10.3.1 The potentiometer and the null method

Name: _____ Class: _____ Date: _____ **Total: 22 marks**

KEY WORDS potentiometer • galvanometer • null method • balance point • electromotive force

Objective

Answer exam questions on the **potentiometer** and **null methods**: why the p.d. along a uniform wire is proportional to length, how a balance point compares two p.d.s, and why a **galvanometer** reading zero means no current is drawn. Syllabus 10.3, learning outcomes 2 and 3.

You must be able to:

- explain why the p.d. across part of a uniform wire is proportional to its length
- use balance lengths to compare two e.m.f.s or p.d.s
- explain what a null method is, and why it measures an e.m.f. when a voltmeter cannot
- state why the driver cell must have a larger e.m.f. than the cells being compared

1 Key knowledge and worked examples

■ Key knowledge: a uniform wire

A **uniform** resistance wire has the same resistance per unit length, so resistance is proportional to length ($R = \rho L/A$ with ρ, A constant). A length of wire is just a potential divider, so the **p.d. across a length is proportional to that length**:

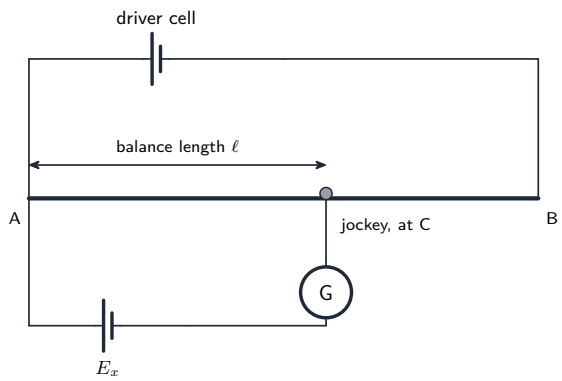
$$V = V_{\text{wire}} \times \frac{L}{L_{\text{total}}}$$

Worked example. A 2.0 V supply is across a uniform wire of length 100 cm. The p.d. across the first 30 cm is a share in proportion to length:

$$V = V_{\text{wire}} \times \frac{L}{L_{\text{total}}} = 2.0\ \text{V} \times \frac{30\ \text{cm}}{100\ \text{cm}} = 0.60\ \text{V}$$

This $V \propto L$ rule is the basis of the **potentiometer**.

■ Key knowledge: the potentiometer and null methods



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 ℓ 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.

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 ℓ from A.

At balance the p.d. across ℓ 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.

- 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.

■ **Worked example: comparing two e.m.f.s**

A standard cell of e.m.f. 1.02 V balances at 51.0 cm from A. With a second cell in its place, the balance point is at 75.0 cm.

1. **Why lengths compare e.m.f.s** – the p.d. along the wire is proportional to length, and at balance each e.m.f. equals the p.d. across its balance length.
2. **The unknown e.m.f.** – the ratio form, rearranged:

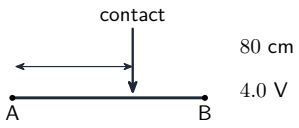
$$\frac{E_2}{E_1} = \frac{\ell_2}{\ell_1} \Rightarrow E_2 = E_1 \times \frac{\ell_2}{\ell_1} = 1.02\ \text{V} \times \frac{75.0\ \text{cm}}{51.0\ \text{cm}} = 1.50\ \text{V}$$

3. **Sense check** – the longer balance length belongs to the larger e.m.f.

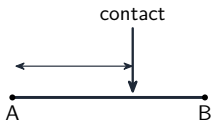
2 Practice

Now use the methods above.

2.1 A uniform wire of length 80 cm has 4.0 V across its ends. Find the p.d. across the first 20 cm. [2]



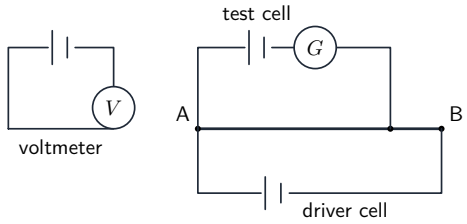
2.2 Explain why the p.d. across part of a uniform resistance wire is proportional to the length of that part. [2]



2.3 Explain what is meant by a **null method**, and name the instrument used in one. [2]

null method

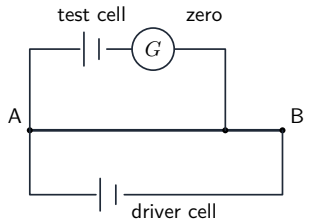
2.4 Explain why a potentiometer measures the **e.m.f.** of a cell, while a voltmeter connected across its terminals does not. [3]



3 Exam-style questions

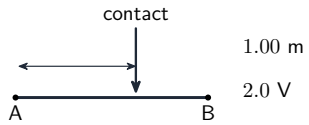
3.1 In a potentiometer experiment the galvanometer reads zero. At that moment the current through the cell being measured is [1]

☐ **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.



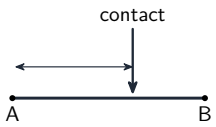
3.2 A uniform potentiometer wire is 1.00 m long with a p.d. of 2.0 V across it. A cell balances at 0.70 m. What is the e.m.f. of the cell? [1]

☐ **A** 0.70 V
B 1.4 V
C 2.0 V
D 2.9 V



3.3 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.

(a) Calculate the e.m.f. of the second cell. [2]



1.00 m

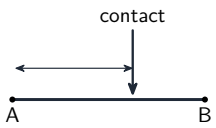
1.018 V

(b) Explain why the driver cell must have an e.m.f. greater than that of either cell being measured. [2]

(c) State **two** advantages of this method over measuring the e.m.f. with a voltmeter. [2]

3.4 A 6.0 V supply of negligible internal resistance is connected to a variable resistor R in series with a uniform resistance wire XY of resistance 8.0 Ω.

(a) R is adjusted so the p.d. across XY is 2.4 V. Calculate R. [3]



6.0 V

8.0 Ω

(b) Explain why the p.d. between any two points on wire XY is **proportional to the distance** between them. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- a uniform wire: $V \propto L$

$$V = V_{\text{wire}} \times \frac{L}{L_{\text{total}}} = 4.0\ \text{V} \times \frac{20\ \text{cm}}{80\ \text{cm}} = \mathbf{1.0}\ \text{V}$$

2.2

- for a uniform wire $R = \dfrac{\rho L}{A}$ with ρ and A constant, so resistance is proportional to **length**
- 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

2.3

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

2.4

- at the balance point the galvanometer reads zero, so **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 full **e.m.f.**
- 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.

3.1 A

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

3.2 B

- the p.d. along a uniform wire is proportional to length, and at balance the e.m.f. equals the p.d. across the balance length

$$E = V_{\text{wire}} \times \frac{\ell}{L} = 2.0\ \text{V} \times \frac{0.70\ \text{m}}{1.00\ \text{m}} = 1.4\ \text{V}$$

- **D** divides by 0.70 instead of multiplying

3.3

(a)

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

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

(b)

- the p.d. available along the whole wire is set by the driver cell
- 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**

(c)

- 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

3.4

(a) the wire and R form a potential divider, so use the output form

$$V_{\text{XY}} = \varepsilon \times \frac{R_{\text{XY}}}{R + R_{\text{XY}}}$$

- rearranged for the total resistance

$$R + R_{\text{XY}} = \frac{\varepsilon R_{\text{XY}}}{V_{\text{XY}}} = \frac{(6.0\ \text{V})(8.0\ \Omega)}{2.4\ \text{V}} = 20\ \Omega$$

- take away the resistance of the wire

$$R = (R + R_{\text{XY}}) - R_{\text{XY}} = 20\ \Omega - 8.0\ \Omega = \mathbf{12}\ \Omega$$

(b) the wire is **uniform**, so its resistance is **proportional to length**

- the same current flows along it, so by $V = IR$ the p.d. across a length is proportional to that length