10.3 Potential dividers and sensing circuits

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS potential divider • thermistor • light-dependent resistor • output voltage • resistance

Objective

Answer exam questions on the **potential divider**: how two resistors share a supply p.d., the two forms of the divider equation, and sensing circuits that use a **thermistor** or an **LDR** to give an output that depends on temperature or light. Syllabus 10.3, learning outcomes 1 and 4.

You must be able to:

- explain the principle of a potential divider, and calculate its output with either form of the equation
- find the output as a variable resistor, thermistor or LDR changes, and a resistance from two p.d.s
- explain, in three steps, why the output of a sensing circuit rises or falls
- design a divider whose output rises in the dark or as it gets warmer

1 Key knowledge and worked examples

Key knowledge: use these earlier methods

- **Networks**: series components carry the same current; parallel branches have the same p.d. Use $R_s = \sum R$ and $1/R_p = \sum(1/R)$, then $V = IR$.
- **Kirchhoff**: currents into a junction equal currents out; around a closed loop the sum of e.m.f.s equals the sum of p.d.s, using a consistent sign direction.
- **Internal resistance**: terminal p.d. is $V = \mathcal{E} - Ir$. Do not put the e.m.f. directly across an external resistor when r is non-zero.

■ Key knowledge: the potential divider

Two resistors in series carry the **same current**, so the supply p.d. is shared **in proportion to their resistances**. The same idea has two forms.

Output form, where R_2 is the resistor the output is taken **across**:

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

Ratio form, where the larger resistance takes the larger share:

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

- The two p.d.s always add up to the supply p.d. (Kirchhoff's second law): $V_1 + V_2 = V_{\text{in}}$.
- Use the output form when you know both resistances, and the ratio form when you know the p.d.s and want a resistance.

■ Worked example: an output, then a resistance

A 9.0 V supply of negligible internal resistance is across $R_1 = 6.0\ \text{k}\Omega$ and $R_2 = 3.0\ \text{k}\Omega$ in series.

1. **Output across** R_2 – the output form:

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2} = 9.0\ \text{V} \times \frac{3.0\ \text{k}\Omega}{6.0\ \text{k}\Omega + 3.0\ \text{k}\Omega} = 3.0\ \text{V}$$

2. **A thermistor replaces** R_1, and the output across R_2 becomes 6.0 V. By the second law the thermistor has the rest of the supply:

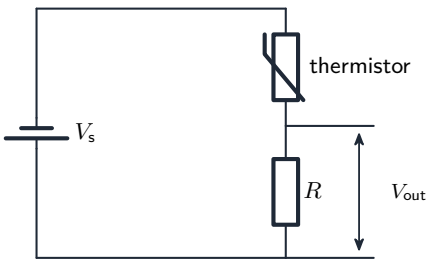
$$V_{\text{T}} = V_{\text{in}} - V_{\text{out}} = 9.0\ \text{V} - 6.0\ \text{V} = 3.0\ \text{V}$$

3. **Its resistance** – the ratio form, rearranged:

$$\frac{R_{\text{T}}}{R_2} = \frac{V_{\text{T}}}{V_{\text{out}}} \Rightarrow R_{\text{T}} = R_2 \times \frac{V_{\text{T}}}{V_{\text{out}}} = 3.0\ \text{k}\Omega \times \frac{3.0\ \text{V}}{6.0\ \text{V}} = 1.5\ \text{k}\Omega$$

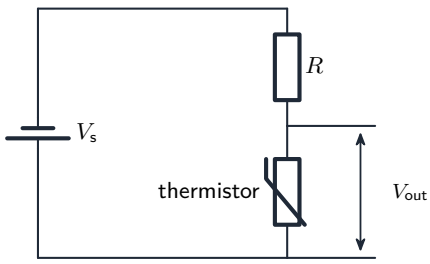
■ Key knowledge: sensing circuits

(a) output across R



temperature **rises** ⇒ thermistor resistance **falls** ⇒ it takes a smaller share ⇒ 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.

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}?

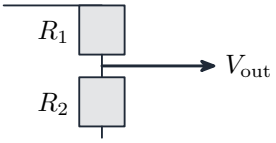
1. the thermistor's resistance **falls**;
2. so it takes a **smaller share** of the supply p.d.;
3. the rest of the supply is across R, so V_{out} **rises**.

- **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**.

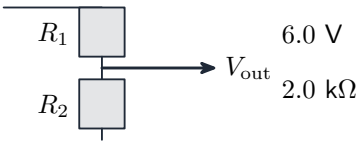
2 Practice

Now apply the methods above.

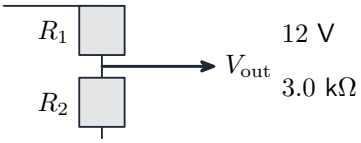
2.1 State the principle of a potential divider, and write the formula for the output taken across one of two resistors in series. [2]



2.2 A 6.0 V supply is across a 2.0 kΩ and a 4.0 kΩ resistor in series. Find the p.d. across the 4.0 kΩ resistor. [2]



2.3 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. [2]



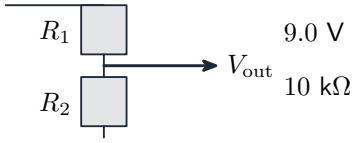
2.4 State what happens to a **thermistor's** resistance as temperature rises. [1]

thermistor

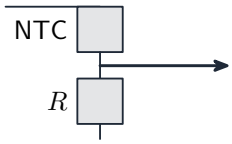
3 Exam-style questions

3.1 A 9.0 V supply of negligible internal resistance is connected across a 10 kΩ resistor in series with a 5.0 kΩ resistor. What is the p.d. across the 5.0 kΩ resistor? [1]

☐ **A** 1.5 V
B 3.0 V
C 4.5 V
D 6.0 V

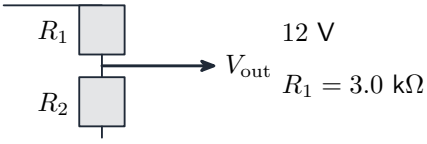


3.2 A thermistor and a fixed resistor are in series across a supply, and the output is taken across the **fixed resistor**. The temperature of the thermistor rises. What happens to the output p.d.? [1]

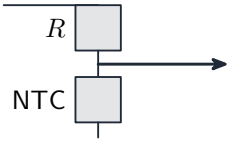


- [ ] **A** It increases, because the thermistor's resistance falls.
- **B** It decreases, because the thermistor's resistance falls.
- **C** It increases, because the thermistor's resistance rises.
- **D** It stays the same, because the supply p.d. is unchanged.

3.3 A 12 V supply is across $R_1 = 3.0$ kΩ and $R_2 = 1.0$ kΩ in series. Find V_{out} taken across R_2. [2]

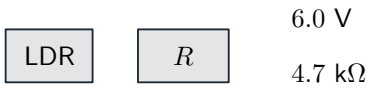


3.4 In a divider, a thermistor is in series with a fixed resistor and the output is taken across the **thermistor**. The temperature **rises**. Explain what happens to the output voltage. [3]



3.5 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.

(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 kΩ 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 output form of the divider equation, with the output across the 4.0 kΩ resistor

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2} = 6.0\ \text{V} \times \frac{4.0\ \text{k}\Omega}{2.0\ \text{k}\Omega + 4.0\ \text{k}\Omega} = \mathbf{4.0}\ \text{V}$$

2.3

- the 3.0 kΩ resistor takes its share of the supply

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2} = 12\ \text{V} \times \frac{3.0\ \text{k}\Omega}{3.0\ \text{k}\Omega + 9.0\ \text{k}\Omega} = \mathbf{3.0}\ \text{V}$$

2.4

- it **decreases**

3.1 B

- the p.d. is shared in proportion to the resistances

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2} = 9.0\ \text{V} \times \frac{5.0\ \text{k}\Omega}{10\ \text{k}\Omega + 5.0\ \text{k}\Omega} = 3.0\ \text{V}$$

- **D** is the p.d. across the 10 kΩ resistor

3.2 A

- as the thermistor warms its resistance falls, so it takes a smaller share of the supply p.d. and the fixed resistor a larger one
- **B** takes the output across the thermistor

3.3

- the output form of the divider equation, with the output across R_2

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2} = 12\ \text{V} \times \frac{1.0\ \text{k}\Omega}{3.0\ \text{k}\Omega + 1.0\ \text{k}\Omega} = \mathbf{3.0}\ \text{V}$$

3.4

- as temperature rises, the thermistor's resistance **decreases**
- it now takes a **smaller share** of the total voltage
- so the output voltage across the thermistor **decreases**

3.5

(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

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

- in darkness

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