

Calculation

D.P. rule Whenever calculating two values that <u>only</u> involve addition and subtraction, the calculated value adopts the least d.p., with a minimum of 0d.p.	S.F. rule Any calculation that involves operators other than addition and subtraction, the calculated value adopts the least s.f., with a minimum of 2s.f.
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Graphical analysis

Plot Y against X , based on the given equation and determine the relationship of the graph.		
<u>Proportional relationship</u> When two quantities are directly or inversely proportional to each other. 1. The graph is a straight line 2. Passes through the origin (0,0)	<u>Linear relationship</u> When two quantities are linearly related. 1. The graph is a straight line.	<u>Non-linear relationship</u> Two quantities create a graph that is curved.
$Y = kX$	$Y = mX + C$	$Y = f(X)$
<u>Constant relationship</u> When two quantities are independent of each other, the graph produces a straight horizontal line.	Note: Some graphs are expected to pass through the origin based on the physical relationship between the variables. - For example, if the dependent variable represents the change caused by a limiting reactant, adding 0 volume of the reactant should produce 0 change in the system. Therefore, the graph should pass through the origin (0, 0).	
$Y = k$		

Quantity Algebra: both the numerical magnitude and unit of a quantity are substituted for its symbol in the equation.	Number Algebra: only the numerical magnitude of a quantity is substituted for its symbol in the equation, converted to the usual units by applying the appropriate multiplying factor.
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Errors and uncertainty

Systemic error Constant deviations of the readings in one direction from the true value. - Zero error - Reaction time - Wrongly calibrated scale Systematic errors can be reduced by calibration curves and control experiments.
Random error Measurements are scattered around a mean value. - Reading a scale by interpolation - Timing oscillations without a reference marker - Taking readings of a quantity that varies with time. - Parallax error. Random error can be mitigated by averaging the values, repeating the experiment or by drawing a graph.
Accuracy: how close a measurement is to the actual value - Note: accuracy has a 10% range from the true value. Precision: how close the measurements are to each other, or to a mean value

Uncertainty is a range of values in which a measurement can fall.

- Uncertainty of a digital equipment is one unit of the smallest scale of the instrument.
- Uncertainty of an analogue instrument is half the smallest division of the scale.

$$M_1 = M_0 \pm \delta_M$$

Average of values, $\sigma_m = \frac{\sum^n x}{n}$

$$\sigma_{m1} = \sigma_m \pm \frac{\max(x) - \min(x)}{2}$$

- Note: when calculating the mean of values, it follows the d.p. rule

Absolute uncertainty, δ

$$\text{Percentage uncertainty, } P_M = \frac{\delta_M}{M_0} \times 100\%$$

Addition or subtraction of uncertainties, $(A_0 + B_0) \pm (\delta_A + \delta_B)$

Multiplication or division of uncertainties, $A_0 B_0 \pm A_0 B_0 (P_A + P_B)$

Power or root of uncertainties, $A_0^K B_0^J \pm A_0^K B_0^J (|K|P_A + |J|P_B)$

Note: d.p. Of both must be the same.

Increasing accuracy

When measuring the diameter of an object, take repeated readings at different positions across the diameter, finding the average of all the readings.

When measuring the time taken, take repeated readings, finding the average of all the readings.

Precision of instrument

For digital measuring instruments, the measurement uncertainty is typically ± 1 in the last displayed digit. Therefore, record all the digits shown by the display.

- Example: If a digital micrometre displays 12.3456 mm, record 12.3456 mm $\pm$ 0.0001 mm. Do not round it to 12.346 mm.
- Includes: Digital multimeter, digital micrometre screw gauge, digital vernier callipers.

For analogue measuring instruments with discrete scale divisions, the measurement uncertainty is typically $\pm \frac{1}{2}$ of the smallest scale division.

- Example: A metre rule has the smallest division of 0.1 cm (1 mm), so the uncertainty is ± 0.05 cm (± 0.5 mm). Measurements are therefore estimated to the nearest 0.05 cm.
- Includes: voltmeter, ammeter, thermometer, ruler, vernier callipers, micrometre screw gauge.

Systematic error

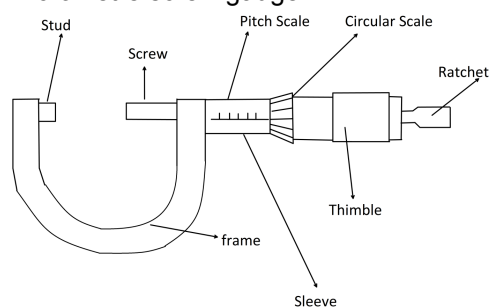
A consistent, repeatable deviation in one direction.

Procedural error

An issue with the design of the experiment.

Using tools

Micrometre screw gauge

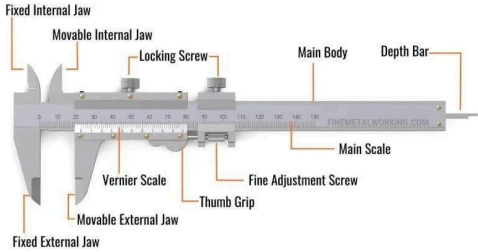


Sleeve (Pitch) Scale:

The sleeve (pitch) scale measures the length to the nearest 0.5 mm. Each division on the sleeve represents 0.5 mm. Read the last visible marking on the sleeve before the edge of the thimble.

Thimble (Circular) Scale:

The thimble (circular) scale measures to the nearest 0.01 mm. Each division on the thimble represents 0.01 mm. Read the value on the thimble that aligns with the reference line on the sleeve.

	Final Reading: The measurement is obtained by adding the sleeve (pitch) scale reading and the thimble (circular) scale reading.
Vernier Calipers 	Main Scale: The main scale measures the length to the nearest 1 mm (0.1 cm). Read the value immediately to the left of the Vernier zero. Vernier Scale: The Vernier scale measures the fractional part of the reading to the nearest 0.1 mm (0.01 cm). Identify the Vernier division that aligns exactly with a division on the main scale. Multiply the Vernier division number by 0.1 mm to obtain the Vernier reading. Final Reading: Add the main scale reading and the Vernier scale reading to obtain the total measurement.

Method for planning experiments

Aim → Variables → Apparatus → Method → Calculation → Graph → Accuracy → Errors → Assumptions

Improving the experiment

Improvement → Mechanism → Effect on measurement

Experiments

Independent variable: the variable you can directly change

- Indirectly changing variables are resistance, current, voltage, etc. These changes are affected by another change, like a rheostat.

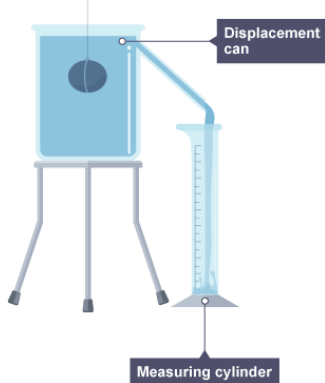
Dependent variable: the variable that changes as a result of changing the independent variable.

- Otherwise, the value you are reading.

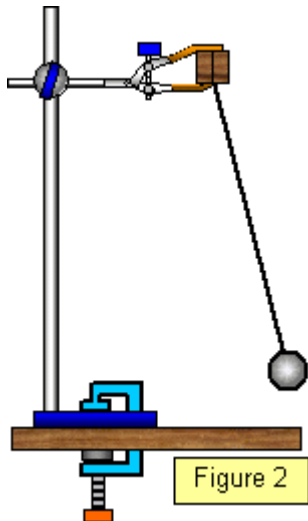
Control variable: conditions of the system that should remain constant.

Measuring density

Volume

	Setting up: 1. Add the liquid to a displacement can, which leads to a measuring cylinder. 2. Tie the object tightly to a rope, and attach the end of the rope to a retort stand. Experimental procedure(: 1. Slowly release the rope on the retort stand so that the object slowly descends into the liquid. 2. Once the object is fully submerged, measure the volume of the liquid displaced into the measuring cylinder. Record this volume as V. 3. Repeat steps 1 to 2 for new values of V, ensuring that the object is dried afterwards and the liquid is refilled. 4. Calculate the average volume by taking the average of V.
Accuracy: 1. Volume of liquid collected - Use a liquid with low viscosity. - This allows the displaced liquid to flow quickly and completely into the measuring cylinder, reducing the amount of liquid retained in the displacement can and therefore reducing the error in the measured volume. 2. Measurement of volume - Use a measuring cylinder with a smaller scale division to measure the volume of displaced liquid, and read the bottom of the meniscus at eye level to reduce parallax error.	
Assumptions: 1. The string has negligible effect on the volume of displaced water. 2. The object and string have negligible absorbancy.	
Mass	
	Setting up: 1. Before measuring, press the zero button to set the current value to 0 Experimental procedure: 1. Place the object on the electronic balance, and wait for the value to stabilise. 2. Measure the value on the electronic balance. Record the mass as M.
Accuracy: 1. Zeroed - To prevent systematic errors due to improper calibration of the electronic balance, press the zero button to ensure the initial value is 0.	
Density	
Experimental procedure: 1. Calculate the density by $\rho = \frac{M}{V}$	

Pendulum



Setting up:

1. Insert an optical pin into the cork.
3. Clamp the cork to the retort stand.
4. Tie one end of the string to a pendulum bob and the other end to the optical pin.
5. Place the retort stand near the edge of the table.
6. Adjust the set-up so that there is a gap between the string and the table.

Experimental procedure:

1. Pull the pendulum bob slightly, making a slight angle displacement.
2. Measure the angle displacement with a protractor. Record angle displacement as θ_1 .
3. Measure the time taken for 20 oscillations using a digital stopwatch. Record the time taken as $t_{20,1}$.
4. Repeat step 3 again for another 20 oscillations. Record the second reading as $t_{20,2}$.
5. Calculate the average time, $\langle t \rangle = \frac{t_{20,1} + t_{20,2}}{2}$.
6. Calculate the average period, $T = \frac{\langle t \rangle}{20}$.
7. Repeat steps 1 to 6 with different initial angle displacements, obtaining new values of $\langle t \rangle$ and T .
8. Tabulate the recorded values in a table.

Graphical analysis,

1. $T^2 \propto L$

Accuracy:

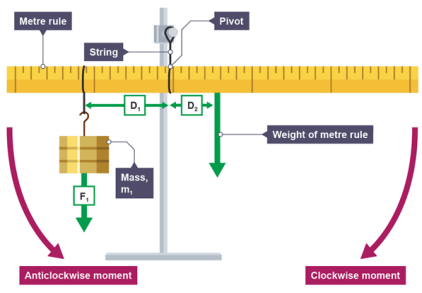
1. Measuring length of string
 - When measuring the length of the pendulum, place the metre rule perpendicular to the ground with the zero mark touching the floor.
 - Place a short rule perpendicular to the metre rule, where the top of the short rule touches the bottom of the bob. Record the reading on the metre ruler based on the position of the short rule, x_1 .
 - Place the short rule at the top of the pendulum. Record the reading on the metre ruler based on the position of the short rule, x_2 .
 - The length of the pendulum is calculated by, $L = x_2 - x_1$
2. Measuring the period
 - Human reaction time is around 0.4 s; hence, if the period nears this range, measuring the period of the pendulum directly will give an inaccurate result.
 - By measuring the oscillations more than or equal to 20 times, it reduces the uncertainty in measurement due to human reaction time, thereby reducing inaccuracy.
3. Identifying an oscillation
 - Add a fiducial marker at the centre to indicate the start and end point of an oscillation.
 - When the bob passes the fiducial marker 3 times, it is one oscillation.
4. Small angle displacements

Assumptions:

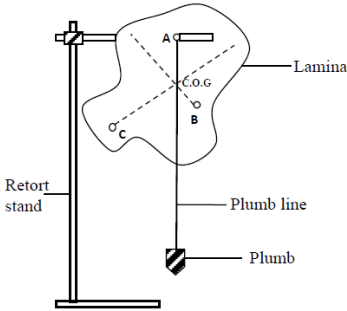
1. Air resistance and resistive forces in the pivot are negligible.
2. The initial angular displacement is sufficiently small such that $\sin(\theta) \approx \theta$, allowing the

pendulum to undergo approximately simple harmonic motion.

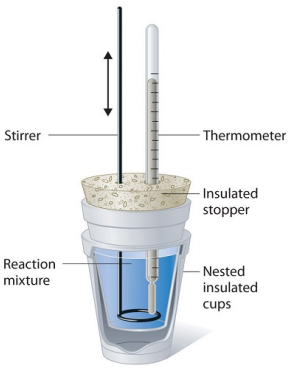
Turning effects of a force

	Setting up: 1. Insert the sharp end of the optical pin through the small hole in the metre rule. 2. Place the sharp end of the optical pin between the two halves of the split cork. Then, clamp the split cork at a height above the tabletop. 3. Ensure the metre rule is centred. 4. Ensure that the metre rule is able to rotate freely about the pin in both the clockwise and anti-clockwise directions. Experimental procedure: 1. Hang the first mass, M_1, onto the metre rule at some fixed distance from the pivot. Record this distance from the pivot as d_1. 2. Hang the second mass, M_2, onto the other side of the metre rule, and shift it until the metre rule is stable. Record this distance from the pivot as d_2. 3. Repeat steps 1 to 2 for different initial distances, d_1, recording the new values of d_2. 4. Tabulate the recorded values in a table. Graphical analysis: 1. $d_2 \propto d_1$ 2. $M_2 \propto M_1$
Accuracy: 1. Centring the ruler - Use a ruler with clearly marked graduations. - View the ruler perpendicularly with a set square from directly above to minimise parallax error when aligning its centre with the reference point. 2. Placing the masses - Gently place the mass on the metre rule. - This is to prevent oscillations and displacement of the apparatus, ensuring that the ruler reaches static equilibrium before taking measurements. 3. Taking measurements - Ensure that the metre ruler is in static equilibrium when measuring.	
Assumptions: 1. The ruler has uniform density, and its centre of mass is at the centre of the ruler. 2. The resistance between the pivot and the metre ruler has negligible moment. 3. The centre of gravity of the masses is directly below the hook.	

Finding the centre of gravity

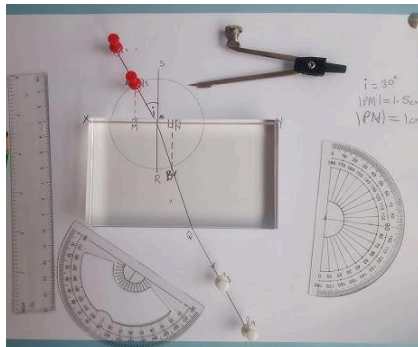
	Setting up: 1. Suspend the Lamina on a retort stand, using an optical pin to secure the Lamina. 2. Suspend a plumb line from the optical pin. 3. Ensure that the Lamina is able to rotate freely. Experimental procedure: 1. Slightly displace the Lamina and allow it to swing. 2. When the plumb line is not moving, mark two points on the Lamina that are far apart. 3. Remove the plumb line and join the two points with a line. 4. Remove the lamina from the retort stand. 5. Set up the experiment again with a new pivot, securing this new point with an optical pin. 6. Repeat steps 1 to 5. 7. Label the intersection of the two lines as CG. This is the centre of gravity of the Lamina.
Accuracy: 1. Marking the points - When marking the positions of the two points, ensure that the plumb line is as close to the Lamina as possible to reduce parallax error. 2. Confirming the position is the centre of gravity. - After marking CG, remove the Lamina from the retort stand and set up the experiment again with a new pivot. - Displace the Lamina and allow it to swing. - If the point of CG is correct, when the Lamina stops moving, the plumb line overlaps CG.	
Assumption: 1. The friction between the Lamina and pin has negligible effect. 2. The shape of the Lamina is constant.	

Heat capacity of something

	Setting up: 1. Pour a liquid into the Styrofoam cup. 2. Place an immersion heater into the liquid, ensuring that the heating element is fully submerged but not touching the sides or bottom of the container. 3. Place a thermometer in the liquid, ensuring that it does not touch the heater or the container. 4. Cover the Styrofoam cup with a lid, ensuring that the thermometer is readable. Experimental procedure (For liquid): 1. Measure the mass of the liquid on an electronic balance. Record the mass as M. 2. Set up the experiment. 3. Stir the liquid gently and record its initial temperature, T_1. 4. Connect the immersion heater to the power supply and switch it on. Record the current I and resistance R of the heater. 5. Start the stopwatch simultaneously with switching on the heater. 6. Heat the liquid for a measured time t. 7. Stir the liquid gently and continuously to distribute the heat
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	evenly throughout the liquid. - After time t, switch off the heater and record the final temperature, T_2. - Calculate temperature change, $\Delta T = T_2 - T_1$ - Calculate the electrical energy supplied to the heater, $E = Pt = I^2 R t$ - Calculate the specific heat capacity of the liquid, $c = \frac{E}{M \Delta T}$. - Repeat steps 1 to 11 for more values of ΔT, E, M, and c. - The average of the calculated c is the specific heat capacity of the liquid. Experimental procedure (For solid): - Measure the mass of the solid on an electronic balance. Record the mass as M_s. - Measure the mass of the known liquid on an electronic balance. Record the mass as M_l. - Place the solid in a beaker of water and heat it using a heater until the solid reaches a known temperature, T_s. Keep the solid completely submerged. - Measure and record the initial temperature of the liquid, T_l. - Quickly remove the heated solid and transfer it into the insulated container containing the liquid. - Ensure that the solid is completely submerged. - Cover the container with a lid and stir the liquid gently to ensure that the temperature becomes uniform. - Monitor the temperature until it reaches a maximum constant value. - Record this as the final equilibrium temperature, T_E. - Calculate the specific heat capacity of the solid, $c_s = \frac{M_l c_l (T_E - T_l)}{M_s (T_s - T_E)}$ - Repeat steps 1 to 10 for more values of c_s. - The average of the calculated c_s is the specific heat capacity of the solid.
	Accuracy: - Reducing heat loss - Perform the experiment using insulating materials to prevent heat loss of the object. Or add a lid. - This reduces error in the calculations of the specific heat capacity. - Thermometer reading - Stir the liquid to ensure that heating is uniform, thus ensuring that the thermometer measures the average temperature of the liquid. - Ensure that the thermometer does not come into contact with the solid or the container walls, as this prevents heat transfer between them and the thermometer, reducing systematic error in the temperature measurement.
	Assumptions: - Temperature is uniform. - The system is in thermal equilibrium at those instances. - There is negligible heat loss to the surroundings.

Refractive index of glass



Setting up:

1. Set the glass block flat in the middle of a sheet of paper.
2. Draw a normal line to one of the longer faces of the glass block at a chosen point of incidence.

Experimental procedure:

1. Draw an incident ray making a known angle i with the normal.
2. Place two pins vertically along the incident ray.
3. Looking through the opposite side of the glass block, place two more pins so that they appear to be in line with the images of the first two pins.
4. Remove the glass block and mark the positions of all four pins.
5. Draw a straight line through the positions of the two pins on the incident side. This gives the incident ray.
6. Draw a straight line through the positions of the two pins on the opposite side. This gives the emergent ray.
7. Extend the incident ray to the point where it meets the glass surface.
8. Draw the refracted ray inside the glass by joining the appropriate points on the two surfaces.
9. Measure the angle of refraction, r , using a protractor
10. Calculate the $\sin(i)$ and $\sin(r)$.
11. Tabulate the recorded values in a table.

Graphical analysis:

1. $\sin(r) \propto \sin(i)$

Accuracy:

1. Choosing the angle of incidence i
 - It is not viable to choose angles of incidence less than 30° , as the deviation of the angle due to refraction would become less noticeable.

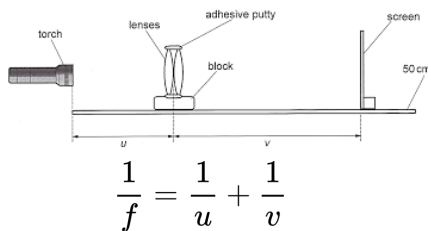
2. Path of light

- Instead of using one pin to define a ray, use two pins separated by a large distance.
- A larger separation makes the line of the ray easier to establish accurately.
- When aligning the second pair of pins, look through the glass so that the images of the first two pins appear to line up with them.
- Alternatively, instead of using pins, replace the light source with a laser pointer, which can minimise parallax error and show a clearer path of the light ray.

Assumption:

1. The transparent object is optically homogeneous, and the refractive index is constant throughout the glass block.
2. The glass has negligible absorption of the light.
3. The light source has a wavelength range that is narrow enough that dispersion effects are negligible.

Converging lens



Setting up:

1. Attach the torchlight to the retort stand. Use a set square to ensure that the torchlight is perpendicular to the ground.
2. Using a short ruler as a marker of the head of the torchlight, align the metre rule to start at the head of the torchlight.
3. Using a set square, align the lens and the screen to be perpendicular to the metre ruler.

Experimental procedure:

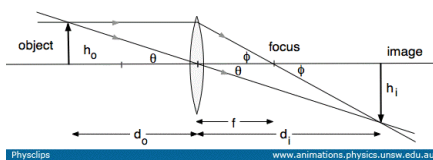
1. Place the screen d metres away from the torchlight.
2. Place the lens at the torchlight and shift the lens away from the torchlight until a focused image forms on the screen.
3. Measure the distance and record it as u_1 .
4. Place the lens at the screen and shift the lens towards the torchlight until a focused image forms on the screen.
5. Measure the distance and record it as u_2 .
6. Calculate the focal length by taking the average of u_1 and u_2 ; record the average as u .
7. Repeat steps 1 to 6 for different initial d , obtaining new values of u .
8. Tabulate the recorded values.

Graphical analysis:

1. $u = m \frac{u}{v} + c$
2. $uv \propto (u + v)$

Accuracy:

1. Finding the focal length.
 - The lens is moved towards the point of focus from opposite directions to bracket the position of the sharpest image.
 - The mean of the two readings is taken, reducing uncertainty due to subjective judgement of when the image is in focus.
2. Focus of image
 - Ensure the object, lens and screen are at approximately the same height and aligned along the same axis.
 - Use a set-square to ensure the heights are the same.



Setting up:

1. Attach the torchlight to the retort stand. Use a set-square to ensure that the torchlight is perpendicular to the ground.
2. Using a short ruler as a marker for the head of the torchlight, align the metre rule to start at the head of the torchlight.
3. Using a set square, align the lens and the screen to be perpendicular to the metre ruler.
4. Attach the triangular hole to the torchlight.

Experimental procedure:

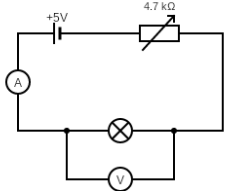
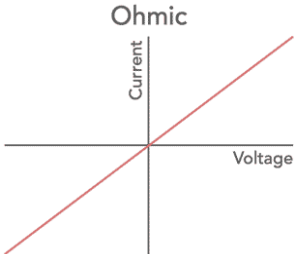
1. Measure the height of the triangular hole. Record the initial height as H_0

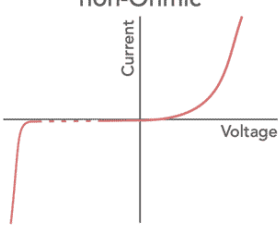
	- Place the torchlight, u, away from the lens, ensuring that it is greater than the focal length. - Shift the screen towards the lens to get a sharp image; approach the focused position from both directions and take the average position. - Measure the distance of the screen from the lens. Record the distance as v. - Measure the height of the image formed using a ruler. Record the image's height as H_1. - Calculate the magnification as $m = \frac{H_1}{H_0}$. - Calculate the ratio of distances, $\frac{v}{u}$. - Repeat steps 1 to 7 for different lengths u, obtaining new values of m, v and $\frac{v}{u}$. - Tabulate the recorded values. Graphical analysis: $m \propto \frac{v}{u}$
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Assumptions:

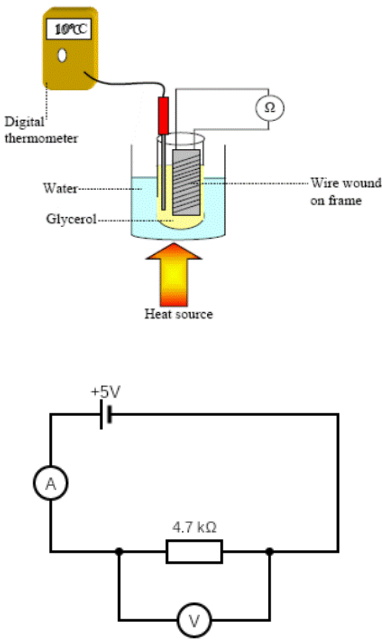
- The lens is a thin lens, so the optical centre of the lens can be treated as a single point from which u and v are measured.
- The lens is approximately ideal, with negligible spherical and chromatic aberration.
 - This means there is a well-defined position where the image is sharp.
- The object, lens and screen are aligned along the same principal axis.
- The screen is perpendicular to the principal axis, so the image is not distorted.
- The image is considered focused when it appears sharp to the observer.
- This assumes the observer can reliably judge focus.

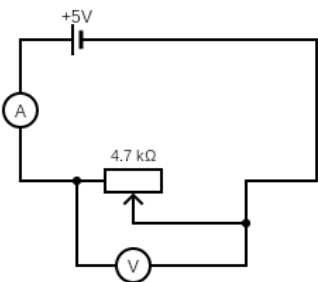
Circuit component

	Setting up: - Build the circuit as shown in the diagram - Positive terminals to the battery's positive terminal. - Negative terminals to the battery's negative terminal.
Ohmic conductors:  Non-Ohmic conductors	Experimental procedure (Resistance): - Shift the variable resistor to change the value of the current to a certain initial value, I. - Measure the reading on the voltmeter. Record the voltage as V. - Calculate R by taking the ratio, $R = \frac{V}{I}$ - Repeat steps 1 to 3 for different initial values of I, obtaining new values of R. - Tabulate the recorded values. Graphical analysis: $R \propto \frac{1}{I}$ $V \propto I$

non-Ohmic 	
	Experimental procedure (Power): 1. Shift the variable resistor to change the value of the current to a certain initial value, I. 2. Measure the reading on the voltmeter. Record the voltage as V. 3. Calculate power by $P = VI$ 4. Repeat steps 1 to 3 for different initial values of I, obtaining new values of P. 5. Tabulate the recorded values.

Circuit resistor

Resistance and temperature relation	
	Setting up: 1. Set up a circuit as shown in the diagram. 2. Set up a water bath. 3. Submerge the resistor in the water, ensuring that it does not touch the container's side or the heat source. 4. Submerge a thermometer in with the resistor, ensuring that it does not touch the container's side or the heat source. Experimental procedure: 1. Heat the system until a certain temperature. 2. Measure the reading on the thermometer. Record the temperature as θ. 3. Measure the reading on the ammeter. Record the current as I. 4. Measure the reading on the voltmeter. Record the voltage as V. 5. Calculate the resistance by taking the ratio, $R = \frac{V}{I}$. 6. Repeat steps 1 to 5 for different temperatures θ, obtaining new values of R. 7. Tabulate the recorded values. Graphical analysis: 1. $R = m\theta + C$
Resistance and length relation	



Setting up:

- Set up a circuit as shown in the diagram.

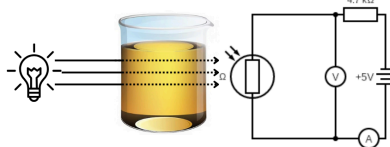
Experimental procedure:

- Set the jockey distance away from the connecting junction. Record this distance as L .
- Measure the reading on the ammeter. Record the current as I .
- Measure the reading on the voltmeter. Record the voltage as V .
- Calculate the resistance by taking the ratio, $R = \frac{V}{I}$.
- Repeat steps 1 to 4 for different distances L , obtaining new values of R .
- Tabulate the recorded values.

Graphical analysis:

- $R \propto L$

LDR, concentration of solution



Setting up:

- Set up a circuit as shown in the diagram.

Experimental procedure:

- Add 100.0cm^3 liquid **X** using a measuring cylinder into a beaker, U_1 .
- Add 50.0cm^3 water using a measuring cylinder into the same beaker, U_2 .
- Stir the solution in the beaker to ensure that **X** mixes with the water.
- Switch on the light source and allow it to warm up for a fixed period of time before taking measurements.
- Measure and record the potential difference across the LDR, V .
- Measure and record the current through the circuit, I .
- Calculate the resistance across the LDR, $R = \frac{V}{I}$.
- Repeat steps 1 to 7 for different volumes of **X** and water, ensuring that the total volume is 150.0cm^3 i.e,

U_1/cm^3	U_2/cm^3	V/V	I/A	R/Ω
0.0cm^3	150.0cm^3	:	:	:
10.0cm^3	140.0cm^3	:	:	:
:	:	:	:	:
150.0cm^3	0.0cm^3	:	:	:

- Tabulate the recordings.

Graphical analysis:

	1. As the volume of X increases, the resistance of the LDR increases, with an increasing gradient. 2. As the volume of X increases, the potential difference across the LDR increases, with a decreasing gradient.
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Crucial equations

Density: $\rho = \frac{m}{V}$	Pendulum: $mL^2\dot{\theta}^2 + mgL \sin(\theta) = 0$ Small angle approximation, $\sin(\theta) \approx \theta$	Torque/Moment: $\tau = \vec{F} \times \vec{r}$
Thermal energy of a substance: $dU = d(mc\theta)$	Snell's law: $n_1 \sin(\theta_i) = n_2 \sin(\theta_r)$	Convergent lens: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
Height of the image $h' = h_0 \frac{f}{f - u} = h_0 \frac{f - v}{f}$	Ohm's law $V = IR$	Potential divider equation: $V_{\Delta} = \frac{R}{R + r} \varepsilon$
Resistance with temperature $R \approx m\theta + R_0$	Resistance and resistivity $R = \rho_r \frac{L}{A}$	Beer-Lambert law $I = I_0 e^{-\alpha \Delta x}$