



AS Level Physics

Chapter 9 – Electrical Circuits

9.3.1 Potential Dividers

Notes

Potential Dividers

A potential divider is a circuit with a source (such as a battery or cell) of fixed potential difference (p.d.) and a couple of resistors in series, at its most basic level.

Since the components in the circuit are connected in series, the source p.d. is split between them.

If the resistance of the two resistors is the same, they receive an equal share of the total voltage from the cell/battery.

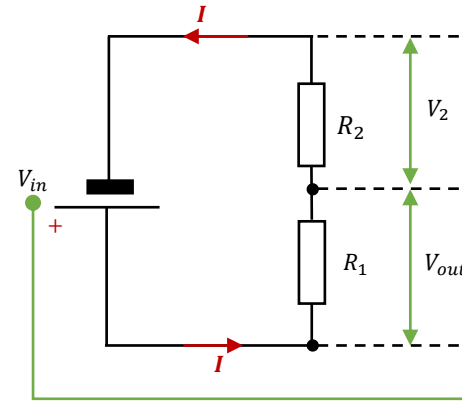
However, the two resistors are unlikely to have the same resistance.

The resistor with the greater resistance will get a larger fraction of the overall voltage. This is because electrons find it more difficult to pass through the resistor with the greater resistance, requiring more energy to do so. As a result, a **higher resistance resistor** has a **higher voltage**.

A potential divider can be used:

- To supply a fixed p.d. between any value from zero to the source p.d. If a cell has 3V, for example, you can fix it to 2V.
- To supply a p.d. that is variable.
- To supply a p.d. that changes in response to a physical condition such as temperature or light intensity.

Supplying a Fixed P.D.



Consider two resistors R_1 and R_2 , which are connected in series to a source of fixed p.d. V_{in} as illustrated opposite.

Think of V_{in} as the voltage going into the resistors from the source and V_{out} is the p.d. produced by the resistor.

Total resistance of the circuit, $R_T = R_1 + R_2$

Therefore, current through the resistors is:

$$I = \frac{\text{p.d. across the resistors}}{\text{total resistance}} = \frac{V_{in}}{R_T} = \frac{V_{in}}{R_1 + R_2}$$

So the p.d. across resistor R_1 is:

$$V_{out} = IR_1 = \left(\frac{V_{in}}{R_1 + R_2} \right) R_1$$

We know that:
 $I = \frac{V_{in}}{R_1 + R_2}$ so substitute it in.

The p.d. across resistor R_2 is:

$$V_2 = IR_2 = \left(\frac{V_{in}}{R_1 + R_2} \right) R_2$$

This formula helps you calculate the output voltage or p.d. across R_1 . This is an important formula we will use later.

Because we know that the resistor with the greater resistance has a greater share of the total voltage (V_{in}) we can use ratios in which the ratio of the resistances is equal to the ratio of the voltages. Giving us:

$$\frac{V_{out}}{V_2} = \frac{R_1}{R_2}$$

We can prove this below:

$$\text{So, } \frac{V_{out}}{V_2} = \left(\frac{V_{in}R_1}{R_1 + R_2} \right) \div \left(\frac{V_{in}R_2}{R_1 + R_2} \right) = \left(\frac{V_{in}R_1}{R_1 + R_2} \right) \times \left(\frac{R_1 + R_2}{V_{in}R_2} \right) = \frac{R_1}{R_2}$$

Supplying a Fixed P.D.

Therefore:

The ratio of the p.d.s across each resistor is equal to the ratio of the resistance.

$$\frac{V_{out}}{V_2} = \frac{R_1}{R_2}$$

The output voltage or p.d. (V_{out}) across R_1 is given by:

$$V_{out} = \left(\frac{V_{in}}{R_1 + R_2} \right) R_1$$

Worked example:

What is the p.d. obtained from R_1 with a 150V supply and by setting R_1 at 1700 Ω and R_2 at 11500 Ω ?

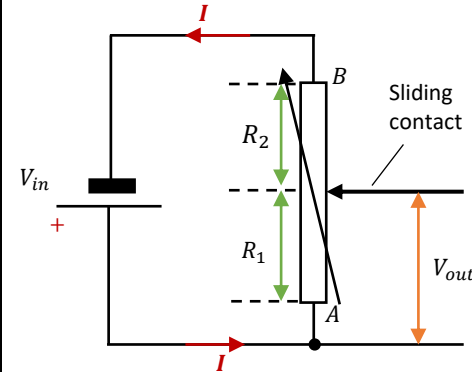
Use:

$$V_{out} = \left(\frac{V_{in}}{R_1 + R_2} \right) R_1$$

$$V_{out} = \left(\frac{150 \text{ V}}{1700 \Omega + 11500 \Omega} \right) 1700 \Omega$$

$$V_{out} = 19.3 \text{ V (1 d.p.)}$$

Supplying a Variable P.D.



A variable resistor is used in the potential divider circuit opposite to produce a continuously variable output p.d. from a fixed input p.d.

The value of the **output p.d. (V_{out})** can be adjusted by moving the sliding contact on the variable resistor:

- From position A, where the value of the voltage is at a minimum of 0V.
- To position B, where the value of the voltage is at a maximum equal to the Input p.d. (V_{in}).

The output voltage or p.d. (V_{out}) across R_1 is calculated as follows:

$$V_{out} = \left(\frac{V_{in}}{R_1 + R_2} \right) R_1$$

- With the sliding contact is at position A, $R_1 = 0\Omega$, so $V_{out} = 0V$
- With the sliding contact is at position B, $R_1 = R$ (max. resistance of the variable resistor)

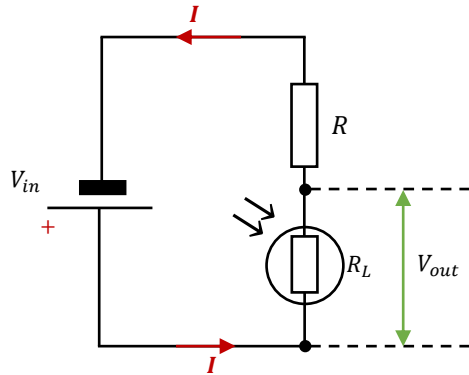
So $R_2 = 0\Omega$,

So,

$$V_{out} = \left(\frac{V_{in}}{R+0} \right) R = V_{in}$$



Light Dependent Potential Divider



A light-dependent resistor (LDR) can be used in a potential divider to generate a variable output p.d. (V_{out}) which varies with light intensity. This is illustrated in the diagram opposite.

An LDR is a resistor made from semiconducting material in which electrons are liberated when light shines on the surface of the material.

In total **darkness**, the LDR's **resistance is very high** because the only free electrons are those that have been 'shaken' free by thermal vibrations of the atoms.

As the amount of light energy incident on the LDR increases, more and more electrons are freed, lowering the LDR's resistance.

The output p.d. (V_{out}) is given by:

$$V_{out} = \left(\frac{V_{in}}{R_L + R} \right) R_L$$

In bright light:

R_L is low compared with R . As a result, the output p.d. (V_{out}) is very small. R_L rises, as the light intensity decreases.

In total darkness:

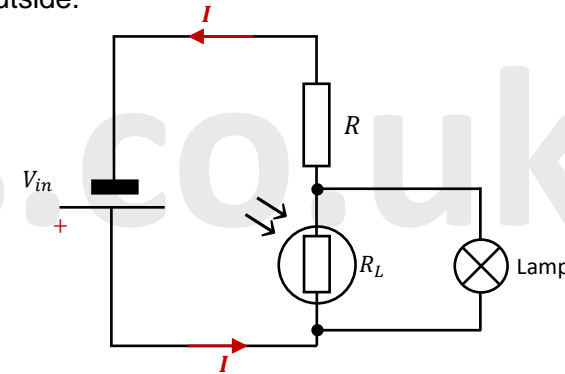
R_L is very high compared with R . As a result, the output p.d. (V_{out}) has reached its maximum value (V_{in}).

Light Dependent Potential Divider

This potential divider could be used to control any light dependent process because the output p.d. is dependent on light intensity.

At its most basic level, this circuit could be used to turn on street lights automatically when darkness falls. This could be achieved when V_o reaches a pre-determined value, corresponding to a specific light intensity level, which in turn activates a switching circuit to turn the lights on/off.

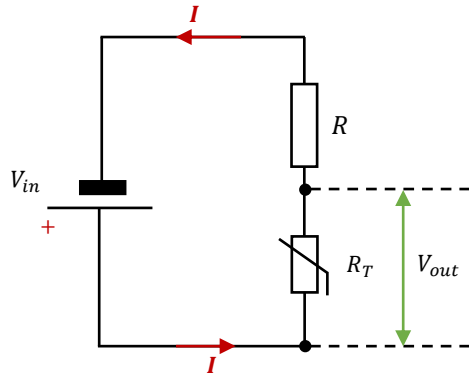
For example, in the darkness, the LDR's resistance increases, which in turn produces a higher voltage. So, if we connect a bulb in series with this LDR, the bulb will share the same voltage as the LDR. As a result, we can use an LDR to turn on street lights automatically when it gets dark outside.



If R were replaced with a variable resistor, the value of V_o (at a specific light intensity) could be adjusted manually. So, if the street lights, for example, were set to turn on at $V_o = \frac{1}{2} V_{in}$, R could be modified to make this happen at any desirable level of illumination.

If you were to swap R and R_L around, V_o will **increase** as the **light intensity increases**. This can be used in a circuit to trigger an alarm when a safe is opened with the lights on.

Temperature-Dependent Potential Divider



A thermistor is a device whose resistance changes significantly in response to temperature.

As the temperature rises,

- A negative temperature coefficient (**NTC**) thermistor's resistance **decreases**.
- A positive temperature coefficient (**PTC**) thermistor's resistance **increases**.

The output p.d. (V_{out}) is given by:

$$V_{out} = \left(\frac{V_{in}}{R_T + R} \right) R_T$$

For an NTC thermistor:

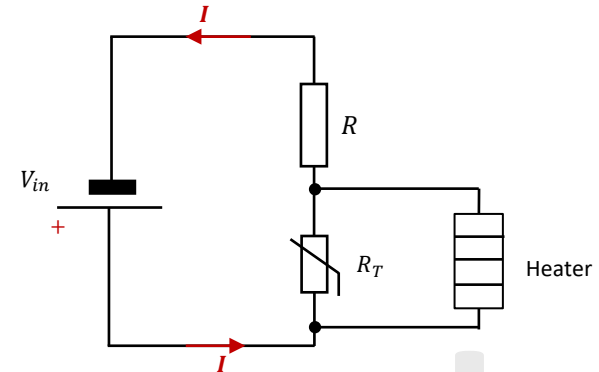
When the temperature is **High**, R_T is small in comparison to R and so V_{out} will be **small**.

When the temperature is **Low**, R_T is large in comparison to R and so V_{out} will be **large**.



Temperature-Dependent Potential Divider

- This temperature-dependent potential divider can be used in a circuit to activate a frost alarm or turn on a heating system to keep the temperature above a specific value.



- Remember when the NTC thermistor becomes colder, the resistance increases. As a result, a greater voltage is produced by the thermistor. So, if we connect a heater in series with this thermistor, it will share the same voltage. Hence, a thermistor can be used to turn on a heater when it is cold.
- The 'trigger' temperature may be manually adjusted by replacing the fixed resistor R with a variable resistor.
- If R_T and R are swapped around, V_0 will **increase** as the temperature rises. A potential divider such as this can form a part of a circuit that turns on an air conditioner when the temperature rises above a specific value.

Please see **'9.3.2 Potential Dividers worked examples'** pack for exam style questions.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.

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