

Work, energy and power

A-Level Physics 9702 · Topic 5 revision notes · AS

One conservation law doing all the work: work done, efficiency and power ($P = Fv$), and gravitational potential and kinetic energy.

8 definitions to learn word for word, 8 equations in their own column, 6 diagrams and graphs. Read it, cover it, test yourself.

1. 5.1a Work done and energy conservation
2. 5.1b Efficiency and power
3. 5.2 Gravitational potential energy and kinetic energy.

Definitions (mark-scheme wording) Equations Exam traps

5.1a Work done and energy conservation

Definitions

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

Joule: the work done when a force of 1 N moves its point of application 1 m 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).

Equations

$$W = Fs \cos \theta$$

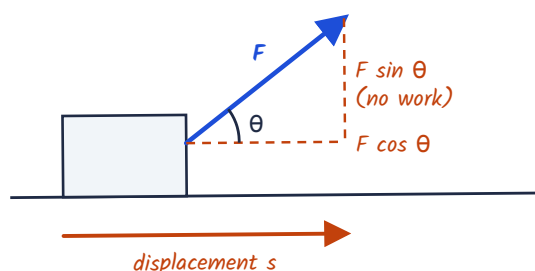
work = force $\times$ displacement $\times \cos(\text{angle between them})$
J

$$W = p\Delta V$$

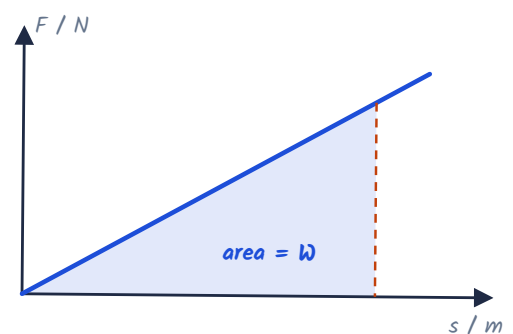
work done by a gas at constant pressure
J

Key points

- ✓ Work done = **energy transferred**.
- ✓ Force at angle θ to the motion: only **$F \cos \theta$** does work.
- ✓ Force perpendicular to motion does **zero work** ($\cos 90^\circ = 0$), e.g. a centripetal force.
- ✓ Force-displacement graph: **area under the graph = work done**.
- ✓ Gas expanding at constant pressure does work **$W = p\Delta V$** on its surroundings.
- ✓ Work done against friction or drag is transferred as **thermal energy**.



Only the component of F along the displacement does work: $W = Fs \cos \theta$.



Force-displacement graph: the area under it is the work done (here a stretched spring).

Watch out!

- ! A large force that does not move its point of application (or acts at 90°) does **no** work.
- ! θ is the angle between the force and the **displacement**, not the horizontal by default.

5.1b Efficiency and power

Definitions

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

Power: the rate of doing work (the work done or energy transferred per unit time).

Watt: a rate of energy transfer of one joule per second.

Key points

- ✓ Efficiency is a ratio or percentage; it is **always less than 1** (100%) for a real machine.
- ✓ Wasted energy usually ends up as **thermal energy** in the surroundings.
- ✓ Moving at constant speed v against a resistive force F : power needed $P = Fv$.
- ✓ At top speed, driving force = resistive forces, so $P = F_{\text{resist}} v_{\text{max}}$.
- ✓ Derivation: $P = W/t = F s/t = Fv$.

Equations

$$\text{efficiency} = \frac{\text{useful output}}{\text{total input}}$$

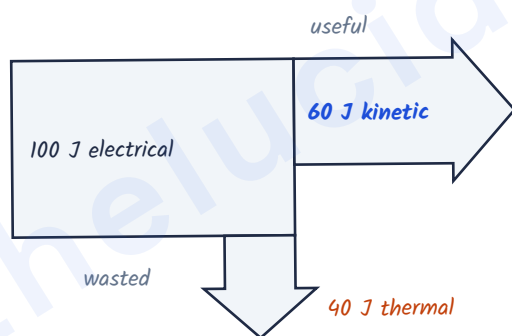
energy or power; $\times 100$ for a percentage
no unit

$$P = W / t$$

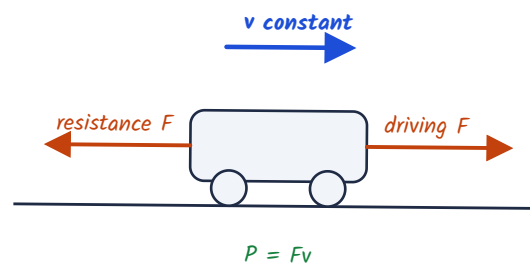
power = work done / time
 W

$$P = Fv$$

power = force $\times$ velocity (in the direction of the force)
 W



Sankey diagram for an electric motor: arrow widths are to scale; efficiency = $60 \text{ J} / 100 \text{ J} = 60\%$.



Car at top speed: driving force equals total resistance, so $P = F v_{\text{max}}$.

Watch out!

- ! Efficiency greater than 100% means input and output were swapped.
- ! $P = Fv$ uses the force in the direction of motion and the **speed at that instant**.

5.2 Gravitational potential energy and kinetic energy

Definitions

Kinetic energy: the energy a body has because of its motion.

Gravitational potential energy: the energy a mass has because of its position in a gravitational field.

Key points

- ✓ Derive E_k : $W = Fs$, $F = ma$, $v^2 = 2as$ (from rest), so $W = m(v^2/2) = \frac{1}{2}mv^2$.
- ✓ Derive ΔE_p : lifting at constant speed needs $F = mg$ over Δh , so $W = mg\Delta h$.
- ✓ $\Delta E_p = mg\Delta h$ only in a **uniform** field (near the Earth's surface).
- ✓ No resistance: loss in $E_p =$ gain in E_k so $v = \sqrt{2g\Delta h}$, independent of mass.
- ✓ With resistance: E_p lost = E_k gained + work done against friction.
- ✓ Doubling the speed **quadruples** the kinetic energy.

Equations

$$E_k = \frac{1}{2}mv^2$$

kinetic energy

J

$$\Delta E_p = mg\Delta h$$

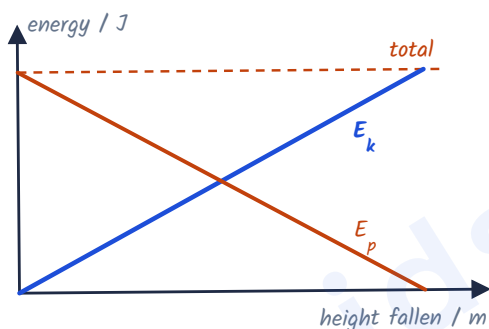
change in gravitational potential energy (uniform field)

J

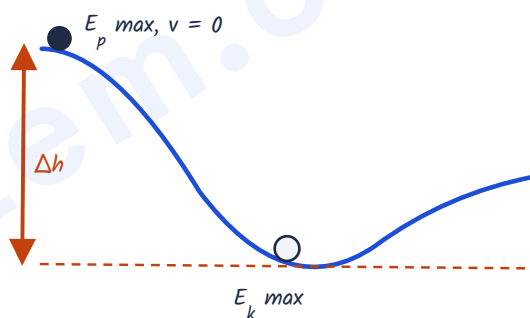
$$mg\Delta h = \frac{1}{2}mv^2$$

fall from rest, no resistance: $v = \sqrt{2g\Delta h}$

J



Falling without air resistance: E_p falls as E_k rises; the total stays constant.



Pendulum or roller coaster: E_p at the top becomes E_k at the bottom.

Watch out!

- ! Equating $mg\Delta h$ and $\frac{1}{2}mv^2$ is only valid when resistive forces are negligible: say so.
- ! Forgetting to square v , or using mass in grams.