FREE EDITION · NOTES + 3 SAMPLE MCQS

CUET · PHYSICS · CLASS XI · CODE 322

Work, Energy and Power

CUET unit: Work, Energy and Power

By **UniDrill** · NCERT-grounded study material

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📌 Snapshot

- Work, kinetic energy, potential energy, power and collisions each have precise physics meanings, distinct from everyday usage.
- It introduces the mathematical prerequisite of the scalar (dot) product of vectors, which is then used to define work as W = F·d.
- The work-energy theorem ($K_f - K_i = W$) is derived first for a constant force and then generalised to a variable force using integration.
- It develops the idea of conservative forces (gravity, spring) leading to potential energy functions V(h) = mgh and $V(x) = kx^2/2$, and the principle of conservation of mechanical energy.
- One- and two-dimensional collisions are analysed using momentum conservation, with elastic, inelastic and perfectly inelastic cases worked out — a high-yield CUET topic.

📖 Detailed Notes

2.1 Core concepts

- The **scalar product** of two vectors is defined as A·B = AB cos θ, where θ is the angle between the vectors; it is a scalar quantity even though A and B have directions (NCERT §5.1.1, p. 72).
- Geometrically, A·B is the product of the magnitude of A with the projection of B on A (B cos θ), or equivalently the magnitude of B with the projection of A on B (A cos θ) (NCERT §5.1.1, p. 72).
- The scalar product obeys the **commutative law** (A·B = B·A) and the **distributive law** [A·(B + C) = A·B + A·C], and for unit vectors $\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$ and $\hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 0$ (NCERT §5.1.1, p. 72).
- For two vectors $A = A_x \hat{i} + A_y \hat{j} + A_z \hat{k}$ and $B = B_x \hat{i} + B_y \hat{j} + B_z \hat{k}$, $A\cdot B = A_x B_x + A_y B_y + A_z B_z$; also $A\cdot A = A^2$ (NCERT §5.1.1, p. 72).
- Starting from $v^2 - u^2 = 2\,a\cdot d$ and multiplying by m/2, one obtains $(½)mv^2 - (½)mu^2 = F\cdot d$, which motivates definitions of kinetic energy K and work W (NCERT §5.2, p. 73).
- **Work-energy (WE) theorem:** the change in kinetic energy of a particle equals the work done on it by the net force, $K_f - K_i = W$ (NCERT §5.2, Eq. 5.3, p. 73).

- For a **constant force**, $W = (F \cos \theta)d = \mathbf{F}\cdot\mathbf{d}$; no work is done if (i) displacement is zero, (ii) force is zero, or (iii) force is perpendicular to displacement (NCERT §5.3, Eq. 5.4, p. 74).
- Work can be positive ($0 \leqslant \theta < 90°$), zero ($\theta = 90°$), or negative ($90° < \theta \leqslant 180°$); friction opposing motion does negative work since $\cos 180° = -1$ (NCERT §5.3, p. 74).
- Dimensions of work and energy are $[ML^2T^{-2}]$; SI unit is the **joule** (J), named after James Prescott Joule (NCERT §5.3, p. 74).
- **Kinetic energy** of a body of mass m moving with velocity v is $K = (½)\, m\, \mathbf{v}\cdot\mathbf{v} = (½)\, m v^2$; it is a scalar and measures the work the body can do by virtue of its motion (NCERT §5.4, Eq. 5.5, p. 74).
- For a **variable force** $F(x)$ in 1-D, the work done over a small displacement Δx is $\Delta W = F(x)\, \Delta x$; summing infinitesimal rectangles gives $W = \int F(x)\, dx$ from x_i to x_f, i.e. the area under the F–x curve (NCERT §5.5, Eqs. 5.6–5.7, p. 75).
- **WE theorem for variable force:** starting from $dK/dt = Fv = F(dx/dt)$, integration gives $K_f - K_i = \int F\, dx$, so the theorem also holds for variable forces (NCERT §5.6, Eq. 5.8, p. 76).
- **Potential energy** is "stored energy" by virtue of position or configuration; the body releases it as kinetic energy when constraints are removed (NCERT §5.7, p. 77).
- **Gravitational PE** near the earth: $V(h) = mgh$, and the gravitational force $F = -dV/dh = -mg$ (downward); when released, $V(h)$ converts to KE so that $(½)mv^2 = mgh$ just before striking the ground (NCERT §5.7, p. 77).
- A force $F(x)$ is **conservative** if (i) it can be derived from a scalar $V(x)$ as $F(x) = -dV/dx$, (ii) work done depends only on end points, or (iii) work done over a closed path is zero (NCERT §5.7 and §5.8, p. 78).
- **Conservation of mechanical energy:** if only conservative forces act, then $\Delta K + \Delta V = 0 \Rightarrow K + V = \text{constant}$; i.e. $K_i + V(x_i) = K_f + V(x_f)$ (NCERT §5.8, Eqs. 5.10–5.11, p. 78).
- For a ball dropped from height H: total energy $E_H = mgH$ at the top, $E_h = mgh + (½)mv_h^2$ at intermediate height h, and $E_0 = (½)m\, v_f^2$ at the ground; conservation gives $v_f = \sqrt{2gH}$ and $v_h = \sqrt{2g(H - h)}$ (NCERT §5.8, Eq. 5.11, p. 79).
- **Spring force** obeys Hooke's law $F_s = -kx$, where k is the spring constant; the force is variable but conservative (NCERT §5.9, p. 80).
- Work done by the spring force when stretched/compressed from 0 to x_m is $W_s = -k\, x_m^2/2$ (area of the F–x triangle); over a cyclic path $W_s = 0$ (NCERT §5.9, Eqs. 5.15–5.18, p. 80–81).
- **Spring PE:** $V(x) = kx^2/2$ (zero taken at the equilibrium position); the speed and KE are maximum at $x = 0$, with $v_m = \sqrt{k/m} \cdot x_m$ (NCERT §5.9, Eq. 5.19, p. 81).
- The zero of potential energy is arbitrary (a matter of convenience), but must be consistently used throughout a problem (NCERT §5.9 remarks, p. 82).

- In presence of a non-conservative force F_{nc}, mechanical energy is no longer conserved: $E_f - E_i = W_{nc}$, where W_{nc} depends on the path (NCERT §5.9, p. 82–83).
- **Power** is the time rate of doing work: average power $P_{av} = W/t$ and instantaneous power $P = dW/dt = F \cdot v$ (NCERT §5.10, Eqs. 5.20–5.21, p. 83–84).
- Power is a scalar; SI unit watt (W) = 1 J s^{-1}; dimensions $[ML^2T^{-3}]$. 1 hp = 746 W. 1 kWh = 3.6×10^6 J — a unit of energy, not power (NCERT §5.10, p. 84).
- **Collisions:** in every collision **total linear momentum is conserved** (follows from Newton's third law: $F_{12} = -F_{21}$ so $\Delta p_1 + \Delta p_2 = 0$); kinetic energy is not in general conserved (NCERT §5.11.1, p. 85).
- **Elastic collision:** both momentum and kinetic energy are conserved. **Inelastic collision:** only momentum is conserved; some KE is lost as heat, sound, deformation. **Completely inelastic:** the two bodies stick and move together (NCERT §5.11.1, p. 85).
- **1-D completely inelastic collision** (m_2 at rest): $m_1 v_{1i} = (m_1 + m_2) v_f$, giving $v_f = m_1 v_{1i}/(m_1 + m_2)$; loss in KE $\Delta K = (½) m_1 m_2 v_{1i}^2/(m_1 + m_2)$ (NCERT §5.11.2, Eq. 5.22, p. 85).
- **1-D elastic collision** (m_2 at rest): final velocities are $v_{1f} = (m_1 - m_2)/(m_1 + m_2) \cdot v_{1i}$ and $v_{2f} = 2 m_1/(m_1 + m_2) \cdot v_{1i}$ (NCERT §5.11.2, Eqs. 5.26–5.27, p. 85).
- Special cases: if $m_1 = m_2$, then $v_{1f} = 0$ and $v_{2f} = v_{1i}$ (first body stops, second moves with v_{1i}); if $m_2 \gg m_1$, then $v_{1f} \approx -v_{1i}$ and $v_{2f} \approx 0$ (heavier body undisturbed, lighter rebounds) (NCERT §5.11.2, p. 85).
- **2-D collisions:** linear momentum conservation gives $m_1 v_{1i} = m_1 v_{1f} \cos \theta_1 + m_2 v_{2f} \cos \theta_2$ and $0 = m_1 v_{1f} \sin \theta_1 - m_2 v_{2f} \sin \theta_2$; for elastic case the KE equation provides a third equation, but one unknown (e.g. θ_1) must still be supplied (NCERT §5.11.3, Eqs. 5.28–5.30, p. 86).
- When two equal masses undergo a glancing elastic collision with one initially at rest, after collision they move at right angles to each other (NCERT §5.11.3, Example 5.12, p. 86).
- **Different forms of energy and their interconvertibility**: the law of conservation of energy, in its broadest sense, says the total energy of an isolated system is constant, although energy may change form (mechanical, heat, electrical, chemical, nuclear). Mechanical-energy conservation is a special case valid when only conservative forces act (NCERT §5.8, p. 79).
- **Mass–energy equivalence (Einstein)**: every form of mass m has an associated rest energy $E = mc^2$. In ordinary mechanics this rest energy is gigantic (1 g ≡ 9×10^{13} J) but unchanging, so we treat KE and PE alone. In nuclear reactions, however, small fractions of mass convert into kinetic energy of products — the basis of fission and fusion (NCERT §5.8 remark; broader development in Class XII Nuclei).
- **Coefficient of restitution e** = (relative velocity of separation)/(relative velocity of approach). $e = 1$ for an elastic, $0 < e < 1$ for an inelastic, and $e = 0$ for a perfectly

inelastic collision — these cases are the three referred to throughout §5.11 (NCERT §5.11.1, p. 85).

- **Vertical-circle motion of a bob on a string**: combining centripetal-force at the top ($T_{top} + mg = mv_{top}^2/L$) with energy conservation gives $v_{bottom} = \sqrt{5gL}$ and $v_{top} = \sqrt{gL}$; these critical-speed results recur in NCERT exercises (NCERT Fig. 5.6, p. 79).

2.2 Definitions to memorise

Term	Definition	Page
Scalar (dot) product	$A \cdot B = AB \cos\theta$; commutative, distributive; gives a scalar from two vectors	72
Work (constant force)	$W = (F \cos\theta)\, d = F \cdot d$; component of force along displacement times displacement	74
Joule (J)	SI unit of work/energy; dimensions $[ML^2T^{-2}]$, named after J. P. Joule	74
Kinetic energy	$K = (½)\, m v^2$; scalar; measure of work a body can do by virtue of its motion	74
Work-energy theorem	$K_f - K_i = W$ (work done by net force equals change in KE)	73
Work by variable force	$W = \int F(x)\, dx$ from x_i to x_f; area under F–x curve	75
Conservative force	$F = -dV/dx$; work is path-independent; work over a closed loop = 0	78
Gravitational PE	$V(h) = mgh$ (near earth's surface, g treated as constant)	77
Hooke's law	$F_s = -kx$; k is the spring constant, unit $N\ m^{-1}$	80
Spring PE	$V(x) = kx^2/2$ (zero at equilibrium position)	81
Conservation of mechanical energy	$K + V$ = constant if only conservative forces do work	78
Power (avg / instantaneous)	$P_{av} = W/t$; $P = dW/dt = F \cdot v$; scalar; SI unit watt ($1\ J\ s^{-1}$)	83–84
Horsepower	1 hp = 746 W	84
Kilowatt-hour	$1\ kWh = 3.6 \times 10^6\ J$ (unit of energy, not power)	84
Elastic collision	Both momentum and KE conserved	85
Inelastic collision	Only momentum conserved (KE partly lost)	85
Completely inelastic collision	Bodies stick together after impact; $v_f = m_1 v_{1i}/(m_1 + m_2)$	85
Coefficient of restitution (e)	Ratio of relative speed of separation to relative speed of approach; e = 1 elastic, e = 0 perfectly inelastic	85

Term	Definition	Page
Spring constant (k)	Force per unit displacement in Hooke's law $F_s = -kx$; SI unit $N\ m^{-1}$	80
Watt (W)	SI unit of power; $1\ W = 1\ J\ s^{-1}$	84
Force from PE	$F(x) = -dV/dx$	78
Variable force	Force whose magnitude or direction depends on x; work is $\int F(x)\,dx$	75
Non-conservative force	Force whose work depends on path (e.g. friction); mechanical energy not conserved	82
Conservation of energy (general)	Total energy of an isolated system is constant; may change form	79
Mass–energy relation	$E = mc^2$ (Einstein)	79 (remark)
Vertical-circle critical speeds	$v_{bottom} = \sqrt{5gL}$, $v_{top} = \sqrt{gL}$	Fig. 5.6, p. 79

2.3 Diagrams / processes to remember

- **Fig. 5.1 (a), (b), (c) (p. 72):** Geometric meaning of the scalar product — A·B as A times the projection of B onto A, and vice versa.
- **Fig. 5.2 (p. 73):** A constant force F acting through displacement d, used to define W = F·d.
- **Fig. 5.3 (a), (b) (p. 75):** Work done by a variable force F(x) — sum of rectangles tending to the area under the curve as $\Delta x \to 0$.
- **Fig. 5.4 (p. 76):** Force applied by a woman pushing a trunk versus the opposing friction f = 50 N; areas give $W_F = 1750$ J and $W_f = -1000$ J.
- **Fig. 5.5 (p. 78):** Ball dropped from a cliff of height H — illustrates conversion of PE to KE with E remaining constant.
- **Fig. 5.6 (p. 79):** Bob on a light string of length L describing a vertical circle — used to derive $v_0 = \sqrt{5gL}$ and $v_C = \sqrt{gL}$.
- **Fig. 5.7 (a)–(d) (p. 80):** Spring on a smooth surface — equilibrium, stretched ($F_s < 0$), compressed ($F_s > 0$), and the F_s vs x plot whose triangular area equals the work done.
- **Fig. 5.8 (p. 81):** Parabolic plots of $V = kx^2/2$ and K for a spring–mass system, complementary, with E = K + V constant.
- **Fig. 5.9 (p. 82):** Forces on a car colliding with a spring in presence of friction — used to obtain the quadratic for x_m.
- **Fig. 5.10 (p. 84):** Two-body collision of m_1 (moving with v_{1i}) with m_2 at rest — basis for 1-D and 2-D collision analysis.

2.4 Common confusions / NTA trap points

- Students confuse the magnitude of force with work: pushing hard against a rigid wall does NO work since displacement is zero (NCERT §5.3, p. 74).
- For a body moving in a circle (e.g. moon around earth), the gravitational force is perpendicular to velocity, so the work done over one orbit is zero — easy to misjudge.
- Newton's third law gives equal and opposite forces, but the works done by them need not be equal and opposite (e.g. cycle stops on road — road does −2000 J on cycle, cycle does 0 J on road since road doesn't move) (NCERT Ex. 5.3, p. 74).
- Distinguish carefully: in an **inelastic** collision only momentum is conserved (KE is lost), while in an **elastic** collision both momentum and KE are conserved. Many students wrongly assume KE is always conserved.
- For the elastic 1-D collision formulae v1f = (m1 − m2)v1i/(m1 + m2) and v2f = 2 m1 v1i/(m1 + m2), watch for the sign — if m2 > m1, v1f is negative (incident body rebounds).
- 1 kWh is a unit of **energy**, not power; students often mark it as a power unit (NCERT §5.10, p. 84).
- Spring potential energy $V = kx^2/2$ is the same whether the spring is stretched or compressed by the same magnitude (sign of x doesn't matter).
- The zero of potential energy is arbitrary; only the change in PE has physical meaning. Standard choices: ground for gravity, equilibrium position for spring.
- **Centripetal force does no work.** For uniform circular motion the force is perpendicular to v, so W = 0 over any closed orbit; mistaking F × distance-around for work is a routine NTA trap.
- **In a perfectly inelastic collision, KE is lost but not all of it.** A common error is to write $\Delta K = \frac{1}{2} m_1 v_{1i}^2$; the actual loss is $\frac{1}{2} \frac{m_1 m_2}{m_1+m_2} v_{1i}^2$ (the rest survives as KE of the combined mass).
- **Power output of a vehicle at constant speed equals F_drag × v.** Doubling v on a flat road requires (approximately) double the engine power if drag is constant — useful for highway-mileage questions.
- **Spring PE depends on x^2, so doubling compression quadruples PE.** Students sometimes write $V \propto x$ or $V \propto k^2$, getting the dependence wrong.

2.5 Key formulas table

Quantity	Symbol / Formula	NCERT reference
Scalar product	$A \cdot B = AB \cos \theta = A_x B_x + A_y B_y + A_z B_z$	§5.1.1, p. 72
Work (constant force)	$W = F \cdot d = Fd \cos \theta$	§5.3, Eq. 5.4, p. 74
Work (variable force)	$W = \int_{x_i}^{x_f} F(x)\, dx$	§5.5, Eq. 5.7, p. 75

Quantity	Symbol / Formula	NCERT reference
Kinetic energy	$K = \frac{1}{2} m v^2$	§5.4, Eq. 5.5, p. 74
Work-energy theorem	$K_f - K_i = W_{net}$	§5.2, Eq. 5.3, p. 73
Gravitational PE (near Earth)	$V(h) = mgh$	§5.7, p. 77
Force from potential	$F = -dV/dx$	§5.7, p. 78
Hooke's law	$F_s = -k x$	§5.9, p. 80
Spring PE	$V(x) = \frac{1}{2} k x^2$	§5.9, Eq. 5.19, p. 81
Mechanical-energy conservation	$K + V$ = constant (conservative force only)	§5.8, Eq. 5.11, p. 78
Average power	$P_{avg} = W/t$	§5.10, p. 83
Instantaneous power	$P = dW/dt = F \cdot v$	§5.10, Eq. 5.21, p. 84
Horsepower / kWh	1 hp = 746 W; 1 kWh = 3.6×10^6 J	§5.10, p. 84
Momentum conservation (collisions)	$\Sigma\ p_{initial} = \Sigma\ p_{final}$	§5.11.1, p. 85
1-D elastic collision (m_2 at rest)	$v_{1f} = (m_1 - m_2)/(m_1 + m_2)\ v_{1i}$	§5.11.2, Eq. 5.26, p. 85
1-D elastic collision (m_2 at rest)	$v_{2f} = 2\ m_1/(m_1 + m_2)\ v_{1i}$	§5.11.2, Eq. 5.27, p. 85
1-D completely inelastic	$v_f = m_1\ v_{1i}/(m_1 + m_2)$	§5.11.2, Eq. 5.22, p. 85
KE lost in perfectly inelastic	$\Delta K = \frac{1}{2}\ (m_1\ m_2)/(m_1+m_2)\ v_{1i}^2$	§5.11.2, p. 85
Vertical-circle critical speeds	$v_{top} = \sqrt{(gL)}$; $v_{bot} = \sqrt{(5gL)}$	Fig. 5.6, p. 79
Speed of free-falling body from height H	$v = \sqrt{(2gH)}$	§5.8, p. 79

🎯 Practice MCQs

📊 PYQ Alignment

Work, Energy and Power is one of the highest-yield chapters in CUET (UG) Physics — the 2023–25 papers consistently set numerical questions on the work-energy theorem, spring/gravitational PE conversions, power (P = Fv) and 1-D elastic/inelastic collisions, along with concept-based items on the meaning of conservative forces and zero-work situations. Expect roughly 10–12 MCQs from this unit per year, with at least two direct calculation questions modelled on the worked NCERT examples.

CUET 2023–25 — Actual PYQs from this chapter

No PYQs from this chapter appeared in CUET 2023, 2024 or 2025.