Exercise walk-through

# 10.3.1

# The potentiometer, null methods and sensing circuits

A-Level Physics

# You must be able to

- understand the principle of a **potential divider 分压器** circuit
- recall and use the principle of the potentiometer as a means of comparing potential differences
- understand the use of a **galvanometer 检流计** in null methods
- explain the use of thermistors and light-dependent resistors in potential dividers, to give a potential difference that depends on temperature or **light intensity 光强**

# 1 The method

# Method — The divider, in one line and in two forms

Two resistors in series carry the **same current**, so the supply p.d. is shared **in proportion to their resistances**:

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

where $R_2$ is the resistor the output is taken **across**.

- For a **uniform resistance wire**, resistance is proportional to length ($R = \rho L/A$ with $\rho$ and $A$ constant), so the p.d. across a length is proportional to **that length**:

$$\frac{V_{\text{AC}}}{V_{\text{AB}}} = \frac{\ell_{\text{AC}}}{\ell_{\text{AB}}}$$

- That single fact is what makes a potentiometer work.

# Method — The potentiometer, and the point of a null method

1. A **driver cell** sends a steady current through the uniform wire AB, so the p.d. increases evenly along it.
2. The cell being measured is connected, through a **galvanometer**, between A and a sliding contact – the **jockey**.
3. Slide the jockey until the galvanometer reads **exactly zero**. That is the **balance point**, at length $\ell$ from A.

At balance the p.d. across $\ell$ of wire is **equal and opposite** to the e.m.f. of the cell, so

$$E \propto \ell \qquad \text{and, for two cells,} \qquad \frac{E_1}{E_2} = \frac{\ell_1}{\ell_2}$$

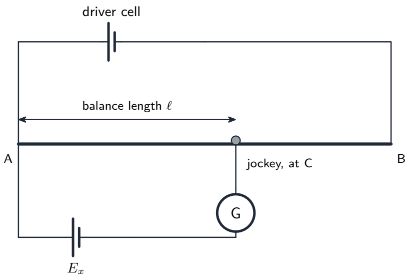
**Why a null method is better than a voltmeter.** At balance **no current flows through the cell being measured**. With $I = 0$ there is no p.d. $Ir$ across its internal resistance, so the p.d. being balanced is the **e.m.f.** itself. Any real voltmeter draws some current, so it always reads the **terminal p.d.**, which is slightly less.

# Method — The potentiometer, and the point of a null method

- Two further advantages: the galvanometer only has to detect **zero**, so its own calibration does not matter; and the result depends on a **length**, which can be measured very precisely.
- The **driver cell must have a larger e.m.f.** than either cell being measured, or no point on the wire has a big enough p.d. and a balance point cannot be found.

# Method — The potentiometer, and the point of a null method

At balance no current flows through the cell being measured .




Slide the jockey until the galvanometer reads **zero**. No current then flows through $E_x$, so there is no lost volts inside it and the p.d. across the length $\ell$ of wire equals its **e.m.f.** exactly. Repeat with a second cell and $\frac{E_1}{E_2} = \frac{\ell_1}{\ell_2}$, because the wire is uniform.

# Method — Sensing circuits: three steps, every time

| **sensor** | **what happens to its resistance** |
|---|---|
| **thermistor** (negative temperature coefficient) | **falls** as temperature **rises** |
| **LDR** | **falls** as light intensity **rises** |

Then answer in three steps, and never skip the middle one:

1. what happens to the **sensor's resistance**;
2. what that does to its **share** of the supply p.d.;
3. therefore what happens to the p.d. across whichever component the **output is taken across**.

# Method — Sensing circuits: three steps, every time

*Worked example. A thermistor is in series with a fixed resistor R, and the output is taken across R. The temperature rises. What happens to $V_{out}$?*

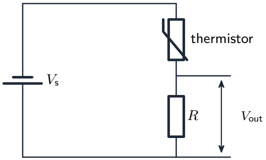
1. the thermistor's resistance **falls**;
2. so it takes a **smaller share** of the supply p.d.;
3. the rest of the supply is across $R$, so $V_{\text{out}}$ **rises**.

- **Swapping the two components reverses the answer**, so always say which component the output is across before you start. Getting this the wrong way round is the most common error on the whole unit.
- To make a lamp come on **in the dark**, you need an output that **rises as it gets darker**: the LDR's resistance rises in the dark, so take the output **across the LDR**.

# Method — Sensing circuits: three steps, every time

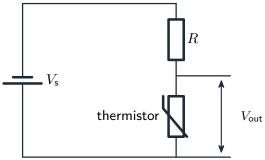
center Then answer in three steps, and never skip the middle one: Worked example.

**(a) output across $R$**




temperature **rises** $\Rightarrow$ thermistor resistance **falls** $\Rightarrow$ it takes a smaller share $\Rightarrow$ $V_{out}$ **rises**

**(b) output across the thermistor**




same change, but now $V_{out}$ is the thermistor's own share, so it **falls**

Answer in three steps every time: what happens to the **sensor's resistance**, what that does to its **share** of the supply, and therefore what happens to the component the output is taken **across**. Swapping the two components reverses the answer.

# 2 Practice

# Practice 2.1 ▪ 2 marks

State the principle of a potential divider, and write the formula for the output taken across one of two resistors in series.

# Solution 2.1

Method: The divider, in one line and in two forms — p.4

## Worked steps

- two resistors in series carry the **same current**, so the supply p.d. is shared between them in proportion to their **resistances** B1

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2}$$ B1

## Practice 2.2 ▪ 2 marks

A $12$ V supply is connected across a $3.0$ kΩ resistor in series with a $9.0$ kΩ resistor. Calculate the p.d. across the $3.0$ kΩ resistor.

# Solution 2.2

**Worked steps**

- the $3.0\ \mathrm{k\Omega}$ resistor takes its share of the supply **M1**

$$V = 12\ \mathrm{V} \times \frac{3.0\ \mathrm{k\Omega}}{3.0\ \mathrm{k\Omega} + 9.0\ \mathrm{k\Omega}} = \mathbf{3.0}\ \mathrm{V}$$ **A1**

## Practice 2.3 ▪ 2 marks

Explain why the p.d. across part of a uniform resistance wire is proportional to the length of that part.

# Solution 2.3

Method: The divider, in one line and in two forms — p.4

## Worked steps

- for a uniform wire $R = \dfrac{\rho L}{A}$ with $\rho$ and $A$ constant, so resistance is proportional to **length** **B1**
- the whole wire carries the same current, so the p.d. across a part is $IR$, which is therefore proportional to that part's length **B1**

## Practice 2.4 ▪ 2 marks

Explain what is meant by a **null method**, and name the instrument used in one.

# Solution 2.4

Method: The potentiometer, and the point of a null method — p.5

## Worked steps

- a null method adjusts the circuit until an instrument reads **exactly zero**, and the measurement is taken at that setting **B1**
- the instrument is a **galvanometer**, which is a sensitive centre-zero ammeter **B1**

## Practice 2.5 ▪ 3 marks

Explain why a potentiometer measures the **e.m.f.** of a cell, while a voltmeter connected across its terminals does not.

# Solution 2.5

Method: The potentiometer, and the point of a null method — p.5

## Worked steps

- at the balance point the galvanometer reads zero, so **no current flows** through the cell being measured **B1**
- with $I = 0$ there is no p.d. $Ir$ across its internal resistance, so the p.d. being balanced is the full **e.m.f.** **B1**
- a voltmeter always draws **some** current, so there is always a small $Ir$ inside the cell and it reads the **terminal p.d.**, which is slightly less than the e.m.f. **B1**

# 3 Exam-style

## Exam-style 3.1 ▪ 1 mark

In a potentiometer experiment the galvanometer reads zero. At that moment the current through the cell being measured is

**A** zero.

**B** equal to the current through the driver cell.

**C** equal to the full-scale current of the galvanometer.

**D** impossible to determine.

# Solution 3.1

Method: The potentiometer, and the point of a null method — p.5

**A** zero. ✓

**B** equal to the current through the driver cell.

**C** equal to the full-scale current of the galvanometer.

**D** impossible to determine.

## Worked steps

**A**

- a zero reading on the galvanometer means **no current** flows in that branch, which is the whole point of the method **B1**

## Exam-style 3.2 ▪ 6 marks

A potentiometer wire AB is $1.00$ m long. A standard cell of e.m.f. $1.018$ V gives a balance point $62.5$ cm from A. A second cell, connected in its place, balances at $78.0$ cm from A.

## Exam-style 3.2 (a) ▪ 2 marks

Calculate the e.m.f. of the second cell.

# Solution 3.2 (a)

Method: The potentiometer, and the point of a null method — p.5

**Worked steps**

- the e.m.f. is proportional to the balance length **M1**

$$E_2 = E_1 \times \frac{\ell_2}{\ell_1} = 1.018\ \mathrm{V} \times \frac{78.0\ \mathrm{cm}}{62.5\ \mathrm{cm}} = \mathbf{1.27}\ \mathrm{V}$$ **A1**

## Exam-style 3.2 (b) ▪ 2 marks

Explain why the driver cell must have an e.m.f. greater than that of either cell being measured.

## Solution 3.2 (b)

**Worked steps**

- the p.d. available along the whole wire is set by the driver cell B1
- if the cell being measured had a larger e.m.f., no length of wire would have a p.d. big enough to balance it and there would be **no balance point** B1

# Exam-style 3.2 (c) ▪ 2 marks

State **two** advantages of this method over measuring the e.m.f. with a voltmeter.

# Solution 3.2 (c)

## Worked steps

- any **two** of: at balance **no current** is drawn from the cell, so the **e.m.f.** is measured rather than the terminal p.d.; the galvanometer only has to detect **zero**, so its calibration does not matter; the result depends on a **length**, which can be measured very precisely **B1** **B1**

## Exam-style 3.3 ▪ 10 marks

A student wants a circuit whose output voltage **rises as it gets darker**, so that it can switch a lamp on at night. A $6.0$ V supply of negligible internal resistance, a light-dependent resistor and a $4.7$ kΩ fixed resistor are available.

## Exam-style 3.3 (a) ▪ 3 marks

Draw the potential divider circuit, showing clearly across which component the output is taken.

# Solution 3.3 (a)

Method: Sensing circuits: three steps, every time — p.8

## Worked steps

- the LDR and the fixed resistor in **series** across the $6.0$ V supply, drawn with correct symbols **B1**
- the output terminals shown **across the LDR** **B1**
- the circuit complete, with correct symbols for the supply and the LDR **B1**

## Exam-style 3.3 (b) ▪ 3 marks

Explain, in terms of resistance and share of the supply p.d., how your circuit produces an output that rises as the light level falls.

# Solution 3.3 (b)

**Worked steps**

- as the light level falls, the resistance of the **LDR rises** B1
- so the LDR takes a **larger share** of the supply p.d. B1
- the output is taken across the LDR, so $V_{\text{out}}$ **rises** as it gets darker B1

## Exam-style 3.3 (c) ▪ 4 marks

The LDR has a resistance of $500\ \Omega$ in bright light and $20\ \mathrm{k}\Omega$ in darkness. Calculate the output voltage in bright light and in darkness.

# Solution 3.3 (c)

## Worked steps

- use the divider formula with the LDR as the output component M1
- in bright light M1

$$V_{\text{out}} = 6.0\text{ V} \times \frac{500\ \Omega}{500\ \Omega + 4700\ \Omega} = \mathbf{0.58}\text{ V}$$ A1

- in darkness

$$V_{\text{out}} = 6.0\text{ V} \times \frac{20\,000\ \Omega}{20\,000\ \Omega + 4700\ \Omega} = \mathbf{4.9}\text{ V}$$ A1