# Edexcel GCSE Physics

Your notes

## Work, Power & Efficiency

### Contents

# Energy Stores & Transfers

Your notes

## Energy Stores

- Energy is stored in objects in different **energy stores**

**Energy Stores Table**

| Energy Store | Description |
|---|---|
| Kinetic | Moving objects have energy in their kinetic store |
| Gravitational | Objects gain energy in their gravitational potential store when they are lifted through a gravitational field |
| Elastic | Objects have energy in their elastic potential store if they are stretched, squashed or bent |
| Magnetic | Magnetic materials interacting with each other have energy in their magnetic store |
| Electrostatic | Objects with charge (like electrons and protons) interacting with one another have energy in their electrostatic store |
| Chemical | Chemical reactions transfer energy into or away from a substance's chemical store |
| Nuclear | Atomic nuclei release energy from their nuclear store during nuclear reactions |
| Thermal | All objects have energy in their thermal store, the hotter the object, the more energy it has in this store |

## Energy Transfers

### Energy Transfer Pathways

- Energy is **transferred** between stores by different energy **transfer pathways**
- The energy transfer pathways are:

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    - Mechanical
    - Electrical
    - Heating
    - Radiation
- These are described in the table below:

**Energy Transfer Pathway Table**

| Transfer Pathway | Description |
|---|---|
| Mechanical working | When a force acts on an object (e.g. pulling, pushing, stretching, squashing) |
| Electrical working | A charge moving through a potential difference (e.g. current) |
| Heating (by particles) | Energy is transferred from a hotter object to a colder one (e.g. conduction) |
| (Heating by) radiation | Energy transferred by electromagnetic waves (e.g. visible light) |

- An example of an energy transfer **by heating** is a hot coffee heating up cold hands

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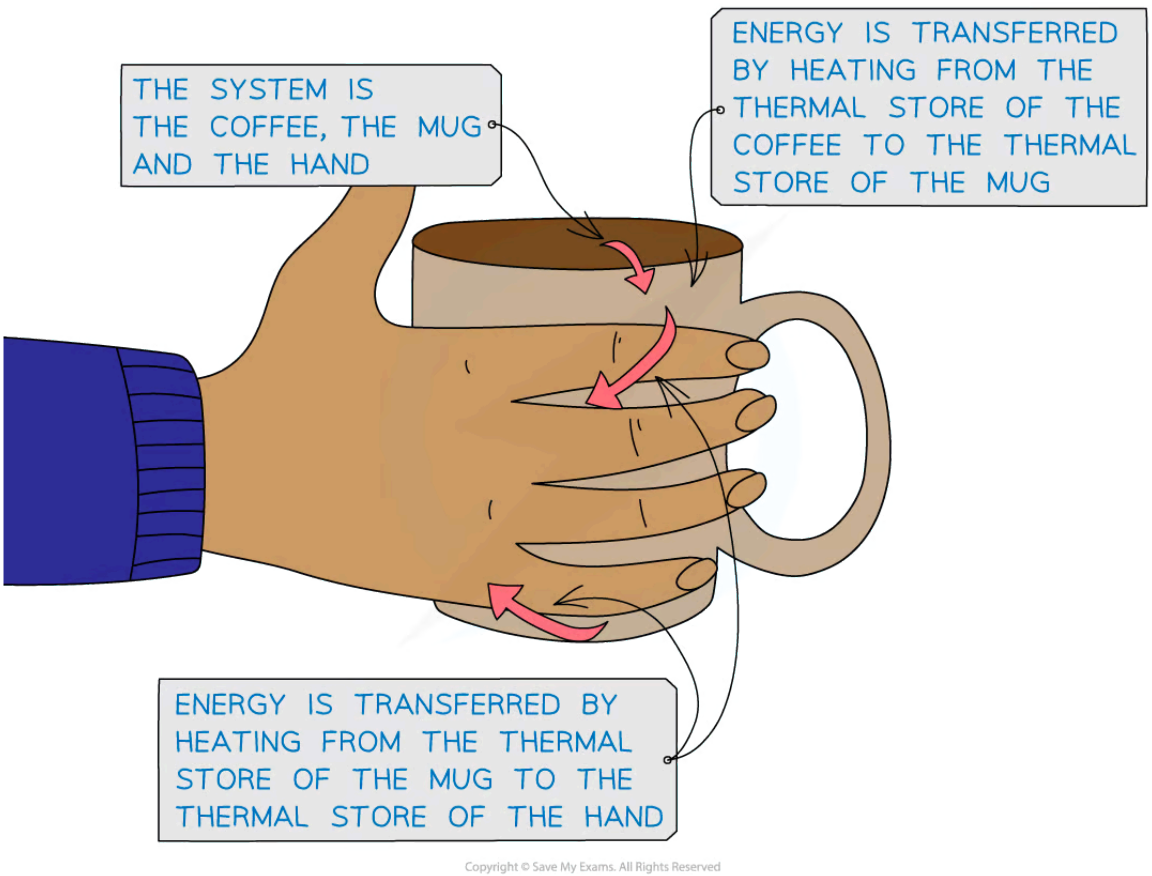


***Energy is transferred by heating from the hot coffee to the mug to the cold hands***

# Energy Transfer Diagrams

## Energy Flow Diagrams

- Energy stores and transfers can be represented using a flow diagram
  - This shows both the stores and the transfers taking place within a system

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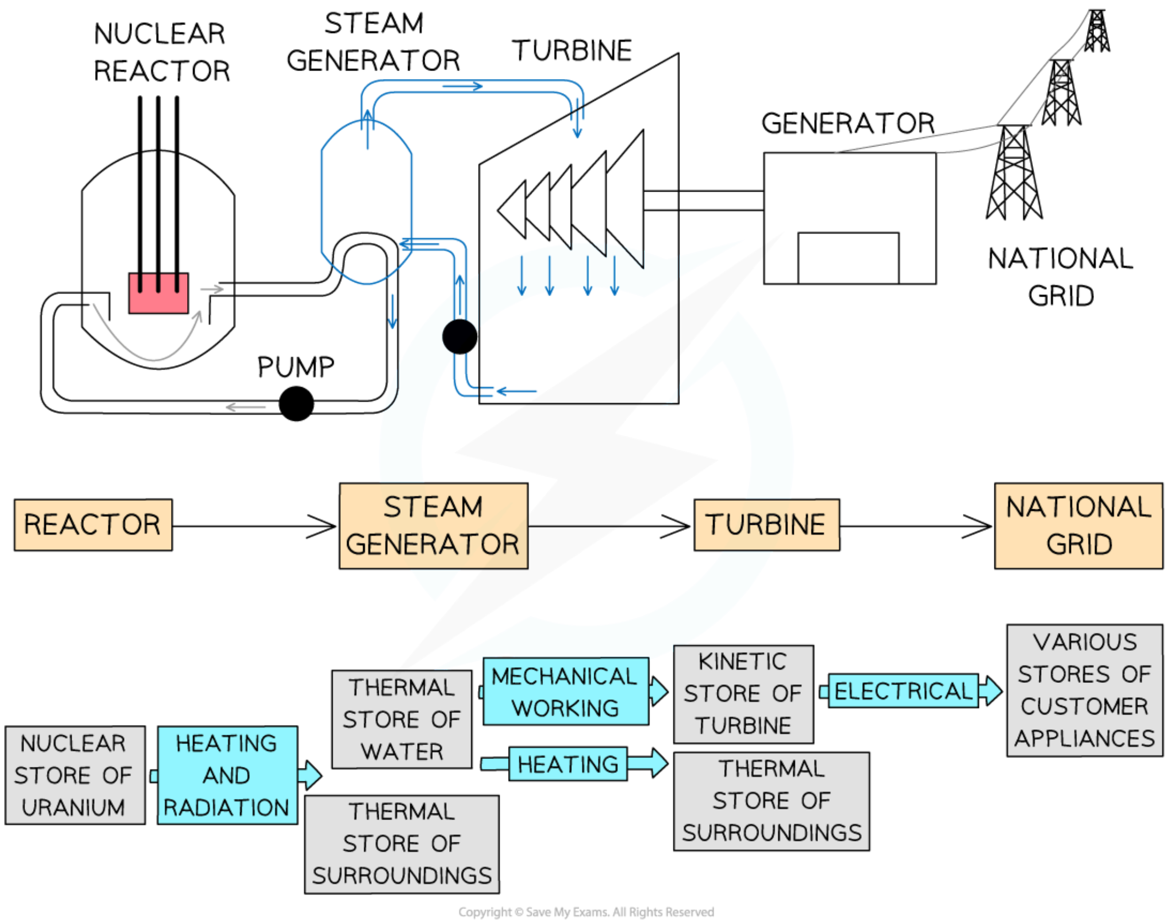


***Energy flow diagram showing energy stores and transfers in a nuclear power plant.***

***Note the colour difference of the labels (stores) and the arrows (transfer pathways)***

## Sankey Diagrams

- **Sankey diagrams** can be used to represent energy transfers
  - Sankey diagrams are characterised by the splitting arrows that show the proportions of the energy transfers taking place
- The different parts of the arrow in a Sankey diagram represent the different energy transfers:
  - The left-hand side of the arrow (the flat end) represents the energy transferred **into** the system

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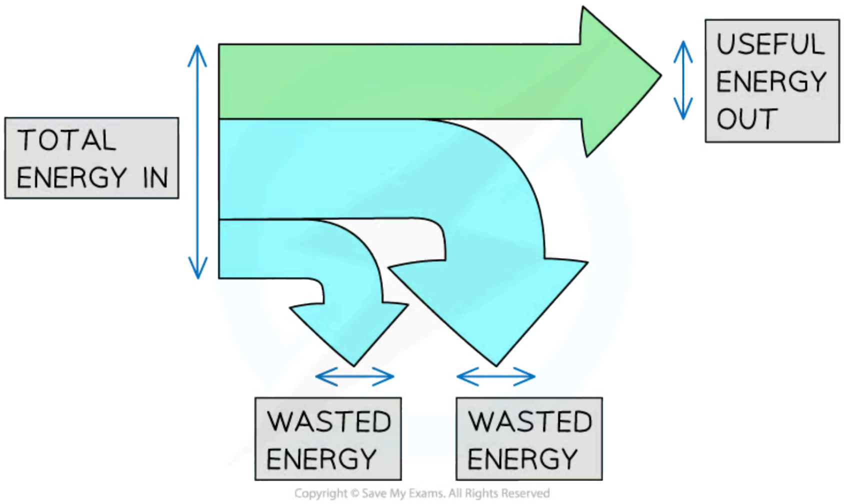
- The straight arrow pointing to the right represents the energy that ends up in the desired store; this is the **useful energy output**
- The arrows that bend away represent the **wasted energy**

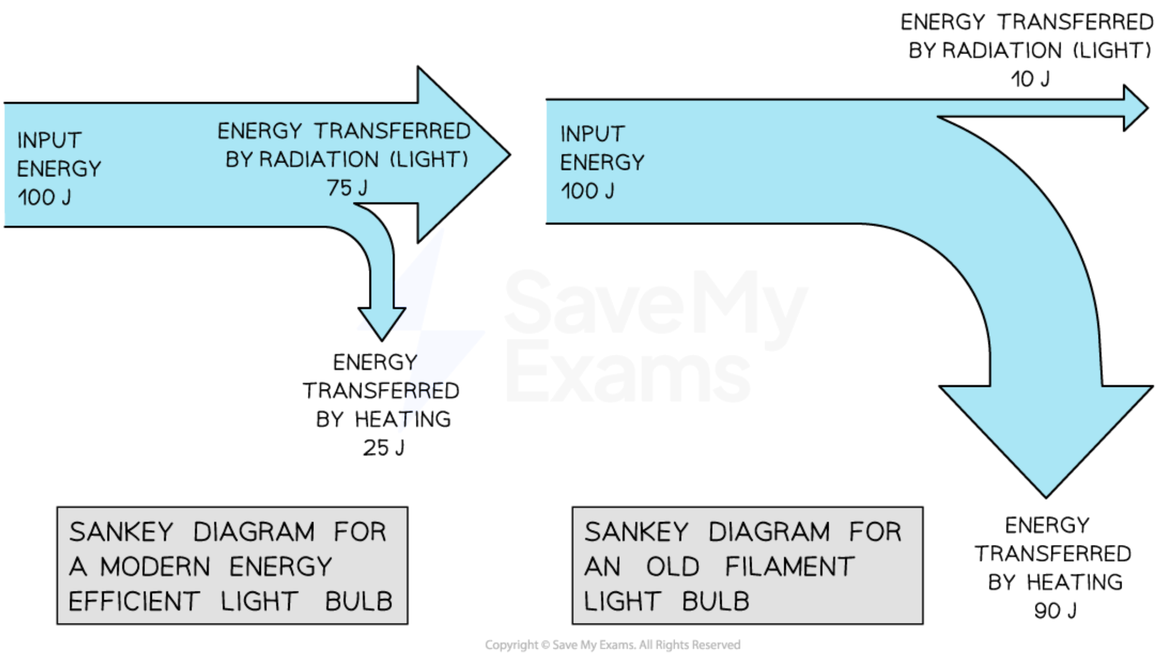



***Total energy in, wasted energy and useful energy out shown on a Sankey diagram***

The width of each arrow is proportional to the amount of energy being transferred As a result of the conversation of energy:

**Total energy in = Useful energy out + Wasted energy**

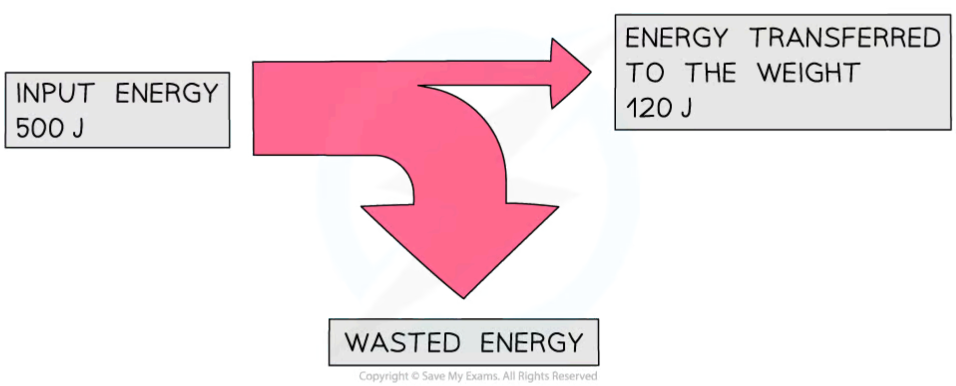
- A Sankey diagram for a modern efficient light bulb will look very different from that for an old filament light bulb
- A more efficient light bulb has **less** wasted energy
    - This is shown by the smaller arrow downwards representing the heat energy




***Sankey diagram for modern vs. old filament light bulb***

## Worked Example

An electric motor is used to lift a weight. The diagram represents the energy transfers in the system.




Calculate the amount of wasted energy.

**Answer:**

**Step 1: State the conservation of energy**

- Energy cannot be created or destroyed, it can only be transferred from one store to another
- This means that:

total energy in = useful energy out + wasted energy out

**Step 2: Rearrange the equation for the wasted energy**

wasted energy = total energy in – useful energy out

**Step 3: Substitute the values from the diagram**

500 – 120 = **380 J**

# Closed Systems & Energy Conservation

## Systems

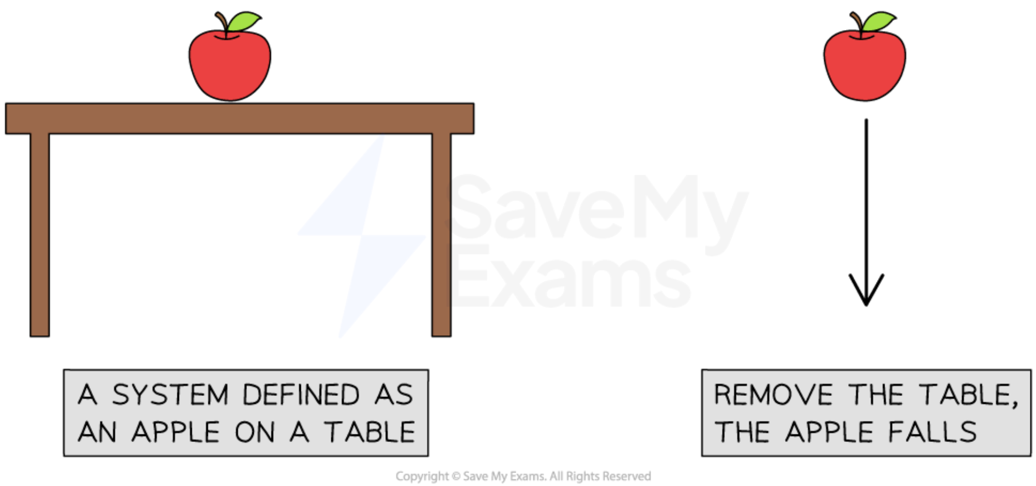
- In physics, a **system** is defined as:

  **An object or group of objects**

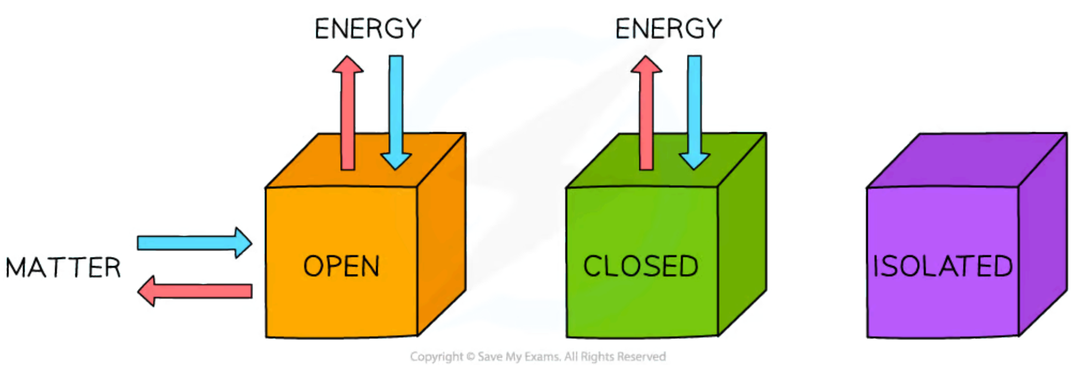
- An apple sitting on a table can be defined as a system
- Defining the system in physics is a way of **narrowing** the parameters to **focus** only on what is relevant to the situation being observed
- When a system is in **equilibrium**, nothing changes and so nothing happens
- When there is a change in a system, things happen, and when things happen **energy is transferred**
- If the table is removed, the apple will fall
- As the apple falls, energy is transferred

Your notes

Your notes




- Energy is measured in units of **joules (J)**
- A thermodynamic system, for example, can be **isolated, closed** or **open**
  - An **open system** allows the exchange of energy and matter to or from its surroundings
  - A **closed system** can exchange energy but not matter to or from its surroundings
  - An **isolated system** does not allow the transfer of matter or energy to or from its surroundings




***A system can be open, closed or isolated***

## Conservation of Energy

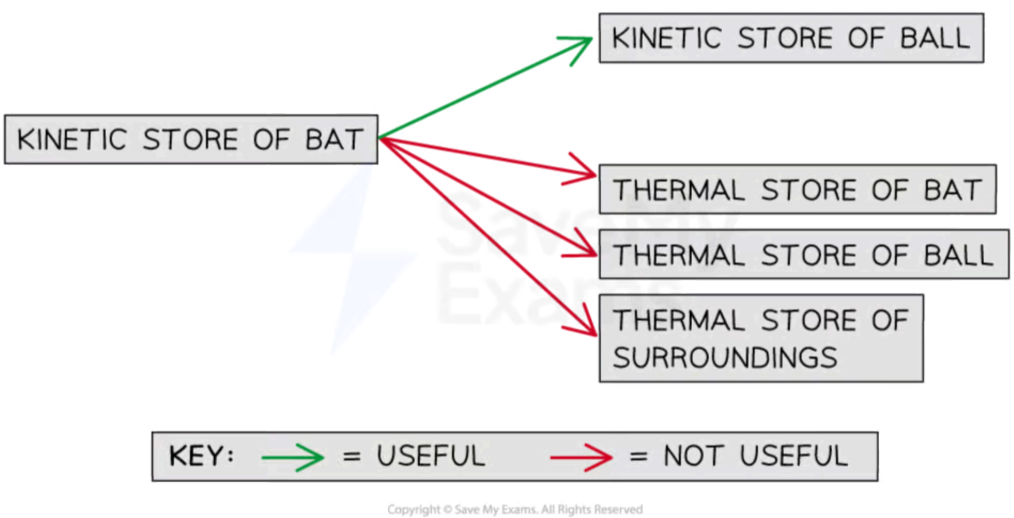
- The principle of conservation of energy states that:

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

- This means the total amount of energy in a **closed system** remains **constant**
- The **total energy** transferred **in**to a system must be **equal** to the **total energy** transferred **out** of the system
- Therefore, energy is never 'lost' but it can be transferred to the surroundings
  - Energy can be **dissipated** (spread out) to the surroundings by heating and radiation
  - Dissipated energy transfers are often **not useful**, and can then be described as **wasted** energy

## Example 1: A Bat Hitting a Ball

- The moving bat has energy in its **kinetic** store
- Some of that energy is transferred **usefully** to the **kinetic** store of the ball
- Some of that energy is transferred from the **kinetic** store of the bat to the **thermal** store of the ball **mechanically** due to the impact of the bat on the ball
- Some of that energy is **dissipated** by **heating** to the **thermal** store of the bat, the ball, and the surroundings



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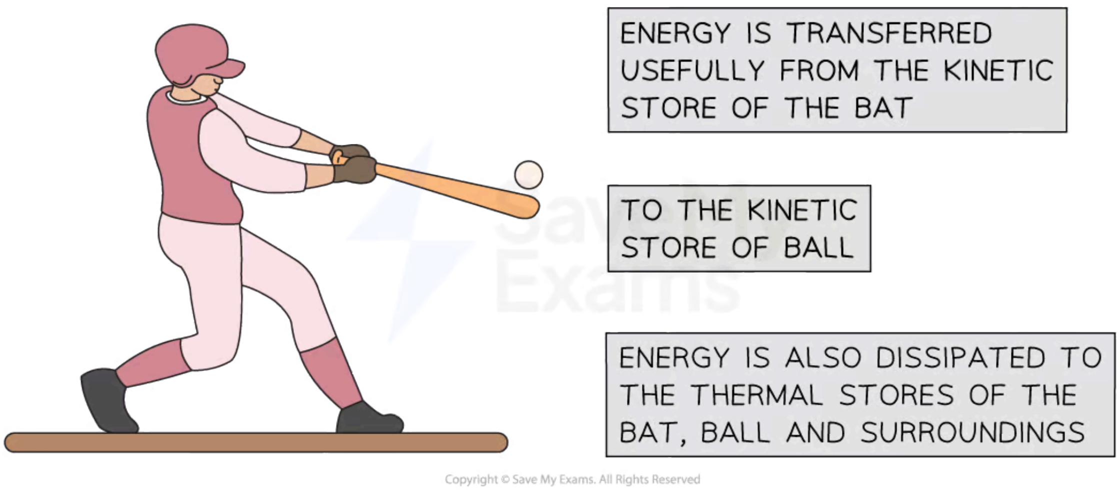



*Energy transfers taking place when a bat hits a ball*

## Example 2: Boiling Water in a Kettle

- When an electric kettle boils water, **energy** is transferred **electrically** from the mains supply to the **thermal store** of the heating element inside the kettle
- As the heating element gets hotter, **energy** is transferred **by heating** to the **thermal store** of the water
- Some of the energy is transferred to the **thermal** store of the plastic kettle (wasted energy transfer)
- And some energy is **dissipated** to the **thermal store** of the surroundings due to the air around the kettle being heated (wasted energy transfer)


*Energy transfer taking place as a kettle boils water*

Your notes

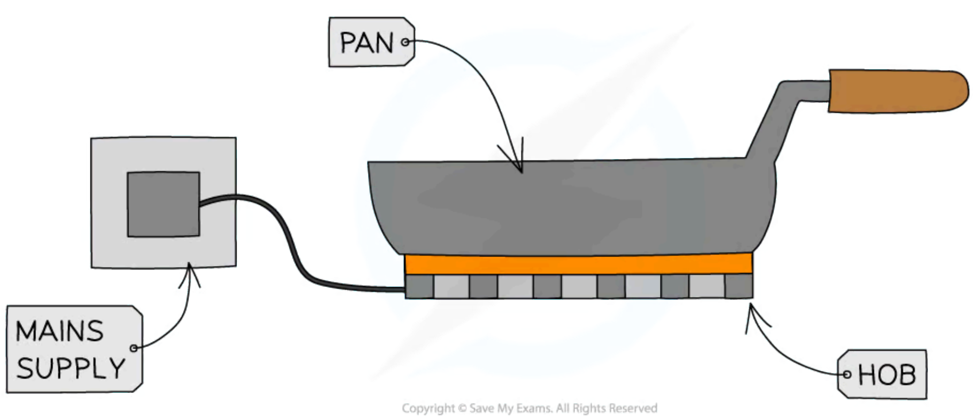
## Changes in Energy

# Changes in Energy

- **Changes** make things happen. When there is a change in a system, **energy is transferred**
- Energy can be transferred via different pathways:
  - Heating by particles
  - Heating by radiation
  - Mechanical work done by forces
  - Electrical work done when a current flows

## Heating

- Energy transfers **by heating** increase the energy in the **kinetic store** of the **particles** that make up that system, which increases the energy in the **thermal store** of the **object**
- This either raises the system's **temperature** or, produces a **change of state** (eg. solid to liquid)
- An example of an energy transfer **by heating** is warming a pan on a hob
  - Energy is transferred electrically from the mains supply to the **thermal store** of the hob which is then transferred **by heating** to the **thermal store** of the pan

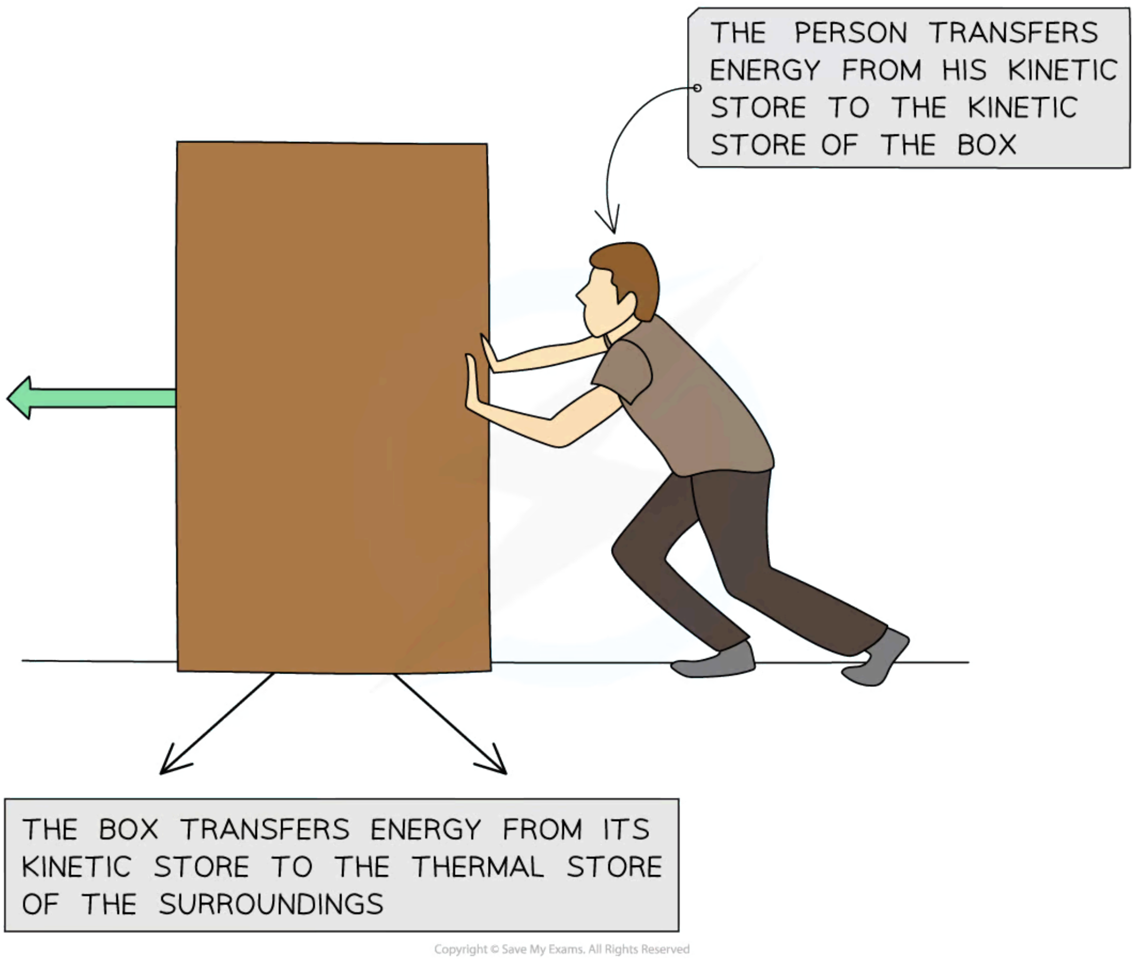



***Energy is transferred by heating from the thermal store of the hob to the thermal store of the pan***

Your notes

## Work Done by Forces

- **Mechanical work** is done when a force acts over a distance
- For example, when a person pushes a box across the floor
- Energy is transferred **mechanically** from the **kinetic store** of the **person** to the **kinetic store** of the **box**




***Energy transfers taking place when a box is pushed across the floor***

- If the system is defined as the man and the box, energy is transferred **mechanically** from the **kinetic store** of the person to the **kinetic store** of the box
- If the system is defined as the box and the floor, energy is transferred **by heating** from the **kinetic store** of the box to the **thermal store** of the floor (due to friction) and **by heating** to the **thermal** store of the

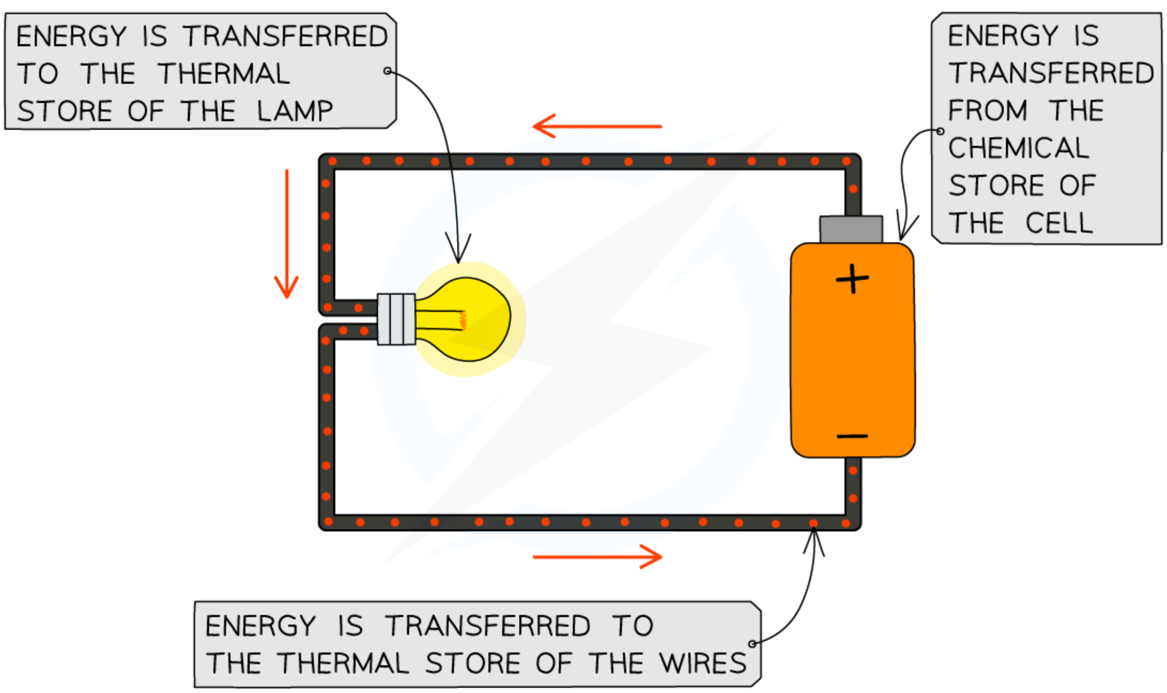
surroundings as the sound waves transfer energy away from the system and cause the air particles to vibrate

Your notes

## Work Done when a Current Flows

- Current is the flow of charge
- A current flows when there is a potential difference applied to the circuit
  - This is provided by the power supply or a cell
- Energy is transferred electrically from the power supply to the components in the circuit
  - This is the **electrical work done** by the power supply when a current flows

- Energy from the **chemical** store of the cell is transferred **electrically** to the **thermal** store of the lamp as the filament heats up
- Energy is transferred from the **thermal** store of the lamp by **heating** and by **radiation** (light) to the **thermal** store of the surroundings
- Energy is also transferred by **heating** to the **thermal** store of the wires (due to resistance)



*Energy transfers taking place in an electrical circuit*

Your notes

## Examiner Tips and Tricks

Don't worry too much about the parameters of the system. They are there to help you keep your answers concise so you don't end up wasting time in your exam.

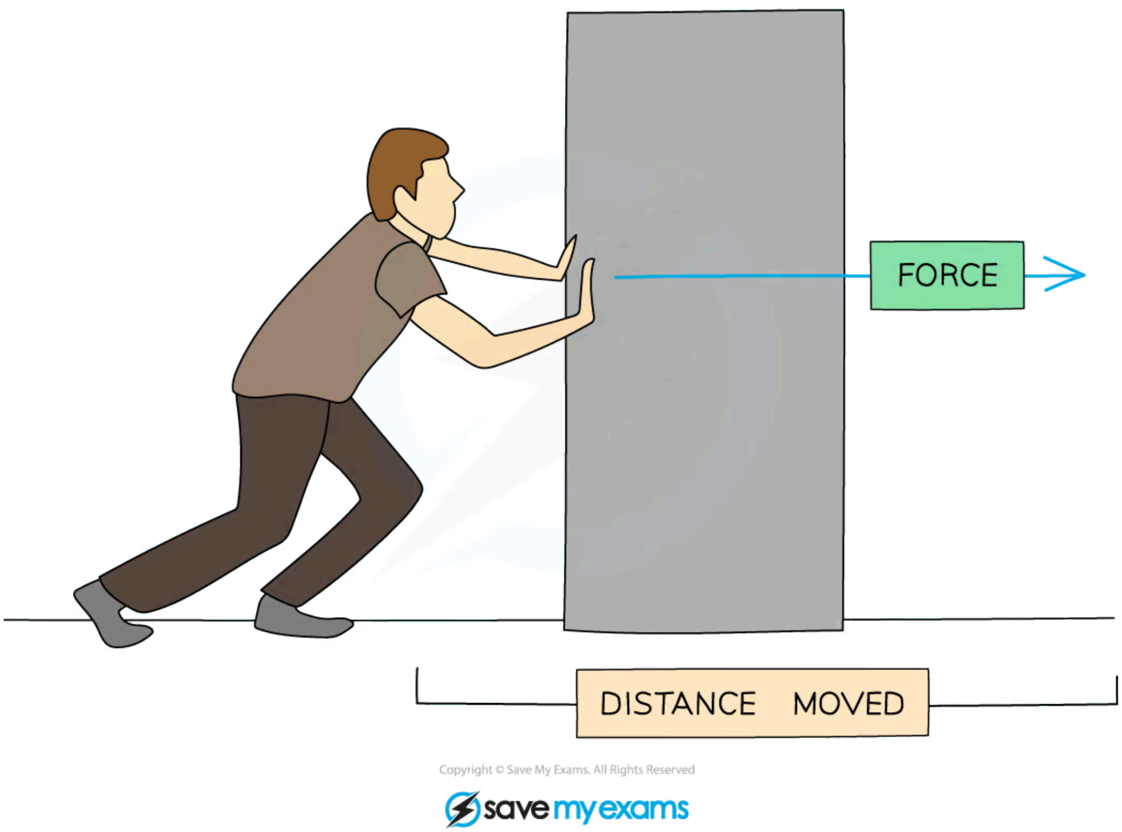
If you follow any process back far enough, you would get many energy transfers taking place. For example, an electric kettle heating water. The relevant energy transfer is from the thermal store of the kettle to the thermal store of the water, with some energy dissipated to the surroundings. But you could take it all the way back to how the electricity was generated in the first place. This is beyond the scope of the question. Defining the system gives you a starting point and a stopping point for the energy transfers you need to consider.

Work & Energy

Your notes

# Work Done

- 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 is done when a force is used to move an object***

# Calculating Work Done

- The amount of work that is done is related to the size of the force and the distance moved by the object in the direction of the force

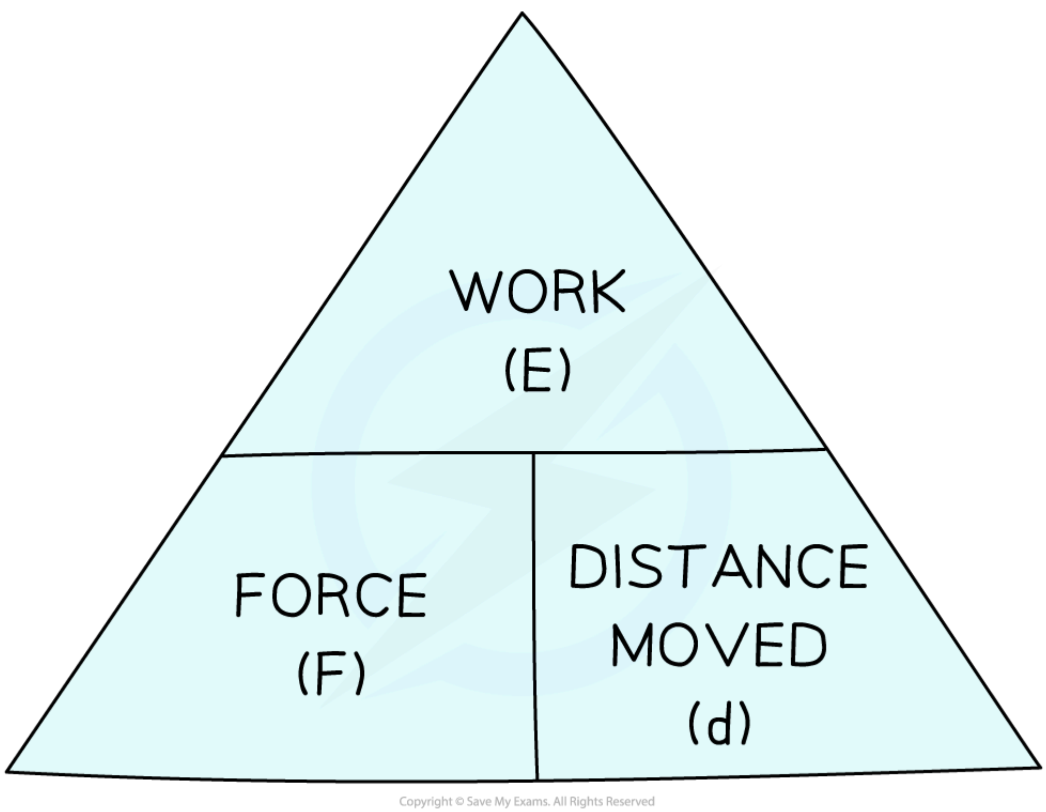
**Work done = energy transferred**

Your notes

- To calculate the amount of work done or energy transferred for an object, the following formula is used

$$E = F \times d$$

- Where:
  - $E$ = work done or energy transferred in joules (J)
  - $F$ = force in newtons (N)
  - $d$ = distance in metres (m)
- This equation can be rearranged with the help of a formula triangle




***Work done, force, distance triangle***

Your notes

### Worked Example

A car moving at speed begins to apply the brakes. The brakes of the car apply a force of 500 N which brings it to a stop after 23 m.


Calculate the work done by the brakes in stopping the car.

**Answer:**

**Step 1: List the known quantities**

- Distance, $d$ = 23 m
- Force, $F$ = 500 N

**Step 2: Write out the equation relating work, force and distance**

$$E = F \times d$$

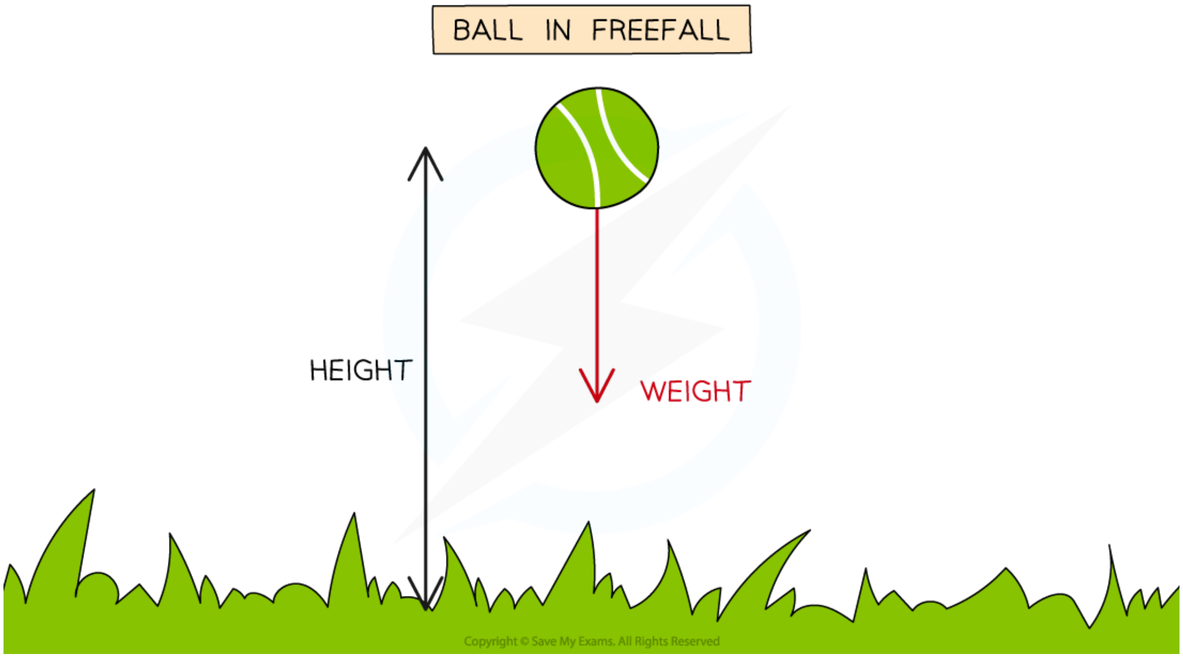
**Step 3: Calculate the work done on the car by the brakes**

$$E = 500 \times 23$$

$$E = 11\ 500 \text{ J}$$

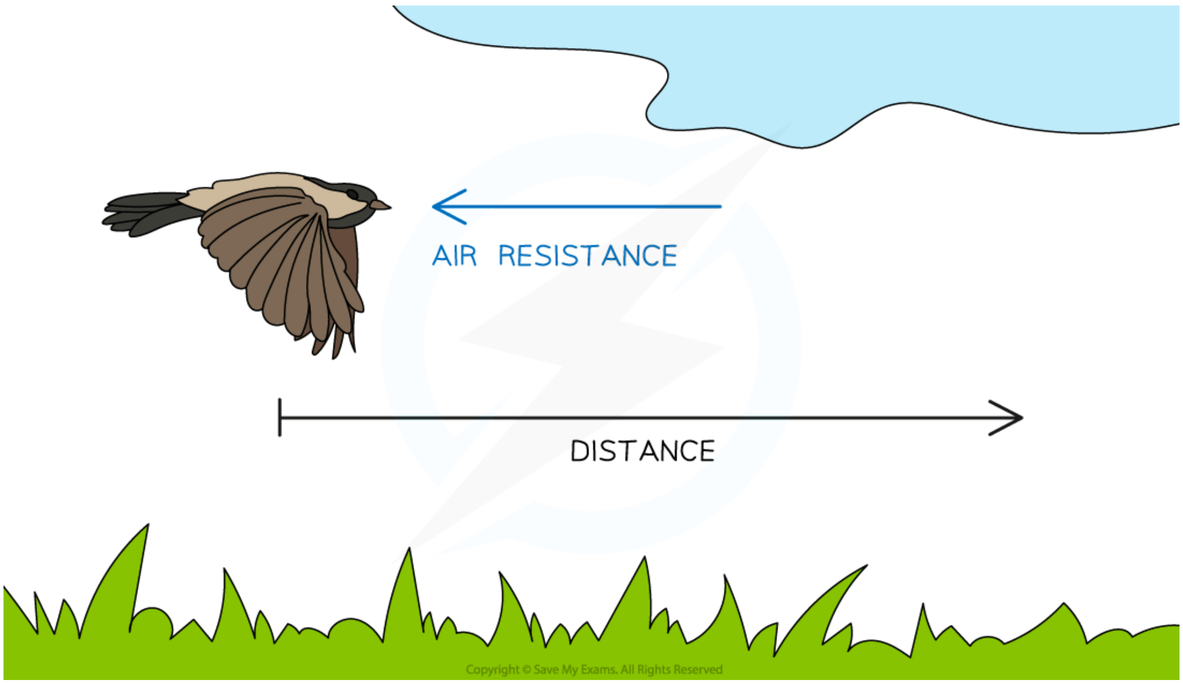
## Examples of Work

- Work is done on a ball when it is lifted to a height
  - The energy is transferred mechanically from the ball's kinetic energy store to its gravitational potential energy store




***The weight on the ball produced by the gravitational field does work on the ball over a distance***

- Work is done when a bird flies through the air
  - The bird must travel against air resistance, therefore energy is transferred from the bird's **kinetic store** to its **thermal store** and **dissipated** to the **thermal store** of the surroundings

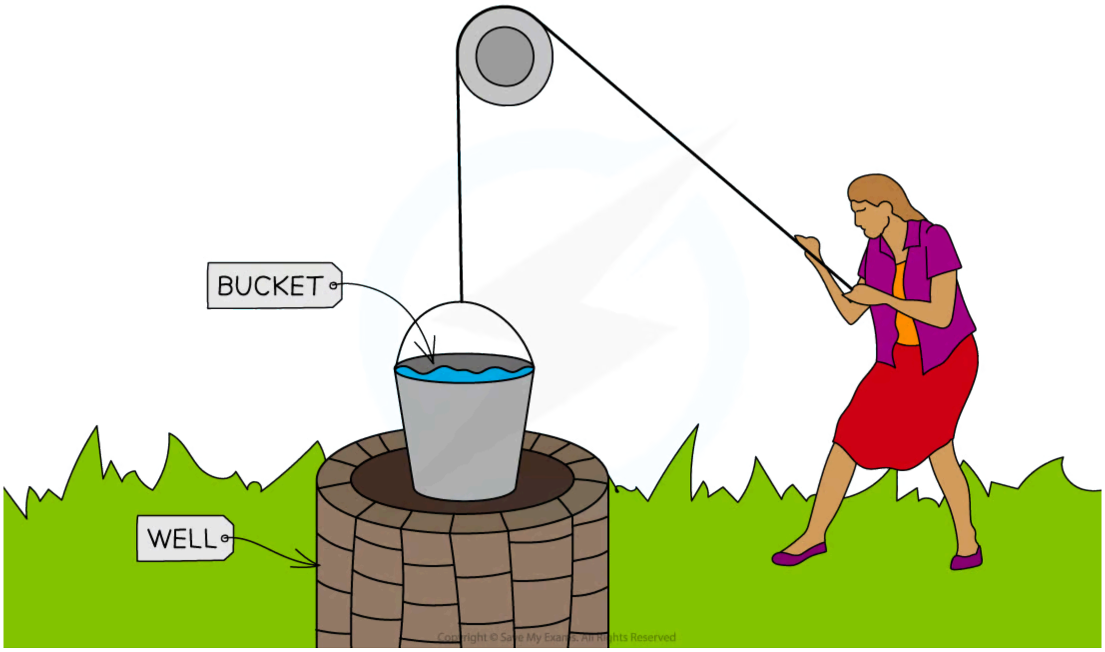



*Air resistance (drag) does work against the bird as it flies through the air*

## Worked Example

A woman draws a bucket up out of a well. The bucket has a mass of 12 kg when filled with water and the well is 15 m deep. Gravitational field strength is 10 N/kg.

Your notes




a) Describe the energy transfer involved in raising the bucket out of the well

b) Calculate the work done on the bucket

**Answer:**

**Part (a)**

- Energy is transferred **mechanically** (a force is acting over a distance)
- **from** the **kinetic store** of the **woman** (as she pulls the rope)
- **to** the **gravitational potential store** of the **bucket** (as it is lifted upwards)

**Part (b)**

**Step 1: List all of the known quantities**

- Mass, $m$ = 12 kg
- Gravitational field strength, $g$ = 10 N/kg
- Height, $h$ = 15 m

**Step 2: Write the equation relating work, force and distance**

$$E = F \times d$$

**Step 3: Write out the equation for weight and substitute it into the work equation**

$$W = m \times g$$

$$E = (m \times g) \times d$$

- Note: This is the equation for gravitational potential energy

$$\Delta GPE = m \times g \times \Delta h$$

**Step 4: Calculate the work done on the bucket**

$$E = 12 \times 10 \times 15$$

$$E = 1800 \text{ J}$$

- The bucket gained 1800 J of gravitational potential energy

## Examiner Tips and Tricks

Remember:

- Changes in **speed** are related to **kinetic energy**
- Changes in **height** are related to **gravitational potential energy**
- Changes in the **shape** of materials are related to **elastic potential energy**

Your notes

## GPE & KE

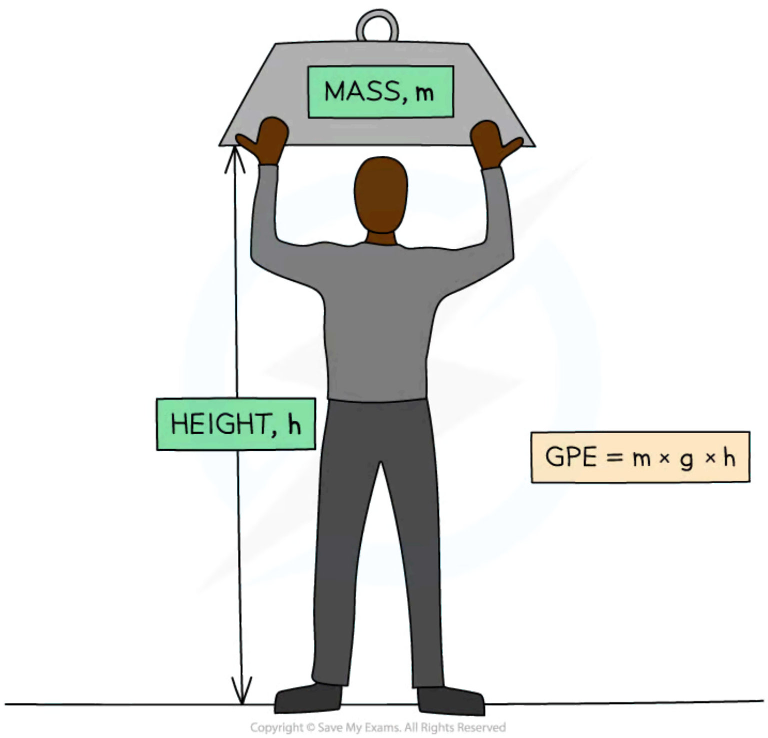
Your notes

# Gravitational Potential Energy

- Energy in the **gravitational store** of an object is defined as:

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

- This means:
  - If an object is **lifted** up, energy is **transferred to** its gravitational potential store
  - If an object **falls**, energy will be **transferred away from** its gravitational potential store

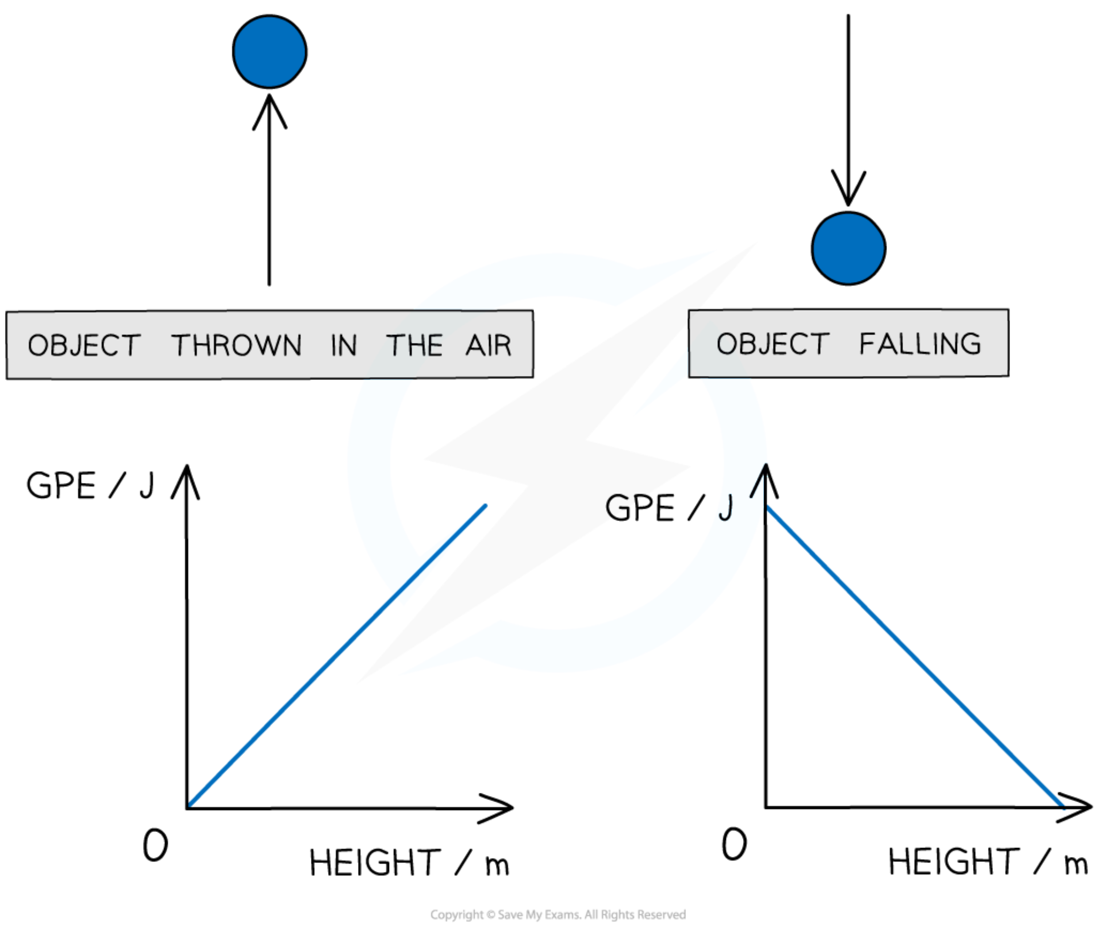



***Energy is transferred to the gravitational potential store of the mass as it is lifted through a gravitational field***

- The change in the gravitational potential energy, ΔGPE of an object can be calculated using the equation:

$$\Delta GPE = m \times g \times \Delta h$$

- Where:
  - $\Delta GPE$ = change in gravitational potential energy, in joules (J)
  - $m$ = mass, in kilograms (kg)
  - $g$ = gravitational field strength in newtons per kilogram (N/kg)
  - $\Delta h$ = change in vertical height in metres (m)
- In Physics, Δ is the capital Greek letter 'delta' which stands for 'change in'
- The two graphs below show how GPE changes with height for a ball being thrown up in the air and when falling down




***Graphs showing the linear relationship between GPE and height***

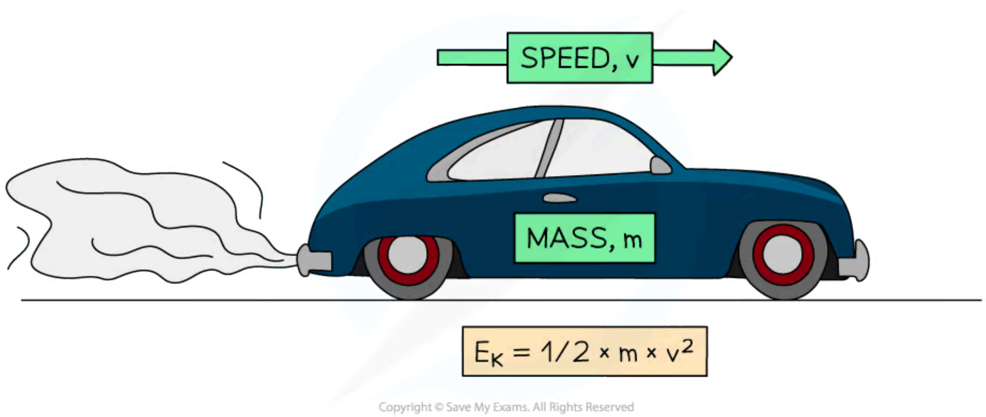
Your notes

# Kinetic Energy

- Energy in an object's kinetic store is defined as:

**The amount of energy an object has as a result of its mass and speed**

- This means that any object in **motion** has energy in its kinetic energy store




- Kinetic energy can be calculated using the equation:

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

- Where:
  - KE = kinetic energy in joules (J)
  - $m$ = mass of the object in kilograms (kg)
  - $v$ = speed of the object in metres per second (m/s)

# Energy Equivalency

- In a **perfect** energy transfer, there is no wasted energy
- Energy transfers can be **assumed** to be perfect if the wasted energy transfer is **negligible**
  - Some exam questions will state to **ignore** air resistance for example
  - In reality, there is **no** such thing as a perfect energy transfer

Your notes

Your notes

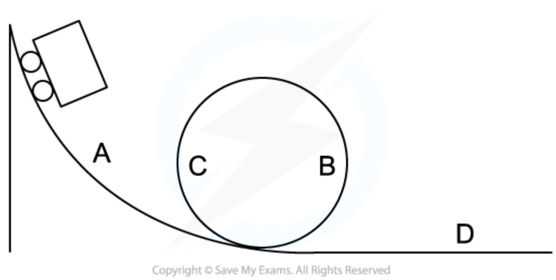
- Ignoring wasted energy transfers is helpful in **calculations** because it allows energy values to be **equated**
- **Pendulums** are often used as examples of perfect energy transfers
  - All of the energy in the **kinetic store** of the pendulum is transferred **mechanically** into its **gravitational potential store**
  - And then all of the energy in the **gravitational potential store** of the pendulum is transferred **mechanically** into its **kinetic store**
  - Energy is transferred back and forth between these two stores as the pendulum swings
  - Therefore, it can be said that:

$$KE_{total} = GPE_{total}$$

## Worked Example

The diagram shows a rollercoaster going down a track.

The rollercoaster takes the path A → B → C → D.




The rollercoaster begins at a height of 15 m above the ground and ends at ground level.

Breaking to stop the ride begins after it passes position D.

The mass of the rollercoaster is 100 kg.

Calculate the maximum speed of the rollercoaster at position D. Ignore any frictional effects before passing point D.

**Answer:**

**Step 1: List the known quantities**

- Height, $h$ = 15 m
- Mass, $m$ = 100 kg
- Gravitational field strength, $g$ = 10 N/kg

**Step 2: Write out the equation for gravitational potential energy**

$$\Delta GPE = m \times g \times \Delta h$$

**Step 3: Calculate the gravitational potential energy**

$$\Delta GPE = 100 \times 10 \times 15$$

$$\Delta GPE = 15\,000 \text{ J}$$

**Step 4: Use energy equivalency to equate the gravitational potential and kinetic energy**

- Frictional effects are to be ignored therefore a perfect energy transfer can be assumed

$$\Delta GPE = KE$$

**Step 5: Write out the equation for kinetic energy**

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

**Step 6: Rearrange to make speed the subject:**

$$v = \sqrt{\frac{2 \times KE}{m}}$$

**Step 7: Calculate the maximum possible speed of the rollercoaster at position D**

- At position D the rollercoaster is at ground level
- Therefore all the energy has been transferred from the gravitational potential to the kinetic store
- The maximum possible speed is using the assumption of a perfect energy transfer

$$v = \sqrt{\frac{2 \times 15\,000}{100}}$$

$$v = 17 \text{ m/s}$$

## Examiner Tips and Tricks

When the question tells you to **ignore** the effects of resistance (ie wasted energy transfers) this is a clue that may need to use **energy equivalency** to find the missing quantity needed for your calculation.

Your notes

Your notes

## Dissipation of Energy

# Energy Loss

- Unintended or **wasted** energy transfers are inevitable
- There is no such thing as a **perfect** energy transfer
- Most wasted energy transfers result in **heating** of the objects and the surroundings
- We say this energy is **dissipated** (spread out) to the thermal store of the surroundings

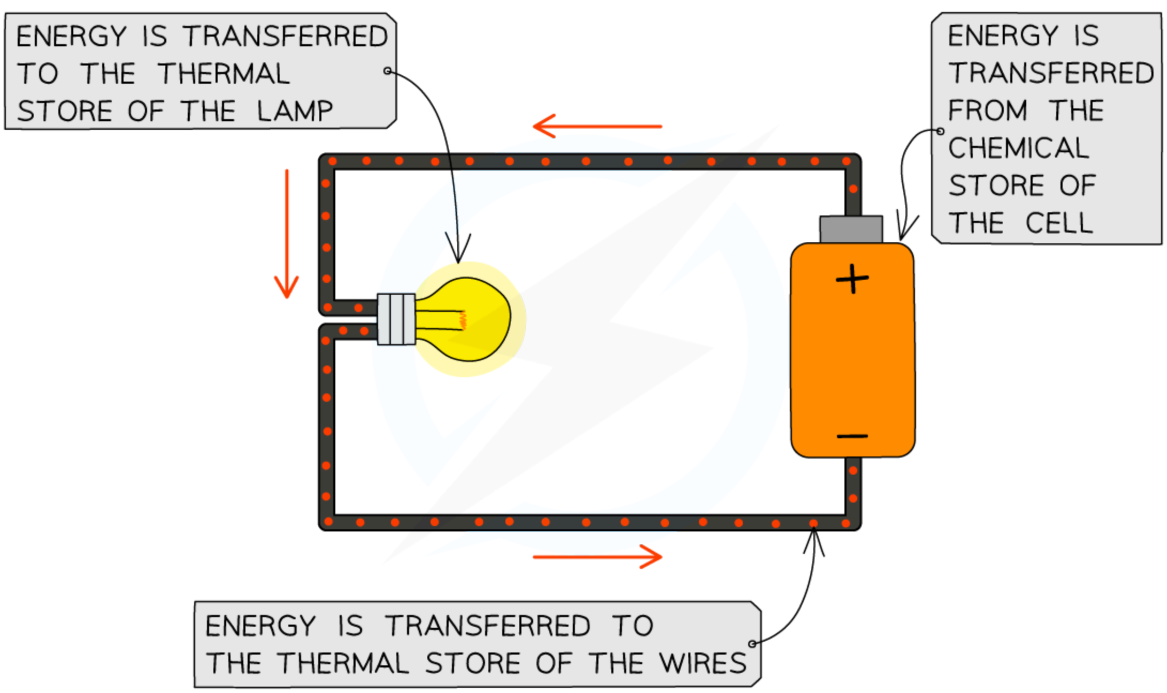
- **Work** done against **air resistance**, **frictional forces**, and **resistance** in wires all result in heating
- That energy is transferred to the **thermal store** of the surroundings **increasing** the **temperature** of the **air particles** and surrounding **objects**
- Once energy is in the thermal store of the surroundings, it can not be 'gathered' for any specific use
- Therefore, it is referred to as **wasted** energy

## Example 1: An Electric Kettle Boiling Water

Your notes

- **Useful** energy transfer
  - Energy is transferred **by heating** from the **thermal** store of the **heating element** in the kettle to the **thermal** store of the **water**
- **Unuseful** energy transfers
  - Energy is transferred from the **thermal** store of the **water** to the **thermal** store of the **kettle casing**
  - Energy is transferred from the **thermal** store of the **kettle casing** to the **thermal** store of the **surroundings** and the temperature of the air in the room will increase slightly
  - Energy is transferred from the **thermal** store of the **water** to the **thermal** store of the **surroundings** as water evaporates

## Example 2: An Electric Circuit Lighting a Filament Bulb






- **Useful** energy transfers
  - Energy is transferred from the **chemical** store of the bulb to the **thermal** store of the **filament wire** (the fact that the filament wire glows hot is how the light is produced)

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    - Energy is transferred from the **thermal** store of the **filament wire** to the **thermal** store of the **surroundings by radiation** as visible light (EM radiation)
- **Unuseful** energy transfers
    - Energy is transferred from the **chemical** store of the **cell** to the **thermal** store of the **wires** due to resistance
    - Energy is transferred from the **chemical** store of the **cell** to the **thermal** store of the **bulb casing** (the metal and glass that make up the bulb)
    - Energy is transferred from the **thermal** store of the **filament wire** to the **thermal** store of the **surroundings** (most of the energy transferred away from the bulb is by heating rather than as light)

### Examiner Tips and Tricks

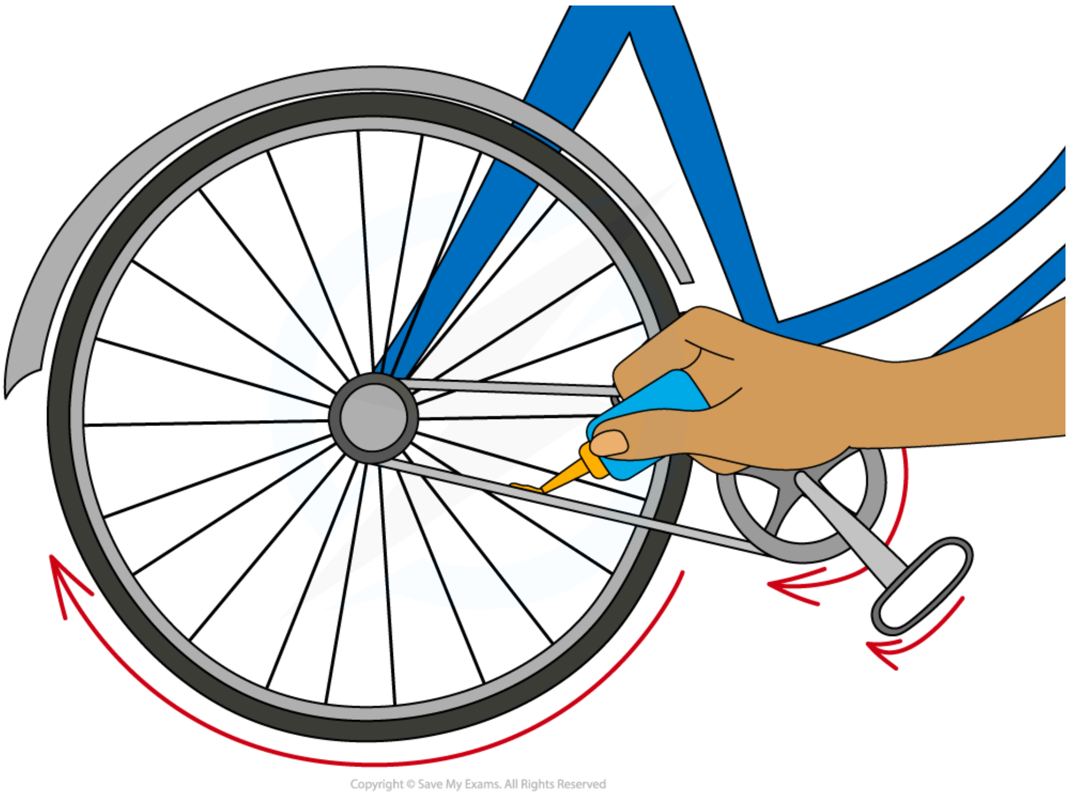
Make sure you are able to identify different types of "useful" and "wasted" energy as this is commonly tested in exams!

# Mechanical Loss

- **Mechanical** processes can become wasteful when they cause a rise in temperature
- These processes often involve **friction**
    - When friction acts, it has the effect of transferring energy from the kinetic store by heating to the objects and the **surroundings**
    - This energy cannot be used in a **useful** way, therefore it is called **wasted** energy
    - Energy that is transferred to the surrounding is said to be **dissipated** (spread out) to the surroundings

- Friction is a major cause of **wasted energy transfers** in machines
- For example, the gears on a bike can become hot if the rider has been cycling for a long time
    - Energy is transferred **wastefully** from the **kinetic energy store** of the bike to the **thermal energy store** of the gears and the chain
    - Since the energy is originally transferred from the **kinetic store** of the **rider** to the **kinetic store** of the **bike**, this means that the person has to do more **work** to make the bike move
- This wasted energy transfer can be reduced if the amount of friction can be **reduced**
    - This can be achieved by **lubricating** the parts that rub together

Your notes




***Lubrication helps reduce friction in the parts of a cycle***

## Reducing Energy Loss

- There are many situations where energy transfers are actually **unwanted**:
  - Keeping a house warm
  - Keeping a hot drink hot or cold
  - Friction of mechanical parts

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***Insulated mugs are used to maintain the temperature of hot or cold drinks***

- When an appliance is used for heating something (a kettle, a heater, a tumble drier, a central heating system etc.), the appliance requires a lot of energy
  - It can become expensive for a household to run such appliances
  - The production of electricity using fossil fuels produces greenhouse gases which contribute to global warming
  - The combustion of (methane) gas produces greenhouse gases which contribute to global warming
- Therefore, it is often useful to explore ways of **reducing** unwanted energy transfers
- Energy that is **dissipated to the surroundings** is often the main source of **wasted** energy transfers
- If these unwanted energy transfers can be prevented, or reduced, the **useful** energy transfers can be made more **efficient**

## Insulation

- **Insulation** reduces energy transfers from **conduction**

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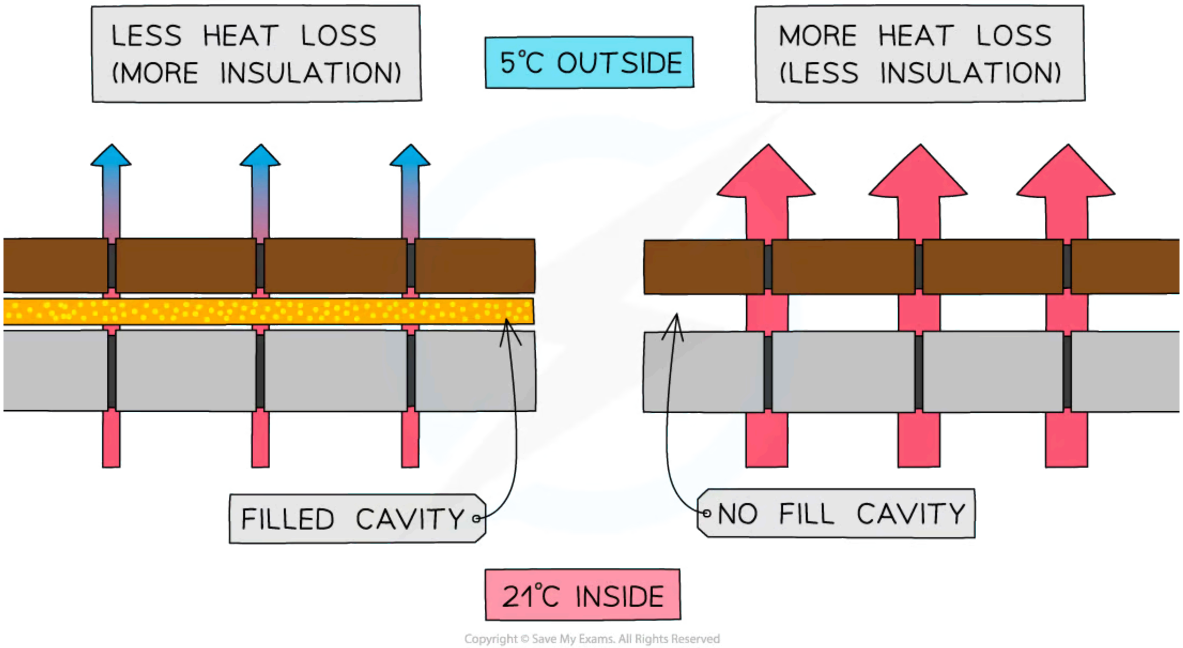
- The effectiveness of an insulator is dependent upon:
  - The thermal **conductivity** of the material
    - The lower the conductivity, the less energy is transferred
  - The **density** of the material
    - The more dense the insulator, the more conduction can occur
    - In a denser material, the particles are closer together so they can transfer energy to one another more easily
  - The **thickness** of the material
    - The thicker the material, the better it will insulate

- Insulating the loft of a house lowers its rate of cooling, meaning less energy is transferred to the surroundings (outside)
- The insulation is often made from fibreglass (or glass fibre)
  - This is a reinforced plastic material composed of woven material with glass fibres laid across and held together
  - The air trapped between the fibres makes it a **good** insulator
- The gaps or cavities between external walls are often filled with insulation
  - This is called **cavity wall insulation**
  - This is often done by drilling a hole through the external wall to reach the cavity and filling it with a special type of foam which is made from blown mineral fibre filled with gas
  - This lowers the **conduction** of heat through the walls from the inside to the outside




***Less energy is transferred by conduction if the cavity is insulated***

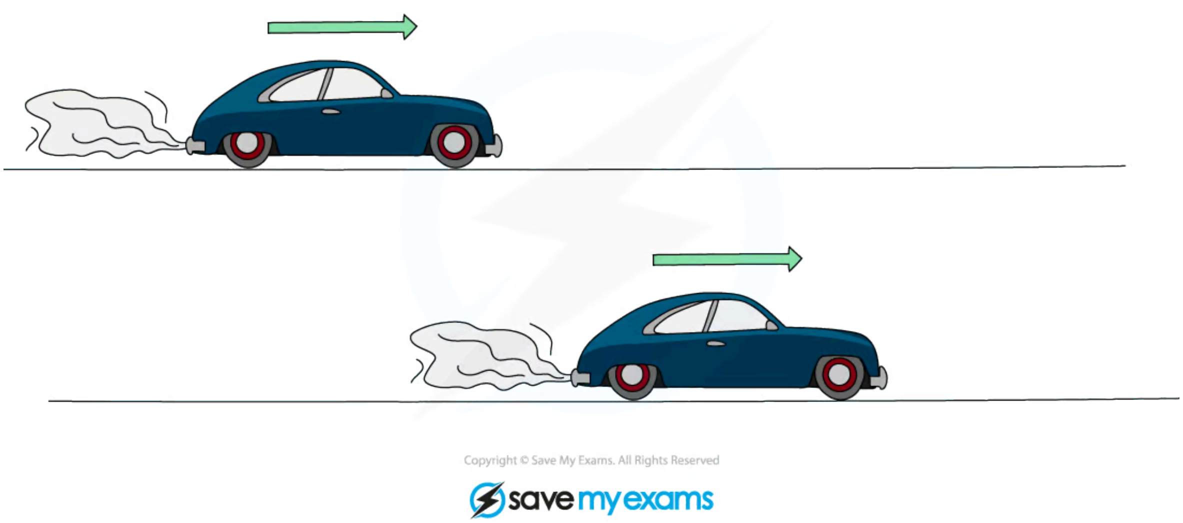
Your notes

## Power

Your notes

# Definition of Power

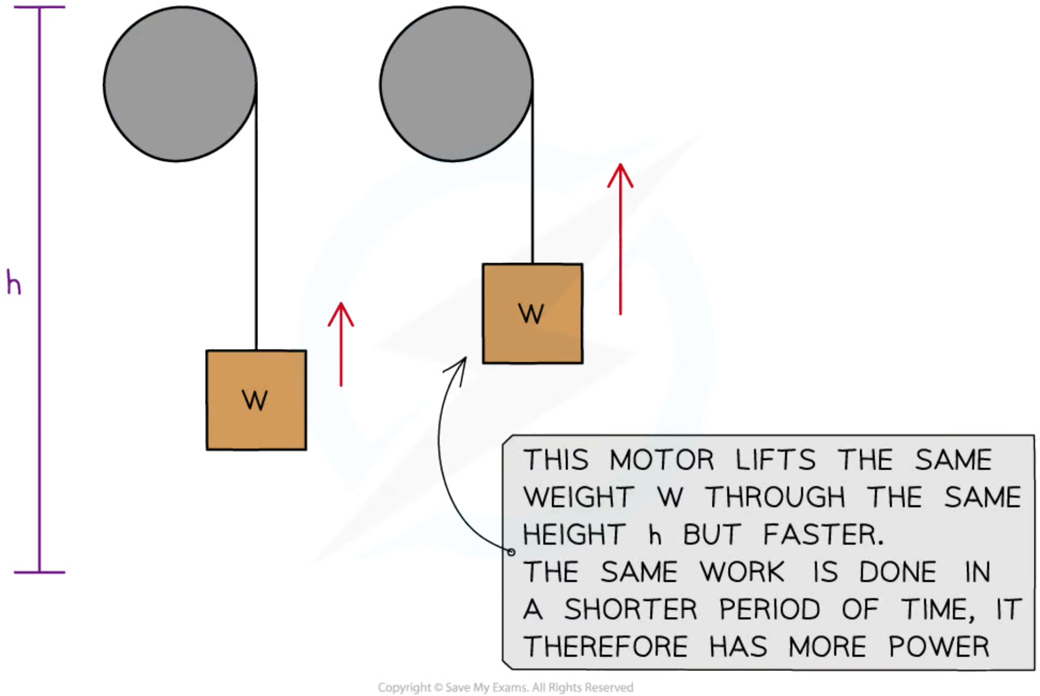
- Machines, such as car engines, transfer energy from one energy store to another constantly over a period of **time**
- The **rate** of this energy transfer, or the rate of work done, is called **power**
- **Time** is an important consideration when it comes to **power**
- Two cars transfer the **same amount of energy**, or do the **same amount of work** to accelerate over a distance
- If one car has **more power**, it will transfer that energy, or do that work, in a **shorter amount of time**




***Two cars accelerate to the same final speed, but the one with the most power will reach that speed sooner***

- Two electric motors:
  - lift the same weight
  - by the same height
  - but one motor lifts it **faster** than the other

- The motor that lifts the weight faster has more **power**




***Two motors with different powers***

- **Power ratings** are given to appliances to show the amount of energy transferred per unit time
- Common power ratings are shown in the table below:

**Power Ratings Table**

| Appliance | Power rating |
|---|---|
| A torch | 1 W |
| An electric light bulb | 100 W |
| An electric cooker | 10 000 W = 10kW (where 1 kW = 1000 watts) |
| A railway engine | 1 000 000 W = 1 megawatt (MW) = 1 million watts |
| A Saturn V space rocket | 100 MW |
| A very large power station | 10 000 MW |
| World demand for power | 10 000 000 MW |
| A star like the Sun | 100 000 000 000 000 000 000 MW |



## Calculating Power

- Power is defined as

  **energy transferred per unit time**

- And

  **work done = energy transferred**

- Therefore, power is also

  **work done per unit time**

- Power can be calculated using the following equation:

$$P = \frac{E}{t}$$

- Where:
  - $P$ = power, measured in **watts** (W)
  - $E$ = energy transferred or work done, measured in **joules** (J)

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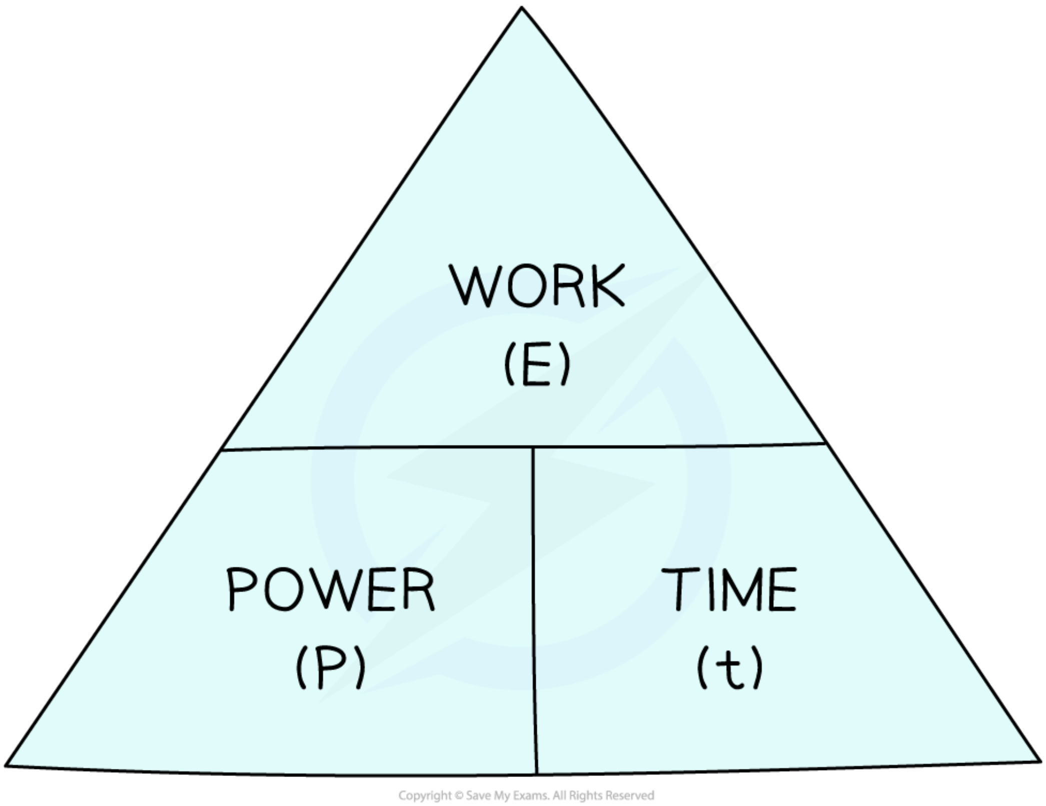
- $t$ = time, measured in **seconds** (s)
- This equation can be rearranged with the help of a formula triangle:




***Work, power, time formula triangle***

## Worked Example

Calculate the energy transferred if an oven of power 2500 W is used for 50 minutes.

**Answer:**

**Step 1: List the known values**

- Power, $P$ = 2500 W
- Time, $t$ = 50 minutes = 50 × 60 = 3000 s

**Step 2: Write down the power equation**

Your notes

$$P = \frac{E}{t}$$

**Step 3: Rearrange to make energy the subject**

$$E = Pt$$

**Step 4: Substitute in the known values**

$$E = 2500 \times 3000$$

$$E = 7\,500\,000 \text{ J}$$

### Examiner Tips and Tricks

Think of power as "energy per second". Thinking of it this way will help you to remember the relationship between power and energy.

# The Watt

- The **watt** is the unit of power
- Since power is energy transferred per second, the watt can also be defined as **1 joule per second**

**1 W = 1 J / s**

- 1 kilowatt (1 kW) is equal to 1000 watts, or 1000 joules of energy transferred per second (1 kJ / s)

### Examiner Tips and Tricks

One way to remember this unit is it remember the saying "watt is the unit of power?"

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## Efficiency & Power

# Efficiency & Power

- The **efficiency** of a system is a measure of the amount of **wasted energy** in an energy transfer
- Efficiency is defined as:

**The ratio of the useful energy output from a system to its total energy output**

- 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**

- Efficiency can be represented as a **decimal** or as a **percentage**
- Efficiency can be calculated using **energy** or **power**  The equations for efficiency are:

$$\text{efficiency} = \frac{\text{useful energy transferred by the device}}{\text{total energy supplied to the device}}$$

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

### Worked Example

An electric motor has an efficiency of 35%. It lifts a 7.2 kg load through a height of 5 m in 3 s.

Calculate the power of the motor.

**Answer:**

**Step 1: List the known quantities**

- Efficiency = 35%
- Mass, $m$ = 7.2 kg
- Height, $h$ = 5 m
- Time, $t$ = 3 s
- Gravitational field strength, $g$ = 10 N/kg

**Step 2: Write down the efficiency equation**

Your notes

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100\%$$

**Step 3: Rearrange to make power input the subject**

$$\text{useful power input} = \frac{\text{power output} \times 100}{\text{efficiency}}$$

**Step 4: Calculate the power output**

$$P = \frac{E}{t}$$

- Energy was transferred from the kinetic store of the motor to the gravitational potential store of the load

$$\Delta GPE = m \times g \, \Delta h$$

$$\Delta GPE = 7.2 \times 10 \times 5$$

$$\Delta GPE = 360 \text{ J}$$

- Therefore, the power output is

$$P = \frac{360}{3}$$

$$P = 120 \text{ W}$$

**Step 5: Substitute values into power input equation**

$$\text{useful power input} = \frac{\text{power output} \times 100}{\text{efficiency}}$$

$$\text{useful power input} = \frac{120 \times 100}{35}$$

$$\text{useful power input} = 343 \text{ J}$$

## Examiner Tips and Tricks

Efficiency can be in a ratio (between 0 and 1) or percentage (between 0 and 100%)

If the answer is required as a percentage, remember to multiply the ratio by 100 to convert it: if the ratio = 0.25, percentage = 0.25 × 100 = 25 %

Remember that efficiency has **no units** (just the % sign)

Your notes