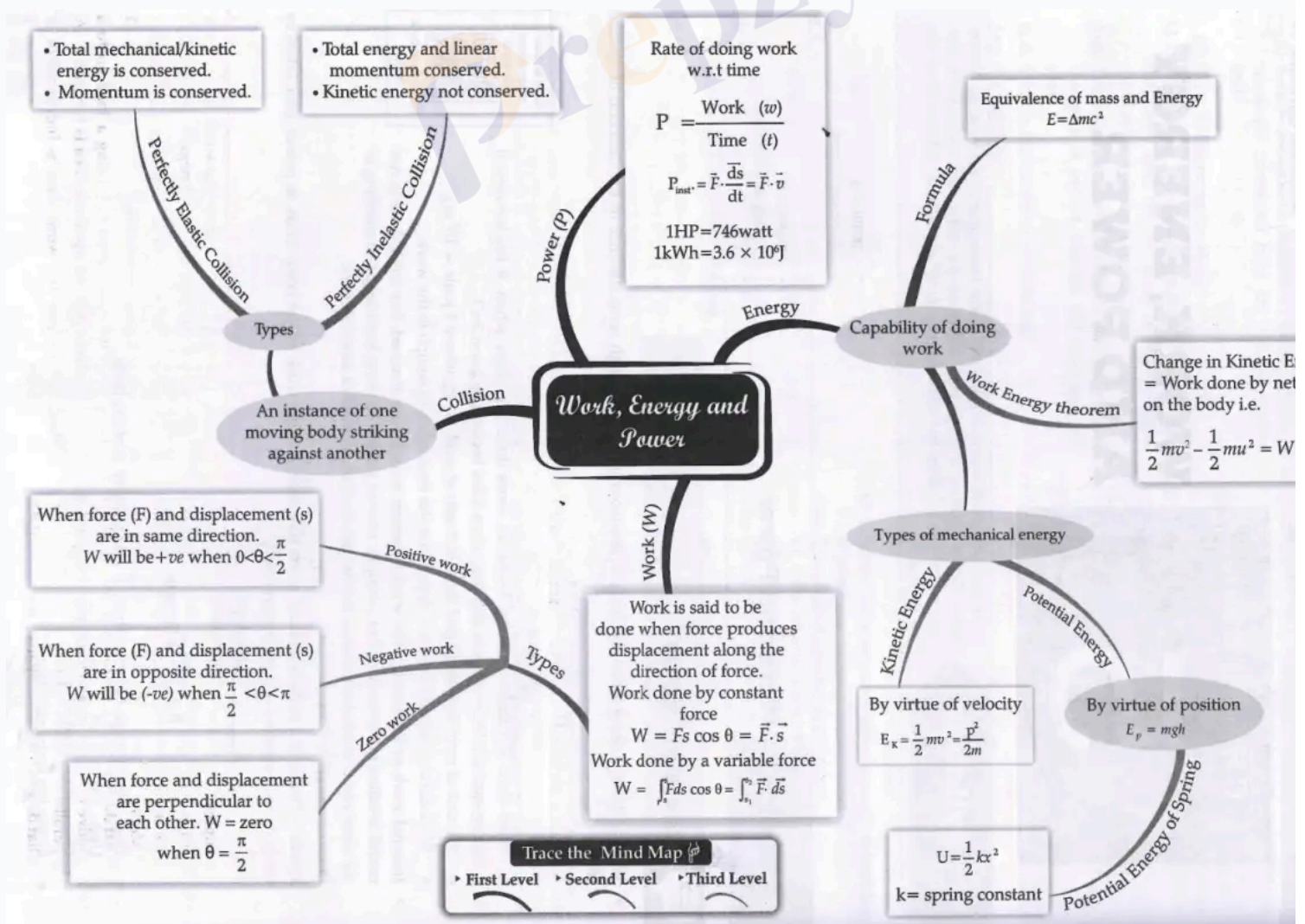
Alternatively, power can be expressed as the dot product of force and velocity:

$$P = \vec{F} \cdot \vec{v} = Fv \cos \theta$$

where θ is the angle between force and velocity vectors.

Properties of Power

- Power is a scalar quantity.
- SI unit of power is watt (W), where 1 watt = 1 joule per second (J/s).
- Dimensions of power are $[ML^2T^{-3}]$.



Solved Examples

Example 1: Calculating Work Done

A force of 10 N is applied to move a box 5 m along the direction of the force. Calculate the work done.

Solution:

Given: $F = 10 \text{ N}$, $s = 5 \text{ m}$, $\theta = 0^\circ$

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

Example 2: Calculating Power

A machine does 200 J of work in 10 seconds. Find the power of the machine.

Solution:

Given: $W = 200 \text{ J}$, $t = 10 \text{ s}$

Power, $P = \frac{W}{t} = \frac{200}{10} = 20 \text{ W}$

Practice Set

- **Level 1:** Define work done and state its SI unit.
- **Level 2:** A force of 15 N acts at an angle of 60° to the displacement of 4 m. Calculate the work done.
- **Level 3:** A person lifts a 50 kg object vertically upward by 2 m in 5 seconds. Calculate the power exerted by the person. (Take $g = 9.8 \text{ m/s}^2$)

Answer Key

Level 1: Work done is the product of force and displacement in the direction of force. SI unit is joule (J).

Level 2: $W = Fs \cos \theta = 15 \times 4 \times \cos 60^\circ = 15 \times 4 \times 0.5 = 30 \text{ J}$

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

Time $t = 5 \text{ s}$

Power $P = \frac{W}{t} = \frac{980}{5} = 196 \text{ W}$

Energy and Collision

Definition of Energy

Energy is the capacity of a body to do work. It is a scalar quantity and has the same units and dimensions as work.

Units of Energy

- 1 calorie = 4.2 joules
- 1 kilowatt hour (kWh) = 3.6×10^6 joules
- 1 electron volt (eV) = 1.6×10^{-19} joules

Work-Energy Theorem

The work done by the net force on a body is equal to the change in its kinetic energy:

$$W = K_f - K_i$$

where K_f and K_i are the final and initial kinetic energies respectively.

Types of Collisions

When two bodies collide, they exchange energy and momentum. Collisions are classified as:

- **Perfectly Elastic Collision:** Total kinetic energy before and after collision remains the same. Example: collisions between atomic particles
- **Perfectly Inelastic Collision:** Kinetic energy is not conserved; bodies stick together after collision. Linear momentum and total energy are conserved.

Key Terms

- **Kinetic Energy (K.E.):** Energy due to motion, always positive. $K. E. = \frac{1}{2}mv^2$
- **Potential Energy (P.E.):** Energy due to position, can be positive or negative. $P. E. = mgh$
- **Gravitational Potential Energy:** Energy due to position relative to Earth's center.
- **Potential Energy of Spring:** Energy stored due to compression or extension of a spring.
- **Internal Energy:** Energy due to molecular configuration.
- **Coefficient of Restitution (e):** Ratio of relative velocity after collision to that before collision.

Important Formulas

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

$$P. E. = mgh$$

$$v = \sqrt{2gh}$$

$$F = -kx$$

(Force in spring)

$$E = mc^2$$

(Mass-energy equivalence)

$$e = \frac{v_2 - v_1}{u_2 - u_1}$$

Elastic Collision in One Dimension

Velocities after collision:

$$v_1 = \frac{m_1 - m_2}{m_1 + m_2} u_1 + \frac{2m_2}{m_1 + m_2} u_2$$

$$v_2 = \frac{2m_1}{m_1 + m_2} u_1 + \frac{m_2 - m_1}{m_1 + m_2} u_2$$

Inelastic Collision in One Dimension

If $u_2 = 0$, velocity after collision:

$$v = \frac{m_1 u_1}{m_1 + m_2}$$

Loss in Kinetic Energy

$$\text{Loss} = \frac{m_1 m_2 u_1^2}{2(m_1 + m_2)}$$

Solved Examples

Example 1: Calculating Kinetic Energy

A 2 kg object moves with a velocity of 3 m/s. Find its kinetic energy.

Solution:

$$K. E. = \frac{1}{2}mv^2 = \frac{1}{2} \times 2 \times 3^2 = 9 \text{ J}$$

Example 2: Coefficient of Restitution

Two balls collide with velocities before collision $u_1 = 5 \text{ m/s}$, $u_2 = 2 \text{ m/s}$ and after collision $v_1 = 3 \text{ m/s}$, $v_2 = 4 \text{ m/s}$. Find the coefficient of restitution.

Solution:

$$e = \frac{v_2 - v_1}{u_1 - u_2} = \frac{4 - 3}{5 - 2} = \frac{1}{3} \approx 0.33$$

Practice Set

- **Level 1:** Define kinetic energy and potential energy.
- **Level 2:** Calculate the potential energy of a 10 kg object raised to a height of 5 m. (Take $g = 9.8 \text{ m/s}^2$)
- **Level 3:** Two objects of masses 3 kg and 2 kg move towards each other with velocities 4 m/s and 3 m/s respectively. They collide perfectly inelastically. Find their velocity after collision and the loss in kinetic energy.

Answer Key

Level 1: Kinetic energy is the energy due to motion, $K. E. = \frac{1}{2}mv^2$. Potential energy is the energy due to position, $P. E. = mgh$.

Level 2: $P. E. = mgh = 10 \times 9.8 \times 5 = 490 \text{ J}$

Level 3: Total mass = $3 + 2 = 5 \text{ kg}$

Initial momentum = $3 \times 4 + 2 \times (-3) = 12 - 6 = 6 \text{ kg m/s}$

Velocity after collision $v = \frac{6}{5} = 1.2 \text{ m/s}$

Initial kinetic energy = $\frac{1}{2} \times 3 \times 4^2 + \frac{1}{2} \times 2 \times 3^2 = 24 + 9 = 33 \text{ J}$

Final kinetic energy = $\frac{1}{2} \times 5 \times (1.2)^2 = 3.6 \text{ J}$

Loss in kinetic energy = $33 - 3.6 = 29.4 \text{ J}$

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