- ***Candidates should be able to:***
  - *Define* ***RESISTANCE.***
  - *Select and use the equation for resistance :* $R = V/I$
  - *Define the* ***OHM.***
  - *State and use* ***OHM'S LAW.***
  - *Describe the* ***I-V CHARACTERISTICS*** *of a* ***resistor at constant temperature, filament lamp and light-emitting diode (LED).***
  - *Describe* ***experiments*** *to obtain the* ***I-V CHARACTERISTICS*** *of a* ***resistor at constant temperature, filament lamp and light-emitting diode (LED).***
  - *Describe the uses and benefits for* ***light-emitting diodes.***
  - *Define* ***RESISTIVITY (ρ)*** *of a material.*
  - *Select and use the equation :* $R = \rho L/A$
  - *Describe how the resistivities of metals and semiconductors are affected by temperature.*
  - *Describe how the resistance of a* ***pure metal wire*** *and of a* ***negative temperature coefficient (NTC) thermistor*** *is affected by temperature.*

ELECTRICAL RESISTANCE (R)

- *Of a conductor or component is a measure of its opposition to the flow of charge (i.e. to electric current).*
- *Is caused by the repeated collisions between the charge carriers (usually electrons) in the material with each other and with the fixed positive ions of the material.*

RESISTANCE (R) *of a conductor or component is defined as :*

$$\text{Resistance} = \frac{\text{potential difference across component}}{\text{current through component}}$$

If the current is (I) when the pd is (V), the resistance (R) is Given by :

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

R (Ω), V (v), I (A)

The unit of ***RESISTANCE (R)*** *is the* ***OHM (Ω)*** *which is defined as follows :*

A conductor has a resistance of ***1 OHM (Ω)*** *if the current in it is* ***1 AMPERE (A)*** *when the pd across it is* ***1 VOLT (V).***

$$1\ \Omega = 1\ V\ A^{-1}$$

- ***OHM'S LAW***

OHM'S LAW *states that the **pd (or voltage)** across a metallic conductor is directly proportional to the **current** through it, so long as the physical conditions (e.g. temperature) remain constant.*

i.e. $V \propto I$

- *This is equivalent to saying that the **RESISTANCE (R)** of a metallic conductor **is constant so long as the physical conditions remain the same.***

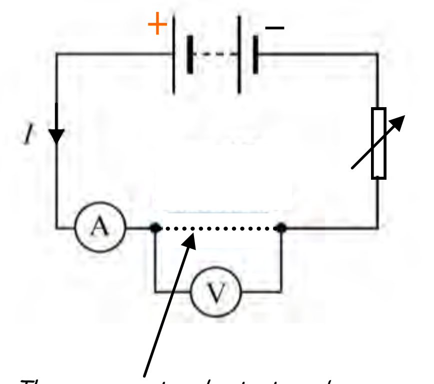
- *An **OHMIC CONDUCTOR** is one which obeys **OHM'S LAW**. For such a conductor :* $V = IR$

- *A **NON-OHMIC CONDUCTOR** is one which does **NOT** obey **OHM'S LAW**.*

- *The graph obtained by plotting corresponding I-V values for an Ohmic conductor yields **a straight line through the origin** whose **gradient = I/V = 1/R.***

- ***CURRENT-VOLTAGE (I-V) CHARACTERISTIC GRAPHS***

- *The circuit shown opposite is used to obtain a set of corresponding I-V values for a given component (fixed resistor, filament lamp or light-emitting diode).*



The component under test can be :

- *A fixed resistor or wire at constant temperature.*
- *A filament lamp.*
- *A light-emitting diode.*

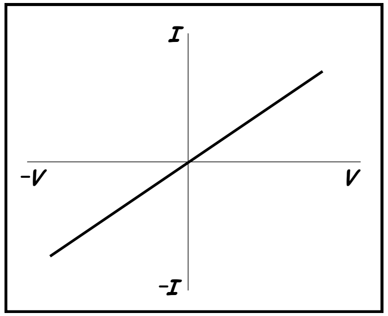
These values are then used to plot a current-voltage (I-V) graph.

The pd (or voltage) across the component is varied by the combined use of a variable power supply and a variable resistor in series with the component.

Alternatively, an ammeter sensor and a voltmeter sensor connected to a data logger can be used to measure and record corresponding I-V readings which can then be displayed directly on a computer screen.

Fixed Resistor or Wire At Constant Temperature

- *A fixed resistor or wire at constant temperature obeys **OHM'S LAW** (i.e. it is an **OHMIC CONDUCTOR**), so its resistance remains constant.*



- *The pd (V) across a fixed resistor or wire is directly proportional to the current (I) through it, so the I-V graph is a **best-fit straight line through the origin.***

- *The I-V Characteristic graph usually includes **negative** as well as **positive** values. The negative values are obtained by simply reversing the power supply connections.*

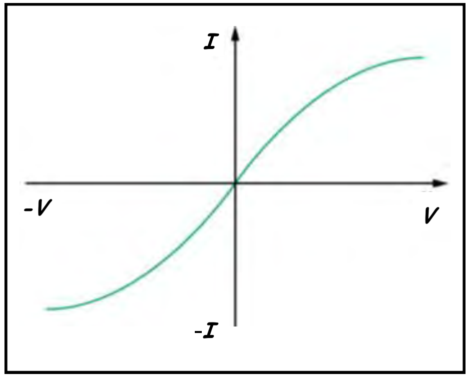
- ***Gradient of the I-V graph = 1/R.***

- *Sometimes (V) is plotted along The y-axis and (I) along the X-axis. When this is the case :*

Gradient of the V-I graph = R

FILAMENT LAMP

- *A filament lamp does **NOT** obey OHM'S LAW (i.e. it is a **NON-OHMIC CONDUCTOR**).*



- *The I-V graph is **curved** with the current (I) being less than expected at the higher values of pd (V).*

- *The filament **RESISTANCE INCREASES** with increasing pd (V). This is because as the **pd (V)** across the filament **increases**, its **temperature increases** and this makes the metal atoms vibrate with **greater amplitude**, causing a **greater opposition** to the flow of electrons (i.e. current).*

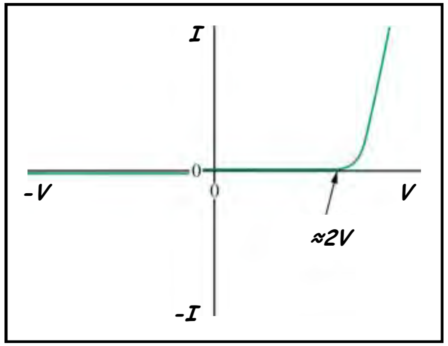
  The Filament resistance may increase by a factor of '10' between the lamp being off ($\theta \approx 20\ ^\circ C$) and when it is at its brightest ($\theta \approx 1800\ ^\circ C$).

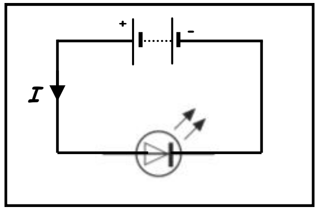
LIGHT-EMITTING DIODE (LED)

- *This is a semi-conductor device which emits light when it is operating.*

- *An **LED** does **NOT** obey **OHM'S LAW** (i.e. it is a **NON-OHMIC CONDUCTOR**).*

- *The I-V graph for a typical LED is shown opposite. The positive side of the graph is obtained with the LED '**positively biased**' as shown below.*





*For pd (V) < ≈ 2V, the current (I) is ≈ 0, so the LED has almost infinite resistance. The LED starts to conduct at its **threshold pd (≈ 2V)** and its resistance decreases dramatically for pd's > 2V.*

*The negative side of the graph is obtained by reversing the connections to the supply. The LED is then said to be '**negatively-biased**'. It then has almost infinite resistance and allows only a tiny current through it.*

- *Different LED's emit light of different wavelength (colour) and they have been traditionally used as indicator lights on appliances such as DVD players, TV sets etc.*

  Some more modern versions are replacing the filament lamps used in traffic lights. Although they are more expensive to manufacture, LED's are much more energy efficient and cheaper to run than filament lamps.

- **PRACTICE QUESTIONS (1)**

1 **Complete** the table shown below by calculating the missing values :

pd	current	resistance
14.0 V	2.0 A	
	0.68 A	24.0 Ω
5.0 V		45.0 kΩ
0.80 V	6.0 mA	
50.0 kV		25 MΩ

2 (a) A car headlamp bulb has a resistance of **40 Ω**. What is the **current** through the bulb when it is connected to the car's **12 V** battery ?

(b) Calculate the **pd** across the terminals of an electric motor having an electrical resistance of **75 Ω** when it is carrying a current of **1.2 A.**

3 A **6 V** battery, a switch, a milliammeter, a diode and a **240 Ω** resistor are connected **in series** with each other.

(a) Draw a circuit diagram for this arrangement, showing the diode connected so that it is **positively-biased.**

(b) When the switch is closed, the reading on the ammeter is found to be **15 mA.** Calculate : (i) The **pd across the resistor.**
(ii) The **pd across the diode.**

(c) What will the **ammeter reading** be if the **240 Ω** resistor is replaced by another having a value of **100 Ω** ?

4 Calculate the **current** through each of the following resistors :

(a) **140 Ω** connected to a **240 V** supply.

(b) **4.8 kΩ** connected to a **12 V** battery.

(c) **6.0 MΩ** connected to a **5.0 kV** supply.

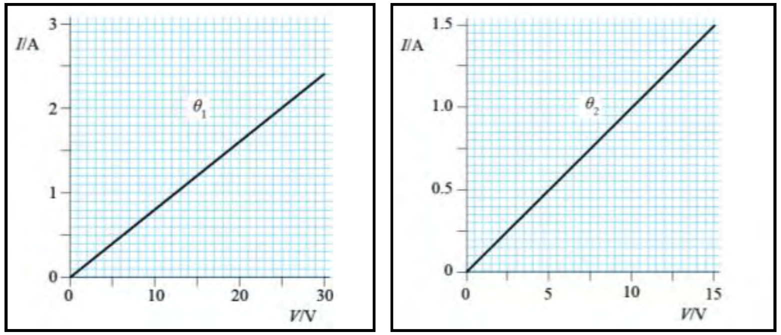
5 (a) Describe, with the aid of a circuit diagram, how the **current-voltage (I-V) characteristic graph** for a filament lamp may be obtained.

(b) (i) Sketch the **shape of the I-V graph** obtained, showing positive and negative values.

(ii) Describe how the **resistance** of the lamp changes as the voltage is **increased.**

(iii) **Explain** why the change described in (b) has occurred.

6

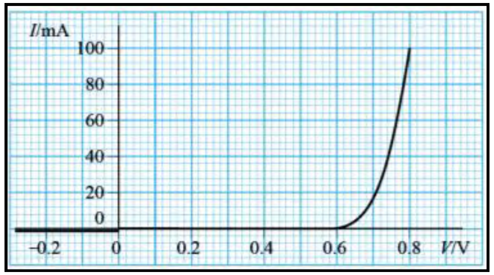


The above graphs show the I-V characteristics for a metal wire at two different temperatures **θ_1** and **θ_2.**

Calculate the wire **resistance** at each temperature and state which temperature is **higher.**

7 (a) State OHM'S LAW.

(b) The I-V characteristic for a particular component is shown below.



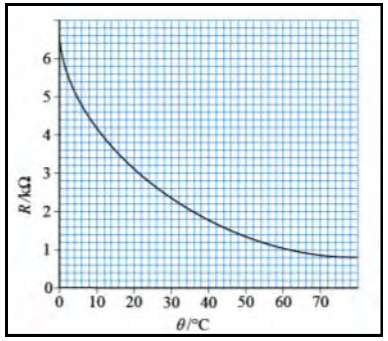
(i) Name the component with the characteristic shown above.

(ii) Describe, making reference to the graph, how the resistance Of the component depends on the potential difference (V) Across it. You are advised to show any calculations.
(OCR AS Physics - Module 2822 - Jan 2004)

• ***THERMISTORS*** *(Thermal Resistors)*

- *These are components (made from metal oxides such as manganese & nickel) whose **RESISTANCE** changes very rapidly with **TEMPERATURE**.*

- *In <u>**NEGATIVE TEMPERATURE COEFFICIENT (NTC)**</u> thermistors, the resistance **decreases** nearly **exponentially** with increasing temperature as shown opposite.*

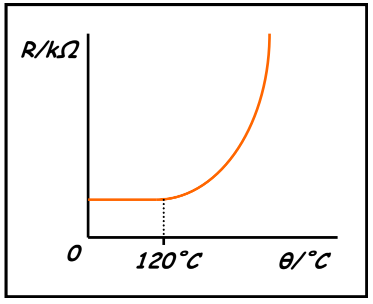


NTC's used in schools have :

R = many 1000s Ω at θ = 20°C

R = 50-100 Ω at θ = 100°C

- *In <u>**POSITIVE TEMPERATURE COEFFICIENT (PTC)**</u> thermistors, the resistance rises very sharply above a certain temperature (≈ 120°C).*



- *Thermistors are used in a wide variety of situations, including for example :*
  - *Baby cot alarms which detect if a baby stops breathing.*
  - *In aircraft wings to sense ice build-up and activate heaters to melt the ice.*
  - *As fire alarm sensors.*

• **PRACTICE QUESTIONS (2)**

1 Use the graph given for the **NTC thermistor** (see opposite) to :

(a) Determine the resistance at : (i) 15°C - ☐

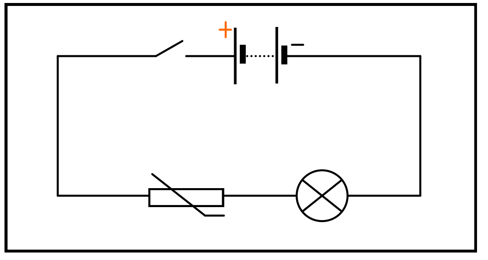
(ii) 50°C - ☐

(b) Determine the thermistor temperature at which the resistance is :

(i) 4200 Ω - ☐

(ii) 800 Ω - ☐

2 A physics student sets up the circuit shown below.



When he closes the switch, he notices that the lamp glows **very dimly**.

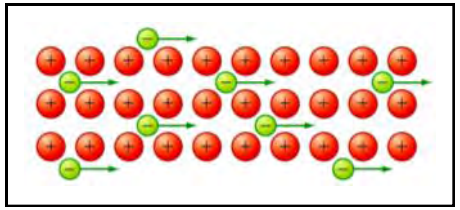
He then warms the thermistor in a hot air current. <u>**Describe**</u> and <u>**explain**</u> the change in lamp brightness which the student observes as the temperature of the thermistor **increases**.

- ***METALLIC RESISTANCE VARIATION WITH TEMERATURE***

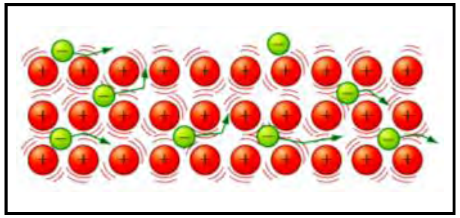
The RESISTANCE of a PURE metal increases linearly with increasing temperature.

Consider a section of a metal wire to which a pd is applied.

*At **LOW** temperatures, the electrons are able to drift past the positive metal ions with relative ease because they have few collisions to slow them down. This means that the **resistance is low**.*

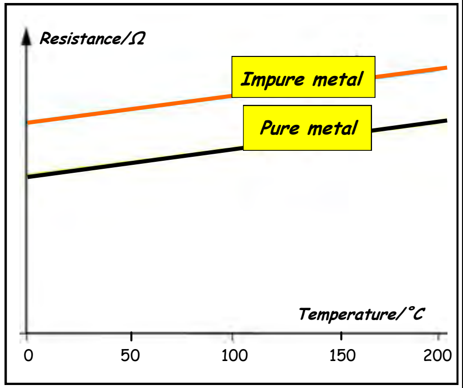


*At **HIGHER** temperatures, the positive ions **vibrate with greater amplitude.***

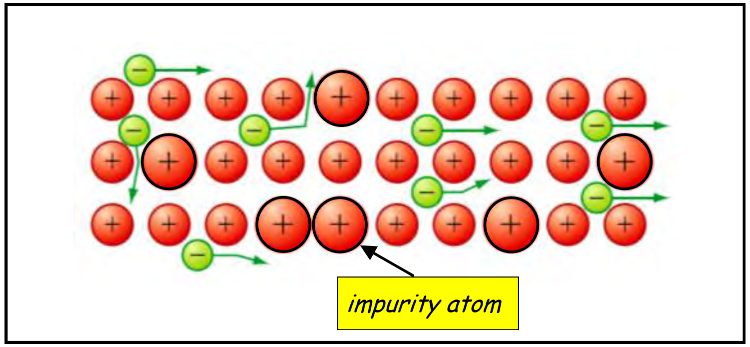


As a result, the electron-ion collisions are more frequent and this means that the flow of electrons is slowed down (i.e. the current is reduced).

*This means that the **resistance is higher than at lower temperatures.***



The RESISTANCE of an IMPURE metal also increases linearly with increasing temperature, but it is greater than that of a PURE metal.



- *The fact that the impurity atoms and the metal ions are different in size causes an increase in the frequency of the collisions experienced by the drifting electrons. This extra opposition to the flow of electrons means that the resistance is made greater by the presence of impurity atoms in the metal.*

- ***RESISTIVITY (ρ)*** *(ρ is the Greek letter 'rho')*

- *The electrical* ***RESISTANCE (R)*** *of a metal wire depends on its :*

  - ***LENGTH (L)***
    The ***greater*** *the* ***length (L)*** *of the wire, the* ***greater*** *is its* ***resistance (R).***

    i.e. R a L

  - ***CROSS-SECTIONAL AREA (A)***
    The ***larger*** *the* ***cross-sectional area (A)*** *of the wire, the* ***smaller*** *is its* ***resistance (R).***

    i.e. R a 1/A

  - ***RESISTIVITY (ρ)***
    This is the property which takes the ***material*** *of the wire into account.*

The ***RESISTIVITY (ρ)*** *of a material is the* ***RESISTANCE (R)*** *of a sample of the material having* ***unit length*** *and* ***unit cross-sectional area.***

$$\text{Resistance} = \frac{\text{Resistivity} \times \text{Length}}{\text{Cross-sectional area}}$$

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

R (Ω), ρ (Ωm), L (m), A (m^2)

SI unit of resistivity is the ***Ohm-metre (Ωm)***

- ***RESISTIVITY VARIATION WITH TEMPERATURE***

- ***METALS*** - ***Resistivity increases with increasing temperature***

  This is because an increase in temperature causes increased vibration of the metal ions and this means an increase in the frequency with which the drifting electrons collide with them.

- ***SEMICONDUCTORS*** - ***Resistivity decreases with increasing temperature***

  An increase in temperature has two effects in a semiconductor :

  - *There is an increase in the electron-ion collision frequency. This means* ***increased resistivity.***

  - *More electrons break free of their atoms, so there is an increase in the number of electrons available for conduction. This means* ***decreased resistivity.***

  The second effect dominates and so the resistivity of a semiconductor decreases with temperature.

• PRACTICE QUESTIONS (3)

1 (a) The resistance of a piece of eureka wire is **5.0 Ω** when it is measured across its ends. If the cross-sectional area of the wire is **2.4 x 10^{-7} m^2**, what is its **length** ?
(resistivity of eureka = **4.9 x 10^{-7} Ωm**).

(b) Calculate the **resistance** of **1 cm^3** of copper when it is in the form of a wire having a cross-sectional area of **4.0 x 10^{-7} m^2**.
(resistivity of copper = **1.69 x 10^{-8} Ωm**).

2 A **1.0 m** length of copper wire has a resistance of **0.5 Ω.**

(a) What is the **resistance** of a **3.5 m** length of the same wire ?

(b) What is the **resistance** of a **1.0 m** length of copper wire having **half the diameter** of the original wire ?

3 A car headlamp bulb is marked **"60 W, 12 V"**. The bulb filament is a wire of cross-sectional area **1.2 x 10^{-2} mm^2** and it is made of a metal of resistivity **3.9 x 10^{-7} Ωm** at the operating temperature of the bulb.

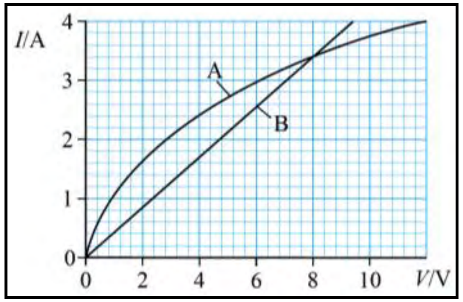
(a) Show that the **resistance of the filament** at its operating temperature is **2.4 Ω.**

(b) Calculate the **total length** of the filament.

(c) **Explain** the result you have obtained in part (b).

• HOMEWORK QUESTIONS

1 The graphs shown opposite give the **I-V characteristic** for two components, a **filament lamp** and a **length of steel wire.**



(a) Identify which graph **(A or B)** relates to each component.

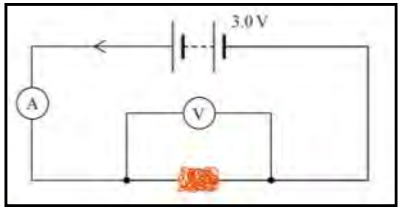
(b) State the **voltage** at which the components have **equal resistance.**

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

2 A steady current of **12.5 mA** exists along the axis of a cylindrical piece of manganin wire of length **5.5 m**, cross-sectional area **2.0 x 10^{-7} m^2** and resistivity **4.4 x 10^{-7} Ωm.**
Calculate the **pd** across the ends of the wire.

3 (a) The electrical resistance of a wire depends on its **temperature** and on the **resistivity** of the material. List **two** other factors that affect the resistance of a wire.

(b) The diagram shows a circuit that contains a thin, insulated copper formed as a bundle. The ammeter and the battery have negligible resistance and the voltmeter has infinite resistance. The wire has length **1.8 m**, diameter **0.27 mm** and resistance **0.54 Ω.**



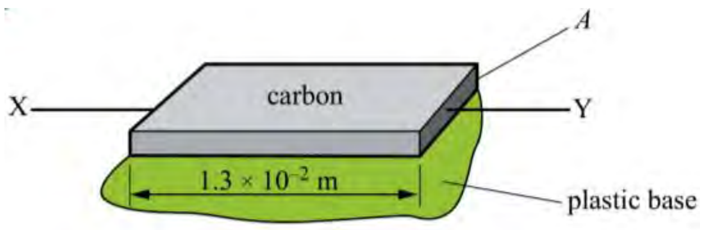
(i) Calculate the **resistivity** of copper.
(ii) **State** and **explain** the effect on the ammeter reading and the voltmeter reading when the **temperature** of the wire bundle is **increased.**

(OCR AS Physics - Module 2822 - June 2005)

4 (a) A wire has **length L, cross-sectional area A,** and is made of a material of **resistivity ρ.** Write an equation for the **electrical resistance R** of the wire in terms of **L, A and ρ.**

(b) A second wire is made of the **same material** as the wire in (a), has the **same length** but **twice the diameter. State** how the **resistance** of this wire compares with the resistance of the wire in (a).

(c) The diagram below shows resistor made by depositing a thin layer of carbon onto a plastic base.



The **resistance** of the carbon layer between X and Y is = **2200 Ω.**
The **length** of the carbon layer is = **1.3×10^{-2} m.**
The **resistivity** of carbon is = **3.5×10^{-5} Ωm.**

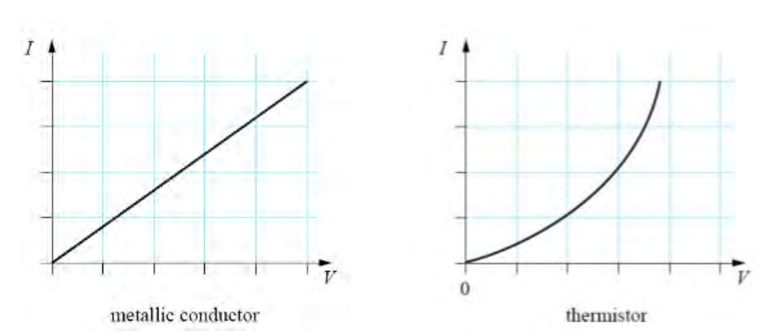
Show that the **cross-sectional area A** of the carbon layer is about **2×10^{-10} m^2**.

(OCR AS Physics - Module 2822 - Jan 2006)

5 (a) **State** the difference between the directions of **conventional current** and **electron flow.** *10*

(b) **State Ohm's Law.**

(c) Current against voltage **(I-V) characteristics** are shown below for a **metallic conductor at constant temperature** and for a particular **thermistor.**



(i) Sketch the variation of **resistance R** with **voltage V** for :

1. The **metallic conductor at constant temperature.**

2. The **thermistor.**

(ii) **State** and **explain** the change, if any, to the graph of resistance against voltage for the **metallic conductor** :

1. When the **temperature is kept constant at a higher value.**

2. When the **length of the conductor is doubled** but the material, temperature and cross-sectional area of the conductor **remain the same.**

(OCR AS Physics - Module 2822 - Jan 2005)