Chapter 8

8 ELECTRICAL RESISTANCE

In this chapter you will learn what resistance is and how it can be useful in electrical appliances. You will learn what factors affect resistance and how to work out the resistance of a component by measuring the current in it and the voltage across it (Ohm's law). You will also read about some special resistors, and their uses.

It is likely that almost every day of your life you will make some adjustments to at least one electrical appliance. You may turn up the volume of your radio or change the brightness of a light. In each of these examples your adjustments are changing the currents and the voltages in the circuits of your appliance. You are doing this by altering the resistance of the circuits. This chapter will help you understand the meaning and importance of resistance and how we make use of it.

▲ Figure 8.1 Turning this dial alters the resistance in the circuit which changes the volume of the sound.

LEARNING OBJECTIVES

- Understand how the current in a series circuit depends on the applied voltage and the number and nature of other components
- Describe how current varies with voltage in wires, resistors, metal filament lamps and diodes, and how to investigate this experimentally
- Describe the qualitative effect of changing resistance on the current in a circuit
- Describe the qualitative variation of resistance of light-dependent resistors (LDRs) with illumination and thermistors with temperature
- Calculate the currents, voltages and resistances of two resistive components connected in a series circuit

RESISTANCE

All components in a circuit offer some resistance to the flow of charge. Some (for example, connecting wires) allow charges to pass through very easily losing very little of their energy. We describe connecting wires as having very low resistance. The flow of charge through some components is not so easy and a large amount of energy may be used to move the charges through them. This energy is transferred, usually as heat. Components like these are said to have a high resistance.

REMINDER

We normally assume that connecting wires have zero resistance.

We measure the resistance (R) of a component by comparing the size of the current (I) in that component and the voltage (V) applied across its ends. Voltage, current and resistance are related as follows:

voltage, V (volts) = current, I (amps) × resistance, R (ohms)

$$V = I \times R$$

We measure resistance in units called ohms (Ω).

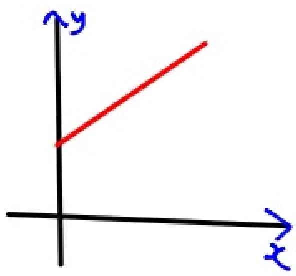
$V = I \times R$

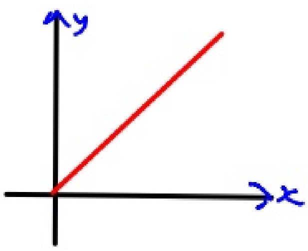
$V = R \times I$

$y = m \times x + c$ → linear (straight line equation)

$y = mx$ ⟶ directly prop. equation

$\frac{y}{x} = m$





HINT

If an examination question asks you to write out the equation for calculating resistance, current or voltage, always give the actual equation such as $V = I \times R$. You may not get the mark if you just draw the triangle.

$V = I \times R$

$R = \frac{V}{I}$

EXAMPLE 1

When a voltage of 12 V is applied across a doorbell there is a current of 0.1 A. Calculate the resistance of the doorbell.

$V = I \times R$

Rearrange the equation.

$$R = \frac{V}{I} = \frac{12\,V}{0.1\,A} = 120\,\Omega$$

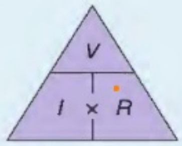


Figure 8.2 You can use the triangle method for rearranging equations like $V = I \times R$.

If there are two or more resistors connected in series in a circuit, their total resistance is found by simply adding the individual resistances together. (This is not true for parallel circuits. You do not need to know how to do this.)

EXAMPLE 2

The circuit on the right contains a 12 V battery and two resistors connected in series.

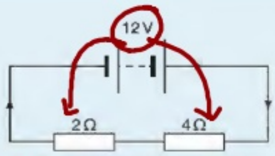


Figure 8.3 Two resistor series circuit

$R_T = 2 + 4 = 6\,\Omega$

$I = \frac{V}{R} = \frac{12}{6\,\Omega} \Rightarrow I = 2A$

the less the resistor, the lower p.d it has

Calculate

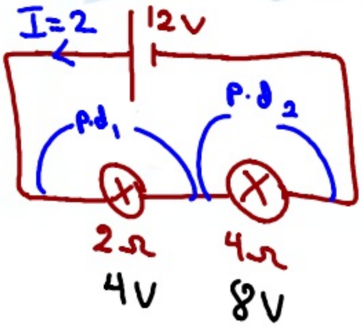
a the current in each of the resistors

b the voltage across each resistor.

a The total resistance the current must pass through is $2\,\Omega + 4\,\Omega = 6\,\Omega$

The current in the circuit (I) is therefore:

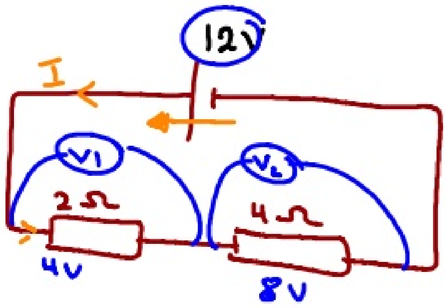
$$I = \frac{V}{R} = \frac{12\,V}{6\,\Omega} = 2\,A$$



p.d: potential difference

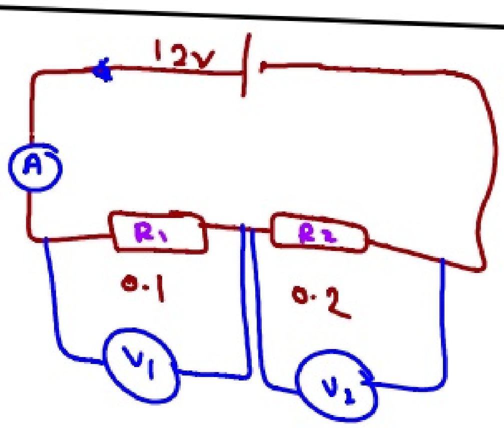
amount of energy used by each unit charge to pass through component

$V = \frac{E}{Q}$



e.m.f = 12 V → energy supplied by each unit charge to flow through the whole circuit.

$$e.m.f = \frac{E}{Q}$$



Calculate reading of (A) [current in R_1 = = R_2]
= = (V1)
= = (V2)

$$I = \frac{V_T}{R_T}$$

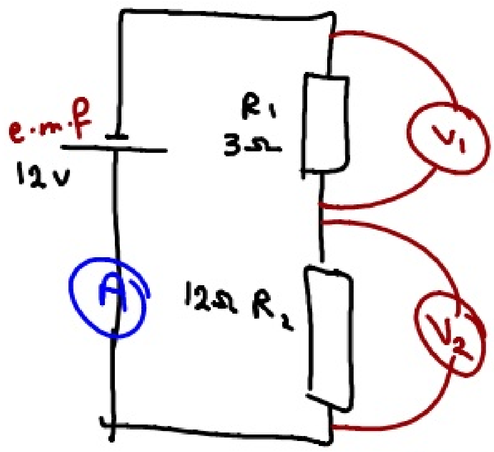
$$\frac{12}{0.3} = 40\,A$$

$V_1 = I \times R_1$
$40 \times 0.1 = 4\,V$

$V_2 = 40 \times 0.2 = 8V$

$40 \times 0.1 = 4V$ + $= 12V$

$V_2 = 40 \times 0.2 = 8V$



reading of (A) $I = \frac{V}{R_T}$
(V1)
(V2)

$$I = \frac{V_T}{R_T} = \frac{12}{15} \quad I = 0.8$$

$V_1 = IR_1$
$V_1 = 0.8 \times 3 = 2.4$
$V_2 = IR_2$
$= 0.8 \times 12$
$= 9.6V$

EXPERIMENT TO INVESTIGATE HOW CURRENT VARIES WITH VOLTAGE FOR DIFFERENT COMPONENTS

> ⚠ The resistance wire in the circuit may get hot enough to burn skin if the current/voltage is increased too much.

1 Set up the circuit shown in Figure 8.4.

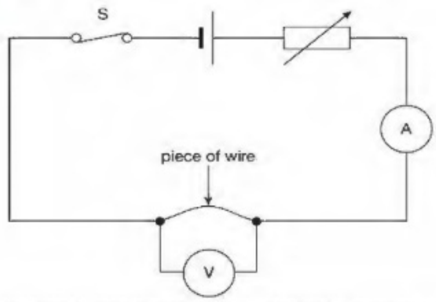
2 Turn the variable resistor to its maximum value.

3 Close the switch and take the readings from the ammeter and the voltmeter.

4 Alter the value of the variable resistor again and take a new pair of readings from the meters.

5 Repeat the whole process at least six times.

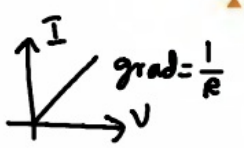
6 Place the results in a table (see the table below) and draw a graph of current (*I*) against voltage (*V*).

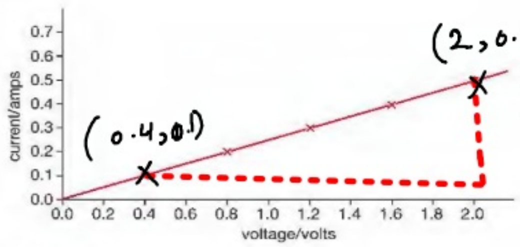


▲ Figure 8.4 This circuit can be used to investigate the relationship between current and voltage.

Current/amps	Voltage/volts
0.0	0.0
0.1	0.4
0.2	0.8
0.3	1.2
0.4	1.6
0.5	2.0

▲ Typical results table





▲ Figure 8.5 Graph of results

$$\text{grad.} = \frac{\Delta y}{\Delta x} = \frac{0.5 - 0.1}{2 - 0.4}$$

$$\text{grad} = 0.25$$

$$R = \frac{1}{\text{grad.}} = \frac{1}{0.25}$$

$$R = 4\,\Omega$$

because

The graph in Figure 8.5 is a straight line graph passing through the origin. The slope of the graph tells us about the resistance of the wire. The steeper the slope the smaller the resistance of the wire.

If we repeat this experiment for other components, such as a resistor, a filament bulb and a diode, the shapes of the graphs we obtain are often very different to that shown in Figure 8.5. By looking very carefully at these shapes we can see how they behave.

CURRENT/VOLTAGE GRAPH FOR A WIRE OR A RESISTOR

B is steeper

So less R

A is closer to V ⇒ greater R

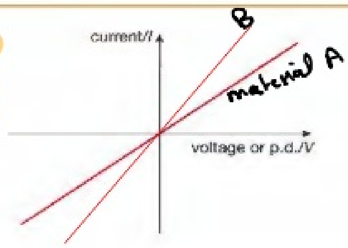


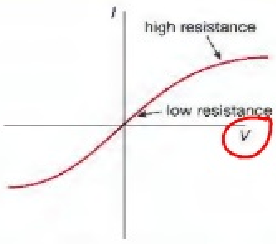
Figure 8.6

The graph is a straight line. It has a constant slope. So the resistance of this component does not change.

CURRENT/VOLTAGE GRAPH FOR A FILAMENT BULB

HINT

The flatter the slope the higher the resistance.

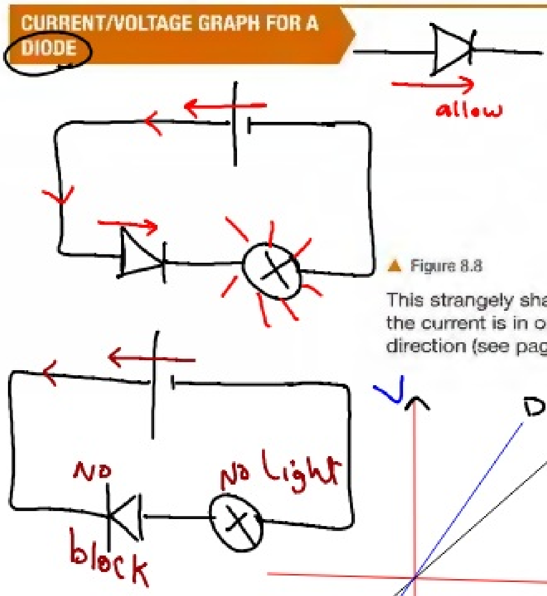


filament

Figure 8.7

This graph is not a straight line. The resistance of the bulb changes. At higher currents and voltages the slope of the graph shows us that the resistance of the filament bulb increases – that is, as the temperature of the filament increases the current decreases.

CURRENT/VOLTAGE GRAPH FOR A DIODE



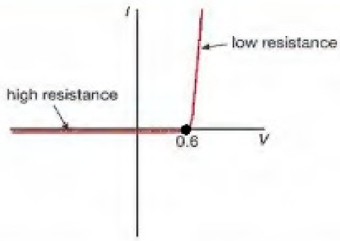
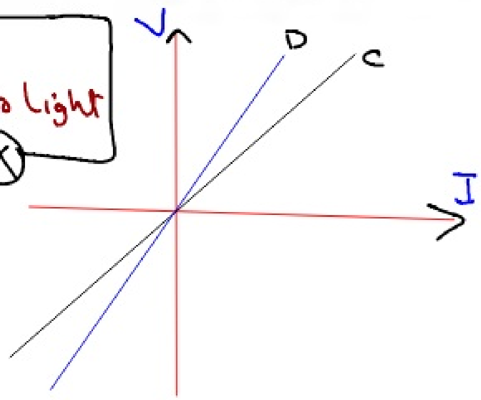


Figure 8.8

This strangely shaped graph shows that diodes have a high resistance when the current is in one direction and a low resistance when it is in the opposite direction (see page 81).



D is steeper

so it has more R

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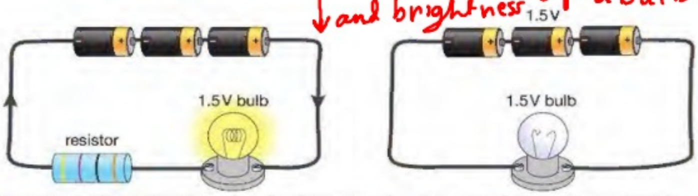
USING RESISTANCE

FIXED RESISTORS

In many circuits you will find components similar to those shown in Figure 8.9. They are called fixed resistors. They are included in circuits in order to control the sizes of currents and voltages. The resistor in the circuit in Figure 8.10 is included so that both the current in the bulb and the voltage applied across it are correct. Without the resistor the voltage across the bulb may cause too large a current and the bulb may 'blow' or break.

and brightness of a bulb

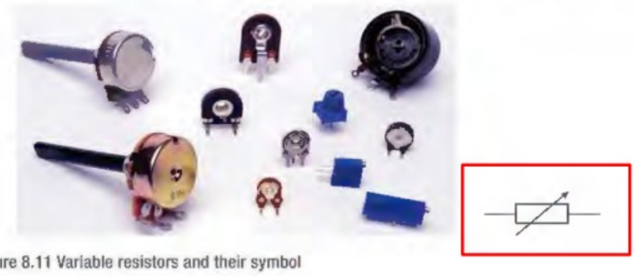
▲ Figure 8.9 A selection of resistors



▲ Figure 8.10 The resistor in the first circuit limits the size of the current. Without the resistor the current in the second circuit is too high and the bulb breaks.

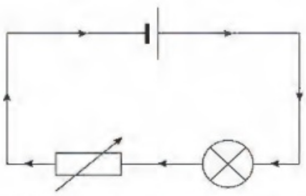
VARIABLE RESISTORS

Figure 8.11 shows examples of a different kind of resistor. They are called variable resistors as it is possible to alter their resistance. If you alter the volume of your radio using a knob you are using a variable resistor to do this.



▲ Figure 8.11 Variable resistors and their symbol

In the circuit in Figure 8.12 a variable resistor is being used to control the size of the current in a bulb. If the resistance is decreased there will be a larger current and the bulb shines more brightly. If the resistance is increased the current will be smaller and the bulb will glow less brightly or not at all. The variable resistor is behaving in this circuit as a **dimmer switch**. In circuits containing electric motors, variable resistors can be used to control the speed of the motor.

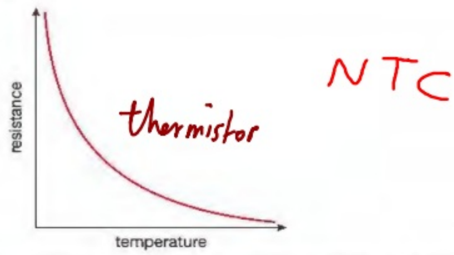


▲ Figure 8.12 Circuit with a variable resistor being used as a dimmer switch

SPECIAL RESISTORS

THERMISTORS

A **thermistor** is a resistor whose resistance changes quite a lot even with small changes in temperature.



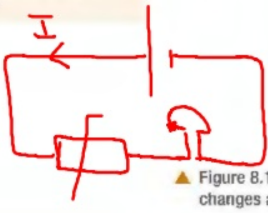
▲ Figure 8.13 A graph showing a thermistor's decreasing resistance with increasing temperature

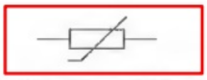
KEY POINT

Some thermistors increase their resistance when the temperature increases. However, for your International GCSE Physics exam you only need to know about thermistors whose resistance decreases with increasing temperature.

Thermistors are used in temperature-sensitive circuits in devices such as fire alarms. They are also used in devices where it is important to make sure there is no change in temperature, for example in freezers and computers.

bell works at 1 A





▲ Figure 8.14 Two examples of thermistors and their symbol – the resistance of a thermistor changes a lot as the temperature changes.

LIGHT-DEPENDENT RESISTORS (LDRs)

A light-dependent resistor (LDR) has a resistance that changes when light is shone on it. In the dark its resistance is high but when light is shone on it its resistance decreases.

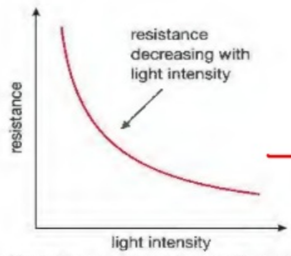
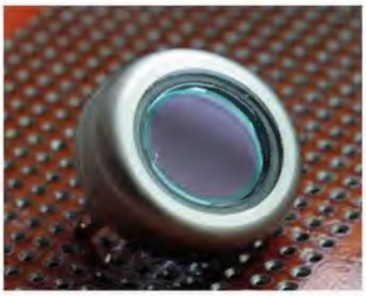


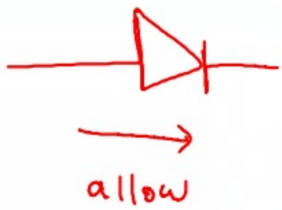
Figure 8.15 A graph showing an LDR's decreasing resistance with increasing light intensity



▲ Figure 8.16 Light-dependent resistor

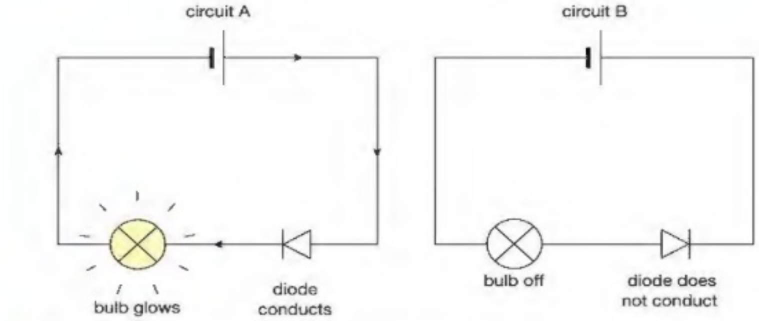
LDRs are often used in light-sensitive circuits in devices such as photographic-exposure equipment, automatic lighting controls and burglar alarms.

DIODES

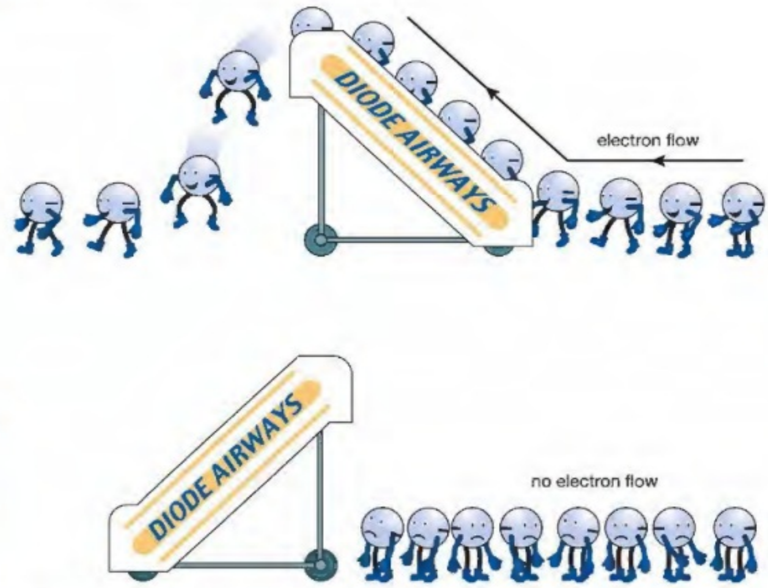


Diodes are very special resistors that allow charges to flow through them easily but only in one direction.

When a diode is connected as shown in circuit A in Figure 8.17, the diode offers little resistance to the charges flowing through it. But if the diode is connected the opposite way round, the diode has a very high resistance and the rate at which the charges can flow through the diode is much less – that is, the current is very small. Diodes are often used in circuits where it is important that electrons flow only in one direction. For example, they are used in **rectifier circuits** that convert alternating current into direct current. Some diodes glow when charges flow through them. They are called **light emitting diodes** (LEDs).



▲ Figure 8.17 Diodes will only let charges flow one way.



▲ Figure 8.18 Diodes are like aeroplane steps – from the ground, you can only climb them in one direction. In a diode the charge can only flow in one direction.

KEY POINT

You can imagine a diode as behaving like a set of aeroplane steps which the charges have to climb over. If the charges are moving towards the correct side of the steps they can 'flow through it'. If, however, they try to move the opposite way there are no steps for them to climb so the flow in this direction is almost zero.

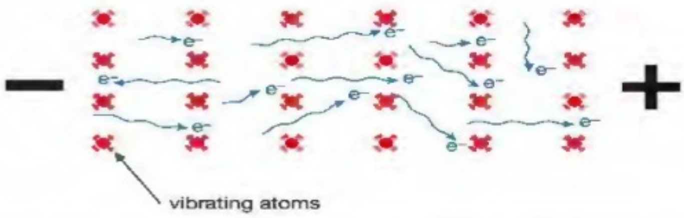
LOOKING AHEAD – OHM'S LAW AND TEMPERATURE

The relationship between the voltage across a component and its current is described by Ohm's law, which states:

The current in a conductor is directly proportional to the potential difference across its ends, provided its temperature remains constant.

So the resistance of a wire can be found by measuring the voltage (V) across it and the current (I) in it when this voltage is applied to the wire and then calculating a value for the **ratio** $\frac{V}{I}$ (see page 75). But the law also states that the temperature of the wire must be constant. This is because if the temperature of the wire changes, its resistance also changes.

This happens because at higher temperatures the atoms in the wire **vibrate** more vigorously, making it more difficult for the electrons to flow.



▲ Figure 8.19 At higher temperatures the increased vibration of the atoms makes it more difficult for charges to flow.

If a wire or conductor is cooled the vibration of its atoms decreases and so its resistance decreases. At very low temperatures, close to absolute zero (−273 °C), these vibrations stop and the conductor offers no resistance to the flow of charge. This event is called superconductivity and could be extremely useful. For example, when electricity flows through a superconductor there is no loss of energy. This means that by using superconductivity we could transmit electrical energy from power stations without losses. Scientists around the world are now searching for materials that are superconductors at temperatures well above absolute zero.

▲ Figure 8.20 Maglev trains use superconducting magnets to help them hover above the tracks.

CHAPTER QUESTIONS

More questions on electrical resistance can be found at the end of Unit 2 on page 93.

SKILLS CRITICAL THINKING

1 a (6) Describe how the current in a wire changes as the voltage across the wire increases.

SKILLS INTERPRETATION

b (7) Draw a diagram of the circuit you would use to confirm your answer to part a.

SKILLS DECISION MAKING

c (6) Describe how you would use the apparatus and what readings you would take.

SKILLS INTERPRETATION

d Draw an *I–V* graph for

i (6) a piece of wire at room temperature

ii a filament bulb

iii (7) a diode.

Explain the main features of each of these graphs.

SKILLS PROBLEM SOLVING

2 a (8) There is a current of 5 A when a voltage of 20 V is applied across a resistor. Calculate the resistance of the resistor.

b Calculate the current when a voltage of 12 V is applied across a piece of wire of resistance 50 Ω.

c (7) Calculate the voltage that must be applied across a wire of resistance 10 Ω if the current is to be 3 A.

SKILLS INTERPRETATION

3 a (6) Describe how the resistance of

i a thermistor changes as its temperature changes

ii a light-dependent resistor changes as an increasingly bright light is shone on it.

iii (7) Draw graphs to illustrate these changes.

SKILLS CRITICAL THINKING

b Name one practical application for each of these resistors.

HINT

Remember when doing calculations like these to show all your working out and include units with your answer.