

Conservation of energy

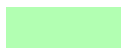
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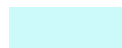
Revision notes for one topic, free to download.

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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Define Energy transfer

- the movement of energy from one store to another, by one of four pathways: mechanically, electrically, by heating, or by radiation.

Define Closed system

- a system into which, and out of which, no energy can pass.

Define Gravitational potential energy

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

Define Elastic potential energy

- energy stored in an object that has been stretched, bent or compressed.

Define Wasted energy

- energy transferred to a store that is not the one you wanted.

Define Sankey diagram

- a flow diagram in which the width of each arrow is proportional to the energy it represents.

Define Thermal conductivity

- a measure of how quickly energy is transferred by heating through a material.

Define Renewable resource

- a resource that is replenished as it is used, so it will not run out.

Define Energy store

- a way in which energy is held in a system (thermal, kinetic, gravitational, elastic, chemical, magnetic, electrostatic, nuclear).

Define System

- an object, or a group of objects, that you choose to think about together.

Define Conservation of energy

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

Define Kinetic energy

- energy stored by an object because it is moving.

Define Dissipated energy

- energy that has been transferred to a less useful store, usually the thermal store of the surroundings.

Define Efficiency

- the fraction (or percentage) of the energy supplied to a device that the device transfers usefully.

Define Lubrication

- reducing friction between surfaces by putting oil or grease between them.

Define Non-renewable resource

- a resource that is used up faster than it is replaced, so it will run out.

Define Reliable resource

- one that can supply energy whenever it is needed, rather than only when conditions allow.

3.1 Energy stores and energy transfers (3.3, 3.5)

Energy is not a substance. It is a number you can calculate for a system, and the number does not change when the system changes — it only moves between **stores**.

The energy stores

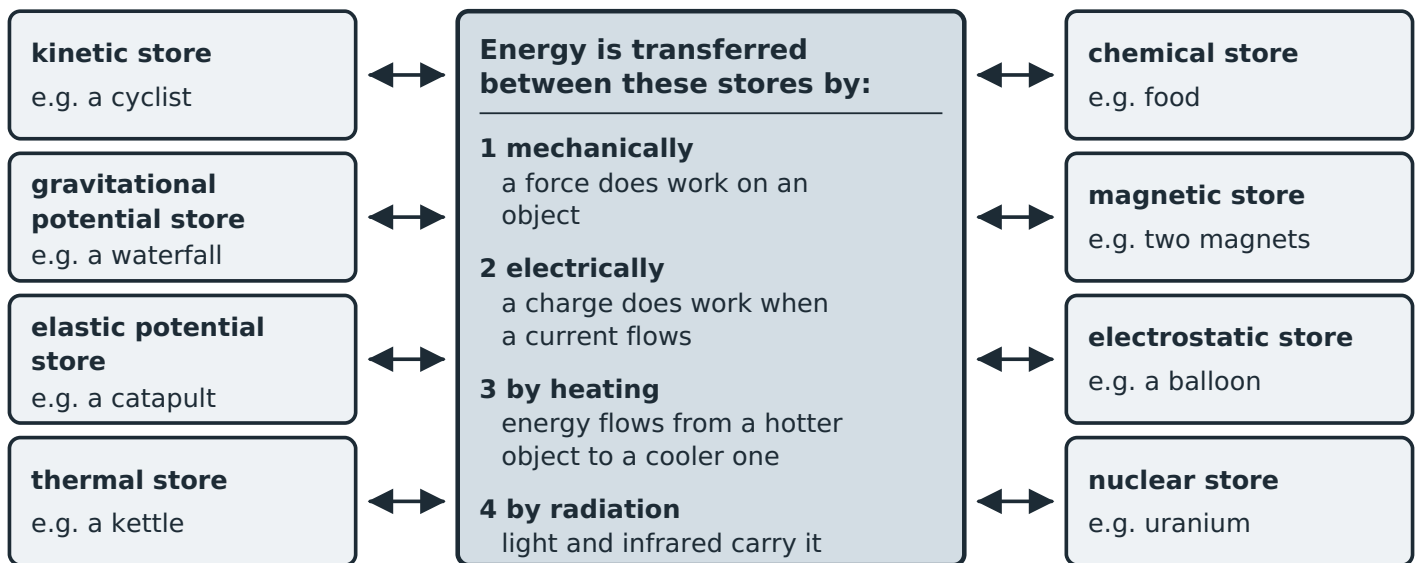
Store	Energy is stored because...	Everyday example
Kinetic	the object is moving	a moving car, a thrown ball
Gravitational potential	the object is raised in a gravitational field	a book on a shelf, water behind a dam
Elastic potential	the object is stretched, bent or compressed	a drawn bow, a wound clock spring
Thermal	the particles of the object are vibrating/moving	hot water in a kettle
Chemical	of the bonds between atoms	food, fuel, a battery
Nuclear	of the forces inside the nucleus	uranium fuel rods, the Sun
Magnetic	of the position of a magnet in a magnetic field	two magnets held apart, repelling
Electrostatic	of the position of charges relative to one another	a charged thundercloud

The four ways energy is transferred

Energy moves **between** stores by one of four pathways:

- **Mechanically** — a force moves an object through a distance (pushing, pulling, stretching).
- **Electrically** — a charge is moved through a potential difference by a current.
- **By heating** — energy passes from a hotter object to a colder one (conduction, convection).
- **By radiation** — energy is carried away as a wave, such as light, infrared or sound.

Energy stores and the pathways 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.

ANALOGY

Stores are **buckets**; transfers are the **pipes** between them. Switch on a kettle and water drains from the "electrical supply" bucket, along the "electrically" pipe, into the "thermal store of the water" bucket — and through a leaky joint into the "thermal store of the kitchen" too. The total volume never changes; only where it sits does. Naming the *pipe* and naming the *bucket* are different questions, and Edexcel asks both.

WATCH OUT

"Sound energy", "light energy" and "electrical energy" are **not stores** — they are ways of *transferring* energy. Name a store (kinetic, thermal, chemical...) when asked where energy is stored, and a pathway (by radiation, electrically...) when asked how it got there.

Drawing and interpreting energy transfer diagrams (3.3)

You must be able to **draw and interpret diagrams to represent energy transfers**. Two kinds are used:

- **Flow (transfer) diagrams** — boxes for stores, arrows labelled with the transfer pathway. Example: chemical store of petrol → (mechanically) → kinetic store of car + thermal store of surroundings.
- **Sankey diagrams** — arrow widths drawn to scale so the useful and wasted amounts can be read off (see 3.4).

Analysing changes in the way energy is stored (3.5)

For each system change you must say **which store empties and which fills**:

- **a — an object projected upwards or up a slope:** kinetic store empties, gravitational potential store fills. (Some also goes to the thermal store of the surroundings through air resistance or friction on the slope.)
- **b — a moving object hitting an obstacle:** kinetic store empties; energy is transferred to the elastic potential and thermal stores of the object and obstacle, and away by radiation as sound.
- **c — an object being accelerated by a constant force:** energy is transferred mechanically by the force, filling the kinetic store.
- **d — a vehicle slowing down:** the kinetic store empties; friction in the brakes fills their thermal store, then that of the surroundings.
- **e — bringing water to a boil in an electric kettle:** energy is transferred electrically from the mains; the thermal store of the water fills, and so do those of the kettle body and the room.

3.2 Calculating energy in stores (3.1, 3.2)

WATCH OUT

Δh is the **vertical** height gained, never the distance walked along a slope. A student who climbs 30 m along a ramp that rises 5 m has gained the GPE for 5 m, not 30 m.

3.3 Conservation of energy, dissipation and wasted energy (3.4, 3.6, 3.7, 3.8)

You must be able to **explain what is meant by conservation of energy** (3.4):

Energy can be **stored, transferred and dissipated**, but it **cannot be created or destroyed**.

And you must **explain that where there are energy transfers in a closed system there is no net change to the total energy in that system** (3.6). Nothing enters and nothing leaves a closed system, so however energy is shuffled between the stores inside it, the total stays the same.

ANALOGY

Dissipation is like **spilling a bag of sugar on a carpet**. Not one grain is destroyed — it is all still in the room — but it is now spread so thinly that you will never scoop it back into the bag. Dissipated energy is spread thinly through the surroundings as a tiny temperature rise: conserved, but useless.

Dissipation (3.7, 3.8)

- You must **explain that mechanical processes become wasteful when they cause a rise in temperature, so dissipating energy in heating the surroundings** (3.7).
- You must **explain, using examples, how in all system changes energy is dissipated so that it is stored in less useful ways** (3.8).

Worked examples of dissipation:

- **Brakes:** kinetic store → thermal store of brake discs → thermal store of the air. The air is very slightly warmer, and that energy can never be gathered back to drive the car.
- **A filament lamp:** electrical transfer → useful radiation (light) + a large amount to the thermal store of the surroundings.
- **A bouncing ball:** each bounce is lower because energy is dissipated to the thermal stores of ball and floor, and by radiation as sound.
- **Any machine with moving parts:** friction raises the temperature of the surfaces.

3.4 Efficiency and Sankey diagrams (3.11, 3.12)

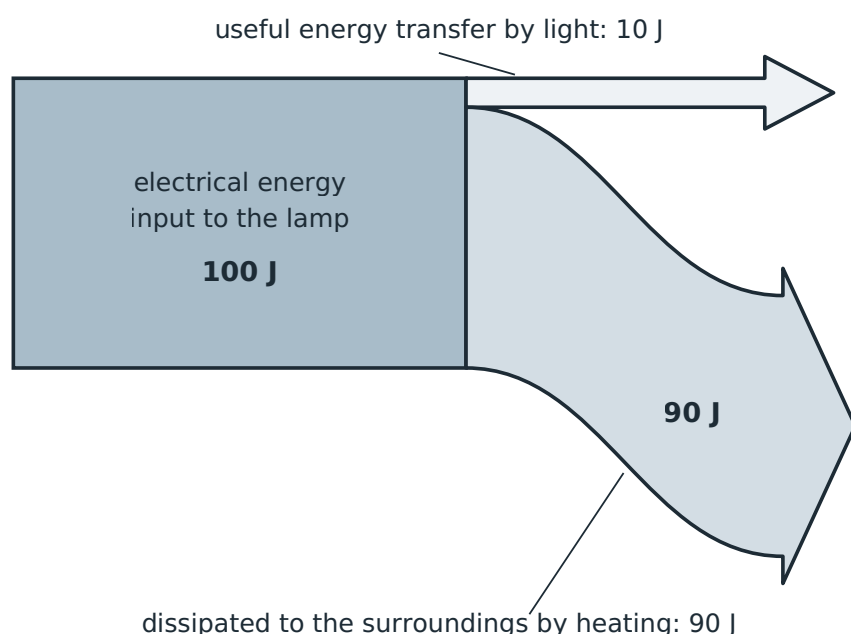
Sankey diagrams

A **Sankey diagram** shows the same information as a picture:

- The arrow enters from the left with a width proportional to the **total energy supplied**.
- It splits: the **useful** output continues straight on, the **wasted** output (almost always thermal) drops away downwards.
- Widths must add up — draw on squared paper, e.g. 1 cm $\equiv$ 100 J. Efficiency = width of useful arrow $\div$ width of input arrow.

For Worked example 5 the input arrow is 8 cm wide, the useful arrow 2.4 cm and the wasted arrow 5.6 cm.

A Sankey diagram and efficiency



Efficiency

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

(or useful power output $\div$ total power input)

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

$$\text{efficiency} = 10\%$$

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 is **pay after deductions**. Your gross pay is the total energy supplied; tax and pension are the wasted transfers; what lands in your account is the useful output. Nothing is destroyed — the money still exists — but only the take-home part does the job you wanted. A Sankey diagram is the payslip.

HIGHER TIER

HT ONLY Increasing efficiency (3.12)

HT ONLY You must **explain how efficiency can be increased**. Efficiency rises when the **wasted** transfer is made smaller, because the useful share of the same input then grows:

HT ONLY Lubricate moving parts so less energy is dissipated by friction. **HT ONLY Streamline** vehicles so less energy is wasted against air resistance. **HT ONLY Insulate** hot devices (a lagged kettle or hot water tank) so less energy leaks to the surroundings by heating. **HT ONLY Reduce the electrical resistance** of wires so less energy is dissipated in heating them. **HT ONLY Recover** what would be wasted: regenerative braking transfers energy from the kinetic store back to a chemical (battery) store.

3.5 Reducing unwanted energy transfer (3.9, 3.10)

You must **explain ways of reducing unwanted energy transfer, including through lubrication and thermal insulation** (3.9).

- **Lubrication** — oil or grease keeps two surfaces apart so they slide rather than rub. Less work is done against friction, so less energy is dissipated to thermal stores, and parts last longer.
- **Thermal insulation** — a material of **low thermal conductivity** (loft insulation, cavity-wall foam, a lagging jacket) slows transfer by heating to the cooler surroundings. Trapped air insulates well because it conducts poorly and, being trapped, cannot carry energy away by convection.
- Other measures: double glazing (trapped gas between panes), draught excluders (stopping convection carrying warm air out), reflective foil behind radiators (reducing radiation).

Rate of cooling of a building (3.10)

You must **describe, qualitatively, the effects of the thickness and thermal conductivity of the walls of a building on its rate of cooling**:

- **Thicker walls** → **slower cooling**. Energy has further to travel through the material, so it is transferred more slowly.
- **Lower thermal conductivity** → **slower cooling**. A material that conducts poorly transfers energy through itself more slowly, so the inside stays warm for longer.
- A building with **thick walls of low thermal conductivity** cools most slowly and is cheapest to heat.

NOTE

"Rate of cooling" means how many degrees the temperature falls **per unit time**. Thickness and conductivity change *how fast* the building cools, not *how much* energy it eventually loses.

3.6 Energy resources (3.13, 3.14)

You must **describe the main energy resources available for use on Earth — including fossil fuels, nuclear fuel, bio-fuel, wind, hydro-electricity, the tides and the Sun — and compare the ways in which both renewable and non-renewable resources are used** (3.13). Resources are used for three main purposes: **generating electricity, transport and heating**.

Non-renewable resources: fossil fuels (coal, oil, natural gas) and nuclear fuel. They will run out. **Renewable** resources: bio-fuel, wind, hydro-electricity, tides, the Sun (solar), and also waves and geothermal.

Non-renewable	Main uses	Advantages	Disadvantages
Coal	electricity generation, heating	very reliable; large reserves; cheap to build stations	releases CO ₂ (global warming) and sulfur dioxide (acid rain); mining scars the land; non-renewable
Oil	transport (petrol, diesel), heating, some electricity	reliable; energy-dense, so ideal for vehicles	CO ₂ and other pollutants; oil spills damage habitats; non-renewable
Natural gas	electricity generation, heating, cooking	reliable; stations start up quickly to meet peak demand; cleanest fossil fuel per joule	still releases CO ₂ ; non-renewable
Nuclear fuel	electricity generation	reliable; no CO ₂ from the reaction; huge energy per kilogram	radioactive waste stays dangerous for thousands of years; very high build and decommissioning costs; risk of a major accident
Renewable	Main uses	Advantages	Disadvantages
Bio-fuel	transport, heating, electricity	roughly carbon-neutral (CO ₂ was absorbed as the crop grew); can use waste; fuel can be stored	land used for fuel is not used for food; burning still releases pollutants; large land area needed
Wind	electricity generation	no fuel cost; no CO ₂ when running; quick to build	unreliable — no output when the wind is calm or too strong; noise and visual impact; low output per turbine
Hydro-electricity	electricity generation	reliable and can be switched on within seconds to meet peaks; no fuel cost; long-lived	valley must be flooded — habitats and homes lost; few suitable sites; high build cost
Tides	electricity generation	very predictable ; no fuel cost; no CO ₂ when running	only four peaks a day; barrages damage estuary habitats; very expensive; few suitable estuaries
The Sun (solar)	electricity (solar cells), heating (solar panels)	no fuel cost; ideal for remote places; no CO ₂ when running	unreliable — no output at night, less in cloud or winter; high initial cost; large area needed

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Reliability is the point examiners return to. Fossil-fuel, nuclear, bio-fuel and hydro-electric stations produce power **on demand**; wind and solar depend on the weather so are **unreliable**, while tidal output is **predictable** though intermittent. Since electricity cannot easily be stored nationally, unreliable resources need a reliable back-up, usually gas.

Patterns and trends in the use of energy resources (3.14)

You must **explain patterns and trends in the use of energy resources**:

- **Overall demand has risen** with population growth, industrialisation and more electrical devices per household.
- **Coal use in the UK has fallen sharply**; gas replaced it because gas stations are cheaper to build, quicker to respond and release less CO₂ per joule.
- **Renewables have grown quickly**, especially wind and solar, driven by concern over global warming, government targets and falling costs as the technology improves.
- **Nuclear has stayed level or fallen** in many countries — old stations are closing, and concern over waste and accidents makes new ones politically difficult.
- **Transport is still dominated by oil**, because liquid fuels store a great deal of energy per kilogram; the shift is to electric vehicles, which moves the problem back to how the electricity was generated.

Reasons behind the trends: **environmental impact**, **cost** (build, fuel, decommissioning), **reliability**, and **how long reserves will last**.

NOTE

Suggested practical (not a core practical): investigate conservation of energy — for example, release a trolley from measured heights down a ramp and compare the GPE lost with the KE gained at the bottom, measured with light gates. The KE is always slightly less than the GPE lost, and the difference is the energy dissipated by friction and air resistance.

NOTE

Uses of mathematics: convert units and compute rates using ratios; calculate stored energy and energy transfers, converting between newton-metres and joules ($1 \text{ N m} = 1 \text{ J}$); express the whole redistribution of energy in a system in joules on one common scale.