IB DP PHYSICS · THEME A SPACE, TIME AND MOTION · A.3 · ~7 MIN READ

A.3 Work, energy and power

Work as energy transfer, kinetic, gravitational and elastic potential energy, conservation of mechanical energy, Sankey diagrams, power P = Fv, efficiency and the energy density of fuels.

Work done | Kinetic & potential energy | Conservation of energy | Sankey diagrams | Power | Efficiency | Energy density

RS by Riyaz Sir
mentorriyaz.in

No tag = **SL and HL** HL ONLY HL students only DATA BOOKLET given in the exam

M1 A1 how marks are awarded highlight = comes up again and again Test yourself at the end

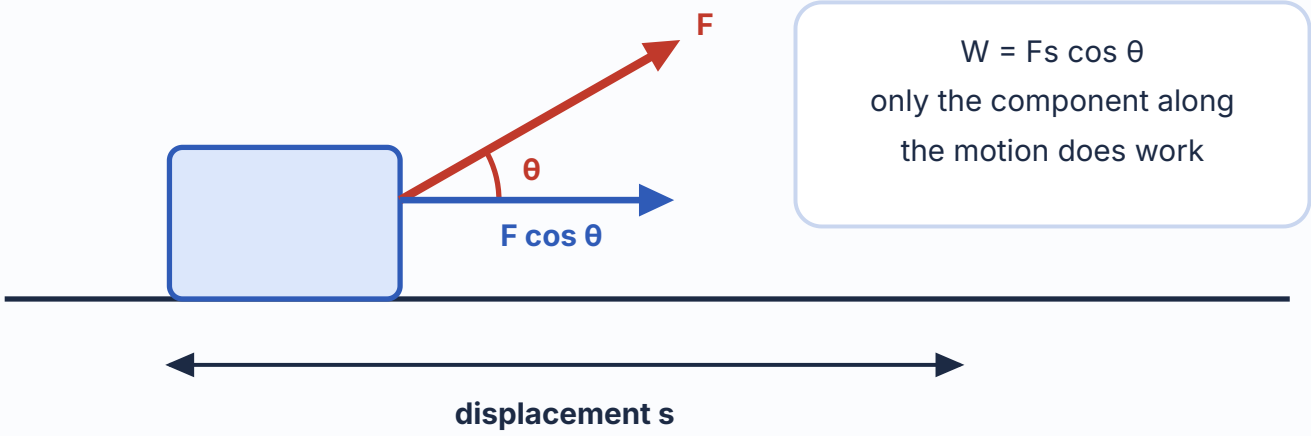
IN 30 SECONDS

- **Energy is conserved.** It is never made or destroyed, only transferred from one store to another. **Work** is energy transferred by a force: W = Fs cos θ.
- **Mechanical energy** = kinetic + gravitational potential + elastic potential. With no friction or drag it stays constant, so speeds and heights follow from $E_p \rightarrow E_k$.
- **Power** is the rate of doing work, P = ΔW/Δt, and for a steady force P = Fv. **Efficiency** = useful out ÷ total in, by energy or by power.
- **A.3 is the same at SL and HL.**

BY THE END YOU CAN

- Calculate work done by a force at an angle, and from the area under a force–displacement graph.
- Use $E_k = \frac{1}{2}mv^2$, $\Delta E_p = mg\Delta h$ and $E_H = \frac{1}{2}kx^2$ with conservation of energy.
- Draw and interpret Sankey diagrams.
- Calculate power, including P = Fv, and efficiency.
- Compare fuels using energy density.

1 Work



W = Fs cos θ
only the component along the motion does work

Only the component of the force along the displacement transfers energy.

$$W = Fs\cos\theta$$ DATA BOOKLET

θ is the angle between F and the displacement; W in joules

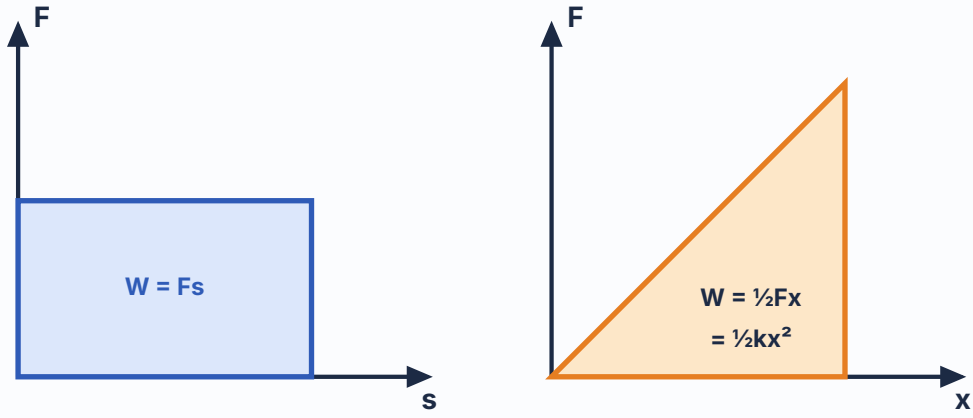
- **θ = 90°:** no work (the centripetal force, the normal force on a level floor). **θ = 180°:** negative work, energy is taken out (friction, braking).
- **The work done by the resultant force equals the change in kinetic energy** (the work–energy principle).

WORKED EXAMPLE

A crate is pulled 5.0 m along the floor by a 20 N rope at 30° to the horizontal. How much work does the rope do?

1. $W = Fs\cos\theta = 20 \times 5.0 \times \cos 30°$ M1
2. **$W = 87$ J** A1

Work done = area under a force–displacement graph



constant force **spring: F = kx**

For any force, work is the area under the F–s graph. For a spring the area is a triangle.

2 Energy stores

$$E_k = \tfrac{1}{2}mv^2 = \frac{p^2}{2m}$$ DATA BOOKLET

kinetic energy

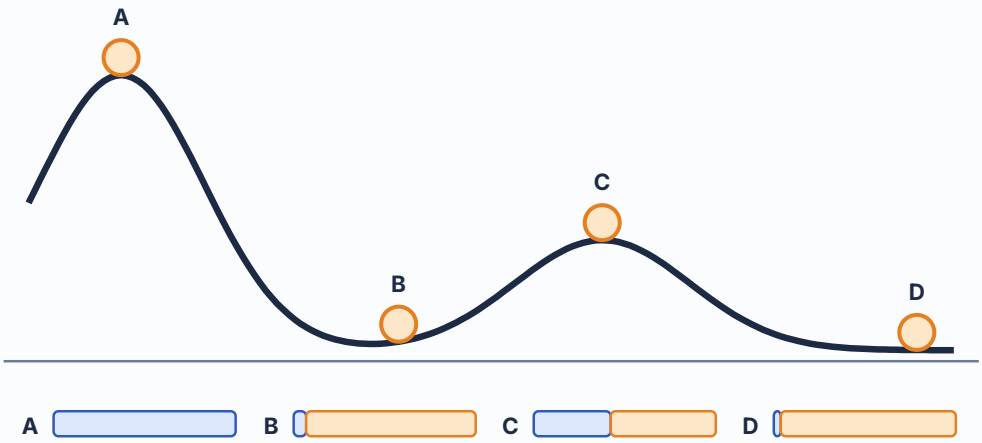
$$\Delta E_p = mg\Delta h$$ DATA BOOKLET

gravitational potential energy near Earth's surface (uniform g)

$$E_H = \tfrac{1}{2}k(\Delta x)^2$$ DATA BOOKLET

elastic potential energy of a spring obeying Hooke's law

Conservation of mechanical energy



blue = E_p, orange = E_k: each bar has the same total length (no friction)

Mechanical energy is conserved, so the trolley can never rise above its starting height.

As the trolley falls, E_p becomes E_k; as it climbs, E_k turns back into E_p. The total stays the same.

WORKED EXAMPLE

A pendulum bob is released from 0.45 m above its lowest point. Find its speed at the bottom (no air resistance).

1. E_p lost = E_k gained: $mgh = \frac{1}{2}mv^2$ M1
2. $v = \sqrt{(2gh)} = \sqrt{(2 \times 9.8 \times 0.45)}$ M1
3. **$v = 3.0\ m\ s^{-1}$, whatever the mass** A1

WORKED EXAMPLE

A spring ($k = 200\ N\ m^{-1}$) compressed by 10 cm launches a 50 g ball horizontally. Find the launch speed.

1. $E_H = \frac{1}{2} \times 200 \times 0.10^2 = 1.0$ J M1
2. $\frac{1}{2} \times 0.050 \times v^2 = 1.0$ M1
3. **$v = 6.3\ m\ s^{-1}$** A1

WORKED EXAMPLE

A 70 kg skier slides 40 m down a slope, dropping 12 m in height, and reaches 12 m s^{-1}. Find the average friction force.

1. E_p lost = $70 \times 9.8 \times 12 = 8232$ J M1
2. E_k gained = $\frac{1}{2} \times 70 \times 12^2 = 5040$ J M1
3. work against friction = 3192 J = $F \times 40$ M1
4. **$F = 80$ N** A1

COMMON MISTAKE

Using h as the length of the slope. $\Delta E_p = mg\Delta h$ uses the **vertical** height change only.

EXAM TIP

Energy methods ignore direction and the shape of the path. If a question asks for a speed after a height change, try energy before suvat: it works on curved paths too.

3 Power and efficiency

$$P = \frac{\Delta W}{\Delta t} = Fv$$ DATA BOOKLET

power in watts (J s^{-1})

$$\eta = \frac{\text{useful work out}}{\text{total work in}} = \frac{\text{useful power out}}{\text{total power in}}$$ DATA BOOKLET

efficiency, a ratio or a percentage

WORKED EXAMPLE

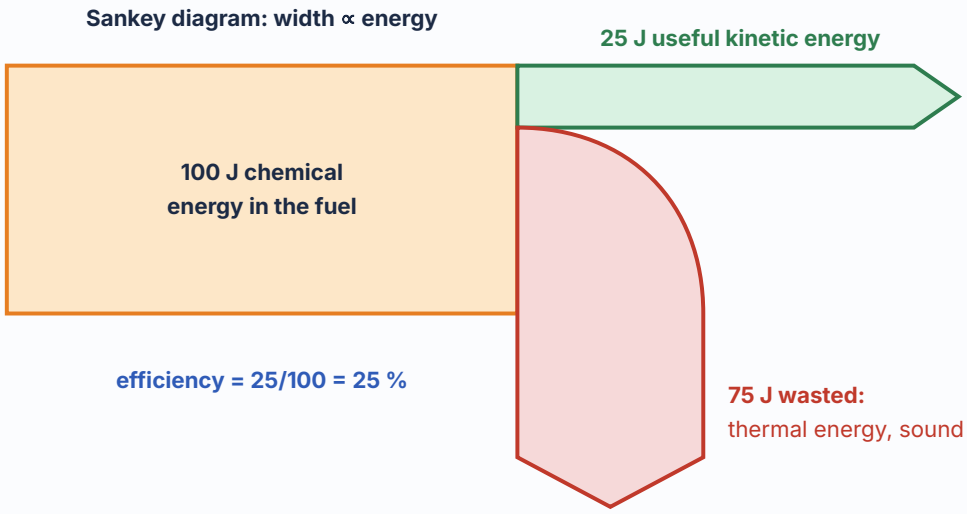
A car's engine delivers 60 kW of useful power at a steady 25 m s^{-1}. Find the resistive force.

1. at constant speed, driving force = resistive force R1
2. F = P/v = 60 000/25 M1
3. **F = 2400 N** A1

WORKED EXAMPLE

A motor lifts a 50 kg load 3.0 m in 4.0 s and draws 600 W from the supply. Find its efficiency.

1. useful work = mgh = 50 × 9.8 × 3.0 = 1470 J M1
2. input energy = 600 × 4.0 = 2400 J M1
3. **η = 1470/2400 = 61 %** A1



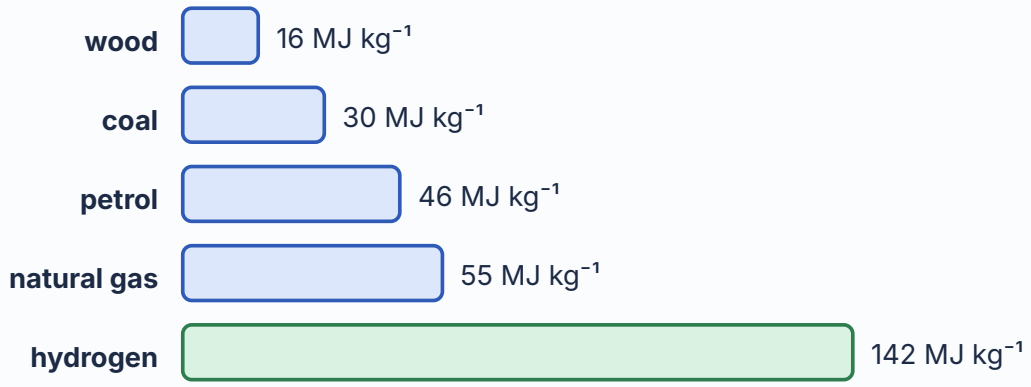
The arrows show where the energy goes. Their widths are drawn to scale.

COMMON MISTAKE

Drawing a Sankey diagram whose output arrows do not add up to the input. Energy is conserved: the widths must add up.

4 Energy density of fuels

Energy density — energy released per unit mass of fuel, in J kg^{-1}. (Some questions use energy per unit volume, J m^{-3}; check the units.)



Approximate specific energies of fuels. Uranium in a reactor: about 8×10^7 MJ kg^{-1}.

Fossil fuels store tens of MJ per kilogram. Nuclear fuel stores about a million times more.

- **Choosing a fuel** is about more than energy density: cost, availability, pollution and CO_2, storage and safety all matter. Hydrogen has a high energy per kilogram but a low energy per litre, so it is hard to store.

WORKED EXAMPLE

A power station burns coal (30 MJ kg^{-1}) at 38 % efficiency to give 500 MW of electrical power. How much coal does it burn per second?

1. input power = 500/0.38 = 1316 MW M1
2. mass per second = $1316 \times 10^6 / 30 \times 10^6$ M1
3. **≈ 44 kg s^{-1}** A1

LINKING QUESTION

Energy conservation reappears everywhere: in collisions (A.2), thermal physics (B.1), circuits (B.5) and orbits (D.1). Which of these problems could you solve with forces alone?

IDEA FOR YOUR IA / EXPLORATION

Measure the efficiency of a small electric motor lifting a mass: record V and I with a joulemeter or multimeters, time the lift, and investigate how efficiency changes with the load.

Test yourself — cover the answers first

QUICK CHECK

1. When does a force do no work on a moving object?
2. What does the area under a force–displacement graph represent?

3. Write two expressions for kinetic energy.
4. A ball is dropped from 5.0 m. Its speed just before landing, ignoring air resistance?
5. State the unit of power in base units.
6. A device takes in 200 J and wastes 150 J. Its efficiency?

EXAM-STYLE

7. A 1500 kg car accelerates from 10 m s^{-1} to 25 m s^{-1} in 8.0 s on a level road. Find the average useful power.
8. A 2.0 kg block is pushed 3.0 m up a frictionless 25° slope by a 20 N force parallel to the slope, starting from rest. Find its final speed.
9. A wind turbine has a useful output of 2.0 MW and an efficiency of 40 %. How much energy does the wind deliver to it in one hour?

Show answers

1. when it is perpendicular to the displacement
2. the work done
3. $\frac{1}{2}mv^2$ and $p^2/2m$
4. $v = \sqrt{(2 \times 9.8 \times 5.0)} = 9.9$ m s^{-1}
5. kg m^2 s^{-3} (W = J s^{-1})
6. 50/200 = 25 %
7. $\Delta E_k = \frac{1}{2} \times 1500 \times (25^2 - 10^2) = 393\,750$ J
   P = 393 750 / 8.0
   ≈ **49 kW**
8. work by push = 20 × 3.0 = 60 J
   $\Delta E_p = 2.0 \times 9.8 \times 3.0 \sin 25° = 24.8$ J
   $E_k = 35.2$ J = $\frac{1}{2}(2.0)v^2$
   v = **5.9 m s^{-1}**
9. input power = 2.0/0.40 = 5.0 MW
   $E = 5.0 \times 10^6 \times 3600$
   = **1.8×10^{10} J**

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