OCR Gateway GCSE Physics: Combined Science

2.4 Work Done & Energy Transfer

Contents

2.4.1 Work Done

Work Done

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

- When work is done on an object, energy is transferred
- The amount of energy transferred (in joules) is equal to the work done (also in joules)

energy transferred (J) = work done (J)
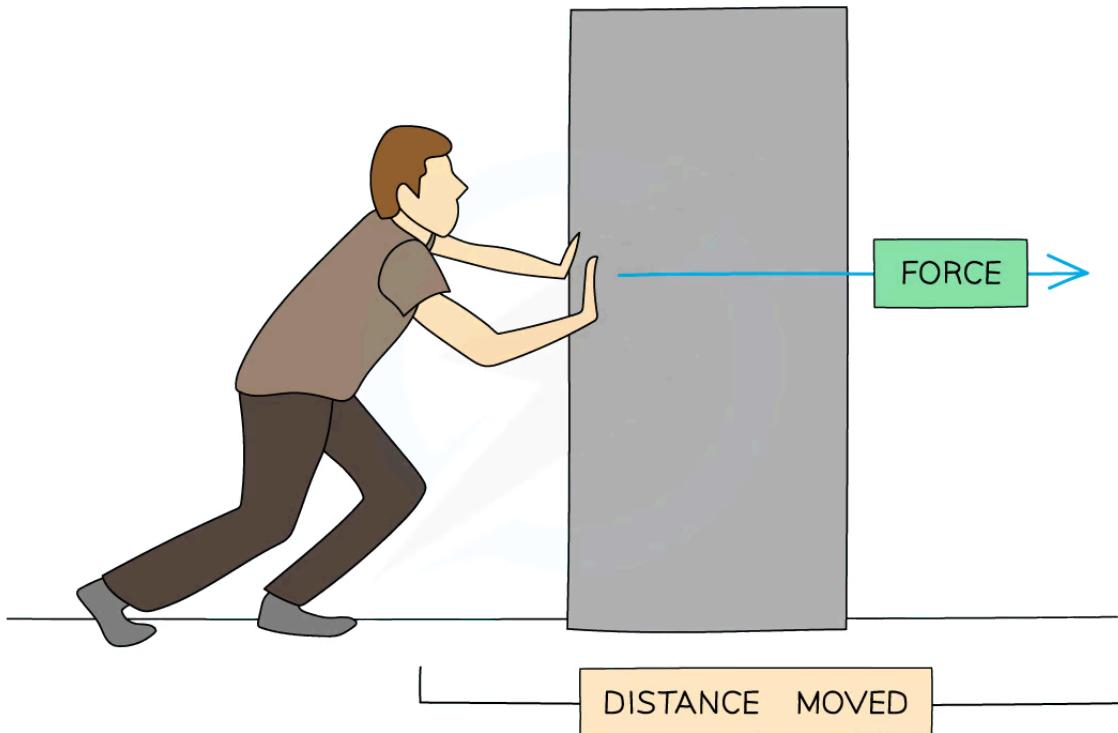
Work is done when a force is used to move an object
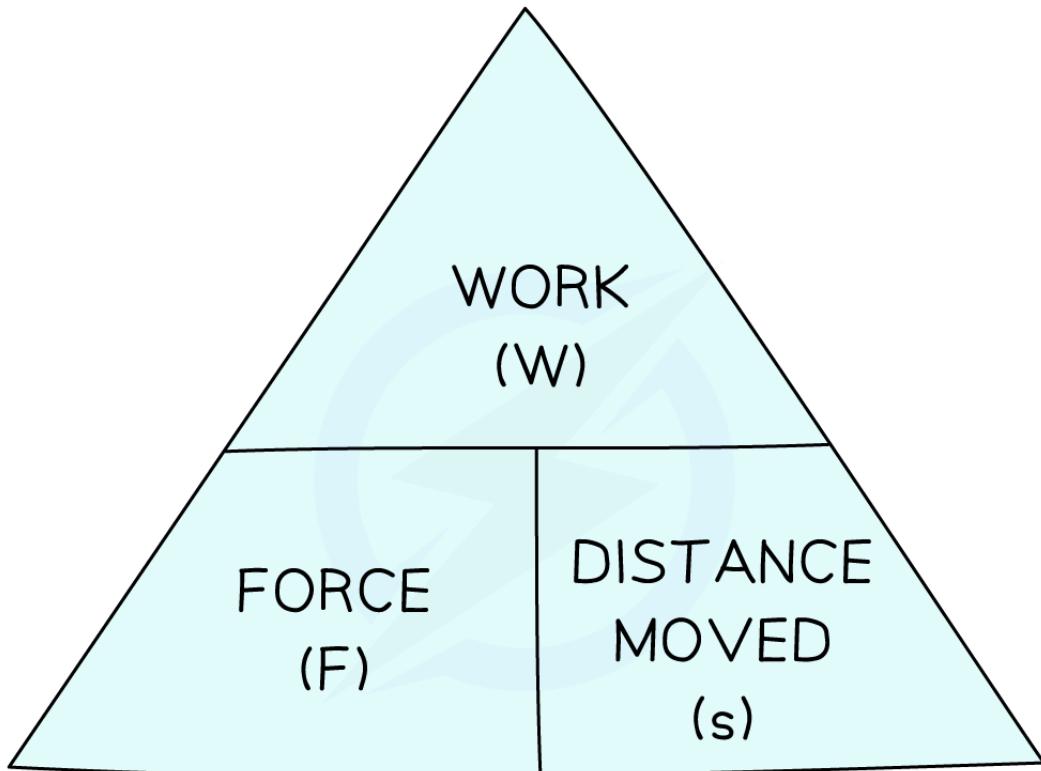
Calculating Work Done

- The formula for work done is:

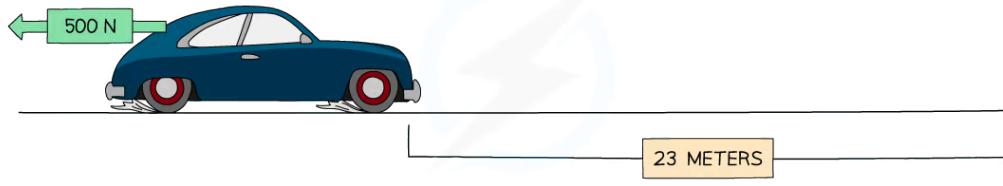**Work done = force × distance**

$$W = Fs$$

- Where:
  - W = work done in **joules** (J) or **newton-metres** (N m)
  - F = force in **newtons** (N)
  - s = distance/displacement in **metres** (m)
- You can rearrange this equation with the help of the formula triangle:

Use the formula triangle to help you rearrange the equation

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.

Step 1: List the known quantities

- Distance, s = 23 m
- Force, F = 500 N

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

$$W = F \times s$$

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

$$W = 500 \times 23$$
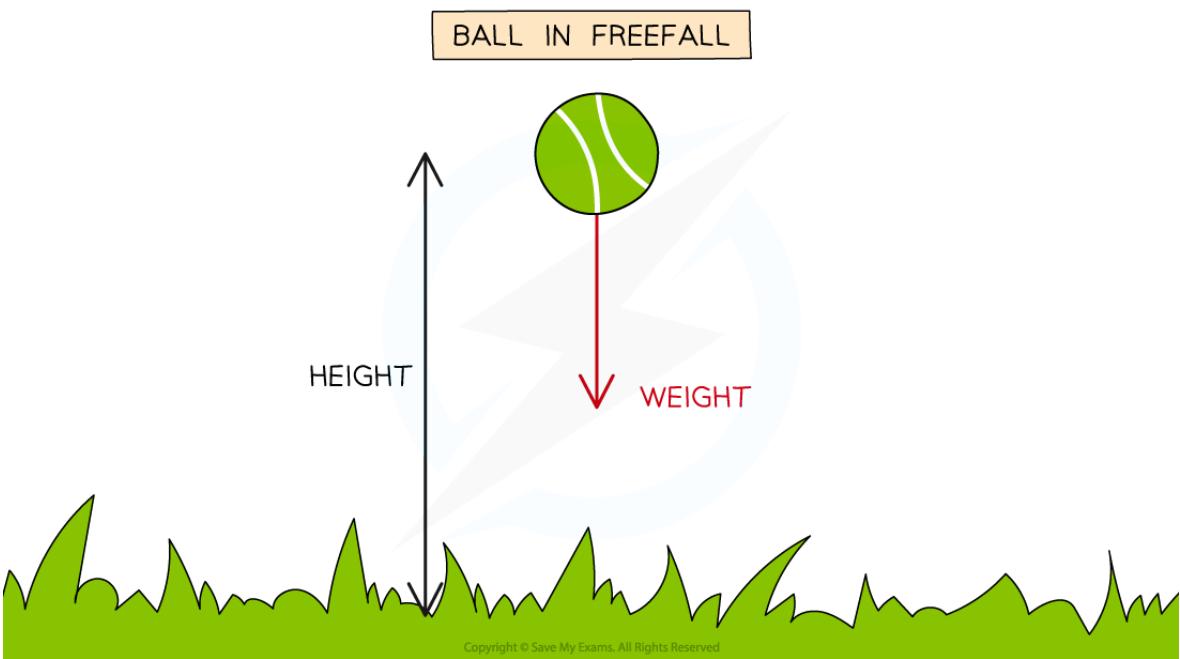
$$W = \textbf{11 500 J}$$

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

BALL IN FREEFALL

HEIGHT

WEIGHT

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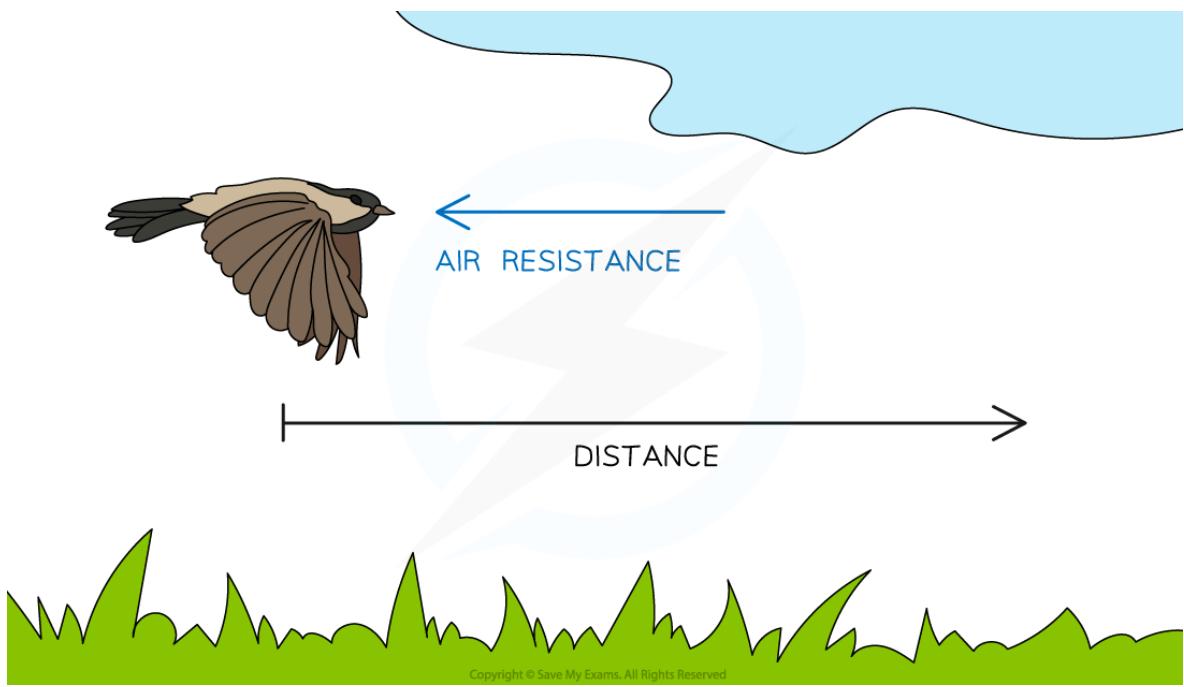*The weight on the ball produced by the gravitational field does work on the ball over a distance*

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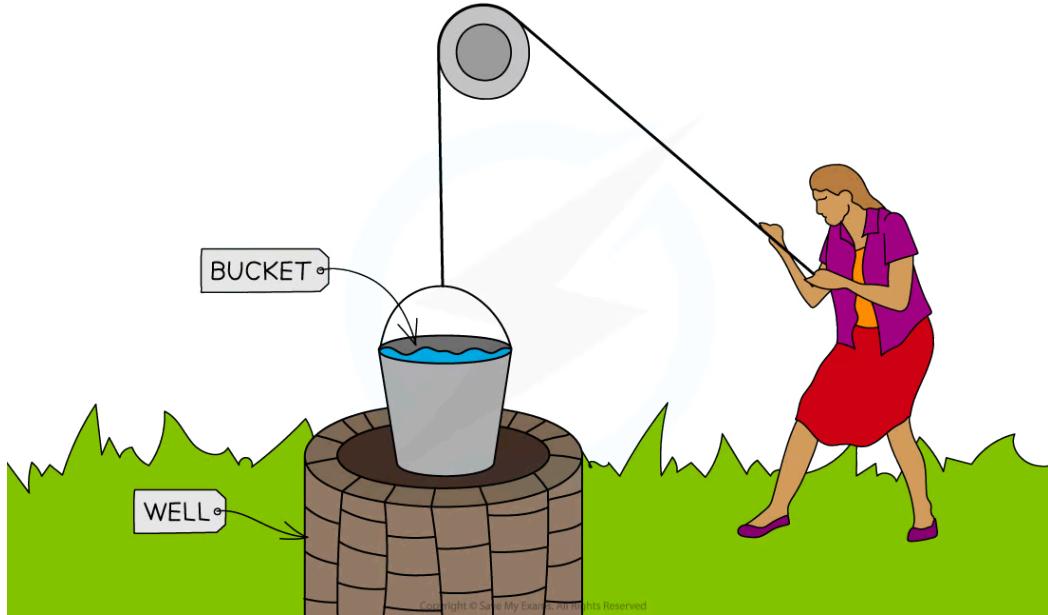
Air resistance (drag) does work against the bird as it flies through the air

✏ 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.

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

b) Calculate the energy transferred to the bucket

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

$$W = Fs$$

Your notes

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

$$Weight = mg$$

$$W = (mg)s$$

- Note: This is the equation for gravitational potential energy

$$E = mgh$$

Step 4: Calculate the work done on the bucket

$$W = 12 \times 10 \times 15$$

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

- The bucket gained 1800 J of gravitational potential energy

💡 Examiner Tip

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**

2.4.2 Energy Stores & Transfers

Energy Stores & Transfers

Energy Stores

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

An object or group of objects

- Defining the system, in physics, is a way of **narrowing** the parameters to **focus** only on what is relevant to the situation being observed
- A system could be large or small, incorporating just one object, or a whole group of objects and their surroundings

- When a system is in **equilibrium**, nothing changes, and so nothing happens
- When there is a **change** to a system, **energy is transferred**

- If an apple sits on a table, and that table is suddenly removed, the apple will fall
- As the apple falls, energy is transferred
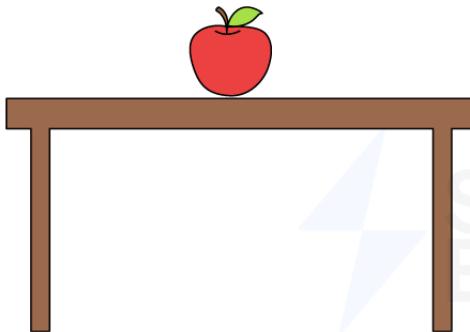
A SYSTEM DEFINED AS AN APPLE ON A TABLE

REMOVE THE TABLE, THE APPLE FALLS

- 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 above ground
Elastic	Objects have energy in their elastic potential store if they are stretched
Electrostatic	Objects with charge (like electrons and protons) interacting with one another have energy in their electrostatic store
Magnetic	Magnets interacting with each other have energy in their magnetic store
Chemical	Objects with energy in their chemical store can release energy in chemical reactions
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 is **transferred** between stores by different energy **transfer pathways**
- The energy transfer pathways are:
  - Mechanical
  - Electrical
  - Heating
  - Radiation

- These are described in the table below:
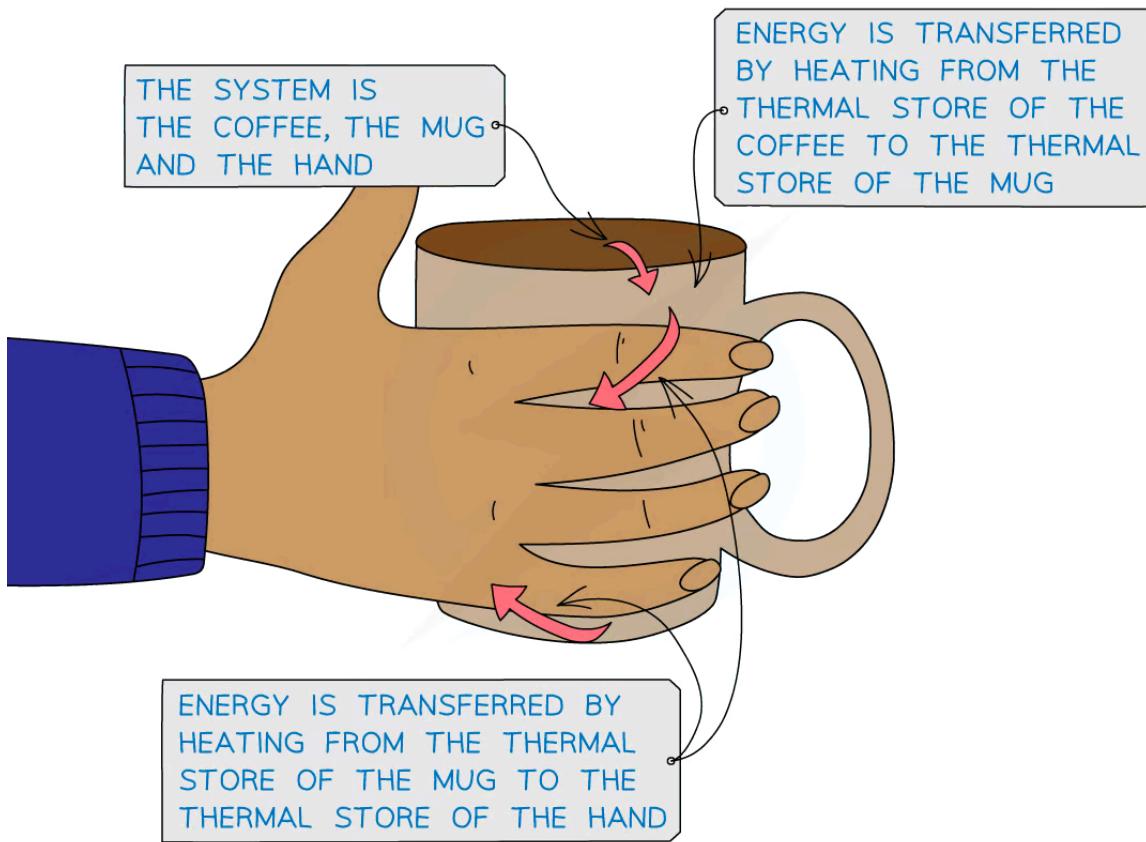
Energy Transfer Pathways Table

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

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

THE SYSTEM IS THE COFFEE, THE MUG AND THE HAND

ENERGY IS TRANSFERRED BY HEATING FROM THE THERMAL STORE OF THE COFFEE TO THE THERMAL STORE OF THE MUG

ENERGY IS TRANSFERRED BY HEATING FROM THE THERMAL STORE OF THE MUG TO THE THERMAL STORE OF THE HAND

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

✏️ Worked example

Describe the energy transfers in the following scenarios:

a) A battery powering a torch

b) A falling object

a)

Step 1: Determine the store that energy is being transferred away from, within the parameters described by the defined system

- For a battery powering a torch
- The system is defined as the energy transfer from the battery to the torch, so this is the transfer to focus on
- Therefore, the energy began in the chemical store of the cells of the battery

Step 2: Determine the store that energy is transferred to, within the parameters described by the defined system

- When the circuit is closed, the bulb lights up
- Therefore, energy is transferred to the thermal store of the bulb
- Energy is then transferred from the bulb to the surroundings, but this is not described in the parameters of the system

Step 3: Determine the transfer pathway

- Energy is transferred by the flow of charge around the circuit
- Therefore, the transfer pathway is electrical

Energy is transferred **electrically** from the **chemical store** of the battery to the **thermal store** of the bulb

b)

Step 1: Determine the store that energy is being transferred away from, within the parameters described by the defined system

- For a falling object
- In order to fall, the object must have been raised to a height
- Therefore, it began with energy in its gravitational potential store

Step 2: Determine the store that energy is transferred to, within the parameters described by the defined system

- As the object falls, it is moving
- Therefore, energy is being transferred to its kinetic store

Your notes

Step 3: Determine the transfer pathway

- For an object to fall, a resultant force must be acting on it, and that force is weight, and it acts over a distance (the height of the fall)
- Therefore, the transfer pathway is mechanical

Energy is transferred from the **gravitational store** to the **kinetic store** of the object via a **mechanical** transfer pathway


💡 **Examiner Tip**

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.

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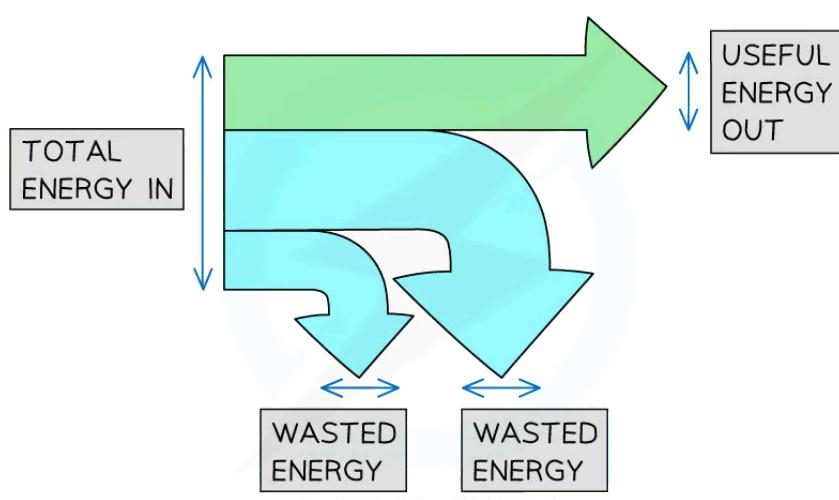
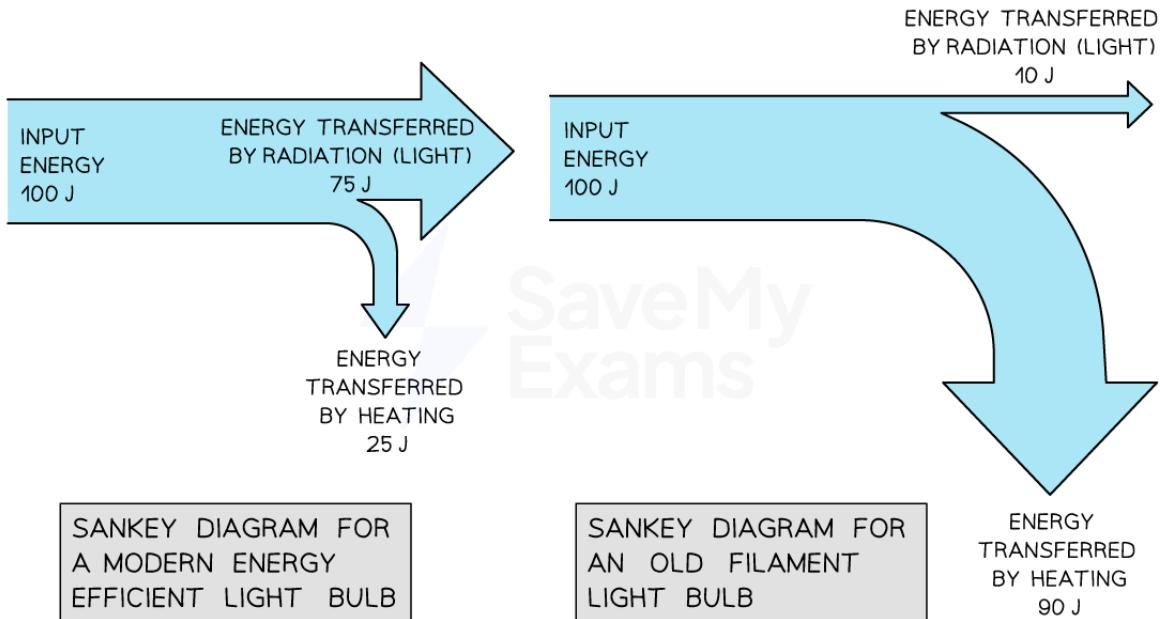*Total energy in, wasted energy and useful energy out shown on a Sankey diagram*

- 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
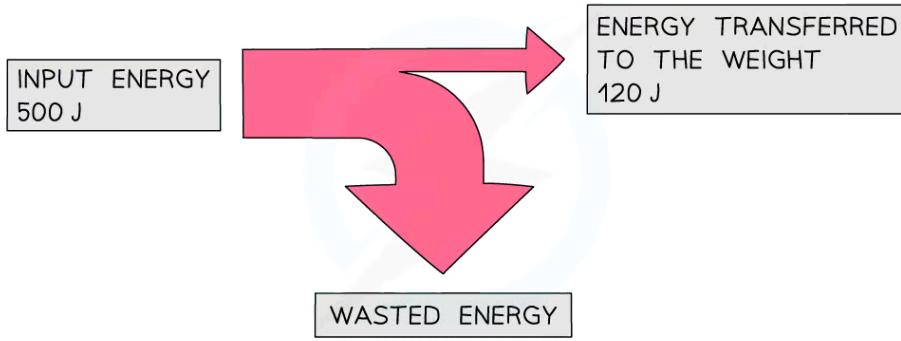
Sankey diagram for modern vs. old filament light bulb

Your notes

✏️ **Your notes**

✏️ **Worked example**

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

INPUT ENERGY 500 J → ENERGY TRANSFERRED TO THE WEIGHT 120 J

WASTED ENERGY

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Calculate the amount of wasted energy.

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:

$$\text{total energy in} = \text{useful energy out} + \text{wasted energy out}$$

Step 2: Rearrange the equation for the wasted energy

$$\text{wasted energy} = \text{total energy in} - \text{useful energy out}$$

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

$$500 - 120 = \mathbf{380\ J}$$

2.4.3 Power

Power

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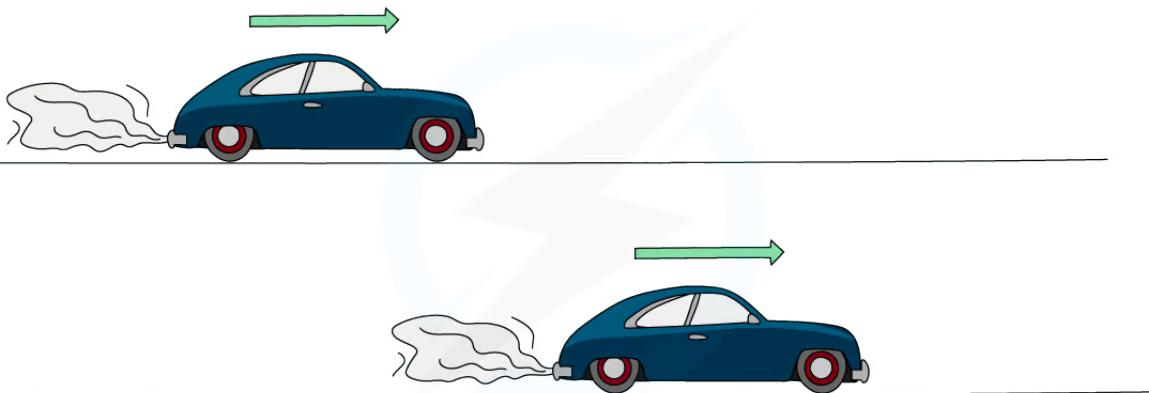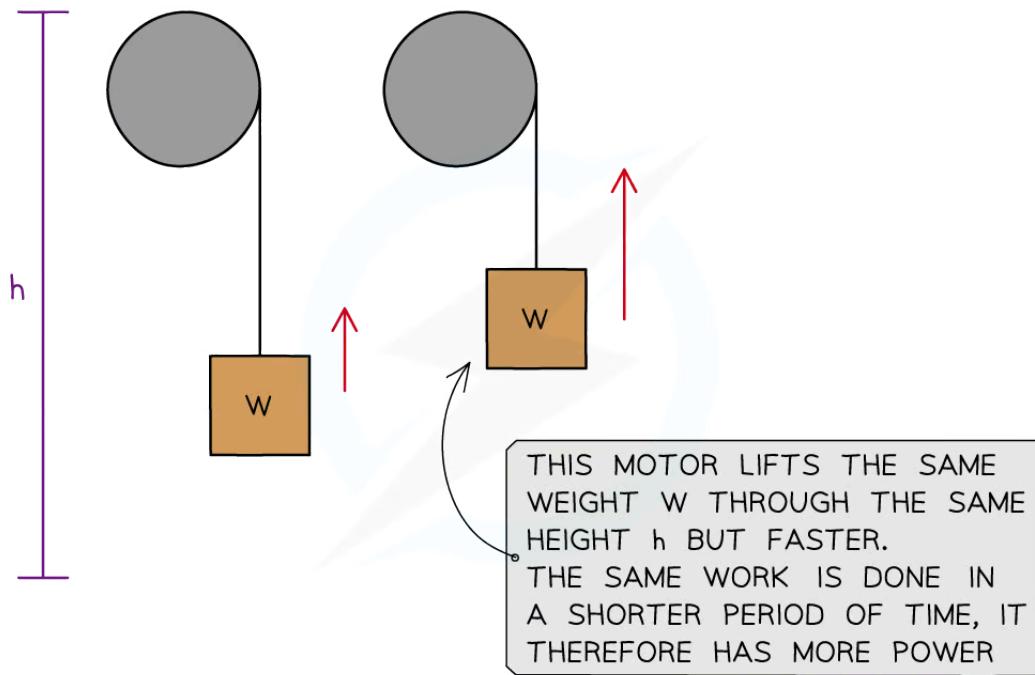
Two cars accelerate to the same final speed, but the one with the most power will reach that speed sooner

- 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**

THIS MOTOR LIFTS THE SAME WEIGHT W THROUGH THE SAME HEIGHT h BUT FASTER.
THE SAME WORK IS DONE IN A SHORTER PERIOD OF TIME, IT THEREFORE 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 Rating Table

Your notes

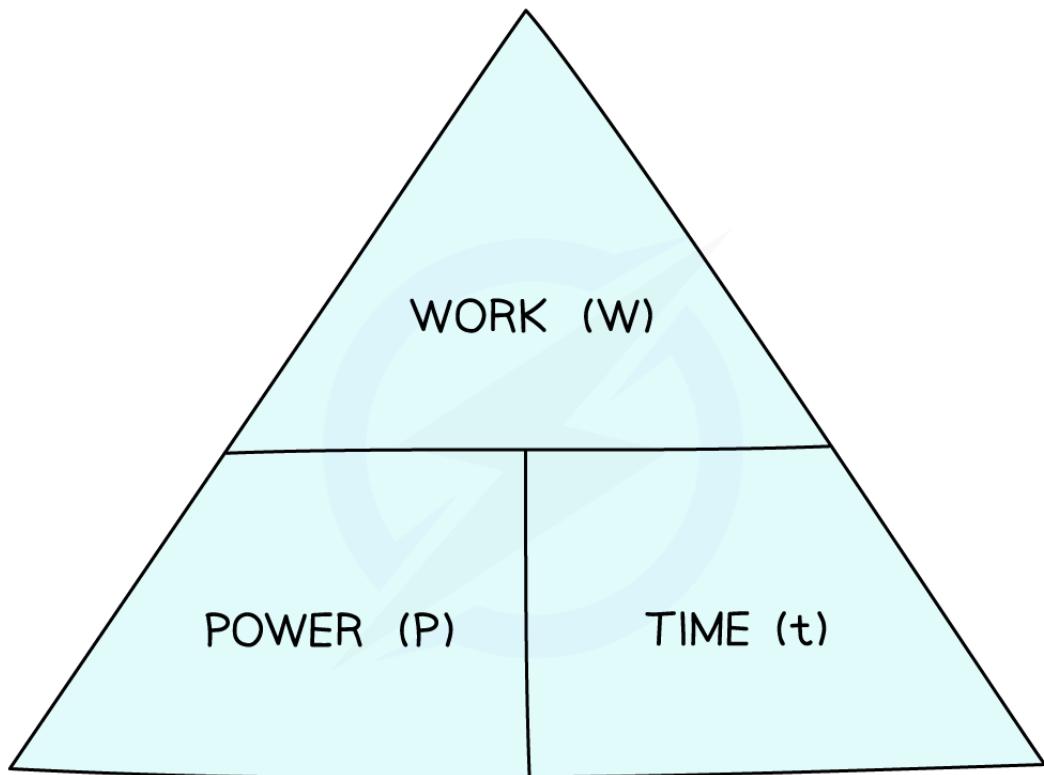| Appliance	Power rating
A torch	1 W
An electric light bulb	100 W
An electric cooker	10 000 W = 10kW (where 1 kW = 1000 watts)
A railway engine	1 000 000 W = 1 megawatt (MW) = 1 million watts
A Saturn V space rocket	100 MW
A very large power station	10 000 MW
World demand for power	10 000 000 MW
A star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

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

- Where:
    - P = power, measured in **watts** (W)
    - E = energy transferred, measured in **joules** (J)
    - W = work done, measured in joules (J)
    - t = time, measured in **seconds** (s)

- This equation can be rearranged with the help of a formula triangle:

Work, power, time formula triangle

Your notes

✏️ Worked example

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

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

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

Step 3: Rearrange to make energy the subject

$$E = Pt$$

Step 4: Substitute in the known values

$$E = 2500 \times 3000$$

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

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**

$$1 \text{ W} = 1 \text{ J / s}$$

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

💡 Examiner Tip

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

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