

10.3.1 The potentiometer, null methods and sensing circuits

Name: _____ Class: _____ Date: _____ **Total: 28 marks**

KEY WORDS galvanometer 检流计 • potentiometer 电位差计 • thermistor 热敏电阻
• potential divider 分压器 • null method 零示法

Objective

Sheet 10.3 covered the divider formula and two short sensor questions. This sheet is the rest of 10.3, and it is the half the exam asks the long questions on: the **potentiometer** 电位差计 as a way of **comparing e.m.f.s**, what a **null method** 零示法 is and why it beats a voltmeter, and designing a sensing circuit with a **thermistor** 热敏电阻 or an **LDR** 光敏电阻 so that the output moves the way you want it to. This sheet covers syllabus 10.3.

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 Worked examples

Study these first. Each one shows a **method** that a question later on this sheet needs.

■ 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**:

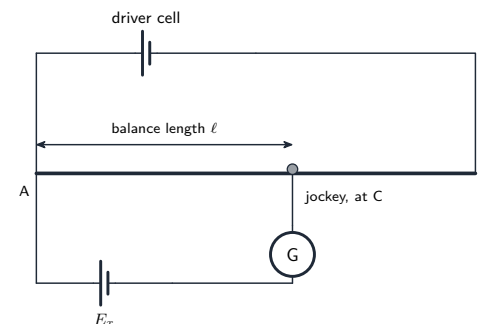
$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2}$$

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 ρ 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.
- The potentiometer, and the point of a null method



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.

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

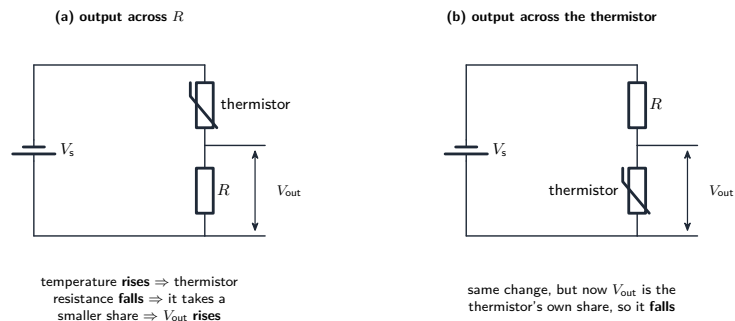
At balance the p.d. across ℓ of wire is **equal and opposite** to the e.m.f. of the cell, so

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

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.

■ Sensing circuits: three steps, every time



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.

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**.

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_{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**.

2 Practice

Now use the methods above.

2.1 State the principle of a potential divider, and write the formula for the output taken across one of two resistors in series. [2]

2.2 A 12 V supply is connected across a 3.0 k Ω resistor in series with a 9.0 k Ω resistor. Calculate the p.d. across the 3.0 k Ω resistor. [2]

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

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

2.5 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 | B |
| C | D |

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 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]

(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]

3.3 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 k Ω fixed resistor are available.

(a) Draw the potential divider circuit, showing clearly across which component the output is taken. [3]

(b) 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. [3]

(c) The LDR has a resistance of 500 Ω in bright light and 20 k Ω in darkness. Calculate the output voltage in bright light and in darkness. [4]

Solutions

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

2.1

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

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

2.2

- the 3.0 k Ω resistor takes its share of the supply

$$V = 12 \text{ V} \times \frac{3.0 \text{ k}\Omega}{3.0 \text{ k}\Omega + 9.0 \text{ k}\Omega} = \mathbf{3.0 \text{ V}}$$

2.3

- for a uniform wire $R = \frac{\rho L}{A}$ 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

2.4

- 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

2.5

- 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

(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

3.3

(a)

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

(b)

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

(c)

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

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

- in darkness

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