WORK POWER AND ENERGY

JEE MAINS Physics — Class 11 — Complete formula Sheet

WORK

$W = \vec{F} \cdot \vec{d} = Fd\cos\theta$

$W = \int \vec{F} \cdot d\vec{r}$

SI unit: Joule (J) = N · m

Special Cases

- $\theta = 0$: $W = Fd$ (max, positive)
- $\theta = 90$: $W = 0$ (normal force, centripetal)
- $\theta = 180$: $W = -Fd$ (friction opposing motion)
- Work by spring: $W = -\frac{1}{2}kx^2$ (on block by spring restoring)
- Work by gravity: $W_g = mgh$ (h = vertical drop)

Work by Variable Force

$W = \int_{x_1}^{x_2} F(x)\,dx$

= Area under F-x graph

KINETIC ENERGY

$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

$p = \sqrt{2m \cdot KE}$

- KE is always ≥ 0
- KE is scalar
- $KE \propto v^2$ (doubles $v \Rightarrow 4 \times KE$)

WORK–ENERGY THEOREM

Work–Energy Theorem

$W_{\text{net}} = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$

- Applies for all forces (friction, normal, gravity)
- Net work by all forces = change in KE
- Work done by normal force = 0 (if ⊥ motion)

POTENTIAL ENERGY

$F = -\frac{dU}{dx}$ (conservative force)

$U_{\text{gravity}} = mgh$ (near Earth)

$U_{\text{spring}} = \frac{1}{2}kx^2$

$U_{\text{gravity}} = -\frac{GMm}{r}$ (universal)

Equilibrium from Potential

- Stable: $\frac{d^2U}{dx^2} > 0$ (U is minimum)
- Unstable: $\frac{d^2U}{dx^2} < 0$ (U is maximum)
- Neutral: $\frac{d^2U}{dx^2} = 0$ (U is constant)

CONSERVATION OF ENERGY

Mechanical Energy Conservation

$KE + PE = \text{const}$ (no friction)

$\frac{1}{2}mv^2 + mgh = \text{const}$

With Non-Conservative Forces

$W_{\text{friction}} = \Delta KE + \Delta PE$

$= E_f - E_i$ (energy lost to heat)

Spring–Mass System

- Max compression x_0: $\frac{1}{2}mv^2 = \frac{1}{2}kx_0^2$
- $x_0 = v\sqrt{m/k}$
- At natural length: all KE; at x_0: all PE

POWER

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

SI unit: Watt (W) = J/s

1 hp = 746 W

- Avg power: $\bar{P} = \frac{\Delta W}{\Delta t}$
- Instantaneous: $P = Fv$
- Power of engine pulling at const v: $P = Fv = f_k v$ (friction)

CONSERVATIVE FORCES

Conservative: work depends only on endpoints

$\oint \vec{F} \cdot d\vec{r} = 0$ (closed path)

Examples: gravity, spring, electrostatic

Non-conservative: friction, air drag, tension (in some cases)

COLLISIONS

Elastic Collision

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$

$v_1 = \frac{(m_1 - m_2)u_1 + 2m_2u_2}{m_1 + m_2}$

$v_2 = \frac{(m_2 - m_1)u_2 + 2m_1u_1}{m_1 + m_2}$

Perfectly Inelastic

$v_{\text{common}} = \frac{m_1u_1 + m_2u_2}{m_1 + m_2}$

$\Delta KE = \frac{m_1m_2(u_1 - u_2)^2}{2(m_1 + m_2)}$ (loss)

Coefficient of Restitution

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

Elastic: $e = 1$; Inelastic: $0 < e < 1$; Perfectly inelastic: $e = 0$

KEY TRICKS

- Work by static friction on system = 0
- Centripetal force does no work
- $W_{\text{tension}} = 0$ for inextensible string
- Equal masses elastic: velocities exchange
- Bullet in block: use momentum then energy