Cambridge (CIE) AS Physics

Your notes

Potential Dividers

Contents

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Potential divider circuit

- When two resistors are connected in series, through Kirchhoff's Second Law, the potential difference across the power source is divided between them
- Potential dividers are circuits which produce an output voltage as a **fraction** of its input voltage
- Potential dividers have three main purposes:
  - To provide a variable potential difference
  - To enable a specific potential difference to be chosen
  - To split the potential difference of a power source between two or more components
- Potential dividers are used widely in volume controls and sensory circuits using LDRs and thermistors
- Potential divider circuits are based on the ratio of voltage between components. This is equal to the ratio of the resistances of the resistors in the diagram below, giving the following equation:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

- The resistance R_2 on the numerator of the fraction is always the resistance of the component that V_{out} is connected to

Potential divider circuit diagram

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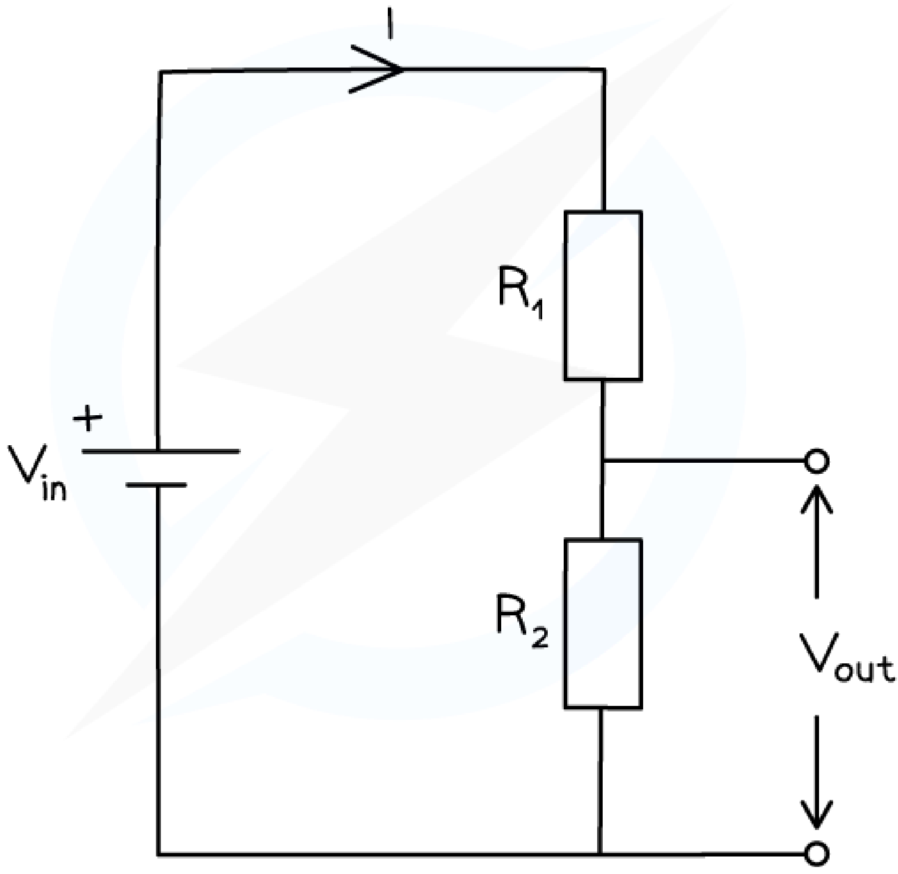


A potential divider circuit is a combination of resistors, voltage in from a source and voltage out

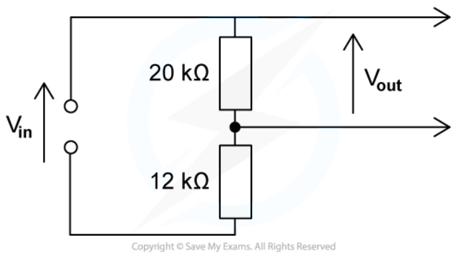
- The input voltage V_{in} is applied to the top and bottom of the series resistors
- The output voltage V_{out} is measured from the centre to the bottom of resistor R_2
- The potential difference *V* across each resistor depends upon its resistance *R*:
  - The resistor with the **largest resistance** will have a **greater potential difference** than the other one from $V = IR$
  - If the resistance of one of the resistors is increased, it will get a greater share of the potential difference, whilst the other resistor will get a smaller share
- In potential divider circuits, the p.d across a component is proportional to its resistance from $V = IR$

Worked Example

Your notes

The circuit is designed to light up a lamp when the input voltage exceed a preset value.

It does this by comparing V_{out} with a fixed reference voltage of 5.3 V.



V_{out} is equal to 5.3

Calculate the input voltage V_{in}.

Answer:

Step 1: List the known quantities

- Resistance of first resistor, R_1 = 20 kΩ
- Resistance of the second resistor, R_2 = 12 kΩ
- V_{out} = 5.3 V

Step 2: State the potential divider equation

- The R_1 is on the numerator as this is the resistor that V_{out} is from

$$V_{out} = \left(\frac{R_1}{R_1 + R_2}\right)V_{in}$$

Step 3: Rearrange for the input voltage, V_{in}

$$V_{in} = \frac{V_{out}}{\left(\frac{R_1}{R_1 + R_2}\right)} = \left(\frac{R_1 + R_2}{R_1}\right)V_{out}$$

Step 4: Substitute in values

$$V_{in} = \left(\frac{12 + 20}{20}\right) \times 5.3 = 8.5 \text{ V } (2 \text{ s.f.})$$

Examiner Tips and Tricks

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Always make sure the correct resistance is in the numerator of the potential divider equation. This will be the resistance of the component you want to find the output voltage of.

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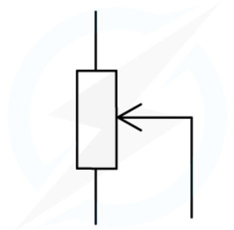
The potentiometer

- A potentiometer is similar to a variable resistor connected as a potential divider to give a continuously variable output voltage
- It can be used as a means of comparing potential differences in different parts of the circuit
- The circuit symbol is recognised by an arrow next to the resistor

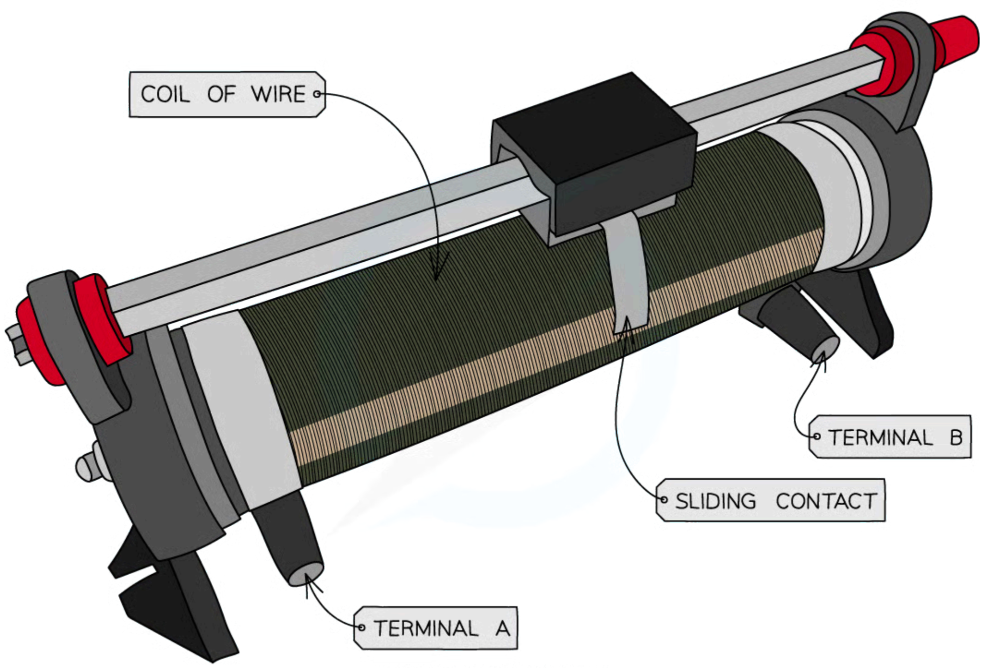
Potentiometer circuit symbol



A potentiometer circuit symbol looks like a resistor with an arrow towards it

- A potentiometer is a single component that (in its simplest form) consists of a coil of wire with a sliding contact, midway along it

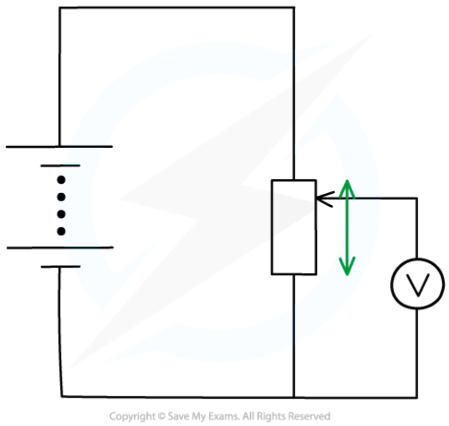
A potentiometer



A potentiometer is a type of variable resistor

- It is recognised on a circuit diagram with a resistor fitted with a sliding contact
- The sliding contact has the effect of separating the potentiometer into two parts (an upper part and a lower part), both of which have different resistances

Potentiometer circuit diagram



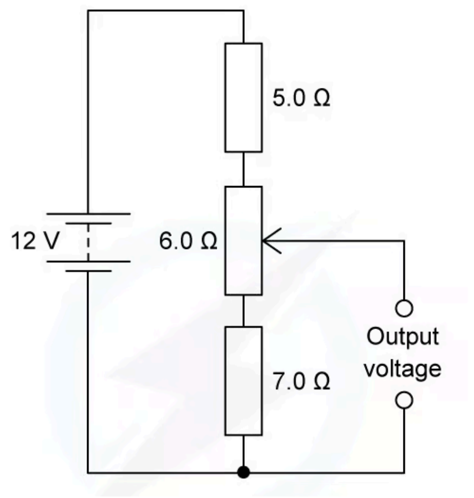
Moving the slider (the arrow in the diagram) changes the resistance (and hence potential difference) of the upper and lower parts of the potentiometer

- If the slider in the above diagram is moved upwards, the resistance of the lower part will increase and so the potential difference across it will also increase
- Therefore, the variable resistor obtains a maximum or minimum value for the output voltage
- If the resistance is 3 Ω:
  - Maximum voltage is when the resistance is 3 Ω
  - Minimum voltage is when the resistance is 0 Ω

Worked Example

A potential divider circuit consists of fixed resistors of resistance 5.0 Ω and 7.0 Ω connected in series with a 6.0 Ω resistor fitted with a sliding contact. These are connected across a battery of e.m.f 12 V and zero internal resistance, as shown.

Your notes



What are the maximum and minimum output voltages of the circuit with the sliding contact?

	Maximum voltage / V	Minimum voltage / V
A.	8.7	4.7
B.	6	0
C.	12	6.5
D.	12.5	4.7

Answer: A

Step 1: List the known quantities:

- Input voltage, V_{in} = 12 V
- First resistor, R_1 = 5.0 Ω
- Second resistor, R_2 = 6.0 Ω
- Third resistor, R_3 = 7.0 Ω

Step 2: Determine the maximum and minimum resistance with the sliding contact

- When the sliding contact is at the top of the 6.0 Ω resistor, the output voltage takes into account the 6.0 Ω and 7.0 Ω resistor
- When the sliding contact is at the bottom of the 6.0 Ω resistor, the output voltage only takes into account the 7.0 Ω

Step 3: State the potential divider equation for the three resistors

- This time, R_2 and R_3 are on the numerator as they are where V_{out} is from

$$V_{out} = \left(\frac{R_2 + R_3}{R_1 + R_2 + R_3}\right)V_{in}$$

Step 4: Calculate the maximum output voltage

- This is when the sliding contact is at the top of the 6.0 Ω resistor

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$$V_{out} = \left(\frac{6.0 + 7.0}{5.0 + 6.0 + 7.0}\right) \times 12.0 = 8.7 \text{ V}$$

Step 5: Calculate the minimum output voltage

- This is when the sliding contact only covers the 7.0 Ω resistor

$$V_{out} = \left(\frac{7.0}{5.0 + 6.0 + 7.0}\right) \times 12.0 = 4.7 \text{ V}$$

Your notes

The galvanometer

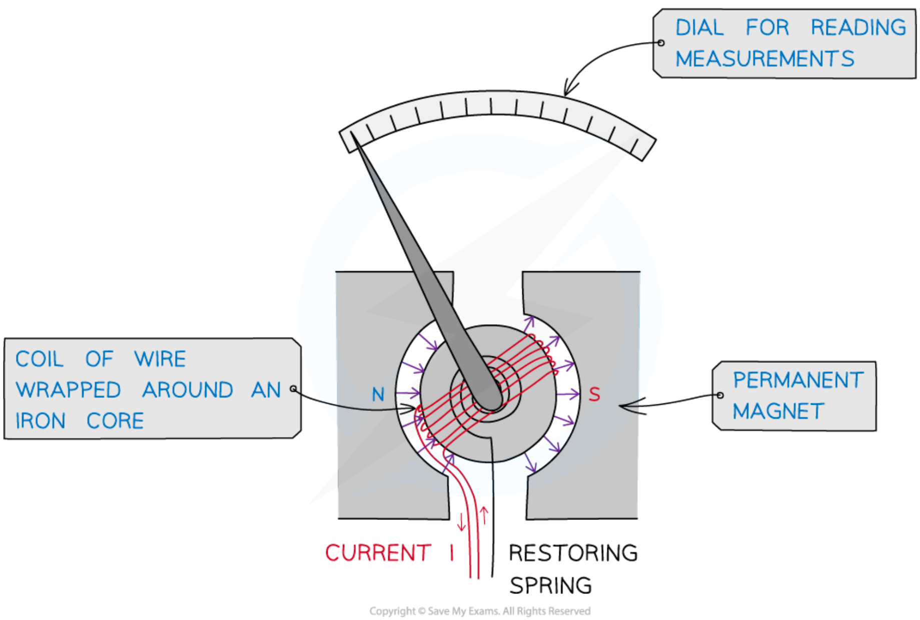
- A galvanometer is a type of sensitive ammeter used to detect electric current
- It is used in a potentiometer to measure e.m.f between two points in a circuit
- The circuit symbol is recognised by an arrow in a circle:

Galvanometer circuit symbol

The galvanometer circuit symbol is a circle with an arrow which deflects

- A galvanometer is made from a coil of wire wrapped around an iron core that rotates inside a magnetic field:

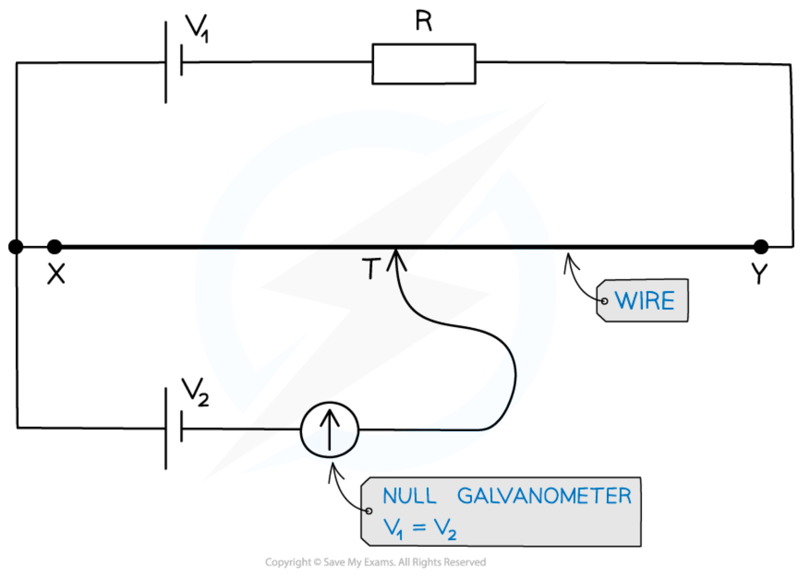
A galvanometer



A galvanometer contains a coil of wire wrapped around an iron core between magnets

- The arrow represents a needle which deflects depending on the amount of current passing through
  - When the arrow is facing directly upward, there is no current
  - This is called **null** deflection
- Ohm's law tells us that the current through a conductor (wire) is directly proportional to the potential difference through it i.e. **no p.d means no current** flows through the galvanometer
- A galvanometer has a p.d of zero when the potential on one side equals the potential on the other side
- This is at the **position at which it is connected on the wire (which varies with the sliding contact) gives a p.d equal to the EMF of the cell connected to the galvanometer**
- The cell should be connected such that its potential **opposes** the potential on the wire i.e. the positive terminal of the power supply faces the positive terminal of the cell:

A null galvanometer



A circuit diagram showing a null galvanometer. The voltage $V_1 = V_2$

- When the sliding contact moves along the potentiometer wire, you add or remove resistance from/to the external circuit. This changes the potential drop across X and Y
- The location of the sliding point is adjusted until the galvanometer reads zero. This is until the potential difference equals E_2
- The direction of the two e.m.fs oppose each other and there is no current

Your notes

Examiner Tips and Tricks

If you're unsure as to whether the p.d will increase as the contact slider is moved along the wire, remember **p.d is proportional to the length of the wire** (from Ohm's law and the resistivity equation). The longer the length of a wire, the higher the p.d.

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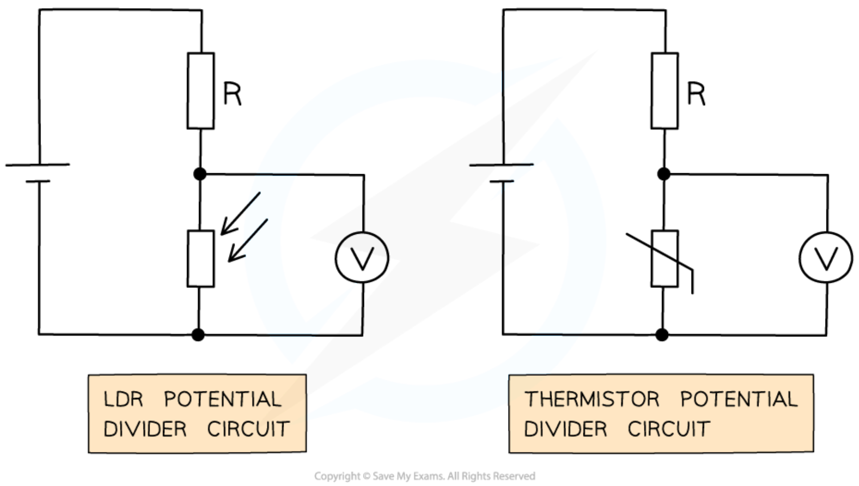
Variable resistance components

- Variable and sensory resistors are used in potential dividers to vary the output voltage
  - This could cause an external component to switch on or off e.g. a heater switching off automatically when its surroundings are at room temperature
- Sensory resistors used are **Light Dependent Resistors (LDRs)** and **thermistors**

LDR and thermistors in a circuit



LDR and thermistor in a potential divider circuit with a fixed resistor R

- The voltmeter in both circuits is measuring V_{out}
- Recall that the resistance of an LDR varies with light intensity
  - The higher the light intensity, the lower the resistance and vice versa
- An LDR circuit is often used for street and security lights
- The resistance of a thermistor varies with temperature
  - The hotter the thermistor, the lower the resistance and vice versa
- A thermistor circuit is used in fire alarms, ovens and digital thermometers
- From Ohm's law $\boldsymbol{V = IR}$, the potential difference V_{out} from a resistor in a potential divider circuit is **proportional** to its resistance
  - If an LDR or thermistor's resistance **decreases**, the potential difference through it also **decreases**
  - If an LDR or thermistor's resistance **increases**, the potential difference through it also **increases**

- Since the total p.d of the components must be equal to V_{in}, if the p.d of the sensory resistor **decreases** then the p.d of the other resistor in the circuit must **increase** and vice versa

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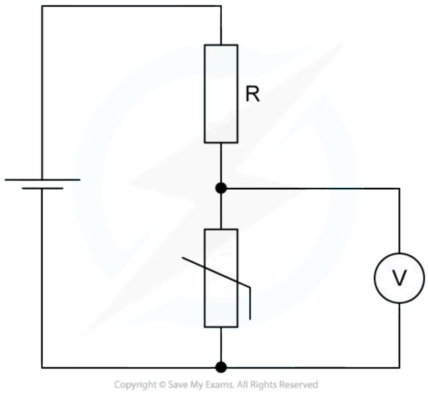
Worked Example

A potential divider consists of a fixed resistor R and a thermistor.



What happens to the p.d through resistor R and the thermistor when the temperature of the thermistor decreases?

	P.d of thermistor / V	P.d of resistor / V
A.	Increases	Increases
B.	Decreases	Increases
C.	Decreases	Decreases
D.	Increases	Decreases

Answer: D

- Due to Ohm's Law ($V = IR$), both the resistor and thermistor are connected in series and have the same current I
- In a thermistor, if the temperature **decreases**, its resistance **increases**
- This means the potential difference across the thermistor also **increases**
- As the resistance R **increases**, the potential difference across the thermistor also **increases**
- In series, the potential difference is shared equally amongst the components. Their sum equals the e.m.f of the supply (Kirchhoff's second law)
- This means the potential difference across the resistance R must **decrease**, to keep the same overall total e.m.f

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