

2.7 Potential dividers, sensors and cells

Name: _____ Class: _____ Date: _____

Total: 25 marks

KEY WORDS potential divider • negative-temperature-coefficient thermistor
• light-dependent resistor • Electromotive force • Internal resistance

Objective

Build the methods for WPH12 statements 74–80: potential dividers, sensors and cells. These are original teaching questions, not copied past-paper items.

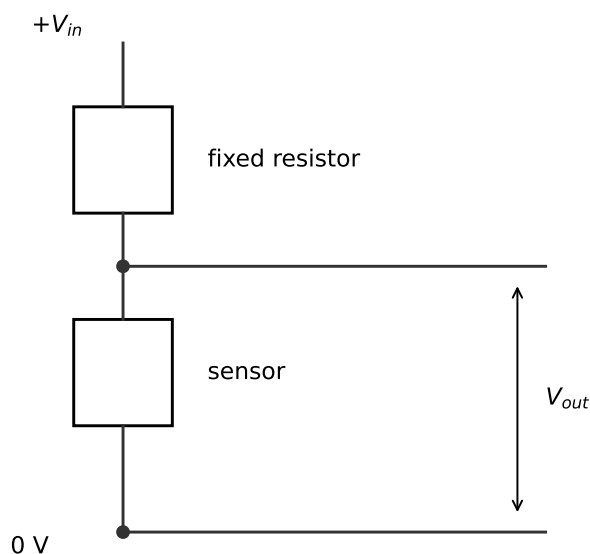
1 Key knowledge and worked examples

Along a uniform wire carrying steady current at constant temperature, resistance grows in proportion to distance. The potential drop therefore grows in proportion to distance too. A potential–distance graph is straight. This assumes uniform material and area; a tapered or unevenly heated wire need not give a straight line.

A **potential divider** uses series resistances to share a supply voltage:

$$V_{\text{out}} = V_{\text{in}} \frac{R_{\text{across output}}}{R_1 + R_2}$$

The expression assumes the output is unloaded, or the attached load draws negligible current. If a load draws significant current, combine it in parallel with the output resistor first. Always identify which resistor the voltmeter spans.



Swapping the sensor and fixed resistor reverses the direction of the output change.

Worked example. A 6.0 V supply feeds a $2.0\text{ k}\Omega$ fixed resistor above an LDR. Find the output across the LDR when its resistance changes from 4.0 to $1.0\text{ k}\Omega$.

$$V_{\text{dark}} = V_{\text{in}} \frac{R_{\text{LDR}}}{R_f + R_{\text{LDR}}} = 6.0\text{ V} \times \frac{4.0}{2.0 + 4.0} = 4.0\text{ V}$$

$$V_{\text{bright}} = V_{\text{in}} \frac{R_{\text{LDR}}}{R_f + R_{\text{LDR}}} = 6.0\text{ V} \times \frac{1.0}{2.0 + 1.0} = 2.0\text{ V}$$

The output across this LDR falls when illumination rises. The output across the fixed resistor rises. Explain the named output, not just “the voltage changes”.

■ Explain sensors using carriers

In a metal, heating increases lattice vibrations. Conduction electrons scatter more often. The mobile electron number stays approximately constant, but drift speed at a given potential gradient decreases, so resistance rises.

In a **negative-temperature-coefficient thermistor**, heating releases more mobile carriers. The carrier-density increase dominates, so resistance falls. Avoid saying heating reduces lattice vibrations.

In a **light-dependent resistor (LDR)**, absorbed light releases additional mobile carriers. Increased illumination raises carrier density and lowers resistance. It does not need to work by electrons leaving its surface.

For linked explanations, give the full chain: environmental change $\rightarrow$ carrier/scattering change $\rightarrow$ resistance change $\rightarrow$ divider fraction change $\rightarrow$ named output change. Keep the circuit arrangement in view throughout.

■ E.m.f., internal resistance and core practical 8

Electromotive force $\mathcal{E}$ is energy supplied by the source per unit charge. It is measured in volts, despite its name. **Internal resistance** r causes energy transfer within the source when current flows. The terminal p.d. is the energy per coulomb available to the external circuit:

$$\mathcal{E} = V + Ir \quad V = \mathcal{E} - Ir \quad I = \frac{\mathcal{E}}{R + r}$$

The source supplies power $\mathcal{E}I$, the external circuit receives VI , and internal heating is I^2r . These add consistently. With negligible current, terminal p.d. approaches e.m.f.

For CP8, connect a cell, ammeter, variable load and switch in series. Connect a high-resistance voltmeter across the cell terminals. Vary the external resistance and record pairs of V and I . Plot V vertically against I horizontally. The best-fit line has intercept $\mathcal{E}$ and gradient $-r$. Take the magnitude of the gradient for r .

Use several settings and repeat. Open the switch between readings, avoid very small load resistance, and keep the cell temperature and charge state as steady as possible. Never short-circuit the cell. A graph that curves may show changing internal resistance or e.m.f.; do not force one fixed r onto it without discussing the limitation.

Worked example. A cell graph passes through (0.20 A, 1.40 V) and (0.60 A, 1.20 V).

- Known: two points on the best-fit line. The gradient of $V = \mathcal{E} - Ir$ is $-r$.

$$r = -\frac{\Delta V}{\Delta I} = -\frac{1.20 - 1.40}{0.60 - 0.20} \Omega = 0.50 \Omega$$

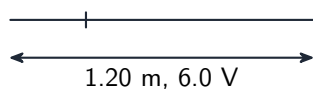
$$\mathcal{E} = V + Ir = 1.40 \text{ V} + 0.20 \text{ A} \times 0.50 \Omega = 1.50 \text{ V}$$

- Check using the second point: $1.20 + 0.60 \times 0.50 = 1.50 \text{ V}$ too. The terminal p.d. falls as current rises.

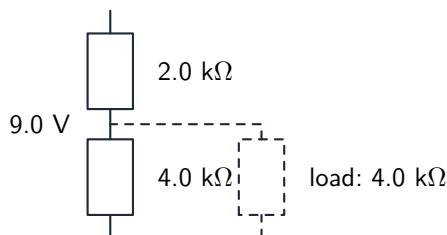
2 Practice

2.1 A uniform wire of length 1.20 m has 6.0 V across it at steady temperature. Find the drop across 0.30 m. Explain why potential varies linearly with distance. [3]

0.30 m

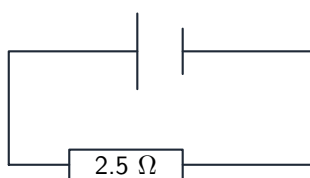


2.2 A 9.0 V unloaded divider contains an upper 2.0 k Ω resistor and lower 4.0 k Ω resistor. Find output across the lower resistor. A 4.0 k Ω load is then attached across the output. Find the new output. [3]



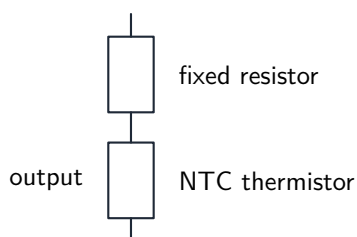
2.3 A cell has e.m.f. 1.5 V and internal resistance 0.50 Ω . It supplies a 2.5 Ω resistor. Find current, terminal p.d. and internal heating power. [3]

cell: 1.5 V, 0.50 Ω

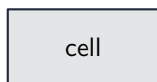


3 Exam-style questions

3.1 A divider has an upper fixed resistor and a lower NTC thermistor. The output is across the thermistor. Explain the full effect of heating on output. Contrast the carrier model with a heated metal wire, and explain what increasing illumination does to an LDR. [6]



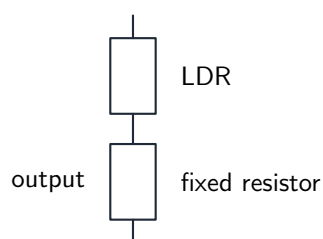
3.2 Plan a graph experiment for cell e.m.f. and internal resistance. A best-fit terminal-voltage line passes through (0.10 A, 1.45 V) and (0.50 A, 1.25 V). Calculate e.m.f. and internal resistance. State why short-circuiting is unsuitable. [6]



0.10 A, 1.45 V

0.50 A, 1.25 V

3.3 An unloaded divider has an upper LDR and a lower fixed resistor. The output is across the fixed resistor. Explain how increasing illumination changes the output, using a carrier model. State why the opposite output trend occurs if the two resistors exchange places. [4]



Solutions

These allocations are for the original questions on this sheet. B1 = one standalone point, M1 = one method point, A1 = one accuracy point.

2.1 $V_x = V_{total}x/L = 6.0 \times 0.30/1.20 = 1.5 \text{ V}$. Uniform wire resistance is proportional to length; the same current flows throughout, so $V = IR$ gives drop proportional to length.

2.2 Unloaded $V_o = V_i R_2/(R_1 + R_2) = 9 \times 4/6 = 6.0 \text{ V}$. Loaded lower resistance is $4 \parallel 4 = 2.0 \text{ k}\Omega$. New $V_o = 9 \times 2/(2 + 2) = 4.5 \text{ V}$.

2.3 $I = \mathcal{E}/(R + r) = 1.5/3.0 = 0.50 \text{ A}$. $V = \mathcal{E} - Ir = 1.5 - 0.50 \times 0.50 = 1.25 \text{ V}$. $P_{int} = I^2 r = 0.50^2 \times 0.50 = 0.125 \text{ W}$.

3.1 Heating the thermistor releases more mobile carriers, reducing its resistance. Its fraction $R_T/(R_f + R_T)$ decreases, so the named output falls. In metal, increased lattice scattering dominates with approximately unchanged carrier density, so resistance rises. Illumination releases more carriers in an LDR, reducing its resistance.

3.2 Use an ammeter and variable external load in series; voltmeter across the cell. Record several V, I pairs and plot V against I . From $V = \mathcal{E} - Ir$, gradient $= -r$ and intercept $= \mathcal{E}$. $r = -\Delta V/\Delta I = -(1.25 - 1.45)/(0.50 - 0.10) = 0.50 \Omega$. $\mathcal{E} = V + Ir = 1.45 + 0.10 \times 0.50 = 1.50 \text{ V}$. Short-circuit current causes heating and can change cell conditions or damage the cell; use current limiting and open the switch between readings.

3.3 Illumination releases additional mobile carriers in the LDR, so its resistance decreases. With fixed resistor below, $R_f/(R_{LDR} + R_f)$ rises, so the output rises. With the LDR below, its own fraction $R_{LDR}/(R_f + R_{LDR})$ falls, so the output falls.