

Cambridge OCR GCSE Combined Science A — Physics

Topic P5

Energy

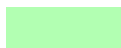
Specification J250 · Cambridge OCR

Free edition

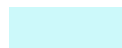
Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

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Cambridge OCR GCSE (9–1) Combined Science A (Gateway Science) J250 · Specification reference P5 · Paper 6 (Foundation) / Paper 12 (Higher), with assumed knowledge of P1–P3

Define Energy store

- where energy is at a given moment: kinetic, gravitational, elastic, thermal, chemical, nuclear, magnetic, electrostatic.

Define System

- the object or group of objects being considered; a **closed system** is one from which no energy enters or leaves.

Define Work done

- the energy transferred when a force moves an object along the line of action of the force; $1 \text{ J} = 1 \text{ N m}$.

Define Gravitational potential energy

- energy stored in an object because of its position in a gravitational field.

Define Specific heat capacity

- the energy needed to raise the temperature of 1 kg of a substance by 1°C .

Define Power

- the rate of energy transfer, or the rate of doing work, in watts (W); $1 \text{ W} = 1 \text{ J/s}$.

Define Efficiency

- the fraction, or percentage, of the input energy transfer that ends up in the useful output.

Define Kilowatt-hour (kW h)

- the domestic unit of energy used for billing; $1 \text{ kW h} = 3.6 \times 10^6 \text{ J}$.

Define Energy

- a quantity, measured in joules (J), that is conserved: it can be stored and transferred but never created or destroyed.

Define Energy transfer

- the route by which energy moves between stores: mechanically (work done by a force), electrically (work done when a current flows), by heating, or by radiation.

Define Law of conservation of energy

- energy cannot be created or destroyed, only stored, transferred or dissipated.

Define Kinetic energy

- energy stored in a moving object because of its mass and speed.

Define Elastic potential energy

- energy stored in a stretched or compressed spring.

Define Dissipation

- the spreading out of energy into less useful stores, usually the thermal store of the surroundings.

Define Power rating

- the power an appliance transfers in normal use, marked on it in W or kW.

Define Thermal conductivity

- a measure of how readily energy is transferred through a material by heating; low conductivity means a good insulator.

P5.1 Work done

How energy can be stored and transferred. This topic consolidates ideas of energy covered in earlier topics, since energy is a fundamental concept underpinning many of the ways in which matter interacts.

ANALOGY

Energy stores — money in accounts. Energy is not a fluid or a fuel; it is a number you can count, like money. The stores are bank accounts — current account for kinetic, savings for gravitational — and the transfers are payments between them: mechanically, electrically, by heating, by radiation. Spending does not destroy money, it moves it; a "wasted" transfer is money paid into an account so scattered you can never get it back. Where it breaks down: unlike lost money, dissipated energy is still there and still counted — it is simply useless.

Conservation of energy in a closed system (P5.1a)

- For situations where there are energy transfers in a system, there is no net change to the total energy of a closed system — **qualitative only**. This is the **law of conservation of energy**.
- Energy is never used up and never lost; it is **redistributed** between stores. When people say energy is "lost", they mean it has been **dissipated** to the surroundings, spread too thinly to be useful.
- Work with a **before and after** list of stores. The totals must match.

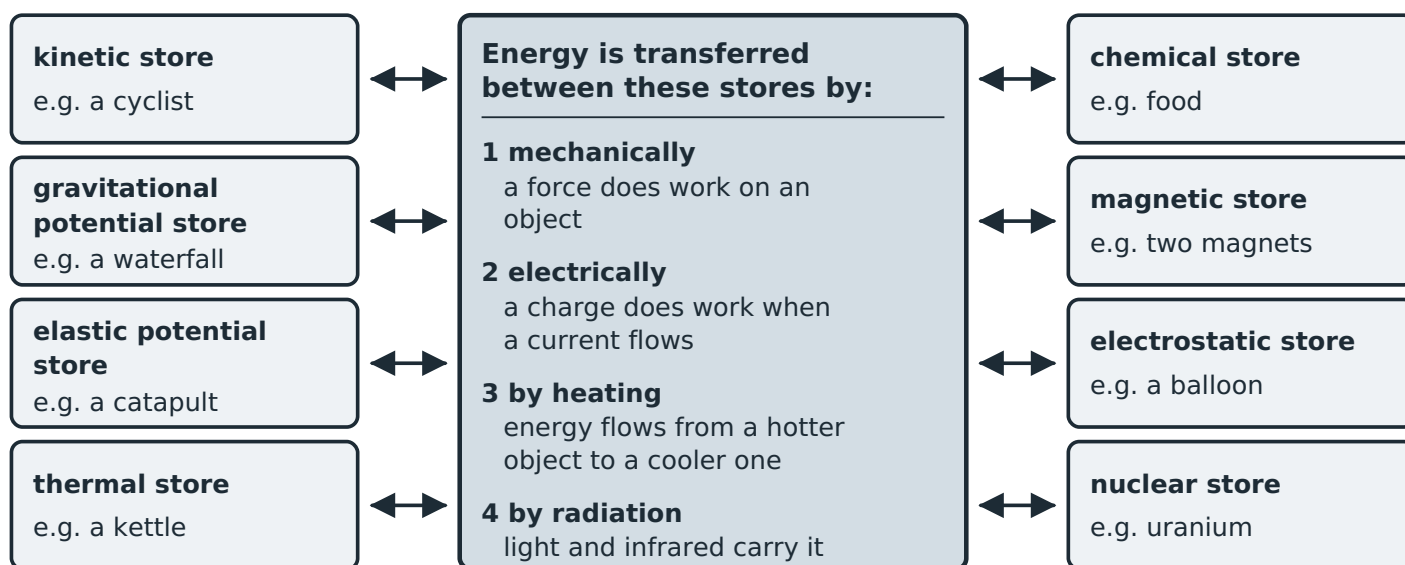
How energy is stored when a system changes (P5.1b)

Describe all the changes involved in the way energy is stored when a system changes for common situations. J250 lists five, and "all the changes" means the wasted transfers too.

Situation	Before → after	Wasted / dissipated
An object projected upwards or up a slope	Kinetic store → gravitational store	Thermal store of air and object, by friction and drag
A moving object hitting an obstacle	Kinetic store → thermal store of both objects, plus elastic store while they deform, plus sound	Nearly all of it ends in the thermal store
An object accelerated by a constant force	Chemical store of the driver → kinetic store, by a mechanical transfer (work done)	Thermal store, by friction and drag
A vehicle slowing down	Kinetic store → thermal store of brakes, tyres and road, by a mechanical transfer	All of it, eventually to the surroundings
Bringing water to a boil in an electric kettle	Chemical store of the fuel at the power station → thermal store of the water, by an electrical transfer	Thermal store of the kettle, bench and room

- The four **transfer routes** are **mechanically** (work done by a force), **electrically** (work done when a charge flows), **by heating**, and **by radiation**.

The energy stores and the four ways energy is transferred between them.



Conservation of energy

Energy can be transferred usefully, stored or dissipated — it can never be created or destroyed.

In a closed system there is no net change to the total energy: the total before a change is equal to the total after it. Dissipated energy is not lost — it is stored in less useful ways.

WATCH OUT

Learners may have misconceptions around **energy being a fuel-like substance that matter has to "use up"**, that **resting objects do not have any energy** and that **all energy is transferred efficiently**. There is also often **confusion between forces and energy**.

- Energy is **never used up**. A "flat" battery holds as much energy as before; it has simply moved to the surroundings.
- A stationary object can hold a great deal of energy: a boulder on a cliff (gravitational), a stretched catapult (elastic), a litre of petrol (chemical).
- **A force is not energy**. A force is a push or pull in newtons; energy is in joules. A force only transfers energy when the object **moves along the line of action of the force** — which is why holding a heavy bag still does no work on it.

Calculating the energy changes (P5.1c, P5.1d, P5.1e)

- **P5.1c** — describe the changes in energy involved when a system is changed **by heating** (in terms of temperature change and specific heat capacity), **by work done by forces**, and **by work done when a current flows**.
- **P5.1d** — make calculations of the energy changes associated with changes in a system, **recalling or selecting the relevant equations for mechanical, electrical and thermal processes**, and thereby express in quantitative form and **on a common scale** the overall redistribution of energy in the system. Every route is measured in **joules**, so the three kinds of change can be added and compared directly.
- **P5.1e** — calculate the amounts of energy associated with a **moving body, a stretched spring and an object raised above ground level**.
- J250's contexts are **work done by forces, current flow, heating, and the use of kW h to measure energy use in electrical appliances in the home**.

P5.2 Power and efficiency

Conservation and dissipation of energy in systems and how this leads to efficiency, and ways of reducing unwanted energy transfers and thereby increasing efficiency.

Energy in domestic devices and power ratings (P5.2b, P5.2c)

- In different domestic devices, energy is transferred from **batteries or the a.c. from the mains** (P5.2b): a torch runs from the chemical store of a cell, a kettle from the mains. The transfer is **electrical** in both cases.
- Describe, with examples, the relationship between the power ratings for domestic electrical appliances and how this is linked to the changes in stored energy when they are in use (P5.2c). The rating in watts or kilowatts is the **energy transferred each second** in normal use, so a higher rating means a **faster** change in the stored energy — and a larger bill for the same running time.

Dissipation (P5.2a)

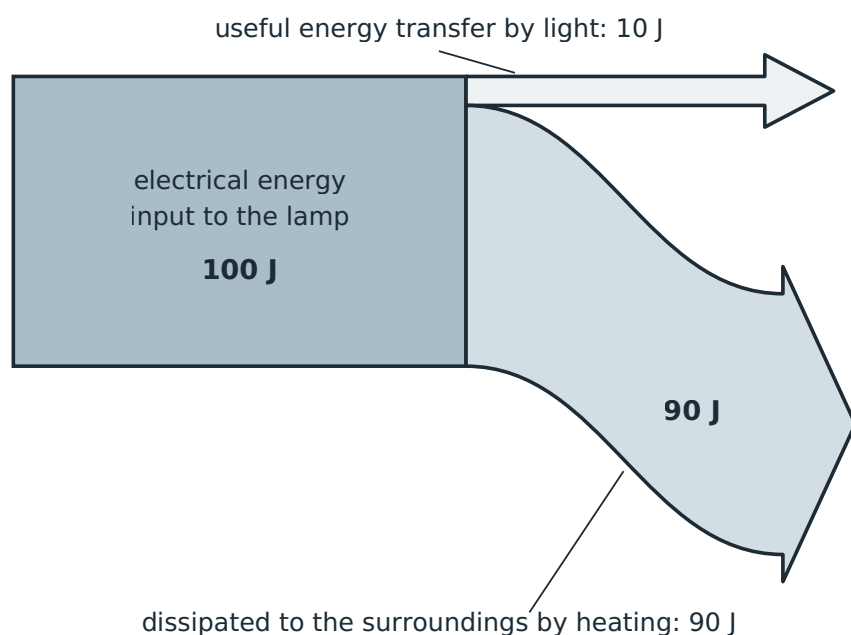
- Describe, with examples, the process by which energy is dissipated, so that it is stored in less useful ways — almost always the **thermal store of the surroundings**, spread so thinly it cannot be recovered.
- J250 asks specifically for **how energy may be wasted in the transfer to and within motors and heating devices**:
- a **motor** — friction in the bearings, air resistance on the moving parts, and the resistance of the coils ($P = I^2 R$) all heat it; some energy leaves as sound and vibration;
- a **heating device** — energy meant for the room is stored in the casing, element supports and wiring, and some escapes up a flue or through a wall;
- wherever a current flows in a wire, the **resistance** of the wire heats it.
- Dissipated energy is **not destroyed**; it is still in the total, just no longer useful.

Appliance	Typical power	Energy in 1 hour	Useful store filled
LED lamp	8 W	0.008 kW h	Radiation (light)
Laptop	60 W	0.06 kW h	Electrical work in the circuits
Washing machine	2.0 kW	2.0 kW h	Thermal store of the water, kinetic store of the drum
Kettle	3.0 kW	3.0 kW h	Thermal store of the water

Efficiency (P5.2d)

- Calculate energy efficiency for any energy transfer.
Efficiency is a **ratio**, so it has **no unit**; multiply by 100 for a percentage.
- Efficiency can never exceed 1 (100%) — that would break conservation of energy. Only a device with **no dissipation at all** could reach it, and none does.
- **useful output + wasted output = total input**, so wasted energy = input – useful output.

A Sankey diagram for a filament lamp, and the efficiency calculated from it.



Efficiency

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

(or useful power output ÷ total power input)

$$\text{efficiency} = 10 \text{ J} \div 100 \text{ J} = 0.1$$

efficiency = 10%

Only 10 J in every 100 J is transferred usefully by light.

The other 90 J is dissipated to the surroundings by heating, which warm up slightly.

ANALOGY

Efficiency — the leaky bucket. Fill a bucket from a tap and carry it: the input is all the water that left the tap, the useful output is what is still in the bucket when you arrive, and the leaks are the dissipation. Efficiency is the fraction that survives the walk. Plugging holes — lubricating bearings, lagging pipes, insulating a house — raises the fraction, but you can never carry **more** water than left the tap, so efficiency above 100% is impossible. Where it breaks down: leaked water is gone from the bucket but not from the world, and neither is dissipated energy.

Rate of cooling of a building (P5.2g)

Describe how the rate of cooling of a building is affected by the thickness and thermal conductivity of its walls — qualitative only.

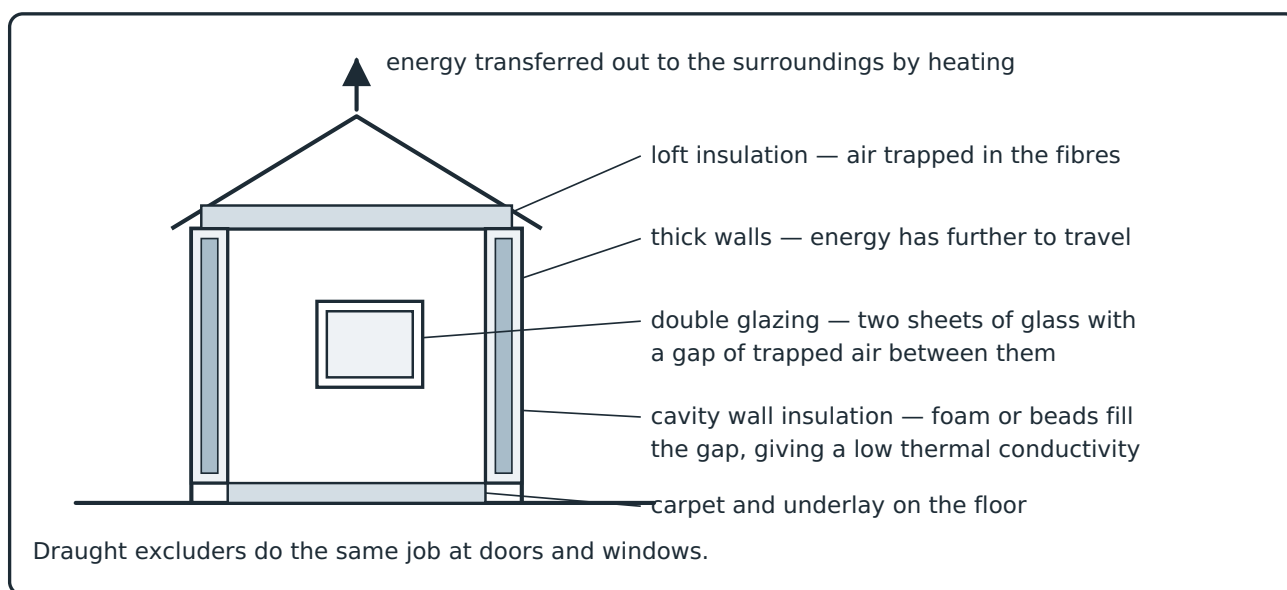
- **Thicker walls cool the building more slowly**, because energy has further to travel to escape.
- **The lower the thermal conductivity, the slower the rate of cooling.** Materials of high thermal conductivity (metal, single glazing, solid brick) transfer energy quickly; materials of low thermal conductivity (foam, mineral wool, trapped air) transfer it slowly and make good insulators.
- A large temperature difference between inside and outside also speeds the transfer, so a building cools fastest just after the heating goes off on a cold night. **Thermograms** show the escaping energy directly, as bright patches at windows, doors and uninsulated roofs.

HIGHER TIER

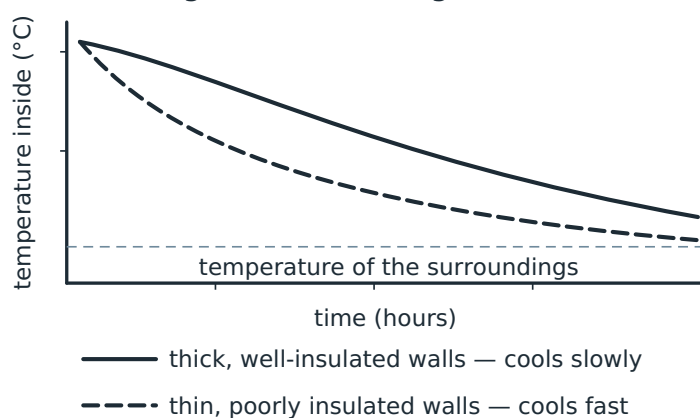
HT ONLY Increasing efficiency (P5.2e), and reducing unwanted transfers (P5.2f)

- **HT ONLY P5.2e — describe ways to increase efficiency.** The route is always to cut the **wasted** output, so the useful output takes a larger share of the same input: **HT ONLY lubricate** moving parts, so less energy is dissipated by friction; **HT ONLY streamline** vehicles and moving parts, reducing work done against air resistance;
- **HT ONLY use thicker, lower-resistance conductors** and lower currents, cutting the $P = I^2 R$ heating; **HT ONLY insulate and lag**, so less energy escapes by heating; **HT ONLY recover** what would be wasted — regenerative braking returns energy from the kinetic store to a chemical store, and a combined heat and power station uses its "waste" heat to warm buildings;
- **HT ONLY reduce moving mass**, and choose better-matched components such as an LED instead of a filament lamp.
- **P5.2f — explain ways of reducing unwanted energy transfer**, which J250 restricts to **lubrication and thermal insulation**:
- **lubrication** — oil or grease keeps surfaces apart so they slide instead of gripping, reducing friction and so the energy dissipated to the thermal store;
- **thermal insulation** — loft and cavity wall insulation, double glazing (a trapped layer of air), draught excluders and carpets all slow the transfer of energy out of a building.

How insulation and wall thickness slow the rate at which a building cools.



Rate of cooling after the heating is switched off



Reducing unwanted transfers

- Thermal insulation traps air, which has a very low thermal conductivity, so energy escapes more slowly.
- The thicker the walls, the slower the building cools.
- The lower the thermal conductivity of the walls, the slower it cools.
- Lubrication with oil or grease keeps sliding surfaces apart, so less energy is dissipated by friction in machines and engines.

WATCH OUT

Learners have the common misconception that **energy can be "used up"**, or that **energy is truly lost in many energy transformations**. They also tend to believe that **energy can be completely changed from one form to another with no energy dissipated**.

- Nothing is lost. Write "**dissipated to the surroundings**", never "lost", and make the numbers balance: input = useful + wasted, every time.
- No real device is 100% efficient. An efficiency above 1 means something has been divided the wrong way round.
- "The battery has run out of energy" is wrong: the **chemical store** has emptied and the energy is now in the surroundings.

NOTE

Where this goes next. Energy **resources** — fossil fuels, nuclear fuel, biofuel, wind, hydroelectricity, tides and the Sun, and the renewable/non-renewable distinction — are **not** in P5. J250 places them in **P6.2 Powering Earth**, with the national grid, transformers and domestic electricity, so that power and efficiency can be applied to a real global problem. The transformer power equation $V_p I_p = V_s I_s$ is **PM6.2i**, and so belongs in **P6**, not here. Both topics sit on **Paper 6 (Foundation) / Paper 12 (Higher)**, which also carries **synoptic** questions, so expect P5 equations inside P6 questions.