

Energy

- Energy is a property that must be transferred to an object in order to perform **work on** or **heat up** that object
- It is measured in units of **Joules (J)**

Law of conservation of energy:

“Energy cannot be created or destroyed. It can only be transferred from one state to another.”

Energy Store	Description
Kinetic	Energy an object has because it's moving
Gravitational	Energy an object has due to its position above the ground. An object gains gravitational energy when lifted and loses it when it falls
Elastic	Energy stored in a stretched spring or elastic band
Electrostatic	Energy due to the force of attraction (or repulsion) between two charges
Magnetic	Energy due to the force of attraction (or repulsion) between two magnets
Chemical	Energy found in fuels, foods, or in batteries. This energy is transferred during chemical reactions
Nuclear	Energy contained within the nucleus of an atom
Thermal	Energy a substance has due to its temperature

Energy Transfer	Description
Mechanical	When a force acts on a body e.g. a collision
Electrical	Electricity can transfer energy from a power source, such as a cell, delivering it to components within a circuit
Heating	Thermal energy can be transferred by conduction, convection or radiation
Radiation	Light and sound carry energy and can transfer this between two points

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Kinetic energy:

The energy due to the motion of an object.

$$E_K = \frac{1}{2} \times m \times v^2$$

Gravitational Potential energy:

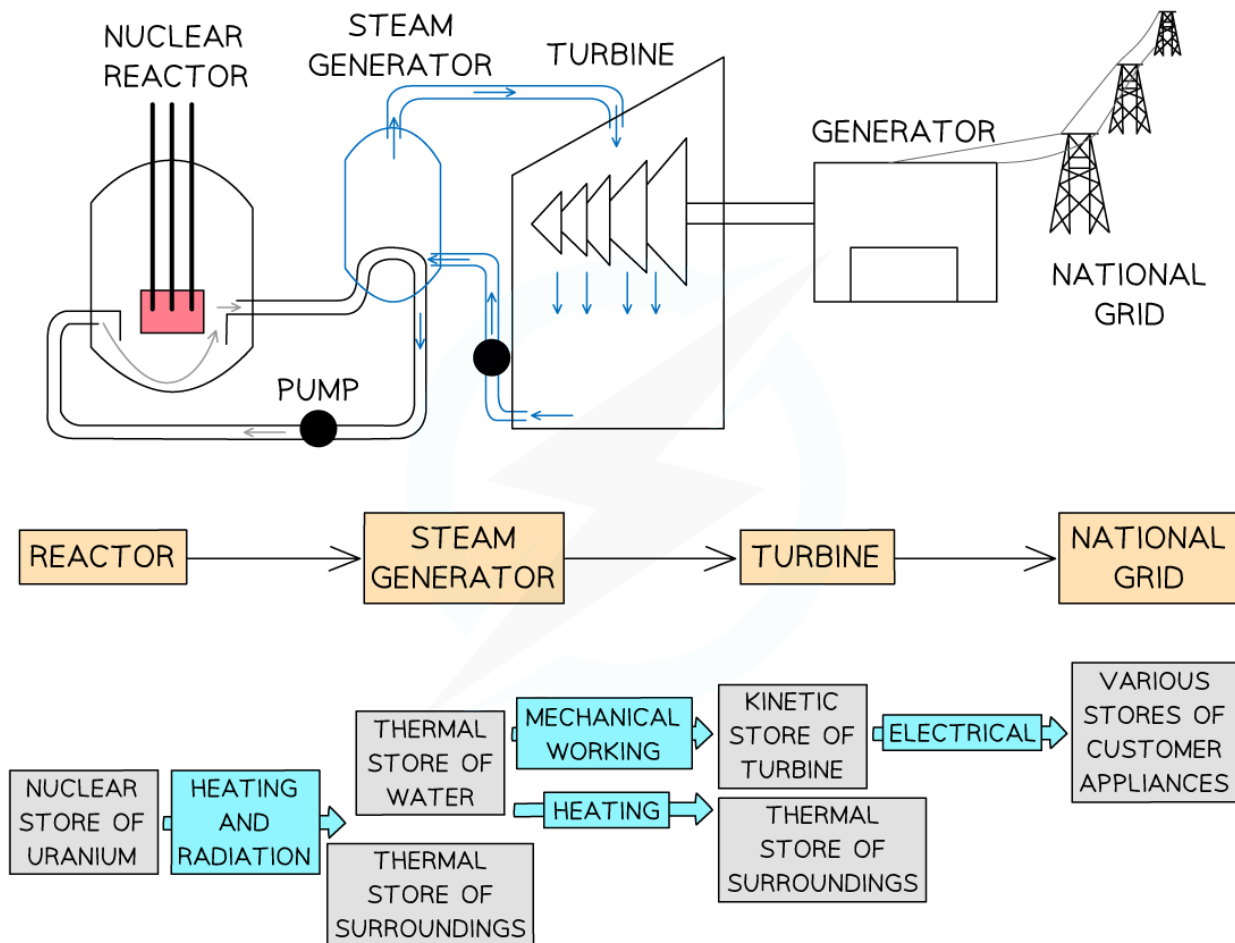
The energy an object has due to its height in a gravitational field.

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

Law of conservation of energy.

Energy cannot be created or destroyed, it can only be transferred from one energy store to another.

- This means the total amount of energy in a closed system remains constant
- Therefore, energy cannot be 'lost', but it can be transferred to the thermal energy store of the surroundings
 - Energy can be dissipated to the surroundings by radiation (by heat, light or sound)
 - This energy is often not useful energy, so it can be described as wasted energy



Work

Work is done when an object is moved over a **distance** by a **force** applied in the **direction** of its displacement

- It is said that the **force does work** on the object
- If a force is applied to an object but doesn't result in any movement, no work is done.

Work done = force × distance

$$W = fd$$

- Whenever any work is done, energy is transferred mechanically from one store to another
- The amount of energy transferred (in joules) is equal to the work done (also in joules)

energy transferred (J) = work done (J)

Power

Power is defined as: **The rate of doing work**

$$P = W / t$$

$$P = E / t$$

Unit = Watt (W)

Efficiency

- The efficiency of a system is a measure of how well energy is transferred in a system
- Efficiency is defined as:

The ratio of the useful power or energy transfer output from a system to its total power or energy transfer input

- If a system has **high** efficiency, this means most of the energy transferred is **useful**
- If a system has **low** efficiency, this means most of the energy transferred is **wasted**

$$\text{EFFICIENCY} = \frac{\text{USEFUL ENERGY OUTPUT}}{\text{TOTAL ENERGY INPUT}} \times 100\%$$

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$$\text{EFFICIENCY} = \frac{\text{USEFUL POWER OUTPUT}}{\text{TOTAL POWER INPUT}} \times 100\%$$

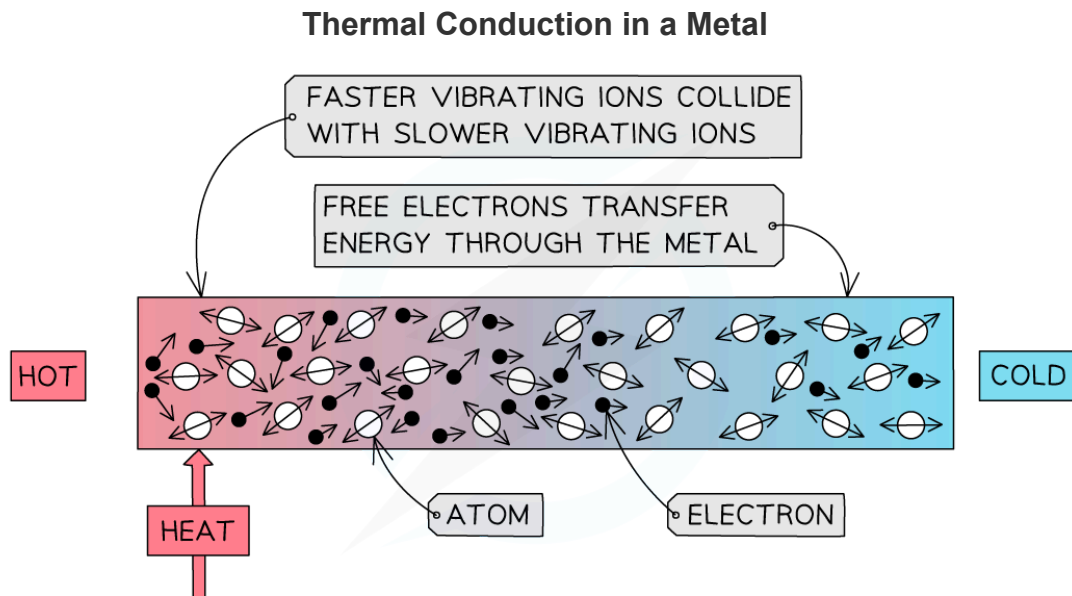
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Thermal Conduction in Solids

- Conduction is the main method of thermal energy transfer in solids
- Conduction occurs when:

Two solids of different temperatures come in contact with one another, thermal energy is transferred from the hotter object to the cooler object

- Metals are the best thermal conductors
 - This is because they have a high number of free electrons



Conduction: the atoms in a solid vibrate and bump into each other

- Conduction can occur through two mechanisms:
 - Atomic vibrations
 - Free electron collisions
- When a substance is heated, the atoms, or ions, start to move around (vibrate) more
 - The atoms at the hotter end of the solid will vibrate more than the atoms at the cooler end
 - As they do so they bump into each other, transferring energy from atom to atom
 - These collisions transfer internal energy until thermal equilibrium is achieved throughout the substance
 - This occurs in all solids, metals and non-metals alike

Experiments Demonstrating Thermal Conductors

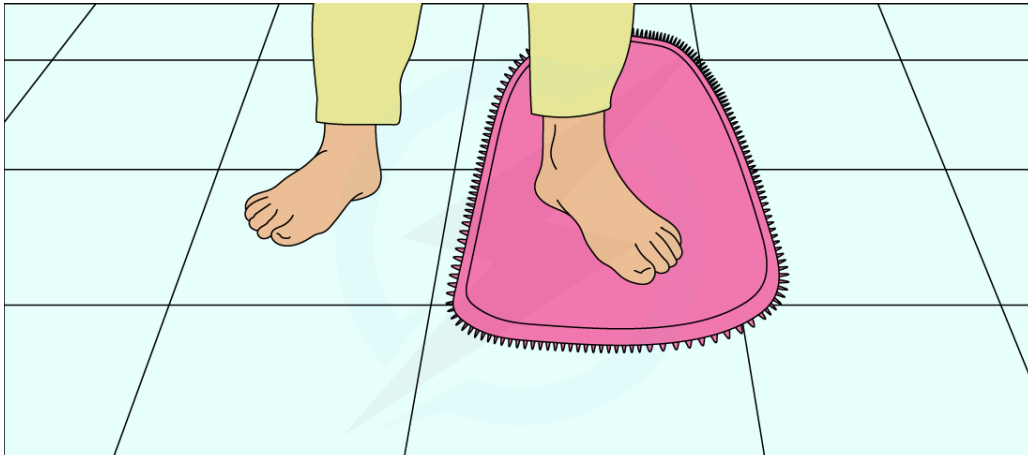
- **Good thermal conductors are solids which easily transfer heat**
 - For example; a metal pan or a ceramic tea cup
- **Bad thermal conductors (also called insulators) are solids which do not transfer heat well**
 - For example; a woolen blanket or layers of cardboard or paper

Comparing Conduction in Tiles and Textiles

This demonstration shows why homes use rugs and carpets

- **Find a tiled or stone area of floor**
 - In the same room leave a rug or bath towel (not a thin cloth, it must be thick)
 - The textile must stay in place on the floor for several hours to ensure they are at thermal equilibrium (the same temperature)

Standing on a Tile and a Rug



One person with a foot on each allows a qualitative comparison of temperature between the two

- **Stand with bare feet (hands can be used)**
 - Place one foot on the tiles or stone area, and the other on the textile (towel or rug)
 - Observe the apparent temperature of the two materials as felt through the feet
 - It will feel as though the tiles are cold while the rug is warm, however, they are at exactly the same temperature

Transfer of Energy through Tile and Rug



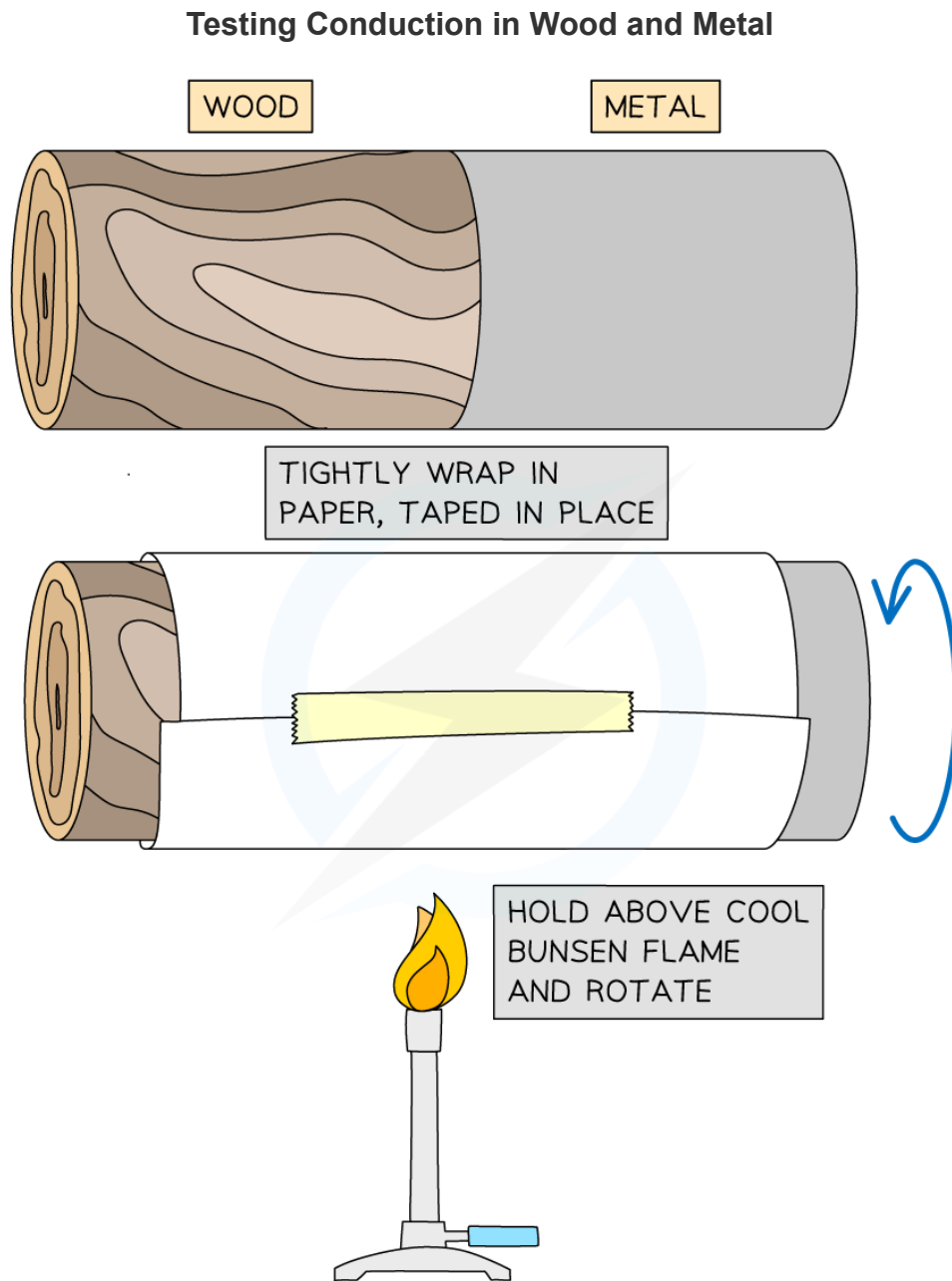
Energy is transferred by heating from the warm body to the cooler tiles by conduction

Explanation

- Tiles and stone are good conductors of heat
 - Where the foot touches the tiles, heat is transferred away from the foot, making it feel cold
 - The foot has become colder since it lost heat to the tiles
- Textiles such as rugs are good insulators, meaning they are poor conductors of heat
 - Where the foot touches the rug, heat is not transferred away from the foot
 - This foot feels relatively warmer than the one which has lost heat to the tiles
 - The foot has stayed at its starting temperature

Comparing Conduction in Wood and Paper

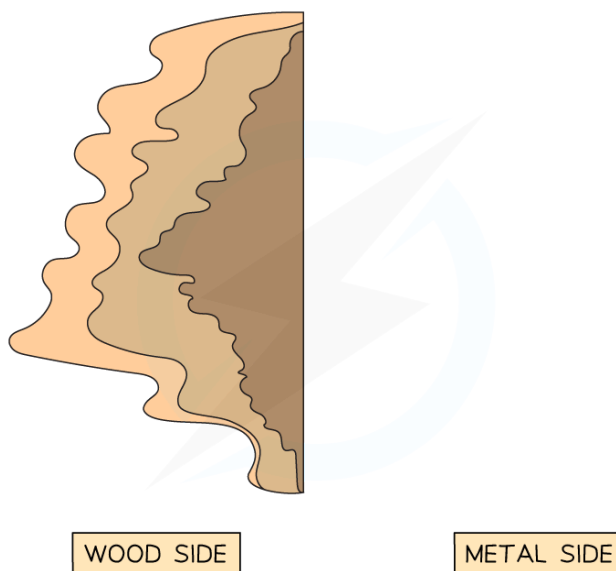
- A cylindrical rod made of half wood and half metal is wrapped tightly in paper



The paper is heated. The two different materials conduct energy away from the paper's thermal store at different rates

- Using a gentle flame, and holding the rod clear of the top of the flame, gently heat the paper at the join of the wood and metal
 - Turn the rod so that the paper is well-heated all around the circumference of the rod
 - Stop when the paper is clearly discoloured
- Remove the rod from the flame, gently unwrap the paper and observe the burn pattern
 - A distinct pattern is seen;
 - Where the paper touched the metal surface it is undamaged
 - Where the paper touched the wood surface it is charred

Pattern of Charring on the Paper after the Experiment



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The side of the paper of the wood shows signs of being burned, so there was more energy in its thermal store on this side

Explanation

- Metal is a good conductor of heat
 - Where the paper touched the metal, heat was transferred from the paper into the metal and along the length of the metal
 - This prevented the paper getting hot
- Wood is a good insulator, meaning it is a poor conductor of heat

- Where the paper touched the wood, heat was not transferred from the paper
- This meant that the paper did get hot enough to start to burn

Convection

- Convection is the main way that heat travels through liquids and gases
 - Convection only occurs in fluids
 - Convection cannot happen in solids

Density & Convection

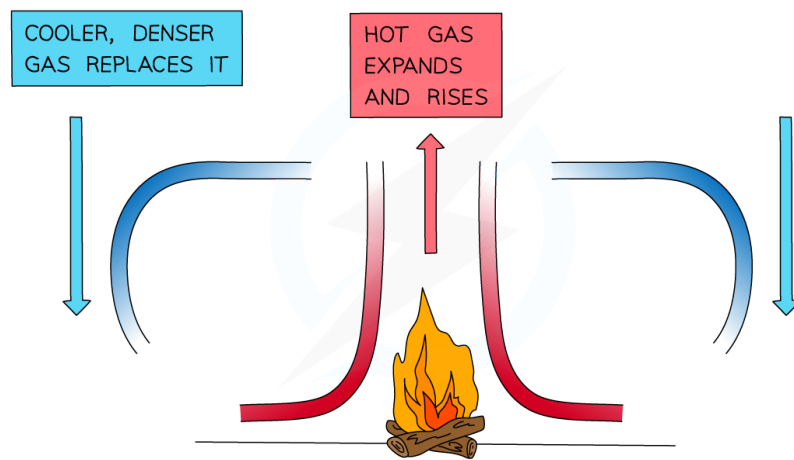
Descriptions of convection currents always need to refer to changes in temperature causing changes in density

- The temperature may fall or rise, both can create a convection current

When a liquid (or gas) is heated (for example by a radiator near the floor):

- The molecules push each other apart, making the liquid/gas expand
- This makes the hot liquid/gas less dense than the surroundings
- The hot liquid/gas rises, and the cooler (surrounding) liquid/gas moves in to take its place
- Eventually the hot liquid/gas cools, contracts and sinks back down again
- The resulting motion is called a convection current

Convection Currents



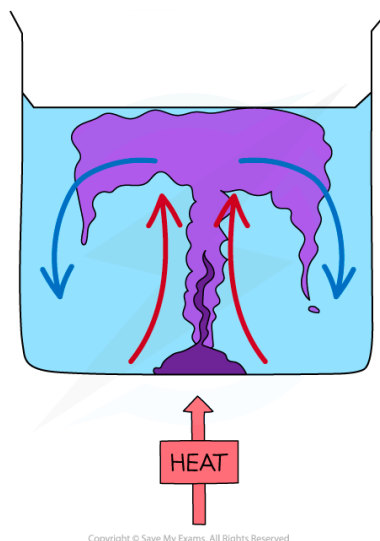
When a liquid or gas is heated, it becomes less dense and rises

- When a liquid (or gas) is cooled (for example by an A.C. unit high up on a wall):
 - The molecules move together, making the liquid/gas contract
 - This makes the hot liquid/gas more dense than the surroundings
 - The cold liquid/gas falls, so that warmer liquid or gas can move into the space created
 - The warmer liquid or gas gets cooled and also contracts and falls down
 - The resulting motion is called a convection current

Demonstrating Convection Currents

- A simple demonstration of convection in liquids involves taking a beaker of water and placing a few crystals of potassium permanganate in it, to one side, as shown in the diagram above
- When the water is heated at that side, the potassium permanganate will dissolve in the heated water and rise along with the warmed water, revealing the convection current

Demonstrating Convection



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Diagram showing an experiment with potassium permanganate to demonstrate convection

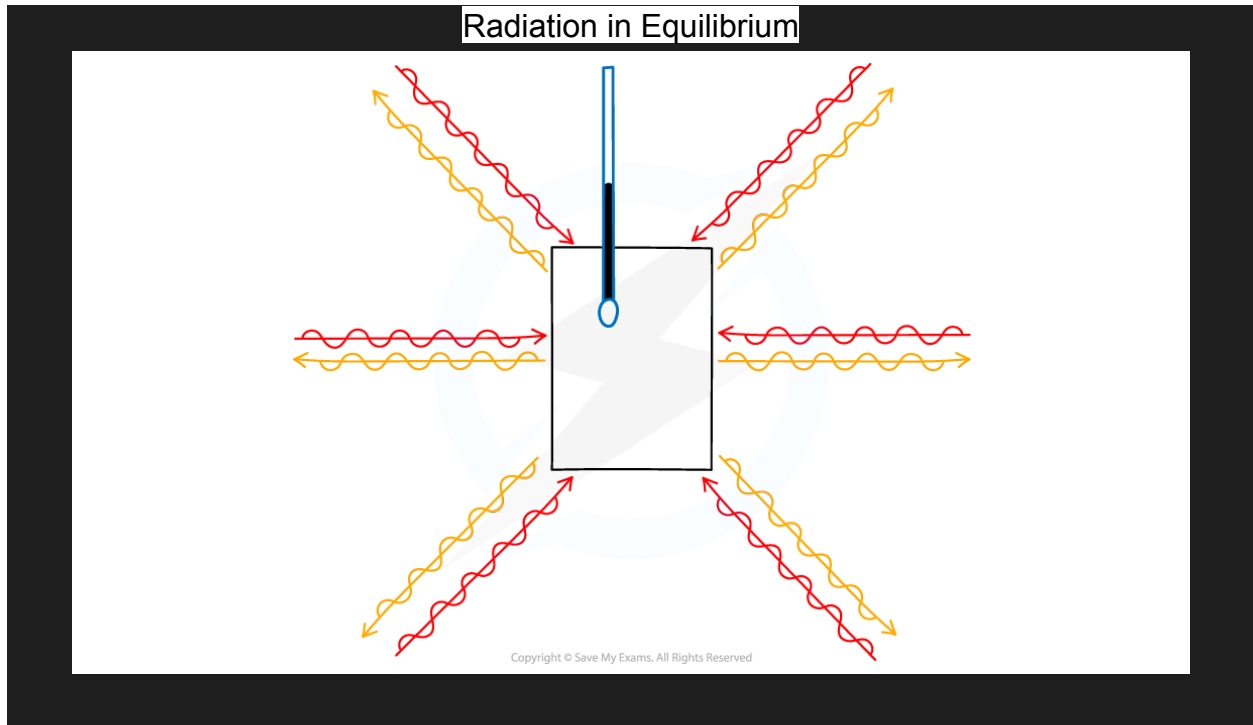
Thermal Radiation

- All objects give off thermal radiation
 - The hotter an object is, the more thermal radiation it emits
 - Thermal radiation is the part of the electromagnetic spectrum called **infrared**
- Thermal radiation is **the only way in which heat can travel through a vacuum**
 - It is the way in which heat reaches us from the Sun through the vacuum of space
- The colour of an object affects how good it is at emitting and absorbing thermal radiation:

Thermal Equilibrium

As an object **absorbs** thermal radiation it will become **hotter**

- As it gets hotter it will also **emit** more thermal radiation
 - The temperature of a body increases when the body absorbs radiation faster than it emits radiation
- Eventually, an object will reach a point of **constant temperature** where it is **absorbing** radiation at the **same rate** as it is **emitting** radiation
 - At this point, the object will be in **thermal equilibrium**



An object will remain at a constant temperature if it absorbs heat at the same rate as it loses heat

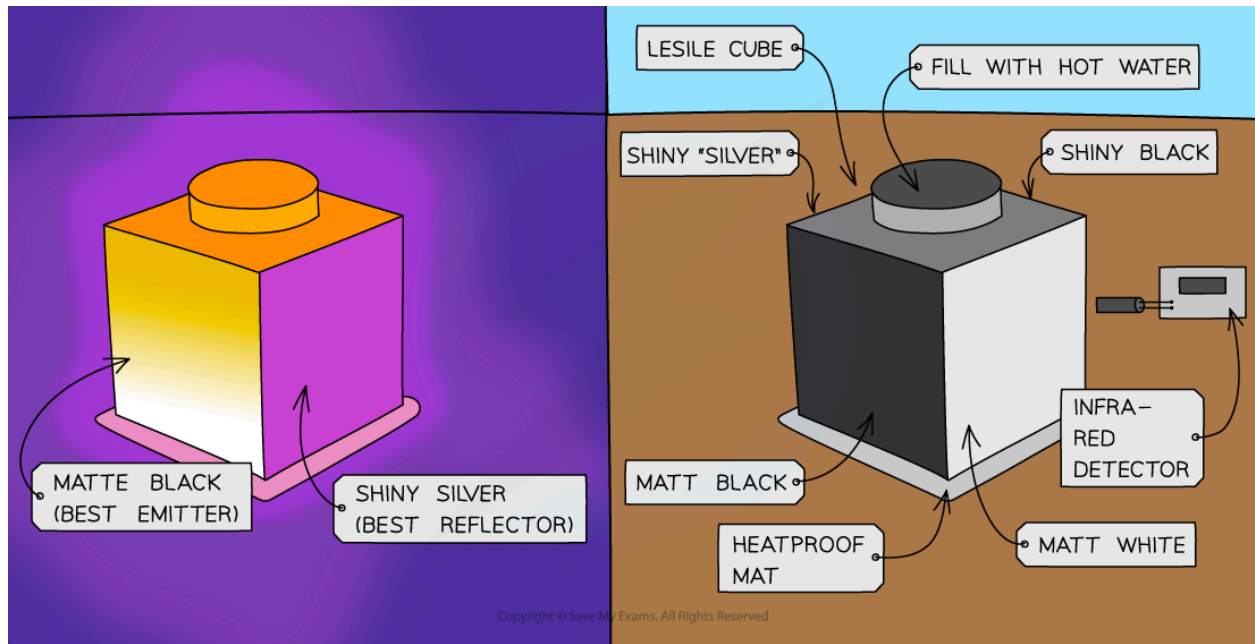
- If the rate at which an object receives energy is less than the rate at which it transfers energy away then the object will cool down
- If the rate at which an object transfers energy away is less than the rate at which it receives energy then the object will heat up
- The process will **always** move towards thermal equilibrium

Effects of Different Surfaces

- The amount of thermal radiation emitted by an object depends on a number of factors:
 - The **surface colour** of the object (black = more radiation)
 - The **texture** of the surface (shiny surfaces = more radiation)
 - The **surface area** of the object (greater surface area = more area for radiation to be emitted from)

Absorbing and Emitting Powers of Different Coloured Objects		
Colour	Absorbing	Emitting
Black	Good absorber	Good emitter
Dull / dark	Reasonable absorber	Reasonable emitter
White	Poor absorber	Poor emitter
Shiny	Very poor absorber (reflects radiation)	Very poor emitter

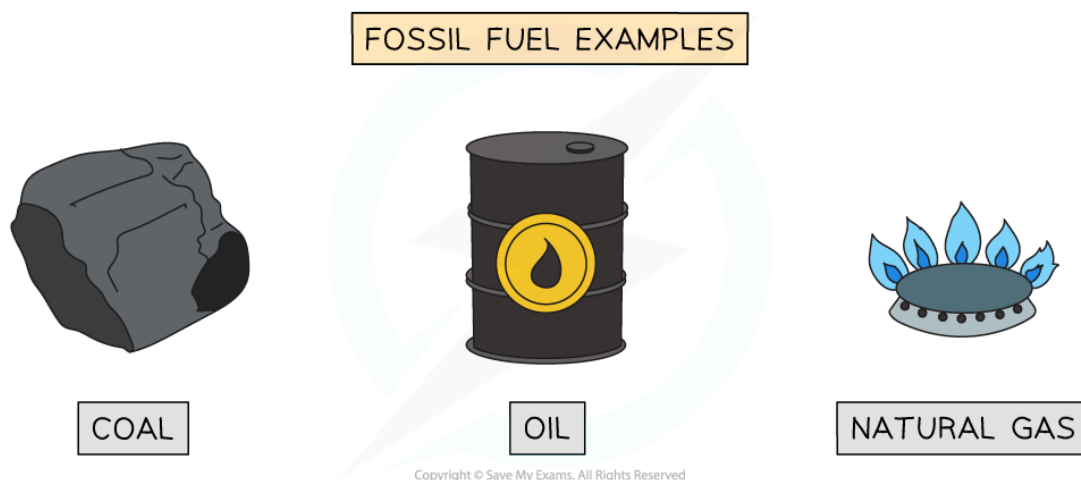
- Black objects are very good at absorbing thermal radiation, for example black clothes make you feel hotter in sunny weather
 - Black objects are also very good at emitting thermal radiation, which is the reason that chargers for laptops, and radiators in cars are coloured black - it helps them to cool down
- Shiny objects reflect thermal radiation and so absorb very little
 - They also emit very little, though, and so take longer to cool down



An image of a hot object taken in both Infrared and visible light. The black surface emits more thermal radiation (infrared) than the shiny surface

Fossil Fuels

- Fossil fuels are:
 - **Coal**
 - **Natural gas** (mostly methane) which is used in domestic boilers and cookers
 - Crude **oil** which is refined into petrol, diesel, and other fuels



Fossil fuels: coal, oil and natural gas

- Fossil fuels are formed from the **remains of plants and animals**
- **Chemical energy** stored in fossil fuels originally came from **sunlight**
 - Energy from the sun was transferred to the chemical energy store of plants by photosynthesis (plants use energy from sunlight to make food)
 - Animals ate the plants and the energy was transferred to their chemical store

Advantages

- The current systems of transport and electricity generation rely heavily on fossil fuels which are generally readily **available** on a daily basis
- In the past fossil fuels have been **reliable** for large scale energy production although this is changing as supplies deplete and prices rise

Disadvantages

- It takes **millions of years** for fossil fuels to form
 - This is why they are considered to be a **non-renewable** energy resource

- The increasing demand for a **decreasing supply** causes prices to increase
- Fossil fuels are predicted to **completely run out** within the next 200 years
- Burning fossil fuels pollutes the atmosphere with harmful gases such as:
 - **Carbon dioxide** which contributes to the **greenhouse effect**
 - **Sulphur dioxide** which produces **acid rain**
 - Both carbon and sulphur can be captured upon burning preventing it from being released into the atmosphere but this is expensive to do

Uses of Fossil Fuels

- Fossil fuels are used for:
 - Transport
 - Generating electricity
 - Heating

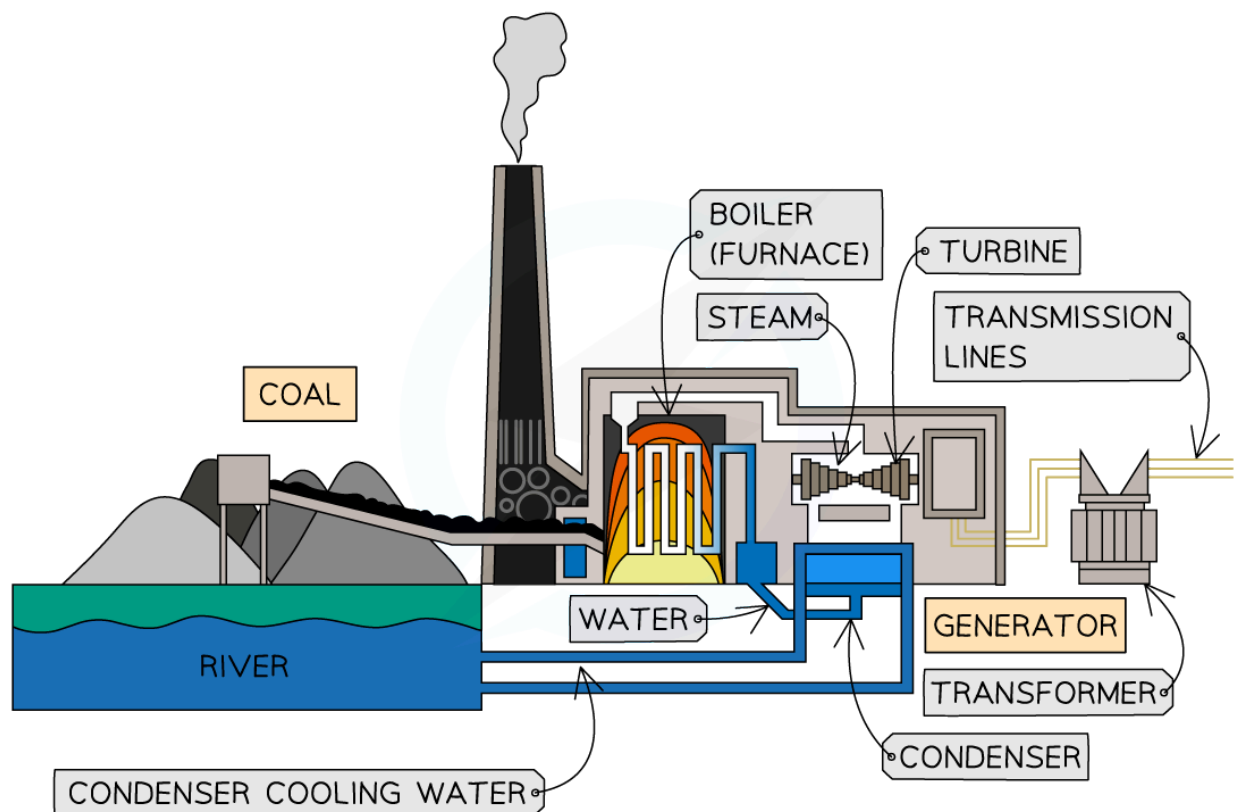
Transport

- The majority of vehicles in the world are powered by **petroleum** products such as petrol, diesel and kerosene
 - These resources all originate from crude oil, which is a **fossil fuel**
- A growing number of vehicles are now being powered by **electricity**
 - The advantage of this is that while the vehicle is being driven, it produces **zero carbon emissions**
 - The disadvantage is that when the vehicle is being charged, it is connected to the National Grid, which currently uses a **combination** of renewable and non-renewable energy sources

Electricity Generation

- Fossil fuels, such as coal and oil, are used to produce energy **on-demand** when energy is needed
 - This is done by **burning** the materials when the energy is required
 - When coal is burned, it produces **thermal energy**
- This is used to **boil water** creating **steam**

- Steam is forced around the system and this turns a **turbine**
- The turbine turns coils in a magnetic field in the generator
 - This generates **electricity**
- The electricity is transferred through a **step-up** transformer and is carried out of the system by **electrical lines**
- The steam within the turbine will cool and **condense** and then be pumped back into the boiler to **repeat the process**

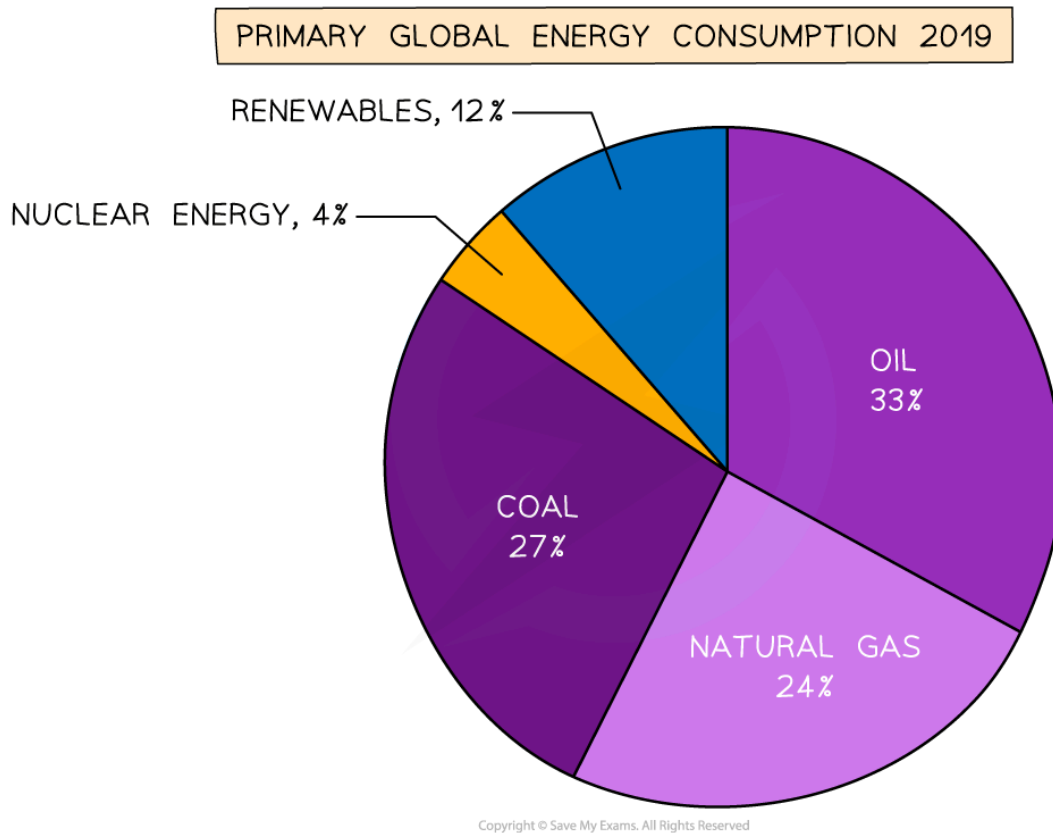


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Electricity generation of coal through a power station

- Electricity plays a bigger role in people's lives than ever before
 - With almost 8 billion people in the world, this means the **demand** for electricity is **extremely high**
 - To keep up with this demand, a combination of **all** the energy resources available is needed
- On the downside, the majority (84%) of the world's energy is still produced by non-renewable, carbon-emitting sources

- This has an enormous **negative** impact on the environment
- Currently, scientists are working hard to develop more and more efficient ways to produce electricity using more carbon-neutral energy resources



Pie chart of global energy consumption

Heating

- Most homes in cold countries are fitted with **central heating systems**
 - These utilise **natural gas** in order to heat up water which can be pumped around radiators throughout the home

Bio Fuels

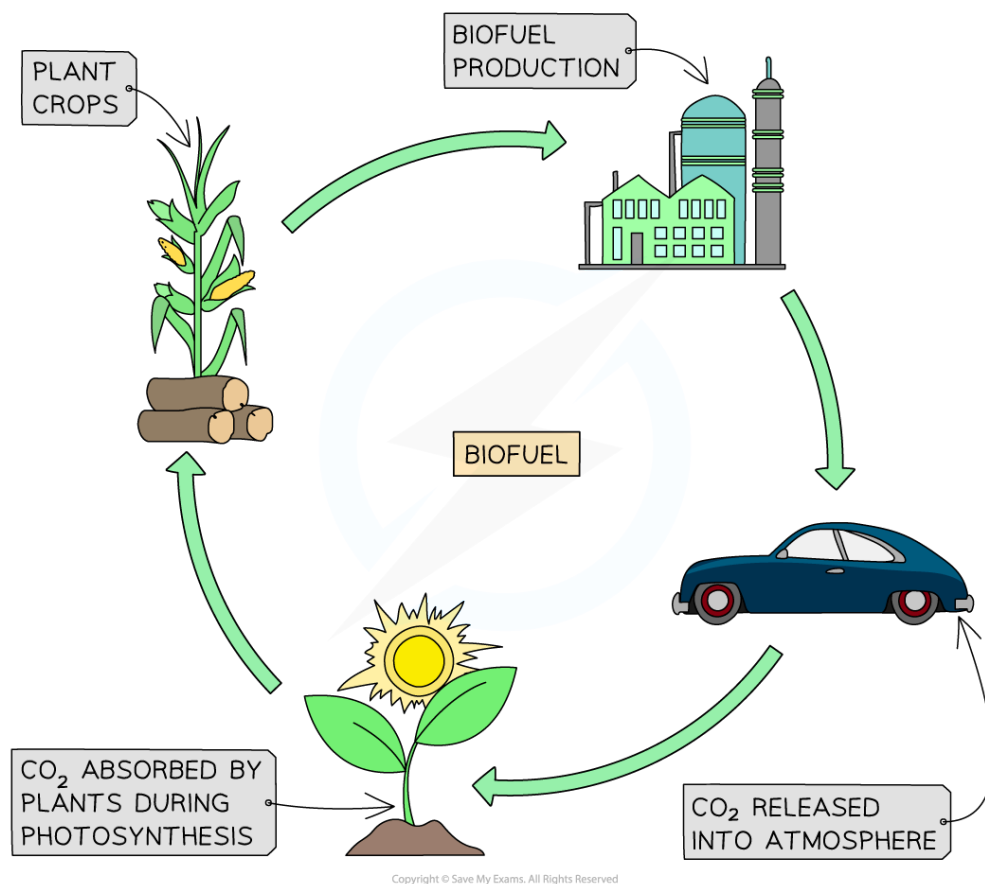
- Biofuels are made from plant matter
 - Energy from sunlight is transferred to the **chemical store** of plants
- **Ethanol** or **methane** can be produced and used in place of fossil fuels
 - However, they have only half the **energy density** of fossil fuels

Advantages

- Biofuel is a **renewable resource**
- Some vehicles can be powered by **biofuel** rather than using fossil fuels
- Biofuel is considered to be **carbon neutral**
- No sulphur dioxide is produced

Disadvantages

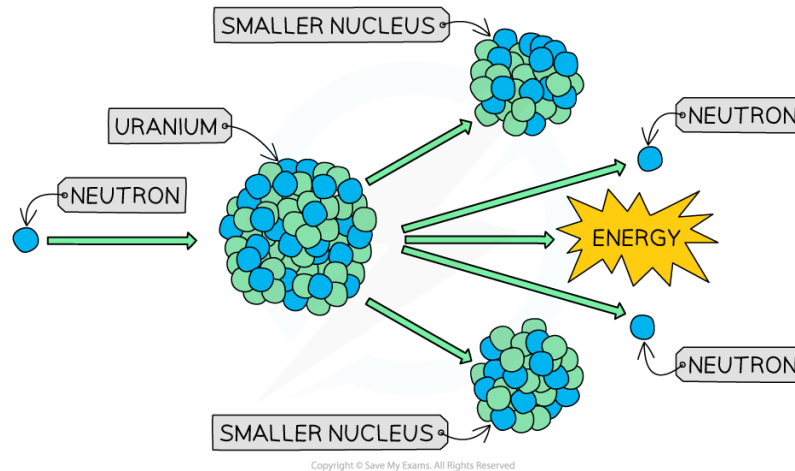
- Crops of biofuel producing plants must be grown which takes **time**
 - Growing the crops takes a lot of **land**, and takes **resources** needed for food production
- Burning biofuels releases **carbon dioxide** into the atmosphere
 - It is considered carbon neutral because plants take in carbon dioxide when they photosynthesise



Plants take in carbon dioxide during photosynthesis, but carbon dioxide is released back into the atmosphere when biofuels are burned

Nuclear Fuel

- Energy stored in the **nucleus** of atoms can be released when the nucleus is broken in two
 - This is known as nuclear **fission**



Nuclear Fission: when a large nucleus is broken into two smaller nuclei energy is released

- Nuclear power stations use fission reactions to **heat water**, to turn turbines to **generate electricity**

Advantages

- **No pollution** released into atmosphere
- Nuclear reactors are perfectly **safe** as long as they are functioning properly
 - Stringent checks must be routinely carried out and rigorous safety procedures followed
- Nuclear power stations can generate electricity **reliably** on a **large scale** which is **available** as needed

Disadvantages

- Uranium ore found in the ground is used for fission reactions and since there is a **finite supply**
Nuclear power is a **non-renewable** resource
- Nuclear fuels produce **radioactive waste**

- Radioactive waste needs to be stored for thousands of years
 - Safe ways of storing radioactive waste is expensive
- If an accident occurs at a nuclear reactor, radioactive waste can leak out and spread over large areas