KSQUARE CAREER INSTITUTE

WORK, ENERGY AND POWER

Class 11 Physics • NEET / JEE Notes

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Today's Goal

1. Work done by constant & variable forces (numericals + formulas)
2. Conservative vs non-conservative forces; test for a conservative force
3. Kinetic energy & its relation with momentum
4. Work–energy theorem
5. Added: potential energy, spring, conservation of mechanical energy, power, collisions — formula sheet

WORK DONE BY A CONSTANT FORCE

Definition

$$W = F \cdot S = |F|\,|S| \cos\theta$$

$$W = (\text{force in the direction of displacement}) \times \text{displacement}$$

$$\theta = \text{angle between } F \text{ and } S$$

Angle θ	Work	Example
θ = 0°	W_{max} = **FS** (positive)	Force along motion
θ = 180°	W_{min} = **–FS** (negative)	Friction, gravity while raising
θ = 90°	**W = 0**	Centripetal force, normal reaction on horizontal motion, coolie walking horizontally

- **SI unit:** N m or **joule (J)**; **CGS unit:** dyne cm or **erg**; **1 J = 10^7 erg**.
- Work is a **scalar** (dot product of two vectors).

Practice — Constant Force

Q1. A body is raised to a height h from the earth's surface. The signs of work done by the applied force and by gravity are

(a) +, +
(b) +, –
(c) –, +
(d) –, –

Answer: (b) — Applied force along motion (θ = 0°); gravity opposite (θ = 180°).

Q2. An external force of 50 N moves a 10 kg block by 5 m on a surface with $\mu = 0.1$. Find the work done by the external force and by friction ($g = 10\ m/s^2$).

(a) 250 J, –250 J
(b) 250 J, –50 J
(c) 250 J, 50 J
(d) 250 J, 250 J

Answer: (b) — $W_{50\,N} = 50 \times 5 = 250$ J; $f = \mu N = 0.1 \times 100 = 10$ N $\Rightarrow W_f = 10 \times 5 \times \cos 180° = -50$ J.

Q3. A cord lowers a block of mass M vertically by distance d with constant downward acceleration g/4. Work done by the cord is **[AIIMS 2011]**

(a) Mgd/4
(b) 3Mgd/4
(c) –3Mgd/4
(d) Mgd

Answer: (c) — $Mg - T = Mg/4 \Rightarrow T = 3Mg/4$ (upward) $\Rightarrow W = -3Mgd/4$.

Q4. A particle moves from $(-2\hat{i} + 5\hat{j})$ to $(4\hat{j} + 3\hat{k})$ under a force $(4\hat{i} + 3\hat{j})$ N. Work done is **[NEET 2016]**

(a) 2 J
(b) 8 J
(c) 11 J
(d) 5 J

Answer: (d) — $S = r_f - r_i = 2\hat{i} - \hat{j} + 3\hat{k}$; $W = F \cdot S = 8 - 3 = 5$ J.

WORK DONE BY A VARIABLE FORCE

Variable force

$$W = \int F \cdot ds = \int F_x\,dx + \int F_y\,dy + \int F_z\,dz \quad \text{(limits from initial to final position)}$$

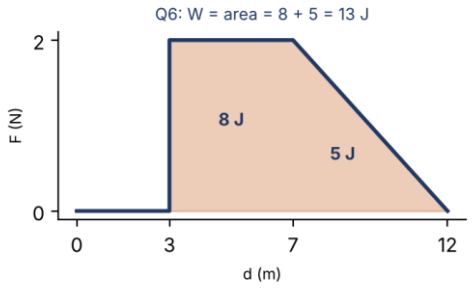
$$W = \text{area under the F–s graph}$$

- Constant force: $F = 2\hat{i} + 3\hat{j}$, or 10 N, 20 N. Variable force: $F = 2x\hat{i} + 3y\hat{j}$, or $2t\hat{i} - 3t^2\hat{j}$.

Q5. A force $F = 20 + 10y$ acts on a particle in the y-direction. Work done from y = 0 to y = 1 m is **[NEET 2019]**

(a) 20 J
(b) 30 J
(c) 5 J
(d) 25 J

Answer: (d) — $W = \int_0^1 (20 + 10y)\,dy = [20y + 5y^2]_0^1 = 25$ J.



Q6. Force F on a particle varies with distance d as shown (F = 0 up to 3 m, 2 N from 3 m to 7 m, then falls linearly to 0 at 12 m). Work done in 12 m is **[2011]**

(a) 18 J
(b) 21 J
(c) 26 J
(d) 13 J

Answer: (d) — Rectangle 2 × 4 = 8 J + triangle ½ × 5 × 2 = 5 J.

CONSERVATIVE & NON-CONSERVATIVE FORCES

Conservative force	Non-conservative force
Work done **does not depend on path** — only on initial and final positions (paths I, II, III from A to B give the same work)	Work done **depends on the path**
Work done in a **round trip is zero**	Work done in a round trip is **not zero**
Examples: **gravitational, spring, electrostatic** force	Examples: **friction, air drag, viscous** force

Q7. A body of mass √2 kg is taken up an incline of length 10 m and angle 45° (μ = 0.5). Find the work done by gravity and friction in the upward and downward journeys and over the round trip (g = 10 m/s²).

Answer: see table — h = 10 sin 45° = 5√2 m; mgh = √2 × 10 × 5√2 = 100 J; f = μmg cos 45° = 5 N ⇒ W_f = –5 × 10 = –50 J each way.

Force	Upward	Downward	Round trip
Gravity	–100 J	+100 J	**0** (conservative)
Friction	–50 J	–50 J	**–100 J** (non-conservative)

How to Check if a Force is Conservative

For $F = F_x\,\hat{i} + F\tilde{}\{y\}\,\hat{j} + F\tilde{}\{z\}\,\hat{k}$, all three must hold

$$\partial F_x/\partial y = \partial F_y/\partial x\,; \quad \partial F_x/\partial z = \partial F_z/\partial x\,; \quad \partial F_y/\partial z = \partial F_z/\partial y$$

$$(\text{i.e. curl } F = 0)$$

- Partial derivative: differentiate w.r.t. one variable keeping others constant — e.g. y = 2x + 4z: ∂y/∂x = 2, ∂y/∂z = 4.

Q8. Check whether the forces are conservative: (a) $F = x\hat{i} + y\hat{j}$ (b) $F = x\hat{i} + xy\hat{j}$

Answer: (a) conservative; (b) non-conservative — (a) $\partial F_x/\partial y = 0 = \partial F_y/\partial x$; (b) $\partial F_x/\partial y = 0$ but $\partial F_y/\partial x = y$.

Q9. An object is displaced from (2, 3) m to (4, 6) m under a conservative force $F = 3x^2\hat{i} + 2y\hat{j}$ N. Work done is
(a) 81 J
(b) 85 J
(c) 63 J
(d) 83 J

Answer: (d) — $W = \int_2^4 3x^2\,dx + \int_3^6 2y\,dy = (64 - 8) + (36 - 9) = 56 + 27 = 83$ J.

KINETIC ENERGY (K.E.)

- Energy possessed by a body **due to its motion**: **K = ½ mv²** (always ≥ 0, scalar).
- K.E. is **frame dependent** — a man sitting in a moving train has K = 0 w.r.t. the train but K ≠ 0 w.r.t. the ground.

Relation with linear momentum

$$K = p^2/2m \; ; \quad p = \sqrt{(2mK)}$$

For small changes (< 5%): $\Delta p/p = \frac{1}{2}(\Delta K/K)$

Q10. Balls of mass 2 kg and 4 kg are dropped together from a 60 ft building. After falling 30 ft their kinetic energies are in the ratio **[CBSE AIPMT 2004]**

(a) √2 : 1
(b) 1 : 4
(c) 1 : 2
(d) 1 : √2

Answer: (c) — Same v = √(2gh) ⇒ K ∝ m.

Q10(b). A particle is projected at 45° with kinetic energy K. Its kinetic energy at the highest point is **[CBSE AIPMT 1997, 2001]**

(a) K/√2
(b) K/2
(c) 2K
(d) K

Answer: (b) — At top v = u cos 45° ⇒ K′ = K cos² 45° = K/2.

Q11. An engine pumps water through a hose; water leaves with velocity v and m is the mass per unit length of the jet. The rate at which kinetic energy is imparted is **[CBSE AIPMT 2009]**

(a) mv³
(b) ½mv²
(c) ½m²v²
(d) ½mv³

Answer: (d) — Mass per second = mv ⇒ dK/dt = ½(mv)v² = ½mv³.

Q12. Two bodies of masses m and 4m have equal kinetic energies. The ratio of their momenta is **[CBSE AIPMT 1989, 97, 98]**

(a) 1 : 2
(b) 1 : 4
(c) 4 : 1
(d) 1 : 1

Answer: (a) — p ∝ √m for the same K.

Q13. If the kinetic energy of a body is increased by 300%, the percentage change in momentum is **[CBSE AIPMT 2002]**

(a) 100%
(b) 150%
(c) 265%
(d) 73.2%

Answer: (a) — K becomes 4K ⇒ p becomes 2p ⇒ +100%. (The ½ ΔK/K shortcut works only below 5%.)

WORK–ENERGY THEOREM

Theorem

$$W_{net} = \Delta K = K_f - K_i = \tfrac{1}{2}mv^2 - \tfrac{1}{2}mu^2$$

$$W_{all\ forces} = W_{conservative} + W_{non\text{-}conservative} + W_{external} = \Delta K$$

- Valid for **all kinds of forces** (constant or variable, conservative or not) and in inertial frames.
- Use it when forces and displacements are given and speeds are asked (no need for acceleration).

POTENTIAL ENERGY & CONSERVATION (ADDITIONAL TOPIC)

Quantity	Formula
Gravitational PE (near earth)	$U = mgh$
Spring PE	$U = \tfrac{1}{2}kx^2$; spring force $F = -kx$
Relation of force with PE	$F = -dU/dx$; $\Delta U = -W_{conservative}$
Conservation of mechanical energy	$K + U$ = constant (only conservative forces act)
Stable / unstable equilibrium	$dU/dx = 0$ with $d^2U/dx^2 > 0$ (stable) / < 0 (unstable)

POWER (ADDITIONAL TOPIC)

Power

$$\text{Average power} = W / t\ ; \quad \text{Instantaneous power } P = dW/dt = F \cdot v$$

$$\text{SI unit: watt (W)} = J\ s^{-1}; \quad 1\ hp = 746\ W; \quad 1\ kWh = 3.6 \times 10^6\ J$$

COLLISIONS (ADDITIONAL TOPIC)

Type	Momentum	Kinetic energy	e (coefficient of restitution)
Perfectly elastic	Conserved	Conserved	1
Inelastic	Conserved	Not conserved	$0 < e < 1$
Perfectly inelastic (bodies stick)	Conserved	Maximum loss	0

- 1-D elastic collision with equal masses → velocities are **exchanged**.

FORMULA SHEET

Quantity	Formula
Work (constant force)	$W = F \cdot S = FS\cos\theta$

Quantity	Formula
Work (variable force)	$W = \int F \cdot ds$ = area under F–s graph
Conservative test	$\partial F_x/\partial y = \partial F_y/\partial x$, etc.
Kinetic energy	$K = \frac{1}{2}mv^2 = p^2/2m$
Work–energy theorem	$W_{net} = \Delta K$
Spring PE	$\frac{1}{2}kx^2$
Power	$P = W/t = F \cdot v$

Practise every PYQ — work-energy is a high-weightage chapter!

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