A Level Physics: Unit 3

Q: How can we measure small length by using vernier calipers?

Vernier callipars is used to measure the length of 5 cm to 15 cm. It has 2 scales: main scale and vernier scale. We can measure the diameter of an object keeping it in between the 2 jaws.

$$\begin{aligned}\text{diameter} &= \text{main scale reading} + \text{vernier scale reading}\\ &= \text{main scale reading} + \text{vernier coincidence} \times \text{vernier constant}\end{aligned}$$

Q: What is vernier coincidence?

When the object is in between the 2 jaws, a line of vernier scale coincides with one line of the main scale. This line of the vernier scale gives the vernier coincidence.

Q: What is vernier constant?

The minimum length we can measure by vernier calipers is called vernier constant.

$$\text{vernier constant} = \frac{\text{smallest one division of main scale}}{\text{total number of division in the vernier scale}}$$

$$VC = \frac{s}{n}$$

Q: How can we get main scale reading?

Keeping the object in between the jaws, the zero line of the vernier scale causes one line of the main scale. This line gives the main scale reading.

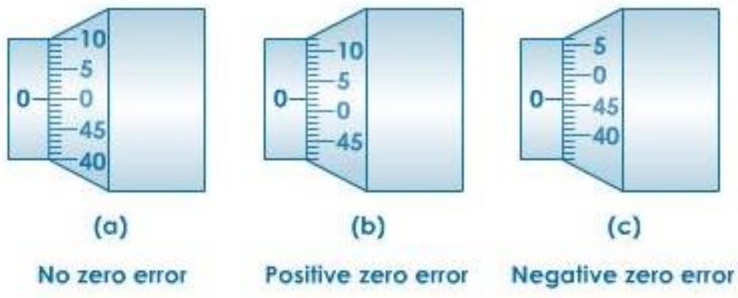
Q: How can we measure a small length by using a micrometer screw gauge?

It can measure the length of several centimeters. It has also 2 scales: main scale and thimble scale. We should keep the object in between the sleeve and spindle. We can measure the length by using the formula

$$\text{diameter} = \text{main scale reading} + \text{thimble scale coincidence} \times \text{least count}$$

Q: 0 error of micrometer screw gauge.

When the sleeve and spindle are touching each other and if the detum line of line scale doesn’t coincide with 0 line of the circular scale, then the error is called 0 error.



$\text{zero error} = \text{how many no. of division below or above the detum line is the zero line } \times \text{least count}$

$\text{diameter} = \text{total reading} - (\pm \text{e})$

Uncertainty

Q: What is uncertainty?

The uncertainty is an actual range of values around a measurement, within which we expect the true value to lie. The uncertainty is an actual number with an unit.

An error is just a problem which causes the reading to be different from the true value. Although a zero error can have an actual value. For example, if we happen to know that the true value of a length is 21.0 cm and an error or problem causes the actual reading to be 21.5 cm, then, since the true value is 0.5 cm away from the measurement, the uncertainty is ± 0.5 cm.

The uncertainty can be estimated in two ways:

1. Using the scale division on the scale.
2. Repeating the readings.

There are two types of uncertainty

1. Instrumental uncertainty: uncertainty of measured value.
2. Absolute uncertainty: uncertainty of any calculated value.

Q: How can we calculate the uncertainty?

Let the true length of a bar, $l = 4.6$cm
the measured length, $l_m = 4.7$cm

Instrumental Δ of this measured value

$$= (4.7 - 4.6) = 0.1 \text{ cm}$$
$$l = (4.7 \pm 0.1) \text{ cm}$$

$$\%\Delta = \frac{\Delta}{\text{measured value}} \times 100\%$$

$$= \frac{0.1}{4.7} \times 100\%$$

$$= 2.1\%$$

Δ of 4 operations

1. Product

Let, $x = x_1 \times x_2$

$$\%\Delta x = \%\Delta x_1 + \%\Delta x_2$$

$$= \frac{\Delta x_1}{x_1} \times 100\% + \frac{\Delta x_2}{x_2} \times 100\%$$

Example:

$x_1 = (5.6 \pm 0.1)$ cm
$x_2 = (9.7 \pm 0.1)$ cm

$$x = x_1 \times x_2$$

$$\%\Delta x = \frac{0.1}{5.6} \times 100\% + \frac{0.1}{9.7} \times 100\%$$

$$= 1.78\% + 1.03\%$$

$$= 2.81\%$$

2. Division

$$x = \frac{x_1}{x_2}$$

$$\%\Delta x = \%\Delta x_1 + \%\Delta x_2$$

3. Subtraction of two numbers

$$x = x_1 - x_2$$

$$\%\Delta x = \frac{\Delta x_1 + \Delta x_2}{x_2 - x_1} \times 100\%$$

4. Addition of two numbers

$$x = x_1 + x_2$$

$$\%\Delta x = \frac{\Delta x_1 + \Delta x_2}{x_2 + x_1} \times 100\%$$

5. Indices of a number

$x = x_1^n$

Now we know, $x_1^2 = x_1 \times x_2$

$\%\Delta x = \%\Delta x_1 + \%\Delta x_2 = 2\%\Delta x_1$

For, $x = x_1^n$

$\%\Delta x = n\%\Delta x_1$

P-1 A student wants to find the density of the material. She found the following results.

$l = (4.6 \pm 0.1)$ cm
$D = (2.43 \pm 0.01)$ mm
$m = (3.6 \pm 0.1)$ g

(a) Calculate the %Δ for each of the measurements.
(b) Calculate the %Δ of volume.
(c) Calculate the density of material and hence determine its %Δ.

Ans:

(a) $\%\Delta l = \frac{0.1}{4.6} \times 100\% = 2.17\%$

$\%\Delta D = \frac{0.01}{2.43} \times 100\% = 0.412\%$
$\%\Delta m = \frac{0.1}{3.6} \times 100\% = 2.78\%$

(b) $V = \pi r^2 h = \pi \left(\frac{\frac{2.43}{2}}{10}\right)^2 \times 4.6 = 0.21$ cm^3

Again, $V = \frac{\pi D^2 h}{4}$

$\%\Delta v = \%\Delta \mathrm{D}^2 + \%\Delta \mathrm{h}$
$= 2\%\Delta \mathrm{D} + \%\Delta \mathrm{h} = 2 \times 0.412\% + 2.17\% = 2.994\%$

(c) $D = \frac{m}{V} = \frac{3.6}{0.21} = 17.14$ g/cm^3

$\%\Delta$ of density $= \%\Delta$ of mass $+ \%\Delta$ of volume

$= 2.78\% + 2.994\%$

$= 5.774\%$

%Δ for repeating readings

$$\%\Delta = \frac{(\text{maximum} - minimum)/2}{\text{Average}} \times 100\%$$

where,

$$\Delta = \frac{\text{maximum} - \text{minimum}}{2}$$

P-2 Diameter of a sphere is 3.64 mm, 3.74 mm, 3.84 mm, 3.00 mm, calculate the average diameter, uncertainty and % uncertainty.

Ans:

avg. diameter $= \frac{3.64+3.74+3.84}{3} = 3.74\text{ mm}$

$\Delta = \frac{(3.84-3.64)/2}{3.74} \times 100\% = 2.67\%$

P-3 A student wants to find the Young modulus of a material. She found the following results: 14.2 GPa, 13.7 GPa, 13.1 GPa. Find %Δ.

Ans:

avg Young modulus $= \frac{14.2+13.7+13.1}{3} = 13.7$

$\%\Delta = \frac{(14.2-13.1)/2}{13.7} \times 100\% = 4.01\%$

P-4 A length is measured five times with a ruler whose smallest division is 0.1 cm and the readings obtained, in cm are 22.9, 22.7, 22.9, 23.0, 23.1. What is the reading obtained and the uncertainty.

Ans:

avg length $= \frac{22.9+22.7+22.9+23.0+23.1}{5}$

$= 22.9$

$\Delta = \frac{23.1-22.7}{2} = 0.2$

Reading = (22.9 ± 0.2) cm

Percentage difference

$$\% \text{ difference} = \frac{\text{difference between the two values}}{\text{average value or standard value}} \times 100\%$$

<u>Example</u>

Theoretically, the value of $g = 9.81$ ms^{-2}

Experimentally we get, $g = 9.87$ ms^{-2}

$$\% \text{ difference} = \frac{9.87 - 9.81}{9.81} \times 100\% = 0.61\%$$

P-1 Experimentally, we get two values of g

$g = 9.86, 9.67$

Average = 9.77

%difference = $\frac{9.86-9.67}{9.77} \times 100\% = 1.94\%$

P-2 The value of $g = 9.81$ ms^{-2}
Experimentally, we have got, $g = 9.78$ ms^{-2}
Given $\%\Delta g = 5.6\%$
Is the experiment valid?

Ans:

Now % difference $= \frac{9.81-9.78}{9.81} \times 100\% = 0.31\%$

%difference < %Δ

Therefore, the experiment is valid.

Q: What is precision?

How close the measured data are is called the precision i.e. if the difference between maximum and minimum measured value is less, the precision is more.

<u>Example</u>

Student A found, $g = 9.81, 9.83, 9.87$
Difference of maximum and minimum value = 0.06

Student B found, $g = 8.61, 8.62, 8.63$
Difference of maximum and minimum = 0.02

Therefore, Student B is more precise while student A is more accurate.

Q: What is accuracy?

If the difference between theoretical value and mean measured value is less, accuracy is more.

Student A:
Theoretical value = 9.81
Measured value = 9.85
Difference = 0.04

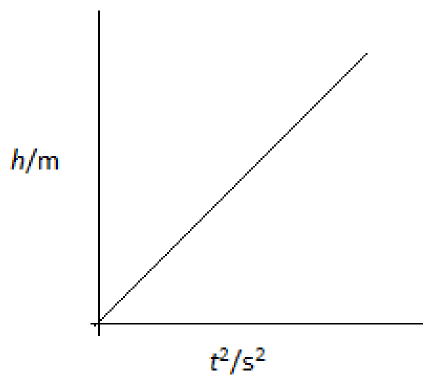
Student B:
Theoretical value = 9.81
Measured value = 8.62
Difference = 1.19

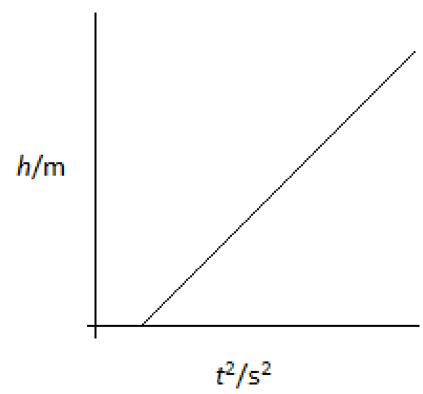
Therefore, Student A is more accurate.

Q: What is systematic error?

It is an error caused by experimental set up or by using wrong instrument. This error can be reduced by using proper instrument or by changing the experimental set up. If systematic error occurs, the graph should not pass through origin.

$h = \frac{1}{2}gt^2$





Systematic error

Q: What is random error?

Random error is caused by unpredictable changes in the experiment. The error produces a random effect on the data. Sometimes data will be higher than usual. This error can be reduced by repeating the experiment and plotting a graph.

Advantages of graphical method of an experiment:

1. It reduces random error.
2. It identifies the systematic error.
3. It identifies the anomalous result.
4. Gradient can be found.
5. y-intercept or x-intercept can be found.

<u>Advantages and disadvantage of data logging device and stopwatch</u>

Data logging device

Advantage:

1. Large number of reading can be found within short time.
2. Graph can be plotted automatically.
3. Simultaneous reading can be found.

Disadvantage:

1. External power supply is required.
2. Expensive.
3. Expert operator is required.

Stopwatch

Advantage:

1. Cheap
2. Anyone can handle
3. External power supply is not required.

Disadvantage:

1. Simultaneous reading cannot be found due to reaction time.
2. Easily broken.
3. Reaction time matters.

Criticizing the measured value

Q: A student wants to find the free fall of acceleration 'g' using a graphical method. She records the following results:

h/cm	t
5.0	1.23
10.0	2.46
20	4.5
25.0	6.36

Criticize:

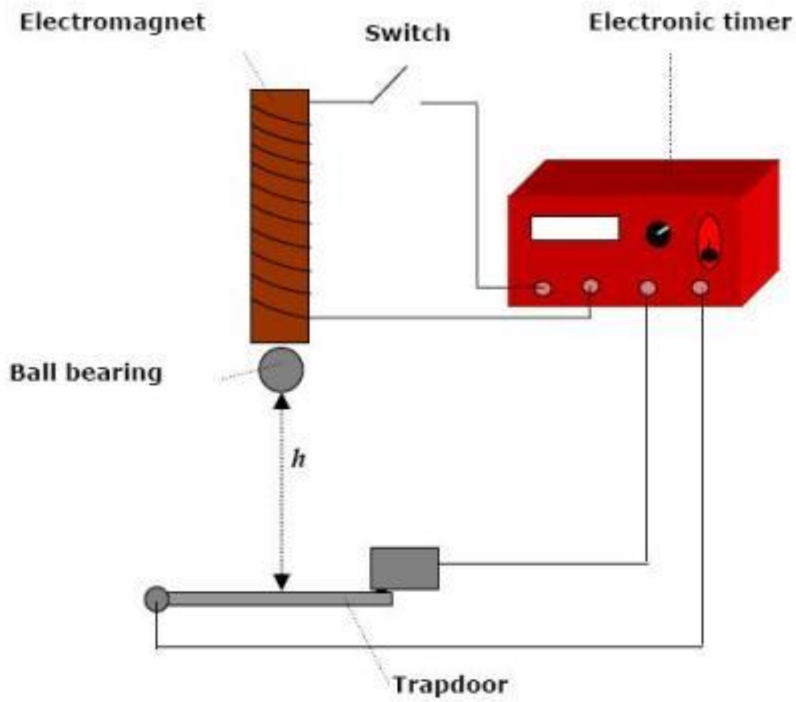
1. Unit of time is missing.
2. Inconsistent significant figures in time and height.
3. Interval in height is inconsistent.
4. No repetition for particular height.
5. Very few readings taken, not enough for drawing a graph, at least 6 sets of reading are required to plot a graph.

Q: Describe an experiment to find the free fall acceleration, g

Requirements:

1. Electromagnet
2. Two way switch
3. Trap door
4. Iron ball
5. Electronic timer

Diagram:



$$h = \frac{1}{2}gt^2$$

$$y = mx$$

$$\text{gradient} = \frac{1}{2}g$$

$$g = 2 \times \text{gradient}$$

Choice of instrument

- Set square is used to make sure the meter rule is vertical.
- Meter rule with millimeter scale is used to measure the height as precision of the meter rule is 1mm.

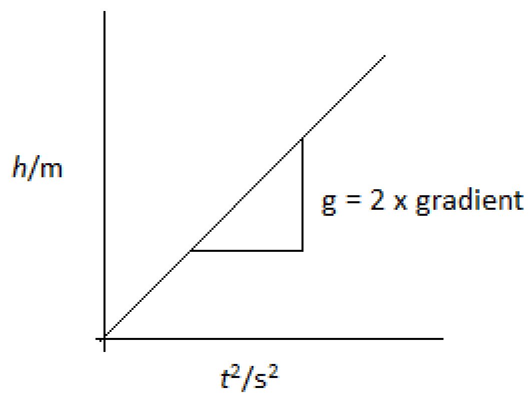
Description

- The switch is connected to A to magnetize the electromagnet.
- Now the height is measured from the bottom of the attracted iron sphere to the trap door using a meter rule.

- Now the switch is connected to B which demagnetized the electromagnet, the sphere is released and the timer starts. The timer stops when the sphere hits the trapdoor. The time is recorded.
- The process is repeated for different heights and corresponding time is recorded.

Calculation

In this experiment the independent variable is height and the dependent variable is time. A graph of h against t^2 is plotted. The graph should be straight line through the origin. The free fall acceleration is found using the gradient of this graph as shown below:



Q: Write down one advantage and one disadvantage if the sphere is released from greater height.
Advantage:

- Percentage uncertainty less

Disadvantage:

- More air resistance

Q: An experiment to demonstrate Hooke's law. You are given a retort stand, a helical spring and some slotted mass.

(a) i. Draw a simple diagram for it to investigate Hooke's law.

ii. What other apparatus is needed to investigate this law. Explain your choice of instrument.

(b) i. Measure the length of spring x_1 before adding any mass. Measure the final length x_2 after adding 100g mass and hence determine extension x for this given load.

ii. Calculate the percentage uncertainty of extension.

(c) i. Repeat process by changing the load until you have four sets of reading. Record all data by using a table.

ii. Criticize your measured value.

iii. Theory suggest that $F = kx$. Use this equation to discuss extent to which the graph should be a straight line or not.

(d) i. Plot a graph of force against extension.

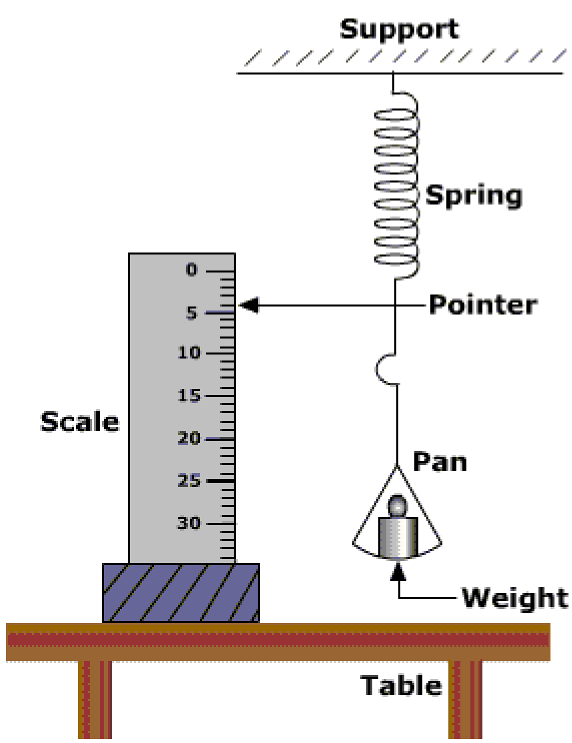
ii. Explain why your graph should or should not pass through the origin.

iii. Calculate the spring constant and elastic potential energy stored in the spring when the load is suspended at the bottom of the spring in 280g.

iv. State and explain two safety precautions.

Ans:

(a) i.



ii. meter rule, because precision of this meter rule is 1mm.

(b) i. $x_1 = 7.5$ cm

$x_2 = 11.2$ cm

$x = x_2 - x_1 = 11.2 - 7.5 = 3.7$ cm

ii. $\%\Delta x = \frac{\Delta x_1 + \Delta x_2}{x_2 - x_1} \times 100\%$
$= \frac{0.1+0.1}{11.2-7.5} \times 100\%$
$= 5.41\%$

(c) i.

mass/kg	initial length/cm	final length/cm	extension/cm	$F = mg$
0.15	7.5	15.1	7.6	1.47
0.2	7.5	19.6	12.1	1.96
0.25	7.5	24.1	16.6	2.45
0.3	7.5	27.5	20	2.94

ii. 1. Very few readings are taken.
2. The readings are not taken in same sig. figures.
3. Unit of force is missing.
4. Repeated readings are not taken for a particular mass.

iii. $F = kx$. If k is constant, the equation is similar to $y = mx$, so the graph should be a straight line.

(d)

ii. The graph should not pass through origin because of systematic error.

iii. $\text{gradient} = \frac{2.9-0.6}{20-100} = 11.5$ Nm^{-1}
spring constant = 11.5 Nm^{-1}

When $m = 280g$,
$F = \frac{280}{1000} \times 9.81 = 2.75$ N

So, $x = 16.65$ cm

EPE = $\frac{1}{2} \times 11.5 \times (16.65 \times 10^{-2})^2$
= 0.159 J

iv. 1. Wear safety goggles.
2. Keep safe distance from the slot of mass hung.

Q: Describe an experiment to find the coefficient of viscosity of glycerine.

For terminal velocity,

$W_s = W_l + \text{Drag force}$

$m_s g = m_l g + \text{Drag force}$

$6\pi r\eta v = m_s g - m_l g$

$6\pi r\eta v = v_s \rho_s g - v_l \rho_l g$

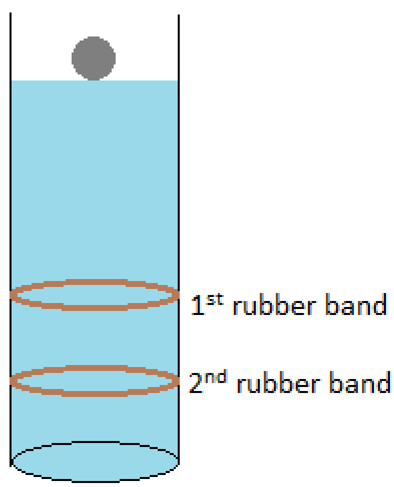
$6\pi r\eta v = \frac{4}{3}\pi r^3(\rho_s - \rho_l)g$

$$v = \frac{2r^2(\rho_s - \rho_l)g}{9\eta}$$

<u>Requirements</u>

1. Tall transparent glass tube
2. Enough glycerin
3. Two rubber bands
4. Different size of sphere made up of same material.

<u>Diagram</u>



<u>Additional apparatus</u>

1. micrometer screw gauge
2. stop watch
3. measuring tape with millimeter scale

<u>Choice of instrument</u>

1. micrometer screw gauge → precision is 0.01 mm.
2. stopwatch → precision 0.01s which is less than the reaction time 0.1s.

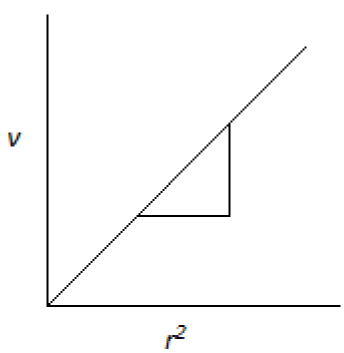
3. measuring tape → precision of instrument is 1mm.

Description

At first the diameter of the sphere is measured, using micrometer screw gauge. The ball is released from the surface of the glycerin and when it reaches the first rubber band, the stopwatch is started and when reaches the 2nd rubber band, the stopwatch is stopped, the time is recorded. The distance between the two rubber band is measured using the measuring tape. Using the formula $v = \frac{x}{t}$, we can find the terminal velocity. We assume that the ball gains terminal velocity before reaching the 1st rubber band. Repeat this process for different diameter of sphere and corresponding velocities are obtained.

Calculation

In this experiment, diameter of a sphere is independent variable and velocity of the sphere is dependent variable. A graph of V against r^2 is plotted. The graph should be a straight line and the coefficient of viscosity can be found by taking the gradient.



$$\underbrace{v}_{y} = \underbrace{\frac{2(\rho_s - \rho_l)g}{9\eta}}_{m} \times \underbrace{r^2}_{x}$$

$$y = mx$$

Therefore, gradient $= \frac{2(\rho_s - \rho_l)g}{9\eta}$

$$\eta = \frac{2(\rho_s - \rho_l)g}{9 \times \text{gradient}}$$

Sources of uncertainty

1. Zero error of micrometer screw gauge
2. Temperature of glycerine

3. Human reaction time while measuring the time taken.

Precaution

1. The sphere should not touch the wall of the tube.
2. Measurements are taken at eye level to avoid parallax error.

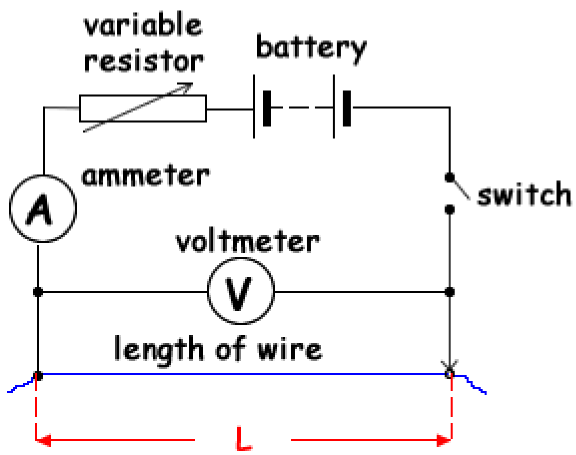
Safety precautions

1. Wearing safety googles

Q: Describe an experiment to find the resistivity of constantan wire

Requirements

1. A fixed length of wire
2. A voltmeter
3. An ammeter
4. A variable resistor



Additional apparatus

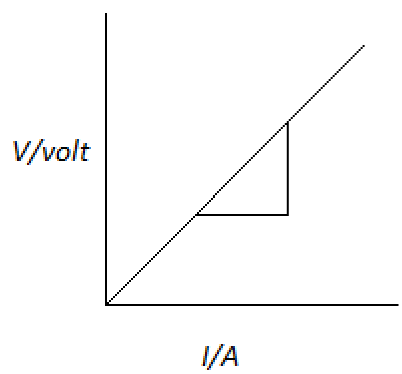
1. Micrometer screw gauge

Choice of instrument

1. Voltmeter and ammeter is used to measure voltage and current.
2. We can change the length of the wire by using the meter rule.
3. Voltmeter gives a precision of 0.1v and the precision of ammeter is 0.1 mA.
4. Precision of micrometer screw gauge is 0.01 mm.

Description

1. Measure the diameter of the wire using micrometer screw gauge.
2. Measure the length of wire using meter rule.
3. Switch is closed and record the voltmeter and ammeter reading.
4. Change the sliding contact point of variable resistor.
5. Record the ammeter and the corresponding voltmeter reading.
6. Repeat this process several times by changing the sliding contact point of variable resistor.
7. Now, a graph of voltage against current is plotted.
8. The gradient of this graph gives resistance.



9. Area of cross-section is found by using $A = \frac{\pi d^2}{4}$ and using the formula $\rho = \frac{RA}{l}$, we can find the resistivity of the wire.

Sources of uncertainty

1. Temperature
2. Zero error of micrometer screw gauge
3. Zero error and parallax error of voltmeter and ammeter

Precaution

1. The wire should be straight while measuring the length.
2. You should wear safety gloves.

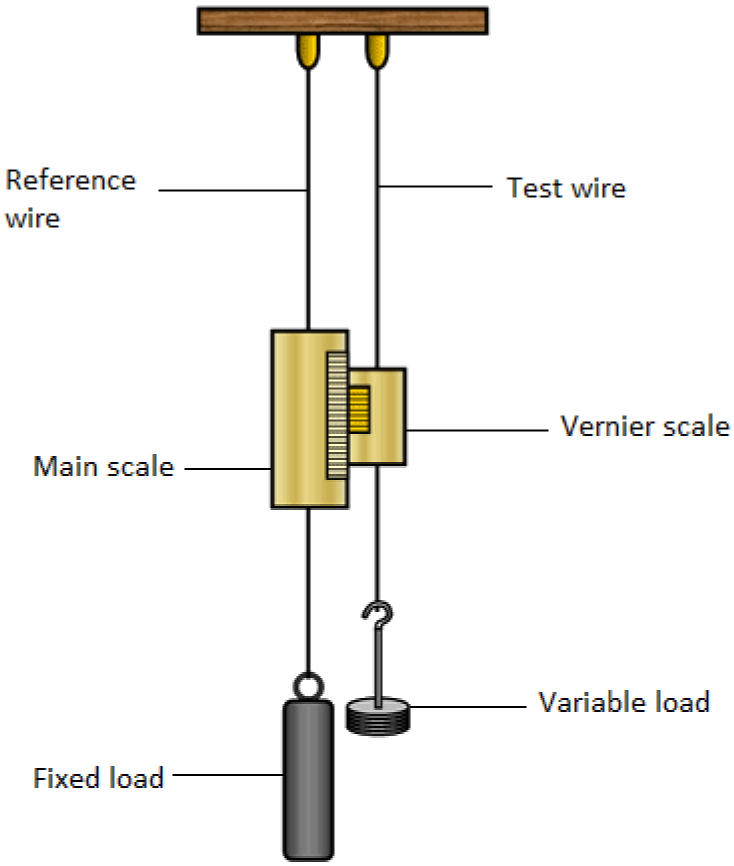
Q: Describe an experiment to find the Young modulus of the copper wire

$$y = \frac{\sigma}{\varepsilon}$$

$$= \frac{F/A}{\Delta x/x}$$

Requirements

1. A long wire
2. A reference wire
3. Vernier calipers
4. Variable loads



Additional requirements

1. Micrometer screw gauge: Precision 0.01 mm
2. Measuring tape: Precision is 1 mm
3. Vernier scale: Precision 0.01 cm

Description

1. The length of the test wire is found by measuring tape and the diameter is found by micrometer screw gauge.
2. Apparatus is setup as in diagram

3. A small fixed load is suspended at the bottom of the reference wire and Vernier scale reading is taken when the wire is in its original length.
4. Variable loads are then suspended under the test wire until the test wire is straight and Vernier scale reading is taken.
5. Initial length is subtracted from the final length.
6. The experiment is repeated with different other loads and a series of extension is taken.

Calculation

Area of cross-section is found by the formula.

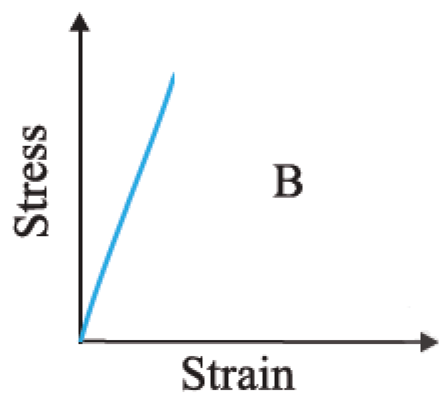
$$A = \frac{\pi d^2}{4}$$

Stress is found by the formula $\sigma = \frac{mg}{A}$.

Strain is found by the formula $\varepsilon = \frac{\Delta x}{x}$

In this experiment, dependent variable is stress and independent variable is strain.

Graph of stress against strain is plotted.



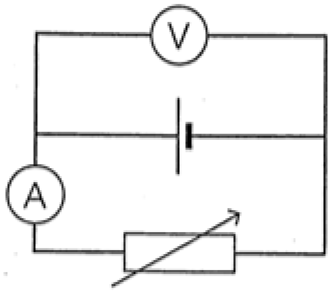
Safety precaution

1. Wear safety googles
2. Keep the feet away from the load.

Sources of uncertainty

1. Zero error of micrometer screw gauge.
2. Diameter of wire.
3. Measurement of extension.

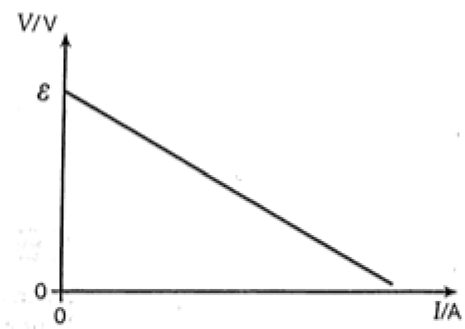
Q: Describe an experiment to determine the internal resistance of battery. You are given a variable resistor, a battery, a voltmeter, an ammeter and some connecting wires. You are given a load resistor.



Starting with the variable resistor at its highest value (to minimize any heating effect), record the current I in the cell and the potential difference, V across its terminals for different settings of the rheostat.

We know, $V = E - Ir$

If a graph of V against I is plotted, we would expect to get a straight line of gradient $-r$ and intercept E on the y-axis.



Significant figures

1. All non-zero numbers (1, 2, 3, 4, 5, 6, 7, 8, 9) are always significant.
2. All zero between non-zero numbers are always significant.
3. All zeroes which are simultaneously to the right of the decimal point and at the end of the number are always significant.
4. All zero which are to the left of the written decimal point and are a number >= 10 are always significant.

Number	**S.F**
48923	5
3.967	4
900.06	5
0.0004	1
8.1000	5
501.040	6
3000000	1

Prefixes

Prefix	**Symbol**	**Multiple**
pico	P	10^{-12}
nano	n	10^{-9}
micro	µ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

SI units

Base quantity	**Base unit**	**Symbol**
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Current	Ampere	A
Temperature interval	Kelvin	K
Amount of substance	Mole	mol

Derived units

Quantity	Derived units	Base units
Speed		ms^{-1}
Acceleration		ms^{-2}
Force	newton (N)	$kgms^{-2}$
Pressure	pascal (Pa)	$kgm^{-1}s^{-2}$
Work	joule (J)	$kgm^{-2}s^{-3}$
Power	watt (W)	$kgm^{-2}s^{-3}$
Charge	coulomb (C)	As
Potential difference	volt (V)	$kg\ m^{-2}A^{-1}s^{-3}$
Resistance	ohm (Ω)	$kg\ m^{-2}A^{-2}s^{-3}$