A LEVEL PHYSICS 9702 · AS LEVEL · TOPIC 5 · ~7 MIN READ

Work, energy and power

Work done by a force, conservation of energy, efficiency, power and deriving P = Fv, and deriving the formulas for gravitational potential energy and kinetic energy, with motion against resistive forces.

Work done | Conservation of energy | Efficiency | Power | P = Fv | ΔEp = mgΔh | Ek = ½mv² | Energy with friction

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Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Work done = force × displacement in the direction of the force.** If the force is at angle θ to the motion, W = Fs cos θ.
- **Energy is conserved:** it is transferred between stores, never created or destroyed. Work done is energy transferred.
- **Power** is work done per unit time, P = W/t. For a force moving an object at speed v, P = Fv.
- **ΔEp = mgΔh** (uniform field) and **Ek = ½mv²**. You must be able to derive both.
- **Efficiency** = useful energy output ÷ total energy input (or the same with power).

BY THE END YOU CAN

- Define work and calculate work done, including forces at an angle.
- Apply conservation of energy, including energy lost to resistive forces.
- Define power and efficiency, derive P = Fv and use it.
- Derive ΔEp = mgΔh and Ek = ½mv² and use them.

Riyaz Sir

1 Work and energy

Definitions

Work done — the product of the force and the displacement in the direction of the force.

Principle of conservation of energy — energy cannot be created or destroyed; it can only be transferred from one form to another. The total energy of a closed system is constant.

$$W = Fs$$ LEARN IT

s = displacement in the direction of F; for a force at θ to the motion, W = Fs cos θ

- **Unit:** joule, J = N m = kg m² s⁻². 1 J is the work done when a force of 1 N moves its point of application 1 m in the direction of the force.
- **No work** is done by a force perpendicular to the motion (e.g. the normal contact force on a horizontal surface, or the centripetal force).

WORKED EXAMPLE

A sledge is pulled 25 m across horizontal snow by a rope at 30° to the horizontal, with tension 40 N. Find the work done by the tension.

1. $W = Fs\cos\theta = 40 \times 25 \times \cos 30°$ C1
2. **= 870 J** A1

Deriving the energy formulas

- **Gravitational PE:** lifting mass m at constant speed through Δh needs a force equal to the weight mg. Work done = force × distance = mg × Δh, so **ΔEp = mgΔh** (in a uniform field, near Earth's surface).
- **Kinetic energy:** a resultant force F accelerates mass m from rest through distance s. From $v^2 = u^2 + 2as$ with u = 0, $s = v^2/(2a)$. Work done = Fs = ma × $v^2/(2a)$ = **½mv²**.

$$\Delta Ep = mg\Delta h \; ; \; Ek = \tfrac{1}{2}mv^2$$ LEARN IT

both must be derived and recalled

WORKED EXAMPLE

A ball is dropped from 5.0 m. Ignoring air resistance, find its speed just before it hits the ground.

1. $mgh = \tfrac{1}{2}mv^2 \Rightarrow v = \sqrt{(2gh)}$ C1
2. **$v = \sqrt{(2 \times 9.81 \times 5.0)} = 9.9$ m s⁻¹** A1 **(independent of mass)**

WORKED EXAMPLE

A 60 kg skier starts from rest and descends a slope 120 m long, dropping 25 m vertically. Her speed at the bottom is 18 m s⁻¹. Find the average resistive force.

1. loss in Ep = 60 × 9.81 × 25 = 14 715 J; gain in Ek = ½ × 60 × 18² = 9720 J C1
2. work done against resistance = 14 715 − 9720 = 4995 J C1
3. **F = 4995/120 = 42 N** A1

COMMON MISTAKE

Assuming the vertical drop equals the distance moved. Work against resistance uses the distance along the slope (120 m); the change in Ep uses the vertical height (25 m). The 2024 Paper 2 report flagged a similar slip with a spring's compression.

2 Power and efficiency

Definitions

Power — work done per unit time (rate of doing work or transferring energy).

Efficiency — the ratio of useful energy output (or power output) to total energy input (or power input).

$$P = W/t \; ; \; P = Fv$$

W = J s^{-1}; F is the force in the direction of motion

- **Deriving P = Fv:** P = W/t = Fs/t = F × (s/t) = Fv, for a constant force and speed v.
- **At maximum speed** a vehicle's driving force equals the total resistive force (no acceleration), so P = (resistive force) × v_max.

WORKED EXAMPLE

A car of mass 1200 kg has an engine power of 40 kW. At 20 m s^{-1} the resistive force is 1200 N. Find its acceleration at this speed.

1. driving force F = P/v = 40 000/20 = 2000 N C1
2. a = (2000 − 1200)/1200 C1
3. **= 0.67 m s^{-2}** A1

WORKED EXAMPLE

A motor lifts a 50 kg load through 8.0 m in 12 s. The input power is 600 W. Find the efficiency.

1. useful power = mgh/t = 50 × 9.81 × 8.0/12 = 327 W C1
2. **efficiency = 327/600 = 0.545 = 55%** A1

COMMON MISTAKE

Mixing up useful and total. State which power is input and which is useful output; in 2024 candidates who wrote "power increases" without saying which one lost the mark.

WORKED EXAMPLE

A cyclist of total mass 80 kg rides up a slope inclined at 5.0° at a steady 6.0 m s^{-1} against a resistive force of 20 N. Find the power output.

1. force needed = mg sin θ + resistance = 80 × 9.81 × sin 5.0° + 20 = 88.4 N C1
2. **P = Fv = 88.4 × 6.0 = 530 W** A1

LINKING QUESTION

Work done by a gas and internal energy extend these ideas in Thermodynamics; the work done stretching a wire is the area under a force–extension graph in Deformation of solids; and gravitational potential energy far from Earth is −GMm/r in Gravitational fields.

Test yourself — cover the answers first

QUICK CHECK

1. Define work done.

2. Define power.
3. Derive P = Fv.
4. What is the efficiency if 400 J of 1000 J input is useful?
5. Why does a vertical force do no work on an object moving horizontally?

EXAM-STYLE

6. Derive Ek = ½mv² from the equations of uniformly accelerated motion.
7. A car's engine delivers a constant 60 kW. The resistive force is $0.80v^2$ N, where v is the speed in m s^{-1}. Find the maximum speed on a level road.
8. A 2.0 kg block slides down a rough slope from rest, dropping 1.5 m vertically, and reaches 4.0 m s^{-1}. Calculate the energy transferred to thermal energy.

Show answers

1. force × displacement in the direction of the force
2. work done per unit time
3. P = W/t = Fs/t = Fv
4. 40%
5. there is no displacement in the direction of the force
6. from rest: $v^2 = 2as$; W = Fs = ma × $v^2/(2a)$ = ½mv²
7. at max speed P = Fv = $0.80v^3 \Rightarrow v^3 = 75\,000 \Rightarrow v = 42$ m s^{-1}
8. Ep lost = 2.0 × 9.81 × 1.5 = 29.4 J; Ek = 16 J; thermal = 13 J

Stuck on a question?

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