

Exercise walk-through

10.3

Potential dividers

A-Level Physics

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:

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

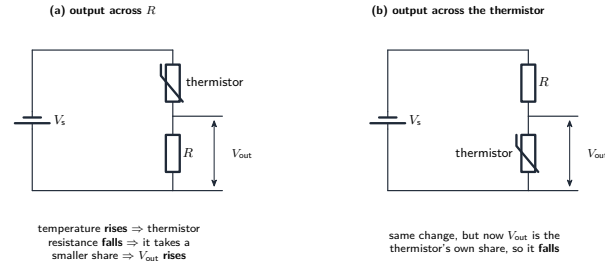
2. **A thermistor replaces R_1** , and the output across R_2 becomes 6.0 V. By the second law the thermistor has the rest of the supply:

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

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



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:

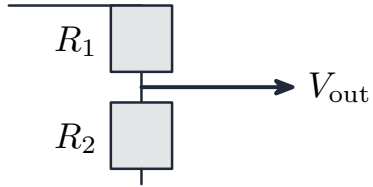
1. what happens to the **sensor's resistance**;
2. what that does to its **share** of the supply p.d.;
3. therefore what happens to the p.d. across whichever component the **output is taken across**.

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**.

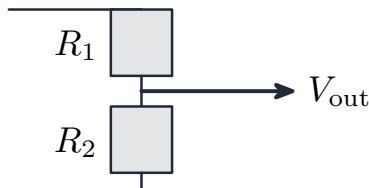
Exercise 2.1

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]



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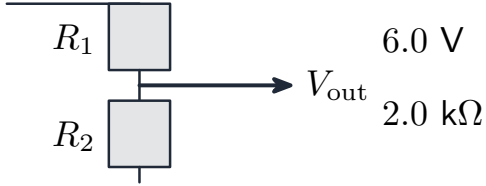
2.1

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

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

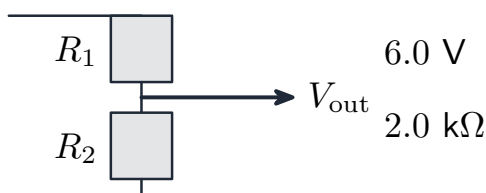
Exercise 2.2

2.2 A 6.0 V supply is across a $2.0 \text{ k}\Omega$ and a $4.0 \text{ k}\Omega$ resistor in series. Find the p.d. across the $4.0 \text{ k}\Omega$ resistor. [2]



Exercise 2.2

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



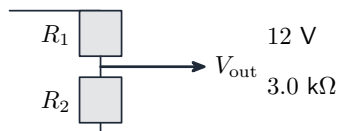
2.2

- the output form of the divider equation, with the output across the 4.0 k Ω resistor

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

Exercises 2.3·2.4

2.3 A 12 V supply is connected across a $3.0\text{ k}\Omega$ resistor in series with a $9.0\text{ k}\Omega$ resistor. Calculate the p.d. across the $3.0\text{ k}\Omega$ resistor. [2]

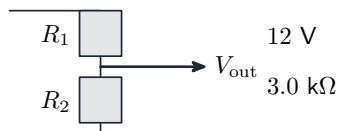


2.4 State what happens to a **thermistor's** resistance as temperature rises. [1]

thermistor

Exercises 2.3·2.4

2.3 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

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

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

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

thermistor

2.4

- it **decreases**

Exercise 3.1

3.1 A 9.0 V supply of negligible internal resistance is connected across a $10\text{ k}\Omega$ resistor in series with a $5.0\text{ k}\Omega$ resistor. What is the p.d. across the $5.0\text{ k}\Omega$ resistor? [1]

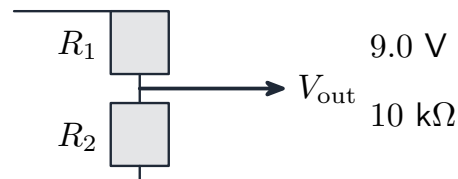
☐

A 1.5 V

B 3.0 V

C 4.5 V

D 6.0 V



Exercise 3.1

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

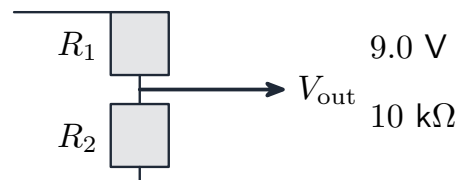
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A 1.5 V

B 3.0 V

C 4.5 V

D 6.0 V



3.1 B

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

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

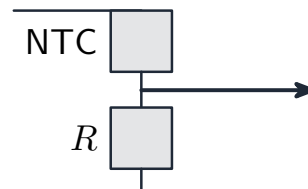
- D** is the p.d. across the 10 k Ω resistor

Exercise 3.2

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.

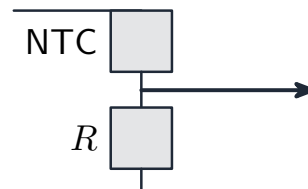


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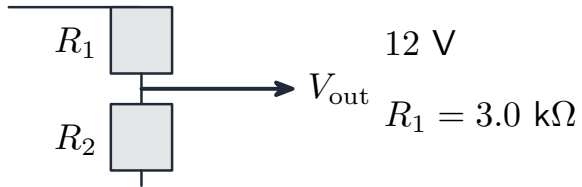


3.2 A

- 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

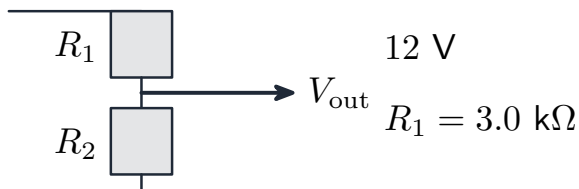
Exercise 3.3

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



Exercise 3.3

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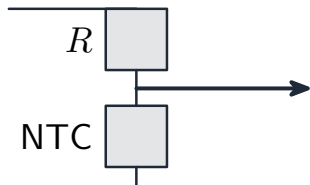
3.3

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

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

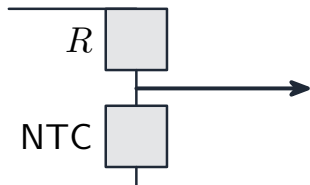
Exercise 3.4

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]



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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**

Setup for exercise 3.5

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 k Ω fixed resistor are available.

Exercise 3.5 (a)

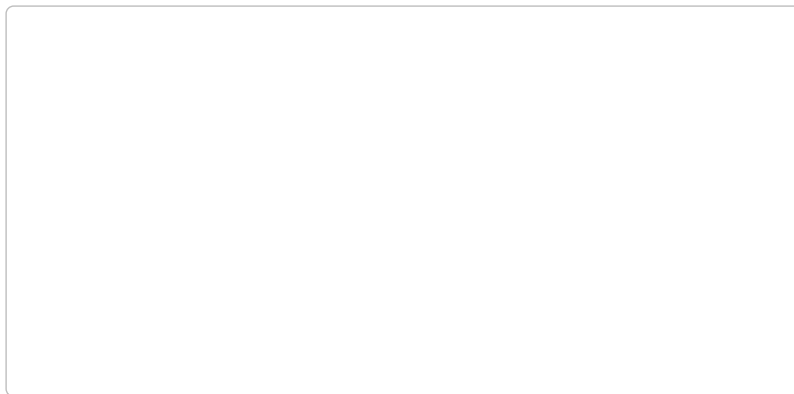
(a) Draw the potential divider circuit, showing clearly across which component the output is taken. [3]

LDR

R

6.0 V

4.7 k Ω



Exercise 3.5 (a)

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

LDR	R	6.0 V
		4.7 kΩ

(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

Exercise 3.5 (b)

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 k Ω fixed resistor are available.

(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]

Exercise 3.5 (b)

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 k Ω fixed resistor are available.

(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]

(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

Exercise 3.5 (c)

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 k Ω fixed resistor are available.

(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]

Exercise 3.5 (c)

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 k Ω fixed resistor are available.

(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]

(c)

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

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

- in darkness

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