Physics Factsheet
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Resistivity of a wire using a micrometer, ammeter and voltmeter

Before dealing with the practical investigation itself, it's worth appreciating what 'resistivity' actually is – and what it isn't!

'Resistivity' is not the same as 'resistance', although the two are linked. The 'resistance' of a conductor is simply a measure of the potential difference needed to drive each Ampere of current through it. For instance, if a potential difference of 6V was required to drive a current of 2A through a length of wire, essentially a p.d. of 3V per Ampere is needed. We describe this as a resistance of 3 Ohms, since 3V/A is equivalent to 3Ω.
This is the basis of Ohm's Law:

$$\text{Resistance} = \frac{\text{potential difference}}{\text{current}}$$

Significantly, though, the conductive properties of this length of wire – its 'resistance' – depend on its physical properties; the length of the wire, its thickness (and ultimately cross-sectional area), and the material the wire is made from. The longer we make the wire the further the current has to travel to get from one end to the other, and the greater the resistance. Equally, the thicker the wire the greater the cross-sectional area, and the more pathways there are from one end to the other, so the lower the resistance.

'Resistivity' is the factor determined by the material the wire is made from, and it is essentially the resistance of a unit length and unit cross-section of the material. It is given the symbol 'rho' or 'ρ'. For a certain material, the resistivity is constant regardless of the size of the sample. It's a property of the material, just like density.

Question 1
The resistance 'R' of a sample is directly proportional to its length 'l' and its resistivity 'ρ', and inversely proportional to its cross-sectional area 'A'. No other constant of proportionality is needed.
(a) Use this information to suggest an equation linking these quantities

Answers
$R \propto l$ and $R \propto \rho$ and $R \propto \frac{1}{A}$ therefore $R \propto \frac{\rho \times l}{A}$
Since there are no other constants of proportionality needed
$R \propto \frac{\rho \times l}{A}$

a) Rearrange this relationship to obtain an equation for resistivity 'ρ' and determine an appropriate unit for resistivity 'ρ'

$$\rho = \frac{R \times A}{l}$$

'R' is measured in ohms 'Ω', area in 'm²' and length in 'm'
Using a unit or dimensional analysis,
If $\rho = \frac{R \times A}{l}$
then units for 'ρ' $= \frac{\text{units for R} \times \text{units for A}}{\text{units for l}} = \frac{\Omega \times m^2}{m} = \Omega m$

When you realise that a unit length is 1m and therefore the unit cross-section is 1m², we have to deal with the resistance of a solid cube of metal 1m along each side!
Needless to say, the resistance through such a solid block of metal will be incredibly small, so resistivity values tend to be of very small orders of magnitude, typically 10^{-7} Ωm, 10^{-8} Ωm.

Determining the Resistivity of a Wire

From the equation $\rho = \frac{R \times A}{l}$

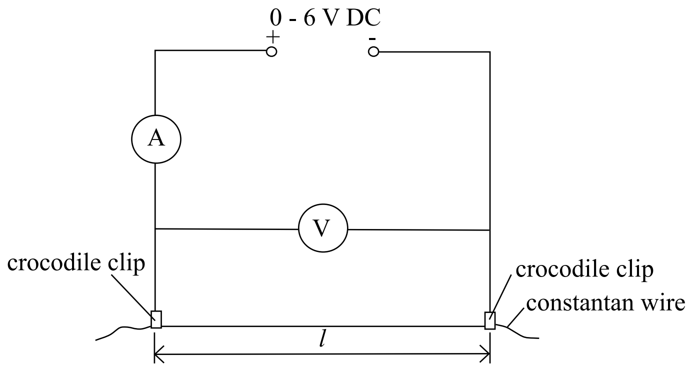
We could calculate the resistivity by knowing the resistance of the wire, its cross-sectional area and its length. From a practical point of view, however, the accuracy of a single value obtained from just one set of data could be significantly influenced by a rogue reading or measurement; we can reduce the effect of errors by taking a series of successive measurements and plotting a graph of the results, the gradient of which will give us the value for resistivity.
If we are to obtain a straight-line graph, we need to plot data that will fit the 'y = mx + c' structure.

Studying the composition of the equation $\rho = \frac{R \times A}{l}$

It should be clear that there is no '+c' term, which leaves us with

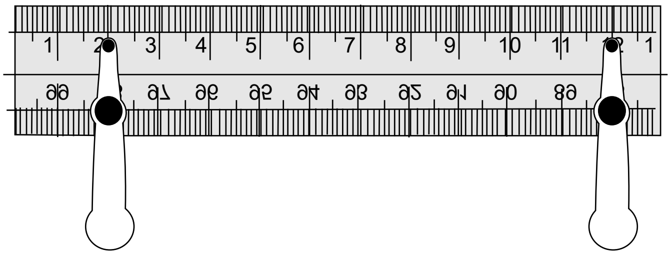
'y = mx' or (rearranged) $m = \frac{y}{x}$.
If we are to obtain the resistivity 'ρ' as the gradient of the straight line, the most obvious equivalent variables are to plot 'R × A' as the 'y'-variable (dependent), and 'l' as the 'x'-variable (independent).

In this experiment, therefore, you will be looking to vary the length 'l' of the wire and measure its resistance 'R' for each length, whilst keeping the cross-sectional area constant.

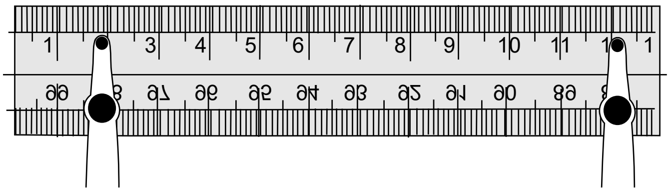


Measuring and Varying the Length of the Wire
To keep the wire straight (and therefore prevent inaccuracies in measuring the length) the wire could be fixed along the length of a metre-stick, secured with tape at each end. The crocodile-clips can be then moved along the wire to obtain other, smaller, lengths at regular intervals.

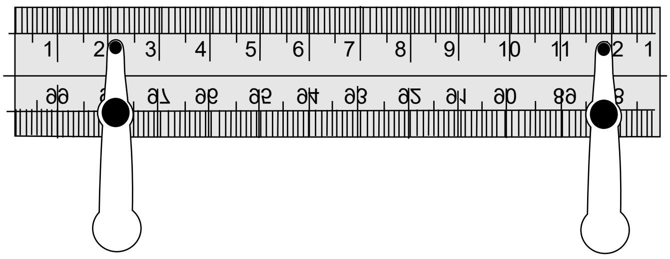
Question 2
In which of the positions below – A, B or C - are the crocodile-clips placed correctly to obtain a length of wire of exactly 10cm? Justify your choice with an explanation.
(a) With the croc-clip centres aligned to the ruler markings



(b) With the inner-edges of the crop-clips aligned to the ruler markings



(c) With the outer-edges of the croc-clips aligned to the ruler markings



Answer
'B'. The current will take the shortest path, therefore the crocodile clip inner-edges need to be 10cm apart regardless of how wide the croc-clips are.

Ensure that you select wire lengths to obtain a suitable range and quantity of values. At least 7 different lengths are advisable, regularly spaced, across a range at least half the length of the wire or more if possible, e.g. 100cm, 90cm, 80cm, 70cm, 60cm, 50cm, 40cm…

Safety and Potential Problems
The set-up shown above will result in you applying the full supply p.d. to the length of wire being investigated. As the length of wire becomes shorter and the length of wire being used has less and less resistance, the current flowing through the wire will increase, and the wire will get hot.

Question 3
Can you support this claim mathematically?

Answer
The heat power developed in a conductor is found from the equation $P = I^2R$ *where 'I' is the current flowing and 'R' is the resistance of the wire.*

For a constant p.d. supplied 'V', the current $I = V/R$,
therefore $I^2 = V^2/R^2$

The heat power developed is therefore $P = V^2 \div R$ *which shows that for a constant 'V' a decreasing 'R' will cause an increase of 'P' i.e greater and greater heating in the wire.*

Exam-Style Question 1
In an experiment to determine the resistivity of a wire, a student made the following measurements:

potential difference across the wire	= 4.5 V
current in the wire	= 0.21 A
diameter of the wire	= 1.8×10^{-4} m
length of the wire	= 0.90 m

(a) Calculate the resistivity of the material from which the wire is made. (3)
(b) Calculate the power dissipated per metre of the wire. (2)
(Total 5 marks)

Answers
(a) resistance = 4.5 / 0.21 = 21.4 Ω C1
or $R = \rho L / A$ quoted C1
or area of cross section = 2.54×10^{-8} (m^2) C1 (Max 2)
resistivity = 6.04×10^{-7} Ω m (c.n.a.o) A1 (3)

(b) total power = VI = 0.945 W C1
power per m = 1050 mW or 1.05 W (c.n.a.o.) A1 (2)

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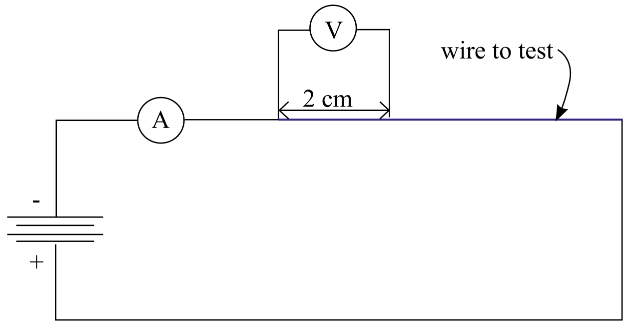
How To Get Around This Issue
1. Use the circuit as shown but each time you move the croc-clips to shorter and shorter lengths, use the controller on the power supply OR a variable resistor to adjust the current back to a low level so the wire doesn't get hot.
2. Use a slightly modified version of the circuit.



If you connect the full metre-length of wire and ammeter up as a series circuit, then connect the voltmeter across the length you are taking measurements for (2cm in this diagram), this will not be a problem because the length of wire in the circuit remains 1m throughout – all you are doing is selecting different lengths to measure the potential difference across to determine the resistance of that section. However, you will still need to adjust the current at the start to a level low enough not to overheat the wire.

What Wire to Use
The wire is likely to get warm to some extent, so it would be smart to use a material in which resistance doesn't change much with variations in temperature. Iron would be a bad choice, but there are alloys called 'constantan' or 'nichrome', whose resistance only varies very slightly with temperature. If you can, use wire made from those.

Measuring Potential Difference and Current
Keep the current low, to avoid overly heating the wire, but not so low that the sensitivity of the meter becomes problematic. Currents notably less than 1A (e.g 0.2A) should be suitable.

Obtaining the Cross-Sectional Area of the Wire and Measuring Its Diameter
In order to determine the cross-sectional area, you will need to measure the diameter of the wire. The wire is likely to be too thin for a standard ruler or even Vernier callipers (which measure to 0.1mm).

Question 3
A student uses Vernier callipers to measure the diameter of a wire of diameter 0.25mm.
(a) What is the percentage uncertainty in this reading?

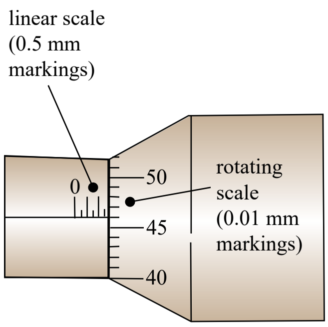
Answer
The ‘zero’ of the instrument can be taken as trustworthy since the sensitivity of the instrument is 0.1mm and the absolute uncertainty is ± 0.05mm.
Percentage uncertainty = ±0.05/0.125 × 100 = ±20%

(b) Calculate the possible percentage uncertainty this would cause in the value for cross-sectional area.

Answer
Cross-sectional area is found from the equation $A = \pi r^2$ or $= \pi D^2/4$
Since the diameter will be squared, the percentage uncertainty will double.
2 × ±20% = ±40%

It is absolutely essential to reduce the error in measuring diameter as this will be doubled as percentage error in subsequent calculations. This is why it is essential to use a micrometer, which will measure to a sensitivity of 0.01mm.

Question 4
Explain why the reading on this micrometer is 2.96mm.



Answer
Each of the linear markings is 0.5mm and five of these are visible, representing 5 × 0.5mm = 2.5mm.
The rotating scale has been turned to one division past ‘45’. Each of these divisions is 0.01mm, so the rotating scale is at
(45 +1)×0.01 = 0.46mm.
0.46mm further than 2.5mm = 2.5 + 0.46 = 2.96mm

For accuracy, you would be advised to take a diameter measurement from at least three points on the wire. To obtain an average, the wire may have been squashed, stretched, or kinked – multiple measurements will help you to reduce the impact of such issues as well as identifying any anomalies.

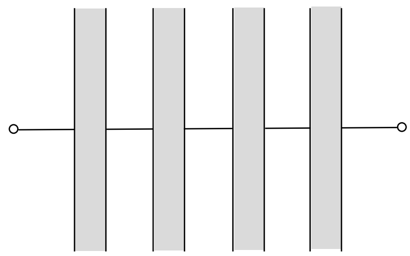
Carrying out the Experiment
Taking this myriad of precautions into account, you should now be in a position to obtain your measurements. Ensure that you record them at the time, not after the experiment has been completed. Rough tables may be needed in the write-up.

Processing Results
1. Calculate the resistance of the wire for each length using ohm’s law R = V/I
2. Obtaining the resistivity ‘ρ’ as the gradient of the straight line on the graph, we identified the most obvious equivalent variables to plot are ‘R × A' as the ‘y’-variable (dependent), and ‘l’ as the ‘x’-variable (independent).
3. Allocate a column in your table for values of 'R × A' and show these values with an appropriate unit in the header of the column.
4. Show how you obtained the average of the cross-sectional area and how you determined this value.
5. Ensure your graph has scales (with labels and units) that allow your points to fill at least half the graph in each direction, using broken axes if necessary.
6. Ensure your line-of-best-fit has points equally distributed along its length if they don’t hit the line perfectly. Error-bars should be used to judge this.
7. Finally, use a triangle larger than 8cm on each edge to obtain the gradient of the line, showing your calculation and the range of uncertainty in your value.

Exam-Style Question 2
(a) The resistivity of a material in the form of a uniform resistance wire is to be measured. The area of cross-section of the wire is known. The apparatus available includes a power-supply, a switch, a variable resistor, an ammeter, and a voltmeter.
  (i) Draw a circuit diagram using some or all of this apparatus, which would enable you to determine the resistivity of the material.
  (ii) Describe how you would make the necessary measurements, ensuring that you have a range of values.
  (iii) Show how a value of the resistivity is determined from your measurements. (9)

(b) A sheet of carbon-reinforced plastic measuring 50 mm × 50 mm × 2.5 mm has its two large surfaces coated with highly conducting metal film. When a potential difference of 230 V is applied between the metal films, there is a current of 1.5 mA in the plastic. Calculate the resistivity of the plastic. (3)

(c) If six of the units described in part (b) are connected as shown in the diagram, calculate the total resistance of the combination.

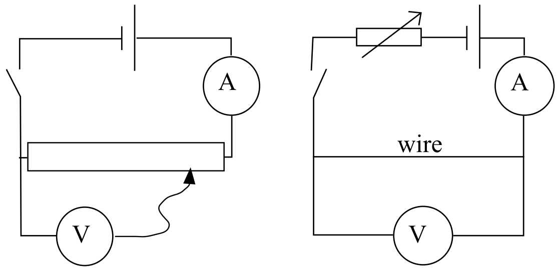


(2)

(Total 14 marks)

Answers

(a) (i)



power-supply, wire, (variable resistor) and ammeter in series with voltmeter connected across wire

(ii) (a) (with switch closed) measure I and V (1)
move contact along the wire (1) (or length of wire changed)
measure new (I and) V (1)
measure l each time (1)
or (b) measure I and V (1)
change variable resistor (1)
measure new I and V (1)
l known (1)

(iii) $R = \frac{\rho l}{A}$ or $\rho = \frac{RA}{l}$ or $\frac{A}{l} \times \frac{V}{I}$ (1)
Obtain values for V and I to determine R for each length (1)
Obtain gradient for RxA 'vs' l to determine ρ directly (1)
OR
(a) obtain gradient of graph of V or R vs l (1)
A (and I) known, hence ρ (1)
or (b) gradient of graph of V vs I (1)
A and l known, hence ρ (1)
[or, for both methods, measure R = V ÷ I for each length (1)
take mean and hence obtain value for ρ (1) (9)

(b) (use of V = IR gives) $R = 230 \div (1.5 \times 10^{-3})$ (1) ($= 153.3 \times 10^3$ (Ω))
$\rho = \frac{R \times A}{l} = \frac{153.3 \times 10^3 \times (0.05 \times 0.05)}{0.0025}$
(allow C.E. for value of R)
$= 1.53 \times 10^5$ Ω m (1) ` (1)

(c) four resistors in series (1)
$R = 6 \times (153.3 \times 10^3) = 9.20 \times 10^5 Ω$ (1)
(allow C.E. for value of R) (2)
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