Unit 5 · Work, Energy and Power

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Mechanics (Units 1–8 together): 26 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** an MCQ on the Kulekhani power station's output power (the water's *mgh* per second)
- **MCQ (1 mark)**
  - ball rebounding from a wall: $\Delta p = 2mu$
  - carrying a bucket on a level road: no work
  - pump's power and water raised
  - $P \propto t$ at constant acceleration; $F \propto s \rightarrow W \propto s^2$
  - dam: PE → KE
  - PE gained by a pivoted rod
  - impulse in a head-on rebound
  - KE–velocity graph (a parabola)
- **Short (5 marks, in parts)**
  - work by a constant force; climbing a hill with a load
  - work–energy theorem; a man sliding down a pole with friction
  - can KE be negative?; momentum doubled → KE × 4
  - mechanical energy of a falling body conserved
  - constant power needs $F \propto 1/v$
  - roller coaster's speed; work with a slanting pull
  - elastic vs inelastic; elastic collision in one dimension
  - engine on a slope; KE shared in an explosion
- **Long (8 marks)**: 1D elastic collision, final velocities and the special cases; energy conserved in free fall

Key terms

Work: product of the force and the displacement along it; scalar; J = N m; $[ML^2T^{-2}]$.

Power: rate of doing work; W = J/s; 1 hp = 746 W; $[ML^2T^{-3}]$.

Energy: capacity to do work; J.

Kinetic energy: energy of motion, $\frac{1}{2}mv^2$; never negative.

Potential energy: stored energy of position or shape; *mgh* near the Earth.

Work–energy theorem: net work on a body = change in its kinetic energy.

Conservation of energy: energy is never created or destroyed, only changed in form.

Conservative force: work independent of path, zero round a closed path, recoverable (gravity, spring, electric).

Non-conservative force: work depends on path, not recoverable (friction, air drag).

Elastic collision: momentum and KE conserved; $e = 1$.

Inelastic collision: momentum conserved, KE not; **perfectly inelastic**: they stick, $e = 0$.

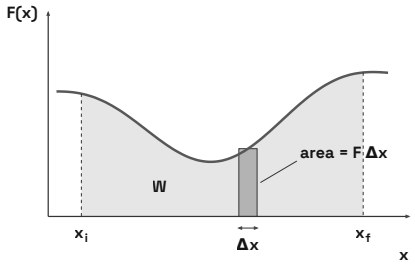
Coefficient of restitution: relative speed of separation ÷ relative speed of approach.

Formulas

$W = Fd\cos\theta = \vec{F}\cdot\vec{d}$	θ between F and d **Use:** constant force
$W = \int F\,dx$	from start to end: area under F–x graph **Use:** variable force
$P = \frac{W}{t};\ P = \vec{F}\cdot\vec{v}$	**Use:** average; instantaneous power
$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$	$p = \sqrt{2mK}$ **Use:** kinetic energy
$W_{net} = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$	**Use:** work–energy theorem
$U = mgh$	**Use:** potential energy
$K_f + U_f = K_i + U_i + W_f$	W_f friction's work (negative) **Use:** energy with friction
$e = \frac{v_2 - v_1}{u_1 - u_2};\ e = \sqrt{h_2/h_1}$	$0 \le e \le 1$ **Use:** restitution; a bouncing ball
$v = \frac{m_1u_1 + m_2u_2}{m_1 + m_2}$	**Use:** perfectly inelastic
$v_1 = \frac{m_1 - m_2}{m_1 + m_2}u_1 + \frac{2m_2}{m_1 + m_2}u_2$	**Use:** 1D elastic
$v_2 = \frac{2m_1}{m_1 + m_2}u_1 + \frac{m_2 - m_1}{m_1 + m_2}u_2$	**Use:** 1D elastic
$\frac{K_1}{K_2} = \frac{m_2}{m_1}$	from rest **Use:** explosion

Work and power

- no work: **no displacement** (guard, man holding a load); force **at 90°** (bucket carried on a level road, satellite in a circle); no force along the motion
- climbing a hill with a load: work **against gravity** = mgh (200 N × 500 m = 10^5 J)
- negative work: force against the motion (friction, braking)
- work done **on** a body increases its energy; work done **by** it decreases it
- 1 kWh = 3.6×10^6 J, an **energy**
- constant force, constant acceleration: $P = Fv \propto t$; for constant P, $F \propto 1/v$



F(x) from start to end; a strip of width Δx has area $F\,\Delta x$; the whole area is the work.

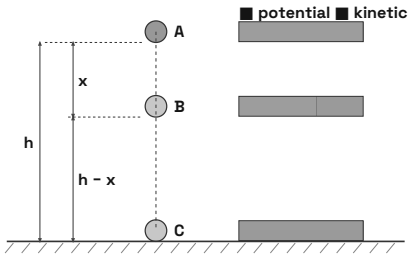
Kinetic energy

1. from rest, constant force: $v^2 = 2as \rightarrow as = v^2/2$
2. $W = Fs = m(as) = \frac{1}{2}mv^2 = \text{KE}$
3. from u: $as = (v^2 - u^2)/2 \rightarrow W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ (work–energy theorem)

- momentum × 2 → KE × 4 (300% more); KE × 4 → momentum × 2
- explosion from rest: equal and opposite momenta → the **lighter** part gets more KE (4 and 40 units: 1000 J vs 100 J)

Potential energy and conservation

- lifting m by h at steady speed: $W = mgh$ stored; $\Delta U =$ work against gravity
- spring, stretched catapult: elastic PE; pendulum and spring swap KE and PE



Released at A (height h), passes B after falling x, reaches C.

Free fall: E stays mgh

- A: $K = 0$, $U = mgh$
- B: $v^2 = 2gx \rightarrow K = mgx$, $U = mg(h - x)$, sum mgh
- C: $K = mgh$, $U = 0$
- with friction: $E_f < E_i$; the lost energy is heat (man sliding down a pole: $mgh = \frac{1}{2}mv^2 + fh$)
- dam → pipe → turbine: PE → KE → electrical
- roller coaster, no friction: $v = \sqrt{2g\Delta h}$, any mass
- conservative: path-independent, zero round a loop, recoverable, keeps $K + U$ constant; non-conservative: the opposite

Collisions

- **always**: momentum and **total** energy conserved
- elastic: KE conserved, no energy changed into other forms (atoms, ideal billiard balls)
- inelastic: some KE → heat, sound, deformation; perfectly inelastic: stick together, most KE lost

1D elastic

1. momentum: $m_1(u_1 - v_1) = m_2(v_2 - u_2)$
2. KE: $m_1(u_1^2 - v_1^2) = m_2(v_2^2 - u_2^2)$
3. divide: $u_1 + v_1 = u_2 + v_2 \rightarrow u_1 - u_2 = v_2 - v_1$ (approach = separation)
4. substitute → v_1, v_2

- equal masses: **exchange velocities** (one at rest: the first stops dead)
- light on a heavy one at rest: bounces back with about $-u_1$
- heavy on a light one at rest: carries on; light flies off at about $2u_1$
- tennis ball on concrete: $e \approx 0.75$

COMMON MISTAKES

✗ carrying a load on a level road is work against gravity
✓ force at 90° to the motion: **no work**.

✗ kWh is a unit of power
✓ it is **energy**.

✗ KE can be negative
✓ $v^2 \geq 0$: never.

✗ momentum and KE both conserved in every collision
✓ KE only in an **elastic** one.

✗ in an explosion both parts get equal KE
✓ equal momenta; the lighter gets more KE.

✗ $e = v_1 - v_2$ over $u_1 - u_2$
✓ separation $v_2 - v_1$ over approach $u_1 - u_2$.