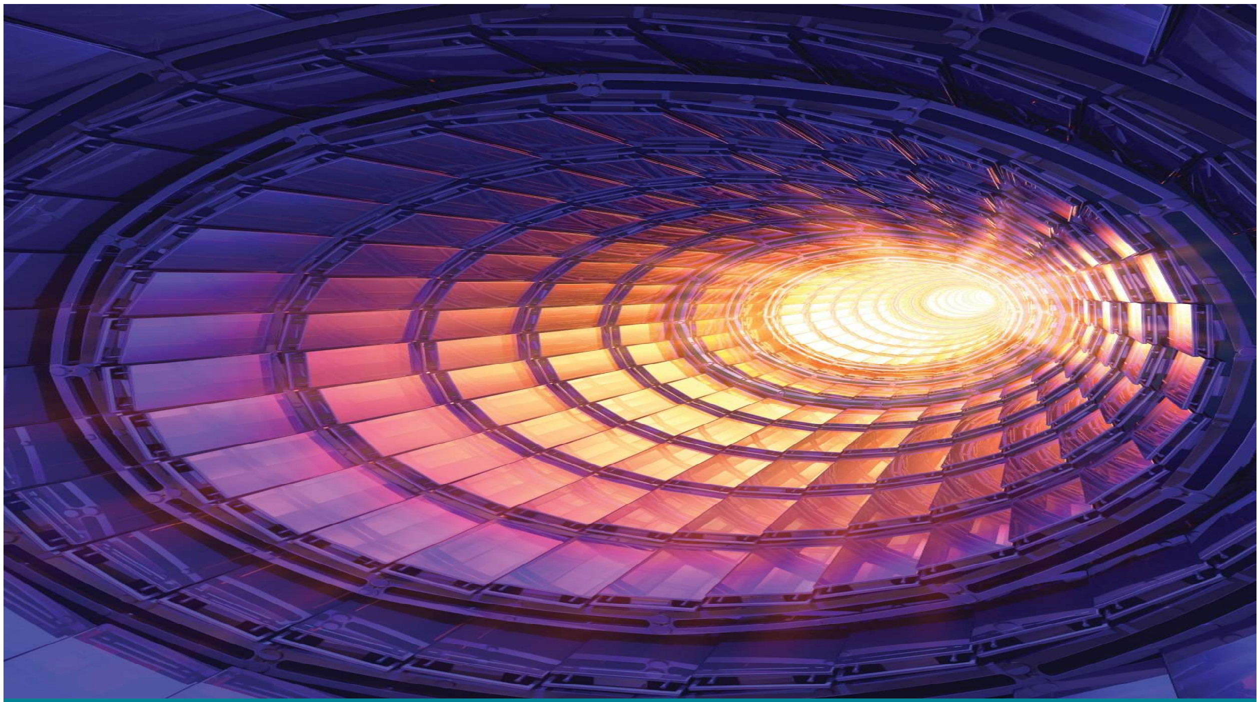

Chapter 10

Resistance and resistivity

LEARNING INTENTIONS

In this chapter you will learn how to:

- state Ohm's law
- sketch and explain the *I*–*V* characteristics for various components
- sketch the temperature characteristic for an NTC thermistor
- solve problems involving the resistivity of a material.

BEFORE YOU START

- Do you understand the terms introduced in Chapters 8 and 9: current, charge, potential difference, e.m.f., resistance and their relationships to one another?
- What are their units?
- Take turns in challenging a partner to define a term or to write down an equation linking different terms. Do not use the textbook or your notes to look up the terms.

SUPERCONDUCTIVITY

As metals are cooled, their resistance decreases. It was discovered as long ago as 1911 that when mercury was cooled using liquid helium to 4.1 K (4.1 degrees above absolute zero), its resistance suddenly fell to zero. This phenomenon was named **superconductivity**. Other metals, such as lead at 7.2 K, also become superconductors.

When charge flows in a superconductor, it can continue in that superconductor without the need for any potential difference and without dissipating any energy. This means that large currents can occur without the unwanted heating effect that would occur in a normal metallic or semiconducting conductor.

Initially, superconductivity was only of scientific interest and had little practical use, as the liquid helium that was required to cool the superconductors is very expensive to produce. In 1986, it was discovered that particular ceramics became superconducting at much higher temperatures – above 77 K, the boiling point of liquid nitrogen. This meant that liquid nitrogen, which is readily available, could be used to cool the superconductors and expensive liquid helium was no longer needed. Consequently, superconductor technology became a feasible proposition.

Uses of superconductors

The JR-Maglev train in Japan's Yamanashi province floats above the track using superconducting magnets (Figure 10.1). This means that not only is the heating effect of the current in the magnet coils reduced to zero – it also means that the friction between the train and the track is eliminated and that the train can reach incredibly high speeds of up to 580 km h^{-1}.

Particle accelerators, such as the Large Hadron Collider (LHC) at the CERN research facility in Switzerland, accelerate beams of charged particles to very high energies by making them orbit around a circular track many times. The particles are kept moving in the circular path by very strong magnetic fields produced by electromagnets whose coils are made from superconductors. Much of our understanding of the fundamental nature of matter is from doing experiments in which beams of these very high speed particles are made to collide with each other.

Figure 10.1: The Japanese JR-Maglev train, capable of speeds approaching 600 km h^{-1}.

Magnetic resonance imaging (MRI) was developed in the 1940s. It is used by doctors to examine internal organs without invasive surgery.

Superconducting magnets can be made much smaller than conventional magnets, and this has enabled the magnetic fields produced to be much more precise, resulting in better imaging.

Imagine you are a scientific consultant for a new science fiction film. You have been instructed to find a use of a superconductor to enable the hero to escape from a villain who is about to destroy the world. What use would you come up with?

10.1 The *I*–*V* characteristic for a metallic conductor

In Chapter 8, we saw how we could measure the resistance of a resistor using a voltmeter and ammeter. In this topic we are going to investigate the variation of the current – and, therefore, resistance – as the potential difference across a conductor changes.

The potential difference across a metal conductor can be altered using a variable power supply or by placing a variable resistor in series with the conductor. This allows us to measure the current at different potential differences across the conductor. The results of such a series of measurements are shown graphically in Figure 10.2.

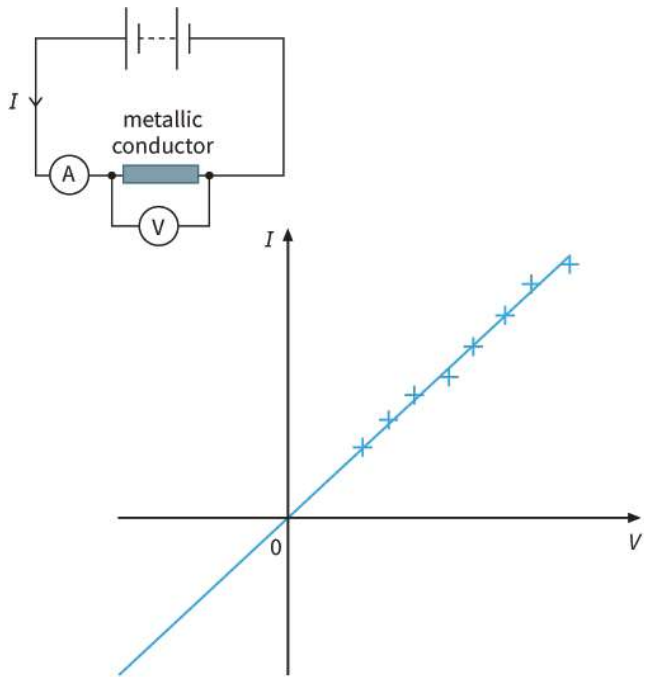

Figure 10.2: To determine the resistance of a component, you need to measure both current and potential difference.

Look at the graph of Figure 10.2. Such a graph is known as an **I–V characteristic**. The points are slightly scattered, but they clearly lie on a straight line. A line of best fit has been drawn. You will see that it passes through the origin of the graph. In other words, the current *I* is directly proportional to the voltage *V*.

The straight-line graph passing through the origin shows that the resistance of the conductor remains constant. If you double the current, the voltage will also double. However, its resistance, which is the ratio of the voltage to the current, remains the same. Instead of using:

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

to determine the resistance, for a graph of *I* against *V* that is a straight line passing through the origin, you can also use:

$$\text{resistance} = \frac{1}{\text{gradient of graph}}$$

(This will give a more accurate value for *R* than if you were to take a single experimental data point. Take care! You can only find resistance from the gradient if the *I*–*V* graph is a straight line through the origin.)

By reversing the connections to the resistor, the p.d. across it will be reversed (in other words, it becomes negative). The current will be in the opposite direction – it is also negative. The graph is symmetrical, showing that if a p.d. of, say, 2.0 V produces a current of 0.5 A, then a p.d. of −2.0 V will produce a current of −0.5 A. This is true for most simple metallic conductors but is not true for some electronic components, such as diodes.

You get results similar to those shown in Figure 10.2 for a commercial **resistor**. Resistors have different resistances, so the gradient of the *I*–*V* graph will be different for different resistors.

Question

1 Table 10.1 shows the results of an experiment to measure the resistance of a carbon resistor whose resistance is given by the manufacturer as 47 Ω ± 10%.

a Plot a graph to show the *I*–*V* characteristic of this resistor.

b Do the points appear to fall on a straight line that passes through the origin of the graph?

c Use the graph to determine the resistance of the resistor.

d Does the value of the resistance fall within the range given by the manufacturer?

Potential difference / V	Current / A
2.1	0.040
4.0	0.079
6.3	0.128
7.9	0.192
10.0	0.202
12.1	0.250

Table 10.1: Potential difference V and current I

10.2 Ohm's law

For the metallic conductor whose I–V characteristic is shown in Figure 10.2, the current in it is directly proportional to the p.d. across it. This means that its resistance is independent of both the current and the p.d.

This is because the ratio $\frac{V}{I}$ is a constant. Any component that behaves like this is described as an **ohmic** component, and we say that it obeys **Ohm's law**. The statement of Ohm's law is very precise and you must not confuse this with the equation $\frac{V}{I} = R$.

A conductor obeys Ohm's law if the current in it is directly proportional to the potential difference across its ends.

Question

2 An electrical component allows a current of 10 mA through it when a voltage of 2.0 V is applied. When the voltage is increased to 8.0 V, the current becomes 60 mA. Does the component obey Ohm's law? Give numerical values for the resistance to justify your answer.

10.3 Resistance and temperature

A conductor that does not obey Ohm's law is described as **non-ohmic**. An example is a filament lamp. Figure 10.3 shows such a lamp; you can clearly see the wire filament glowing as the current passes through it. Figure 10.4 shows the I–V characteristic for a similar lamp.

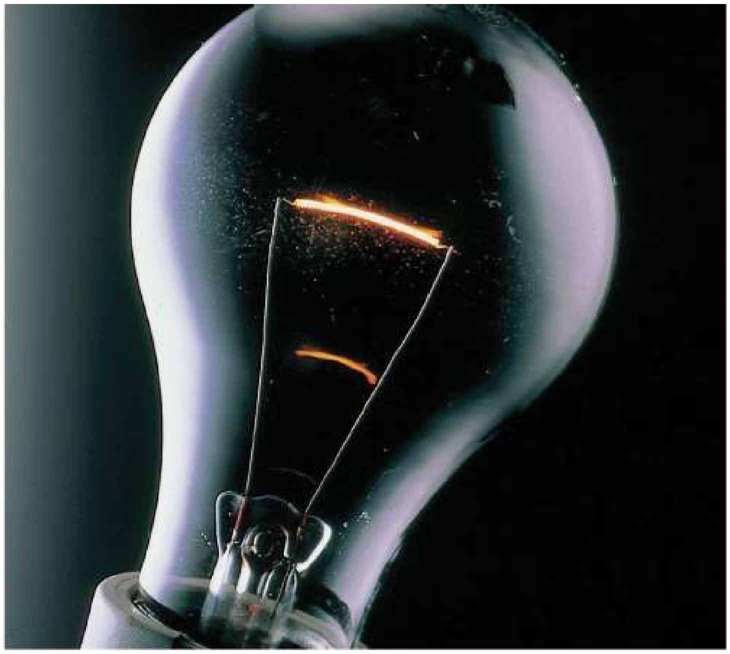

Figure 10.3: The metal filament in a lamp glows as the current passes through it. It also feels warm. This shows that the lamp produces both heat and light.

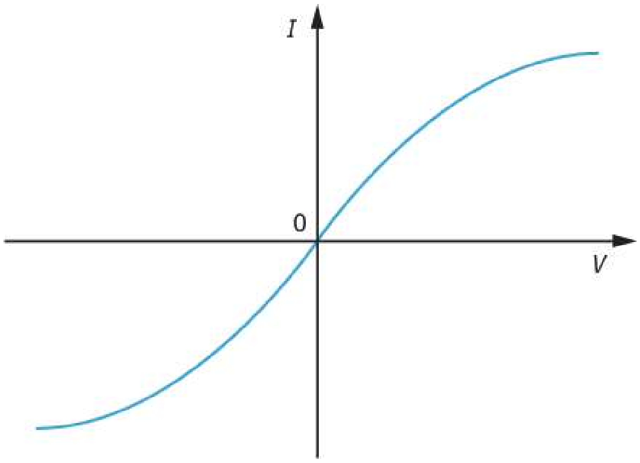

Figure 10.4: The I–V characteristic for a filament lamp.

There are some points you should notice about the graph in Figure 10.4:

- The line passes through the origin (as for an ohmic component).
- For very small currents and voltages, the graph is roughly a straight line.
- At higher voltages, the line starts to curve. The current is a bit less than we would have expected from a straight line. This suggests that the lamp's resistance has increased. You can also tell that the resistance has increased because the ratio $\frac{V}{I}$ is larger for higher voltages than for low voltages.

The graph of Figure 10.4 is not a straight line–this shows that the resistance of the lamp depends on the temperature of its filament. Its resistance may increase by a factor as large as ten between when it is cold and when it is brightest (when its temperature may be as high as 1750 °C).

Thermistors

Thermistors are components that are designed to have a resistance that changes rapidly with temperature. Thermistors ('**thermal** res**istors**') are made from metal oxides such as those of manganese and nickel.

There are two different types of thermistor:

- Negative temperature coefficient **(NTC) thermistors** – the resistance of this type of thermistor decreases with increasing temperature. Those commonly used for physics teaching may have a resistance of many thousands of ohms at room temperature, falling to a few tens of ohms at 100 °C. You should become familiar with the properties of NTC thermistors.
- Positive temperature coefficient (PTC) thermistors–the resistance of this type of thermistor rises abruptly at a definite temperature, usually around 100–150 °C.

In this course, you only need to know about NTC thermistors. So, whenever thermistors are mentioned, assume that it refers to an NTC thermistor.

The change in their resistance with temperature gives thermistors many uses. Examples include:

- water temperature sensors in cars and ice sensors on aircraft wings – if ice builds up on the wings, the thermistor 'senses' this temperature drop and a small heater is activated to melt the ice
- baby breathing monitors–the baby rests on an air-filled pad, and as he or she breathes, air from the pad passes over a thermistor, keeping it cool; if the baby stops breathing, the air movement stops, the thermistor warms up and an alarm sounds
- fire sensors – a rise in temperature activates an alarm
- overload protection in electric razor sockets – if the razor overheats, the thermistor's resistance decreases, the current increases rapidly and cuts off the circuit.

Questions

3 The two graphs in Figure 10.5 show the I–V characteristics of a metal wire at two different temperatures, θ_1 and θ_2.

a Calculate the resistance of the wire at each temperature.

b State which is the higher temperature, θ_1 or θ_2.

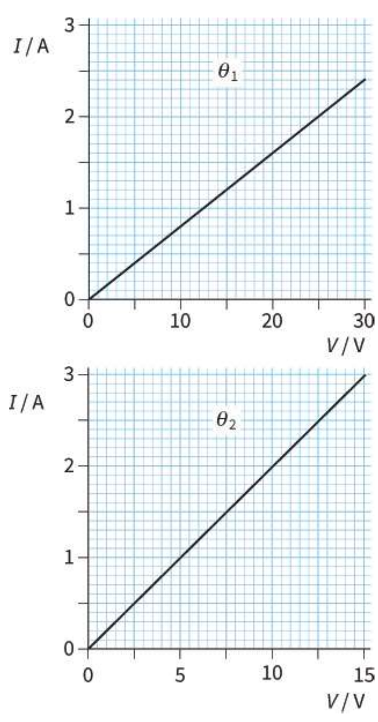

Figure 10.5: I–V graphs for a wire at two different temperatures. For Question 3.

4 The graph in Figure 10.6 shows the I–V characteristics of two electrical components, a filament lamp and a length of steel wire.

a Identify which curve relates to each component.

b State the voltage at which both have the same resistance.

c Determine the resistance at the voltage stated in part **b**.

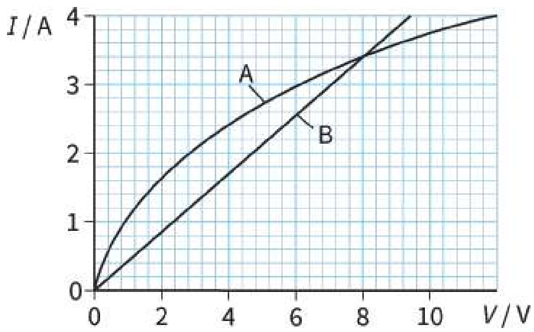

Figure 10.6: For Question 4.

Diodes

The semiconductor diode is another example of a non-ohmic conductor. A diode is any component that allows electric current in only one direction. Most diodes are made of semiconductor materials. One type, the light-emitting diode or LED, gives out light when it conducts.

Figure 10.7 shows the *I*–*V* characteristic for a diode. There are some points you should notice about this graph.

- We have included positive and negative values of current and voltage. This is because, when connected one way round, forward-biased, the diode conducts and has a fairly low resistance. Connected the other way round, reverse-biased, it allows only a tiny current and has almost infinite resistance.
- For positive voltages less than about 0.6 V, the current is almost zero and hence the diode has almost infinite resistance. It starts to conduct suddenly at its **threshold voltage**. The resistance of the diode decreases dramatically for voltages greater than 0.6 V.

KEY IDEA

Most modern diodes are made from silicon and will start conducting when there is a potential difference of about 0.6 V across them. You need to remember this key 0.6 V value.

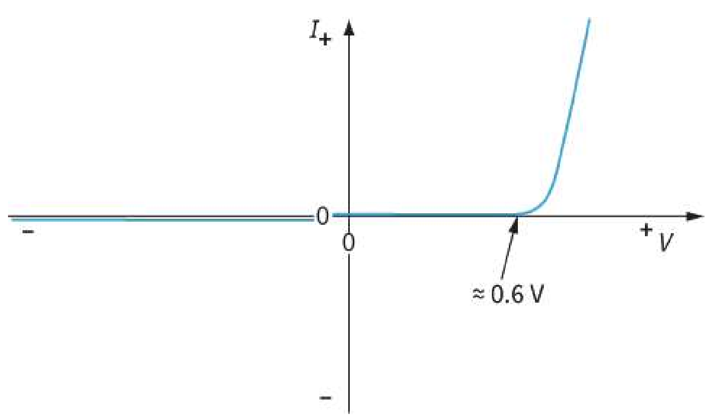

Figure 10.7: The current against potential difference (*I*–*V*) characteristic for a diode. The graph is not a straight line. A diode does not obey Ohm's law.

The resistance of a diode depends on the potential difference across it. From this we can conclude that it does not obey Ohm's law; it is a non-ohmic component.

Diodes are used as rectifiers. They allow current to pass in one direction only and so can be used to convert alternating current into direct current. (There is more about this in Chapter 27.) Most modern diodes are made from silicon and will start conducting when there is a potential difference of about 0.6 V across them. You need to remember this key 0.6 V value.

LEDs have traditionally been used as indicator lamps to show when an appliance is switched on. Newer versions, some of which produce white light, are replacing filament lamps, for example, in traffic lights and torches (flashlights) – see Figure 10.8. Although they are more expensive to manufacture, they are more energy-efficient and hence cheaper to run, so that the overall cost is less.

The threshold voltage at which an LED starts to conduct and emit light is higher than 0.6 V and depends on the colour of light it emits, but may be taken to be about 2 V.

Figure 10.8: This torch has seven white LEDs, giving a brighter, whiter light than a traditional filament lamp.

Questions

5 The graph in Figure 10.9 was obtained by measuring the resistance R of a particular thermistor as its temperature θ changed.

a Determine its resistance at:

i 20 °C

ii 45 °C.

b Determine the temperature when its resistance is:

i 5000 Ω

ii 2000 Ω.

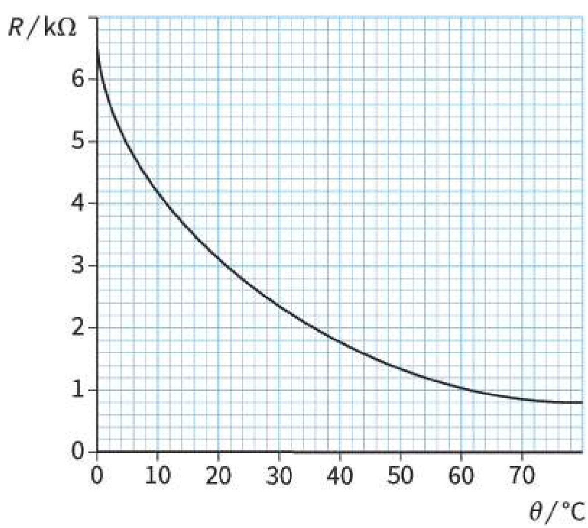

Figure 10.9: The resistance of an NTC thermistor decreases as the temperature increases. For Question 5.

6 A student connects a circuit with an NTC thermistor, a filament lamp and a battery in series. The lamp glows dimly. The student warms the thermistor with a hair dryer. What change will the student notice in the brightness of the lamp? Explain your answer.

The light-dependent resistor (LDR)

A **light-dependent resistor (LDR)** is made of a high-resistance semiconductor. If light falling on the LDR is of a high enough frequency, photons are absorbed by the semiconductor. As some photons are absorbed, electrons are released from atoms in the semiconductor. The resulting free electrons conduct electricity and the resistance of the semiconductor is reduced.

The graph in Figure 10.10 shows the variation of the resistance of a typical LDR with light intensity. Only a narrow range of light intensity, measured in lux, is shown. A typical LDR will have a resistance of a few hundred ohms in sunlight, but in the dark its resistance will be millions of ohms.

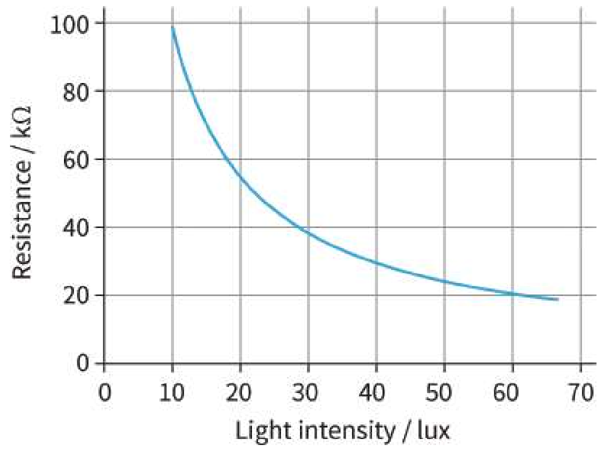

Figure 10.10: Resistance plotted against light intensity for an LDR.

Understanding the origin of resistance

To understand a little more about the origins of resistance, it is helpful to look at how the resistance of a pure metal wire changes as its temperature is increased. This is shown in the graph in Figure 10.11. You will see that the resistance of the pure metal increases linearly as the temperature increases from 0 °C to 100 °C. Compare this with the graph in Figure 10.9 for an NTC thermistor; the thermistor's resistance decreases very dramatically over a narrow temperature range.

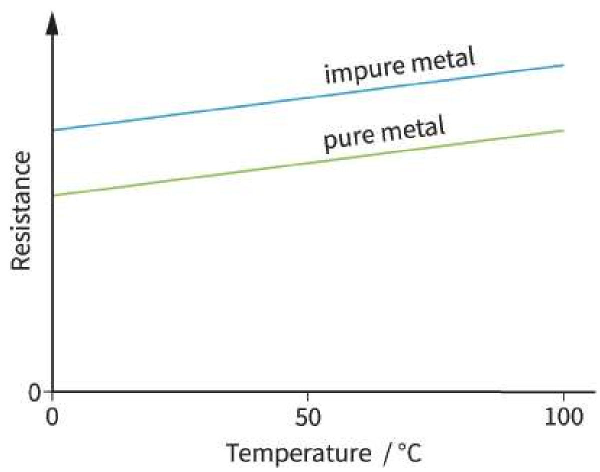

Figure 10.11: The resistance of a metal increases gradually as its temperature is increased. The resistance of an impure metal wire is greater than that of a pure metal wire of the same dimensions.

Figure 10.11 also shows how the resistance of the metal changes if it is slightly impure. The resistance of an impure metal is greater than that of the pure metal and follows the same gradual upward slope. The resistance of a metal changes in this gradual way over a wide range of temperatures–from close to absolute zero up to its melting point, which may be over 2000 °C.

This suggests there are two factors that affect the resistance of a metal:

- the temperature
- the presence of impurities.

Figure 10.12 shows a simple model that explains what happens in a metal when electrons flow through it.

In a metal, a current is due to the movement of free electrons. At low temperatures, they can move easily past the positive ions (Figure 10.12a). However, as the temperature is raised, the ions vibrate with larger amplitudes. The electrons collide more frequently with the vibrating ions, and this decreases their mean drift velocity. They lose energy to the vibrating ions (Figure 10.12b).

If the metal contains impurities, some of the atoms will be of different sizes (Figure 10.12c). Again, this disrupts the free flow of electrons. In colliding with impurity atoms, the electrons lose energy to the vibrating atoms.

You can see that electrons tend to lose energy when they collide with vibrating ions or impurity atoms. They give up energy to the metal, so it gets hotter. The resistance of the metal increases with the temperature of the wire because of the decrease in the mean drift velocity of the electrons.

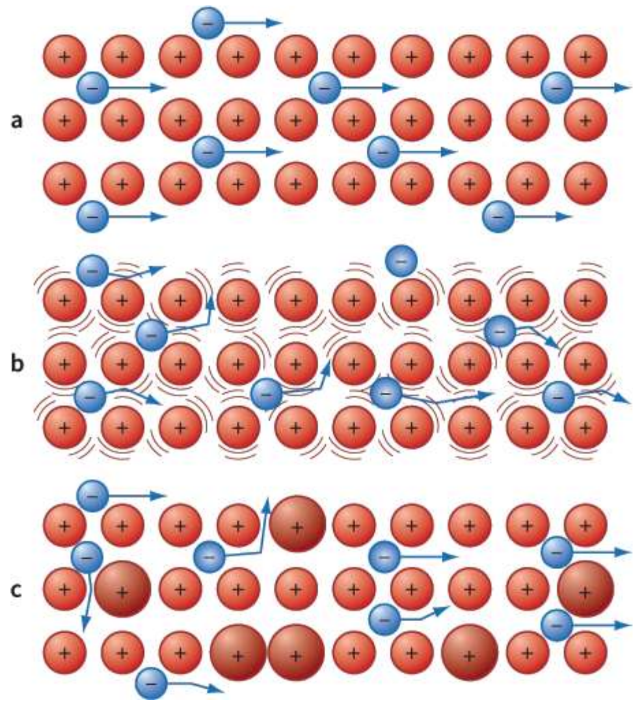

Figure 10.12: A model of the origins of resistance in a metal. **a:** At low temperatures, electrons flow relatively freely. **b:** At higher temperatures, the electrons are obstructed by the vibrating ions and they make very frequent collisions with the ions. **c:** Impurity atoms can also obstruct the free flow of electrons.

Conduction in semiconductors is different. At low temperatures, there are few **delocalised**, or free, electrons. For conduction to occur, electrons must have sufficient energy to free themselves from the atom they are bound to. As the temperature increases, a few electrons gain enough energy to break free of their atoms to become conduction electrons. The number of conduction electrons thus increases and so the material becomes a better conductor. At the same time, there are more electron–ion collisions, but this effect is small compared with the increase in the number of conduction electrons.

Question

7 The resistance of a metal wire changes with temperature. This means that a wire could be used to sense changes in temperature, in the same way that a thermistor is used.

- **a** Suggest **one** advantage a thermistor has over a metal wire for this purpose.
- **b** Suggest **one** advantage a metal wire has over a thermistor.

10.4 Resistivity

The resistance of a particular wire depends on its size and shape. A long wire has a greater resistance than a short one, provided it is of the same thickness and material. A thick wire has less resistance than a thin one. For a metal in the shape of a wire, R depends on the following factors:

- length L
- cross-sectional area A
- the material the wire is made from
- the temperature of the wire.

At a constant temperature, the resistance is directly proportional to the length of the wire and inversely proportional to its cross-sectional area:

$$\text{resistance} \propto \text{length}$$

and

$$\text{resistance} \propto \frac{1}{\text{cross-sectional area}}$$

We can see how these relate to the formulae for adding resistors in series and in parallel:

- If we double the length of a wire it is like connecting two identical resistors in series; their resistances add to give double the resistance. The resistance is proportional to the length.
- Doubling the cross-sectional area of a wire is like connecting two identical resistors in parallel; their combined resistance is halved (since $\frac{1}{R_{\text{total}}} = \frac{1}{R} + \frac{1}{R}$).

  Hence the resistance is inversely proportional to the cross-sectional area.

Combining the two proportionalities for length and cross-sectional area, we get:

$$\text{resistance} \propto \frac{1}{\text{cross-sectional area}}$$

or

$$R \propto \frac{L}{A}$$

But the resistance of a wire also depends on the material it is made of. Copper is a better conductor than steel, steel is a better conductor than silicon, and so on. So if we are to determine the resistance R of a particular wire, we need to take into account its length, its cross-sectional area and the material. The relevant property of the material is its **resistivity**, for which the symbol is ρ (Greek letter **rho**).

The word equation for resistance is:

$$\text{resistance} = \frac{\text{resistivity} \times \text{length}}{\text{cross-sectional area}}$$

$$R = \frac{\rho L}{A}$$

KEY EQUATION

$$\text{resistance} = \frac{\text{resistivity} \times \text{length}}{\text{cross-sectional area}}$$

$$R = \frac{\rho L}{A}$$

We can rearrange this equation to give an equation for resistivity. The resistivity of a material is defined by the following word equation:

$$\text{resitivity} = \frac{\text{resistance} \times \text{cross-sectional area}}{\text{length}}$$

$$\rho = \frac{RA}{L}$$

KEY EQUATION

$$\text{resitivity} = \frac{\text{resistance} \times \text{cross-sectional area}}{\text{length}}$$
$$\rho = \frac{RA}{L}$$

Values of the resistivities of some typical materials are shown in Table 10.2. Notice that the units of resistivity are ohm metres (Ω m); this is not the same as ohms per metre.

Material	**Resistivity / Ω m**
silver	1.60×10^{-8}
copper	1.69×10^{-8}
nichrome[(a)]	1.30×10^{-8}
aluminium	3.21×10^{-8}
lead	20.8×10^{-8}
manganin[(b)]	44.0×10^{-8}
eureka[(c)]	49.0×10^{-8}
mercury	69.0×10^{-8}
graphite	800×10^{-8}
germanium	0.65
silicon	2.3×10^{3}
Pyrex glass	10^{12}
PTFE[(d)]	10^{13}–10^{16}
quartz	5×10^{16}

[(a)] Nichrome – an alloy of nickel, copper and aluminium used in electric heaters because it does not oxidise at 1000 °C.

[(b)] Manganin – an alloy of 84% copper, 12% manganese and 4% nickel.

[(c)] Eureka (constantan) – an alloy of 60% copper and 40% nickel.

[(d)] PTFE – Poly(tetrafluoroethene) or Teflon.

Table 10.2: Resistivities of various materials at 20 °C.

WORKED EXAMPLE

1 Find the resistance of a 2.6 m length of eureka wire with cross-sectional area 2.5×10^{-7} m^2.

Step 1 Use the equation for resistance:

$$\text{resistance} = \frac{\text{resistivity} \times \text{length}}{\text{cross-sectional area}}$$
$$R = \frac{\rho L}{A}$$

Step 2 Substitute values from the question and use the value for ρ from Table 10.2:

$$R = \frac{49.0 \times 10^{-8} \times 2.6}{2.5 \times 10^{-7}}$$
$$= 5.1 \Omega$$

So the wire has a resistance of 5.1 Ω.

Resistivity and temperature

Resistivity, like resistance, depends on temperature. For a metal, resistivity increases with temperature. As we saw earlier, this is because there are more frequent collisions between the conduction electrons and the vibrating ions of the metal.

Questions

8 Use the resistivity value quoted in Table 10.2 to calculate the lengths of 0.50 mm diameter manganin wire needed to make resistance coils with resistances of:

a 1.0 Ω

b 5.0 Ω

c 10 Ω.

9 1.0 cm^3 of copper is drawn out into the form of a long wire of cross-sectional area 4.0×10^{-7} m^2. Calculate its resistance. (Use the resistivity value for copper from Table 10.2.)

10 A 1.0 m length of copper wire has a resistance of 0.50 Ω.

a Calculate the resistance of a 5.0 m length of the same wire.

b What will be the resistance of a 1.0 m length of copper wire having half the diameter of the original wire?

11 A piece of steel wire has a resistance of 10 Ω. It is stretched to twice its original length. Compare its new resistance with its original resistance.

REFLECTION

Imagine you are helping a younger cousin who is studying for her IGCSE (or similar course). She finds it difficult to understand why the resistivity does not change when the dimensions of a sample are changed, but resistance does.

Think about how you might help her understand.

Now that it is completed, what are your first thoughts about this activity? Are they mostly positive or negative?

SUMMARY

A conductor obeys Ohm's law if the current in it is directly proportional to the potential difference across its ends.
Ohmic components include a wire at constant temperature and a resistor.
Non-ohmic components include a filament lamp and a light-emitting diode.
A semiconductor diode allows current in one direction only.
As the temperature of a metal increases, so does its resistance.
A thermistor is a component that shows a rapid change in resistance over a narrow temperature range. The resistance of an NTC thermistor decreases as its temperature is increased.
The resistivity ρ of a material is defined as: $$\rho = \frac{RA}{L}$$ where R is the resistance of a wire of that material, A is its cross-sectional area and L is its length. The unit of resistivity is the ohm metre (Ω m).

EXAM-STYLE QUESTIONS

1 An element of an electric fire is made up from a length of nichrome wire of diameter 0.40 mm and length 5.0 m.

The resistance of this element is R_1.

Another element, also made from nichrome, for a different electric fire, has a length of 2.0 m and a diameter of 0.20 mm. This element has a resistance of R_2.

What is the relationship between R_1 and R_2? **[1]**

A $R_2 = 0.80\ R_1$

B $R_2 = 1.6\ R_1$

C $R_2 = 5.0\ R_1$

D $R_2 = 10\ R_1$

2 This is a circuit.

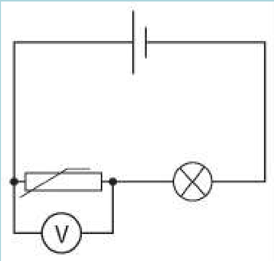

Figure 10.13

Which line in the table shows the changes to the lamp and the voltmeter reading when the temperature rises? **[1]**

	Lamp	**Voltmeter reading**
A	gets brighter	decreases
B	gets brighter	increases
C	gets dimmer	decreases
D	gets dimmer	increases

Table 10.3

3 This shows the *I–V* characteristic of an electrical component.

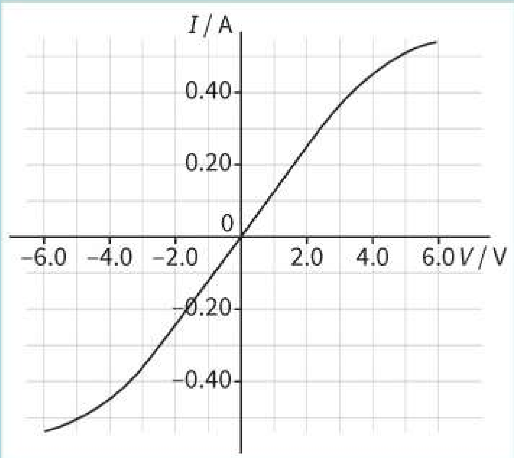

Figure 10.14

a Calculate the resistance of the component when the potential difference across it is:

i 2.0 V **[2]**

ii 5.0 V. **[1]**

b Suggest what the component is. **[1]**

[Total: 4]

4 A student connects a thermistor to a battery and an ammeter. He places the thermistor in a beaker of water and gradually heats the water from 10 °C to its boiling point, recording the value of the current as he does so. He then plots a graph of the current in the thermistor against the temperature of the water.

a Sketch the graph you would expect the student to obtain from the experiment. **[1]**

b Explain how the student could now use the thermistor as a thermometer. **[2]**

[Total: 3]

5 **a** Describe the difference between the conduction processes in copper and in silicon, a semiconductor. **[3]**

b Explain why the resistance of a metallic conductor increases with temperature while that of a semiconductor decreases. **[3]**

[Total: 6]

6 A nichrome wire has a length of 1.5 m and a cross-sectional area of 0.0080 mm^2. The resistivity of nichrome is 1.30×10^{-8} Ω m.

a Calculate the resistance of the wire. **[2]**

b Calculate the length of this wire that would be needed to make an element of an electric heater of resistance 30 Ω. **[2]**

[Total: 4]

7 This is a circuit.

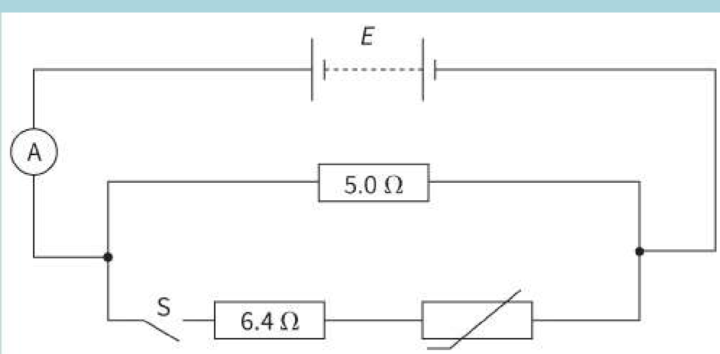

Figure 10.15

a When switch S is open the current in ammeter A is 0.48 A. Calculate the e.m.f. of the battery. You may assume the battery has negligible internal resistance. **[2]**

b When switch S is closed the current in the ammeter increases to 0.72 A.

i Determine the current in the 6.4 Ω resistor. **[1]**

ii State the current in the thermistor. **[1]**

c State and explain how the reading on the ammeter changes when the temperature of the thermistor is increased. **[3]**

[Total: 7]

8 **a** Explain why the resistance of a metal increases when its temperature increases. **[2]**

b State **two** other factors that determine the resistance of a stated length of wire. **[2]**

c When a potential difference of 1.5 V is applied across a 5.0 m length of insulated copper wire, a current of 0.24 A is measured in it.

i Calculate the resistance of the length of wire. **[2]**

ii The resistivity of copper is 1.69×10^{-8} Ω m. Calculate the diameter of the wire. **[3]**

d The wire is now made into a tight bundle. State and explain how you would expect the current in it to change. **[3]**

[Total: 12]

9 This diagram shows a piece of silicon of width 32 mm and length 36 mm. The resistance of the silicon between the points P and Q is 1.1 MΩ. Silicon has a resistivity of 2.3×10^{3} Ω m.

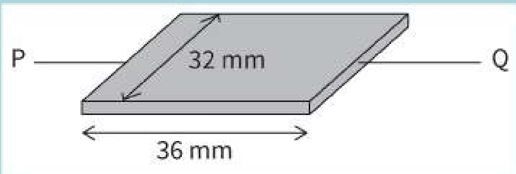

Figure 10.16

a Calculate the thickness of the piece of silicon. **[3]**

b Calculate the current that would pass through the silicon if a potential difference of 12 V were applied across P and Q. **[2]**

c Describe how the current would change if it were large enough to cause the silicon to become significantly warmer. **[3]**

[Total: 8]

10 A student is investigating the properties of a semiconducting diode. This diagram shows the circuit she builds.

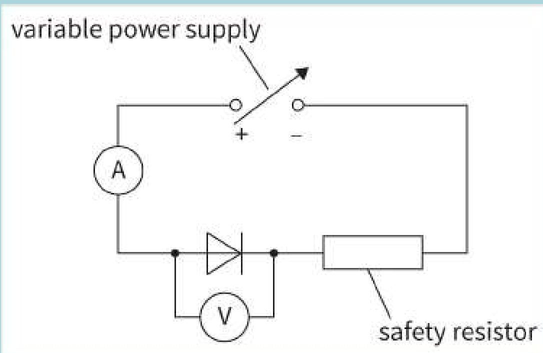

Figure 10.16

a **i** Sketch a graph to show how the current in the diode would vary as the voltage across it is increased from 0 V to 1.0 V. **[1]**

ii The supply is now connected in the reverse direction and once more the potential difference across the diode is increased from 0 V to 1.0 V. Complete the *I*–*V* graph. **[1]**

b Suggest why the safety resistor is required. **[2]**

c When the potential difference across the safety resistor is 1.4 V, the current in it is 20 mA. Calculate the resistance of the safety resistor. **[2]**

[Total: 6]

11 **a** Explain what is meant by an **ohmic conductor**. **[2]**

b **i** Sketch a graph of resistance R against voltage V for a wire of pure iron kept at constant temperature. Label this line X. **[1]**

ii Sketch a graph of resistance R against voltage V for a second wire of impure iron, of the same diameter and the same length, which is kept at the same temperature. Label this line Y. **[1]**

iii Explain how the graphs would change if the wires were kept at a higher, but still constant, temperature. **[1]**

c Deduce how the resistance of a wire made of pure iron would change if both the diameter and the length were doubled. **[3]**

[Total: 8]

12 The readings in this table are recorded from an experiment to measure the resistivity of silver.

Diameter of the wire	0.40 ± 0.02 mm
Length of the wire	2.25 ± 0.05 m
Resistance of the wire	0.28 ± 0.01 Ω

Table 10.4

a Calculate the resistivity of silver. **[2]**

b **i** Calculate the percentage uncertainty in each of the variables. **[2]**

ii Use your answers to **i** to calculate the absolute uncertainty in the value of the resistivity obtained in the experiment. **[2]**

[Total: 6]