Physics Factsheet

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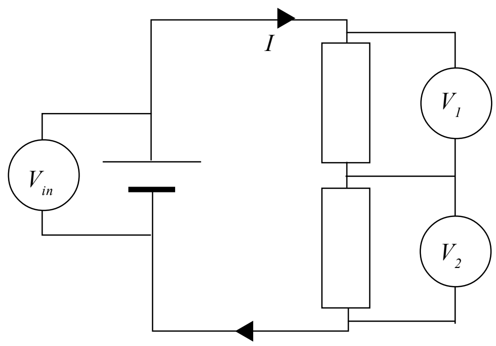
The Potential Divider and its Uses

The potential divider is an electrical device that supplies a range of potential differences (voltage drops) of anywhere between 0V to a maximum of the supply potential difference by using a combination of resistances.

In order to understand how the potential divider works it is necessary to remind ourselves, briefly, of some more basic ideas in electricity.

The simpliest form of the potential divider uses two fixed resistors in series.

Fig. 1: A simple potential divider circuit



$V_{in} = V_1 + V_2$ I is constant throughout circuit

Any resistance in a circuit will have a voltage drop across it, we know this from $V = IR$. In series the total of the voltage drops across all components in the circuit must equal the potential difference supplied, this is simply a statement of conservation of energy but is also expressed as Kirchoff's second law. The electrons in the current have no option but to flow through both as there are no alternative routes for them, so current is the same for both resistances.

*Series components will have the **same current** through them whereas they will **share the supply potential difference** across them.*

***Exam Hint:** Remember potential differences and voltage drops are always **across** components, this is because they are the difference in energy per unit charge between when they enter and then when they emerge from a component. This is why voltmeters are always attached across components. Voltages **never** flow or travel **through** components – this makes no sense and is therefore wrong.*

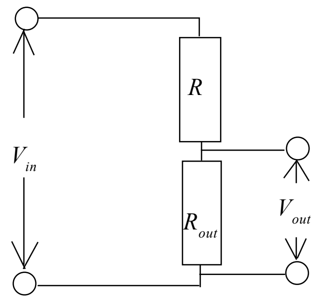
Potential dividers make use of the fact that the amount of potential difference across resistances in series is directly proportional to their resistances - $V \propto R$ (from Ohm's law) – as current is constant for both components. We can then tap off a voltage by placing our component across only one of the resistors in series.

The larger the resistance of resistor in a potential divider the greater its share of the voltage. The voltages will always add up to the supply potential difference.

Potential dividers can supply a potential difference of any value up to the value of the supply potential difference by varying the size and arrangement of the resistors. This means we can tap off varying potential differences from a fixed supply.

The fraction of the supply voltage a resistor will take is equal to its fraction of the total resistance. This is expressed by the equation below (Fig 2):

Fig. 2: A typical potential divider showing input and output voltages



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

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

Worked Example: Using the above circuit,find the value of V_{out}, given that V_{in} = 12V, R = 6kΩ, R_{out} = 3kΩ.

We can (i) Use the formula:

$$V_{out} = \left(\frac{R_{out}}{R + R_{out}}\right) \times V_{in} = \left(\frac{3000}{6000 + 3000}\right) \times 12 = 4\text{V}$$

Or (ii) use ratios

R_{out} forms $\frac{1}{3}$ of the total resistance $\frac{3000}{9000}$

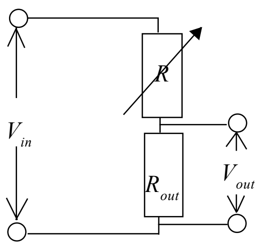
so it will take $\frac{1}{3}$ of the supply voltage.

$V_{out} = \frac{1}{3} \times 12 = 4\text{V}$

More complicated potential dividers use other components in conjunction with fixed resistances.

A variable resistor or rheostat can be used to change the portion of the supply voltage being used. One example is the volume control on a stereo system.

Fig 3: Simplified diagram of the potential divider (volume control)



This time one of the fixed resistors has been replaced with a rheostat. By varying the resistance of *R*, because the voltage drop depends on the resistance, we can change the value of the output signal across R_{out}. If the resistance of the rheostat is increased this increases its total share of the potential difference, this leaves less for R_{out} and its share falls, as their total has to remain equal to the supply. Because V_{out} falls then the volume will also fall.

Typical Exam Question
A potential divider is formed with a rheostat connected in series with a fixed resistor of 4kΩ. Both are connected across a 12V supply. Initially the rheostat is set at 10KΩ.
(a) Calculate the potential difference across R_{out} (V_{out}). [2]
(b) Explain without further calculation what happens to the value of the output signal if the resistance of R is decreased. [2]

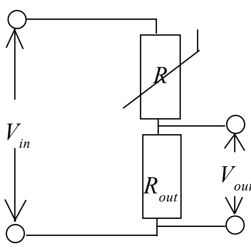
(a) $V_{out} = \left(\frac{R_{out}}{R + R_{out}}\right) \times V_{in} = \left(\frac{4000}{10000 + 4000}\right) \times 12 \checkmark = 3.4V \checkmark$

(b) If R is increased then the voltage across it decreases ✓
This means the voltage across R_{out}, V_{out}, *increases ✓*

There are various other components that can be placed in a potential divider but they all work on the same principle as the simple volume control above. Following are some possible arrangements.

A thermistor is a resisting device made of a semiconductor, as its temperature increases its resistance decreases as more charge carriers are liberated and can form a larger current. A thermistor can be used in a potential divider to provide a device that responds to temperature variation.

Fig 4. A temperature dependent potential divider using a fixed resistor and thermistor.

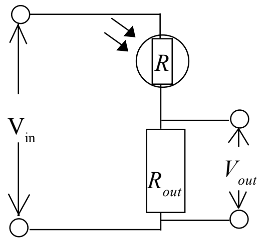


As temperature increases, then the resistance of the thermistor decreases, this in turn lowers the voltage across it. Hence the voltage across R_{out} (V_{out}) increases. If we connect an LED or a buzzer across R_{out} then the rise in temperature could trigger a warning. Alternatively a fan could be triggered to cool the object in question, for example the radiator in a car.

Notice that if we tap the voltage drop across the thermistor itself rather than the fixed resistor then the opposite effect occurs – the colder something is the higher V_{out}; possibly triggering a relay linked to a heater or an LED showing an ice warning in a car.

A light dependent resistor (LDR) as the name suggests has a resistance that varies with light intensity. As the intensity of light falling on it increases its resistance decreases as more energy is supplied, enabling more charge carriers to be released and form a larger current.

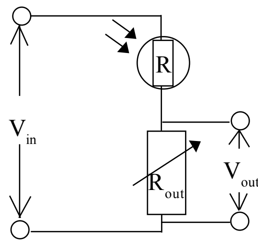
Fig 5: A light sensitive potential divider using a LDR and a resistor



In the LDR circuit above, as the light levels increase then the resistance of the LDR decreases and so does the potential difference across it. V_{out} would increase and could trigger a light sensitive alarm in a safe, for example. As before with the thermistor, if we swap V_{out} so it is across the LDR then as light levels fall our output voltage would increase, possibly triggering a nightlight.

It is important to realise that the above circuits are simplified versions of the circuits used in applications discussed. Often the output voltage is connected across a transistor or relay rather then the output device directly, this allows it to trigger a definite switch on rather than a gradual increase in voltage and allows a larger current to supply the component. One alteration that can be made is using a rheostat in series with an LDR or Thermistor, as show below.

Fig. 6: Use of a rheostat to change sensitivity of potential divider



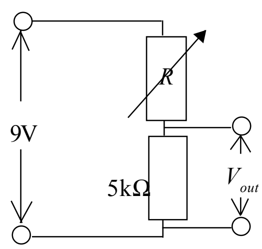
If the rheostat's resistance is decreased then more voltage will drop across the LDR at a given light intensity, this increases the light intensity needed to give the same value of V_{out} across R_{out}. In this way circuits can be fine tuned to respond in the desired way.

Practice questions

1. A potential divider is used to detect changes in temperature using a thermistor with a resistance that varies between 1000Ω and 20000Ω.
   (a) Apart from some form of power supply what other component is required?
   (b) Suggest a reasonable resistance for it to be set to.

2. An LDR varies between 500Ω and 12kΩ according to the level of light intensity on it. If it is used in a potential divider in conjunction with 15V power supply and 2.0kΩ fixed resistor calculate the range of voltages that can be tapped off across the fixed resisitor.

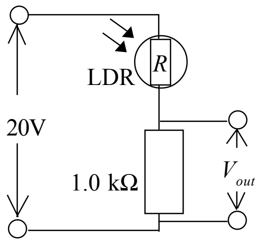
3. A variable resistor is used in a potential divider as shown below.



R is set at 7kΩ.
(a) Find the reading on a voltmeter used to measure V_{out}.
(b) If the value of R is doubled what is the reading on V_{out} now?

Exam Workshop
This is a typical poor student's answer to an exam question. The comments explain what is wrong with the answers and how they can be improved. The examiner's mark scheme is given below.

The following question relates to the potential divider shown below.



The LDR is exposed to a reasonably high level of light intensity. The reading on a voltmeter attached across the terminals labelled V_{out} is 10V.

(a) What is the resistance of the LDR at this intensity? [1]
1kΩ ✓ 1/1

> The student has correctly realised that for the two resistances to share the supply p.d. equally they must have the same resistance.

(b) (i) Find the reading on the meter when the LDR has a resistance of 0.7KΩ. [2]

$$V_{out} = \left(\frac{R_{out}}{R + R_{out}}\right) \times V_{in} = \left(\frac{0.7}{1.0 + 0.7}\right) \times 20 = 8.2V \qquad 0/2$$

> The student has mixed up the two resistances using the LDR resistance in place of the fixed resistance. Student has also forgotten that resistances are quoted in kΩ; although they cancel in this particular case it is still good practice to indicate you are aware of this

(ii) What is the voltage drop across the LDR at this intensity?[1]
20 – 8.23 = 11.8V ✓ ecf 1/1

> the correct technique has been used but the wrong answer is obtained due to the error in (b) (i). This has already been penalised so student gains an error carried forwards mark.

(c) The light intensity is altered and an increase in the value of V_{out} is observed. State and explain whether this represents an increase or decrease in light intensity. [3]

The light intensity has decreased as the voltage through the LDR has decreased because the voltage through the resistor is larger. 0/3

> Voltage is always across and never through. The light intensity must increase to lower its resistance and therefore the voltage drop across it.

Examiner's answers
(a) 1.0kΩ ✓

(b) (i) $V_{out} = \left(\frac{R_{out}}{R + R_{out}}\right) \times V_{in} = \left(\frac{1k}{0.7k + 1k}\right) \times 20$ ✓ $= 11.76V$ ✓

(ii) 20 – 11.76 = 8.24V ✓

(c) The light intensity increases ✓
because the voltage across the LDR must fall ✓
so its resistance must fall, for V_{out} to increase ✓

Answers
1. (a) Fixed resistor, rheostat/variable resistor
   (b) 5kΩ – 10kΩ – must give a reasonable variation between max and min thermistor resistance

2. Greatest V_{out} when LDR resistance is lowest.

$$V_{out} = \left(\frac{R_{out}}{R + R_{out}}\right) \times V_{in} = \left(\frac{2000}{500 + 2000}\right) \times 15 = 12V.$$

Lowest when LDR resistance is highest.

$$V_{out} = \left(\frac{R_{out}}{R + R_{out}}\right) \times V_{in} = \left(\frac{2000}{12000 + 2000}\right) \times 15 = 2.1V$$

Range is 2.1V – 12V.

3. (a) $V_{out} = \left(\frac{R_{out}}{R + R_{out}}\right) \times V_{in} = \left(\frac{5k}{7k + 5k}\right) \times 9 = 3.75V$

   (b) $V_{out} = \left(\frac{R_{out}}{R + R_{out}}\right) \times V_{in} = \left(\frac{5k}{14k + 5k}\right) \times 9 = 2.4V$

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