



A2 Edexcel Physics Unit 6 Revision

Objectives

able to:

- choose measuring instruments according to their sensitivity and precision
- identify the dependent and independent variables in an investigation and the control variables
- use appropriate apparatus and methods to make accurate and reliable measurements
- tabulate and process measurement data
- use equations and carry out appropriate calculations
- plot and use appropriate graphs to establish or verify relationships between variables
- relate the gradient and the intercepts of straight line graphs to appropriate linear equations.
- distinguish between systematic and random errors
- make reasonable estimates of the errors in all measurements
- use data, graphs and other evidence from experiments to draw conclusions
- use the most significant error estimates to assess the reliability of conclusions drawn

Significant figures

1. All non-zero digits are significant.
2. Zeros are only significant if they have a non-zero digit to their left.

In the examples below significant zeros are in **red**.

$$2\mathbf{0}3 = 3\text{sf}$$

$$023 = 2\text{sf}$$

$$23\mathbf{0} = 3\text{sf}$$

$$0.034 = 2\text{sf}$$

$$0.034\mathbf{0} = 3\text{sf}$$

$$0.03\mathbf{0}4 = 3\text{sf}$$

$$5.45 = 3\text{sf}$$

$$5.4\mathbf{0}5 = 4\text{sf}$$

$$5.45\mathbf{0} = 4\text{sf}$$

$$0.037 = 2\text{sf}$$

$$1.\mathbf{0}37 = 4\text{sf};$$

$$1.\mathbf{0}37\mathbf{0} = 5\text{sf}$$

Example

Consider the number **3250.040**

It is quoted to **SEVEN** significant figures

SIX s.f. = **3250.04**

FIVE s.f. = **3250.0**

FOUR s.f. = **3250** (This is NOT 3 s.f.)

THREE s.f. = **325×10^1** (as also is **3.25×10^3**)

TWO s.f. = **33×10^2** (as also is **3.3×10^3**)

ONE s.f. = **3×10^3** (3000 is FOUR s.f.)

10^3 is **ZERO** s.f. (Only the order of magnitude)

Complete:

number	s.f.	number	s.f.
3.24	3	2.0×10^5	2
0.0560	3	9×10^{23}	1
780	3	0.073×10^3	2
400	3	10^{-3}	0
7.83×10^5	3	030×10^6	2

Significant figures in calculations

Example: Calculate the volume of a metal of mass 3.52g if a volume of 12.3cm³ of the metal has a mass of 55.1g.

density of metal = mass / volume

= 55.1 / 12.3 (original information given to 3sf)

= 4.4797

(Intermediate calculations should be performed to at least 2sf more than the original information – calculator had '4.4796747')

volume = mass / density

= 3.52 / 4.4797

= 0.78576

volume = 0.786 cm³

(The final answer should be given to the same sf as the original information.)

Results tables

potential difference / V	current / A			average current / A
	1st set	2nd set	3rd set	
3.05	0.15	0.13	0.14	0.14

Headings should be clear

Physical quantities should have units

All measurements should be recorded (not just the 'average')

Correct s.f. should be used.

The average should have the same number of s.f. as the original measurements.

Sensitivity

The sensitivity of a measuring instrument is equal to the output reading per unit input quantity.

For example an multimeter set to measure currents up to 20mA will be ten times more sensitive than one set to read up to 200mA when both are trying to measure the same 'unit' current of 1mA.

Precision

A precise measurement is one that has the maximum possible significant figures. It is as exact as possible.

Precise measurements are obtained from sensitive measuring instruments.

The precision of a measuring instrument is equal to the smallest non-zero reading that can be obtained.

Examples:

A metre ruler with a millimetre scale has a precision of $\pm 1\text{mm}$.

A multimeter set on its 20mA scale has a precision of $\pm 0.01\text{mA}$.

A less sensitive setting (200mA) only has a precision of $\pm 0.1\text{mA}$.

Accuracy

An accurate measurement will be close to the correct value of the quantity being measured.

Accurate measurements are obtained by a good technique with correctly calibrated instruments.

Example: If the temperature is known to be 20°C a measurement of 19°C is more accurate than one of 23°C .

An object is known to have a mass of exactly 1kg. It has its mass measured on four different scales. Complete the table below by stating whether or not the reading indicated is accurate or precise.

scale	reading / kg	accurate ?	precise ?
A	2.564		
B	1		
C	0.9987		
D	3		

Reliability

Measurements are reliable if consistent values are obtained each time the same measurement is repeated.

Reliable: 45g; 44g; 44g; 47g; 46g

Unreliable: 45g; 44g; 67g; 47g; 12g; 45g

Validity

Measurements are valid if they are of the required data or can be used to give the required data.

Example:

In an experiment to measure the density of a solid:

Valid: mass = 45g; volume = 10cm³

Invalid: mass = 60g (when the scales read 15g
with no mass!);

resistance of metal = 16Ω (irrelevant)

Dependent and independent variables

Independent variables CHANGE the value of dependent variables.

Examples:

Increasing the mass (INDEPENDENT) of a material causes its volume (DEPENDENT) to increase.

Increasing the loading force (INDEPENDENT) increases the length (DEPENDENT) of a spring

Increasing time (INDEPENDENT) results in the radioactivity (DEPENDENT) of a substance decreasing

Control variables.

Control variables are quantities that must be kept constant while some independent variable is being changed to see its affect on a dependent variable.

Example:

In an investigation to see how the length of a wire (INDEPENDENT) affects the wire's resistance (DEPENDENT). Control variables would be wire:

- thickness
- composition
- temperature

Plotting graphs

Graphs are drawn to help establish the relationship between two quantities.

Normally the **dependent** variable is shown on the **y-axis**.

If you are asked to plot **bananas** against **apples** then bananas would be plotted on the **y-axis**.

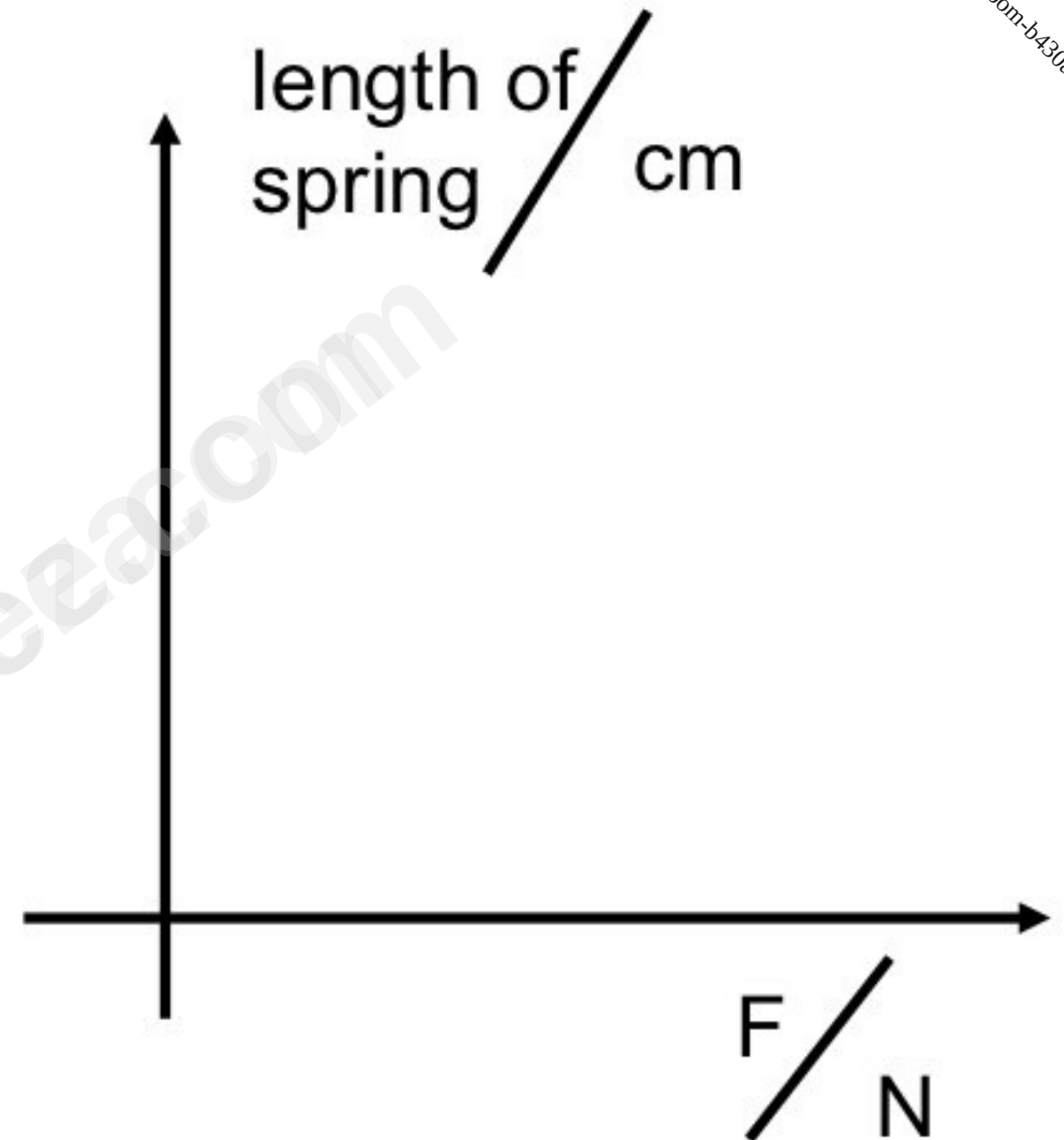
Each axis should be labelled with a quantity name (or symbol) and its unit.

Scales should be sensible.

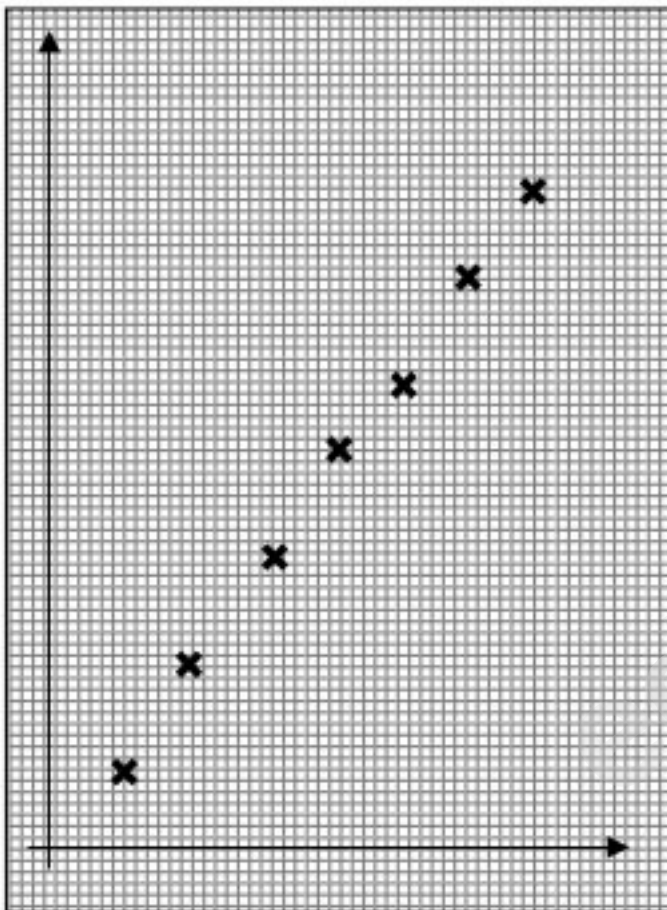
e.g. 1:1, 1:2, 1:5

avoid 1:3, 1:4, 1:6 etc...

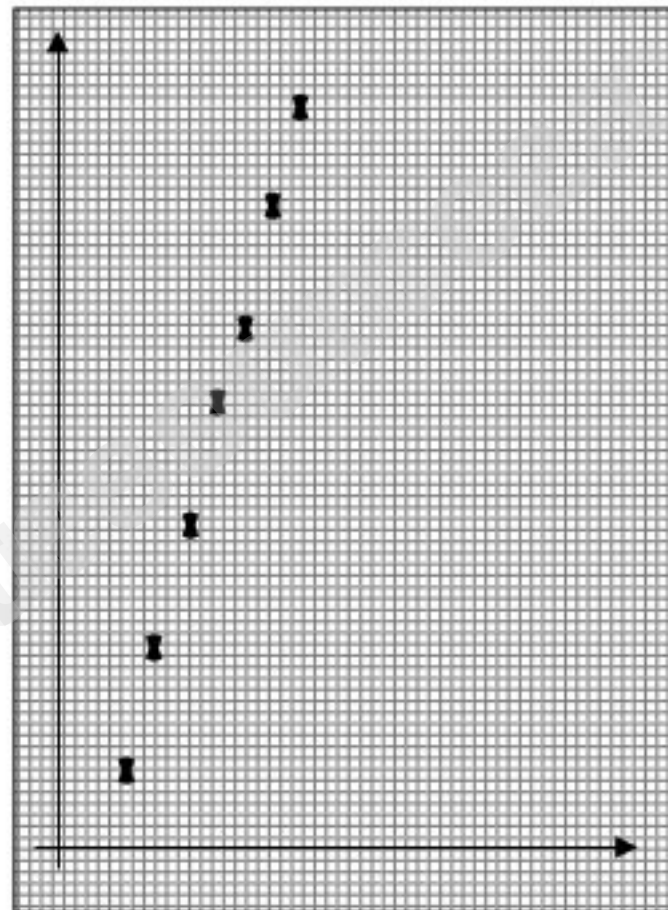
The origin does not have to be shown.



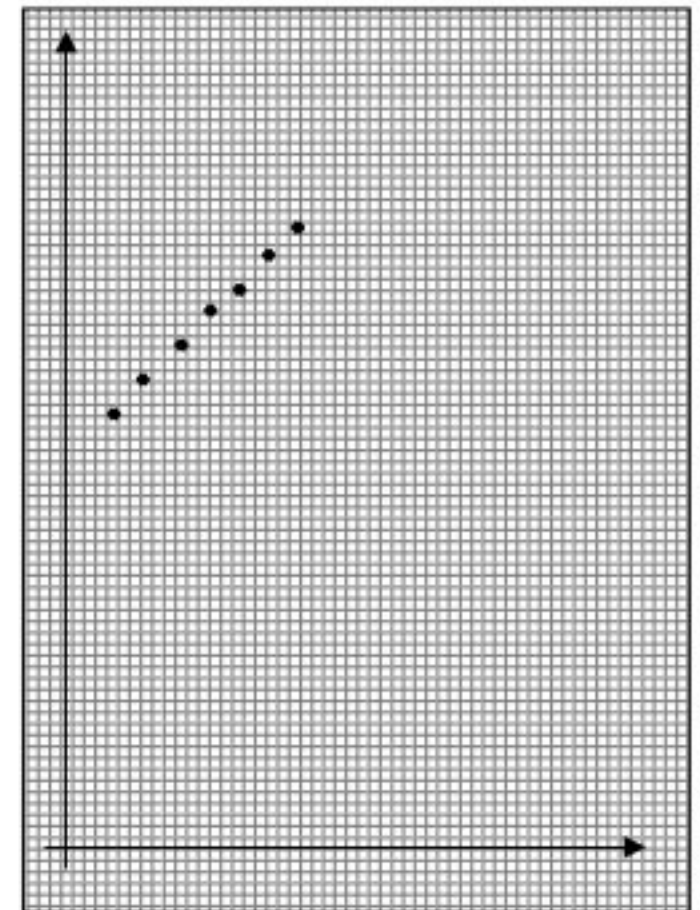
Both vertically and horizontally your points should occupy at least **half** of the available graph paper



GOOD



POOR



AWFUL

Best fit lines

Best fit lines can be curves!

The line should be drawn so that there are roughly the same number of points above and below and below.

Anomalous points should be rechecked. If this is not possible they should be ignored when drawing the best-fit line



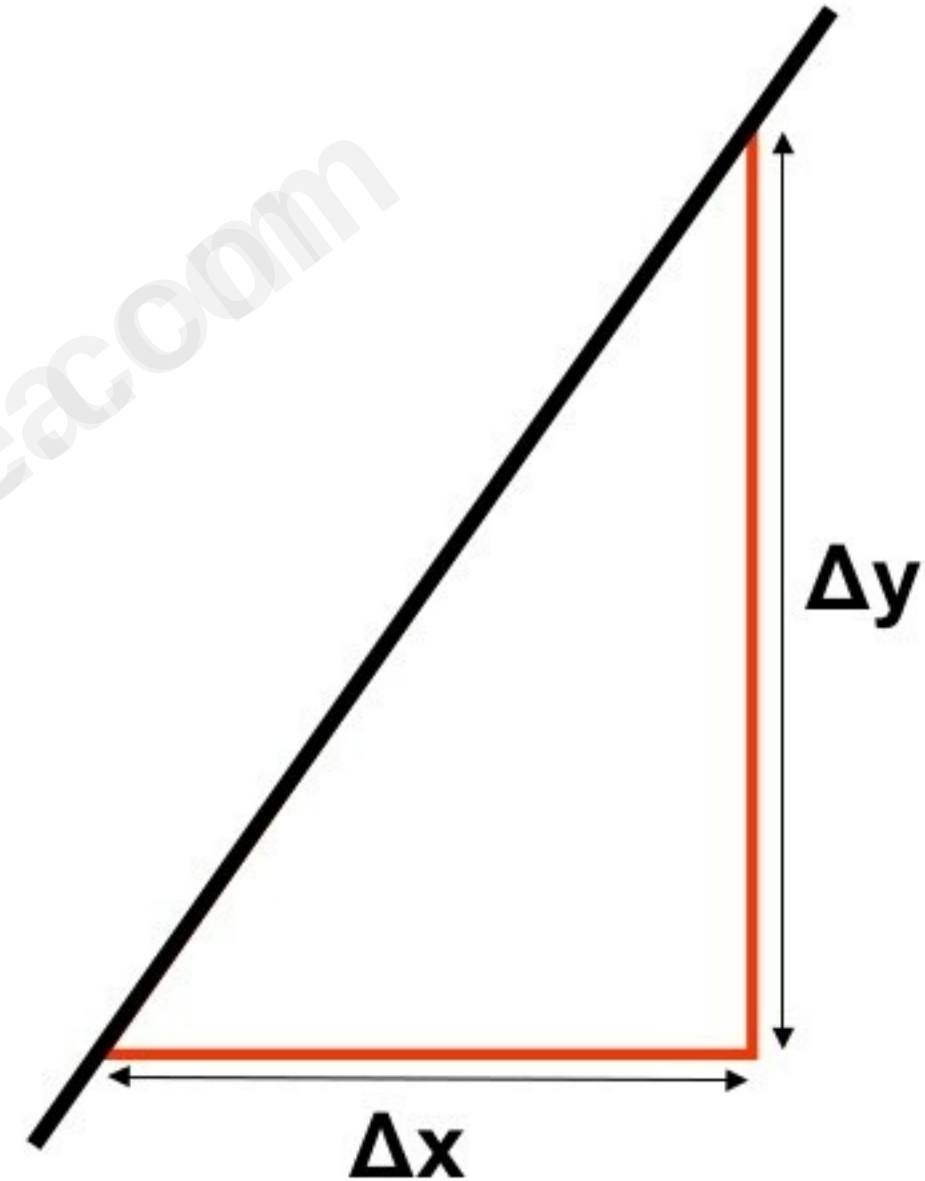
Measuring gradients

$$\text{gradient} = \frac{\text{y-step } (\Delta y)}{\text{x-step } (\Delta x)}$$

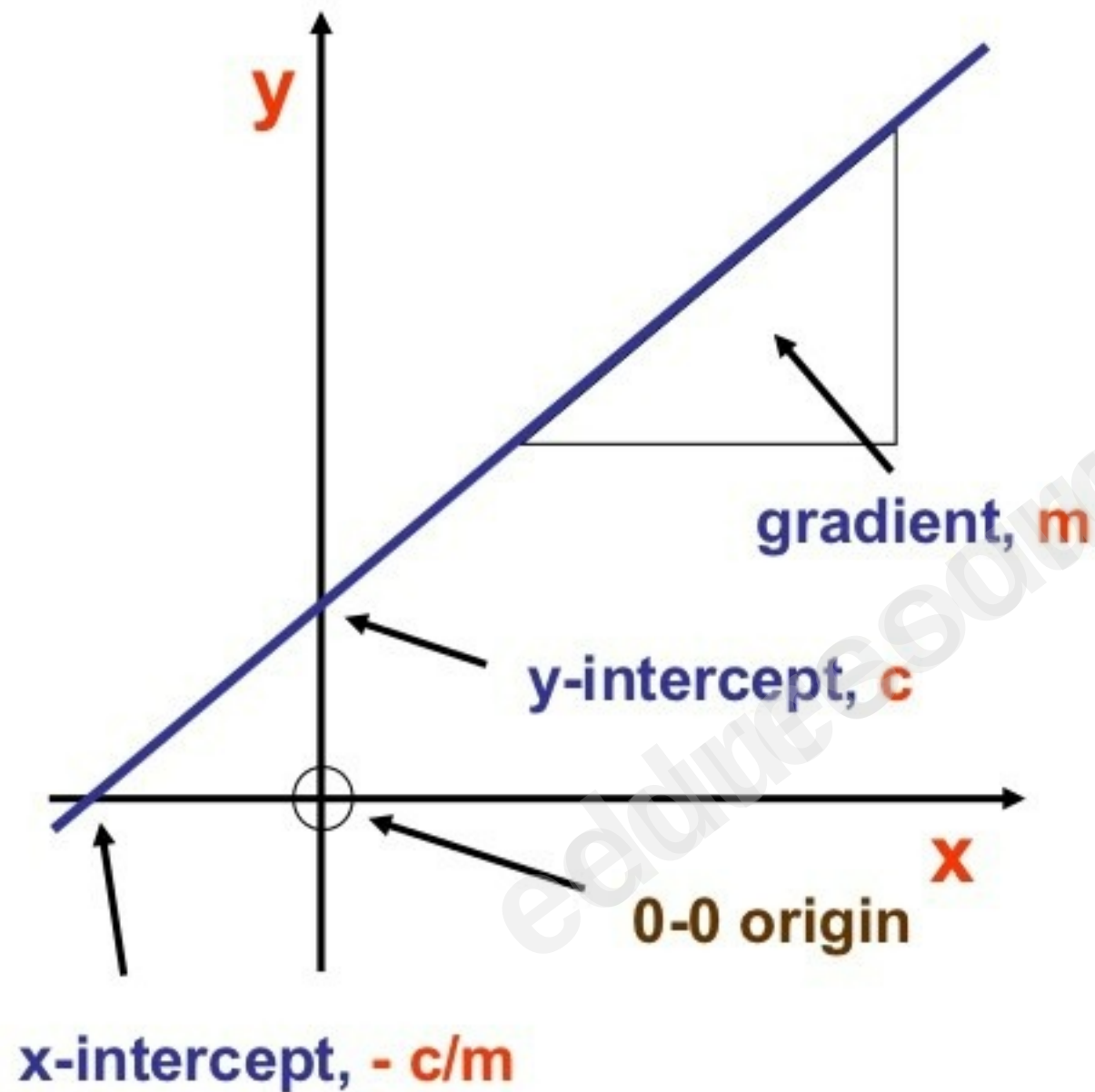
The triangle used to find the gradient should be shown on the graph.

Each side of the triangle should be at least **8cm** long.

Gradients usually have a unit.



The equation of a straight line



For any straight line:

$$y = mx + c$$

where:

m = gradient

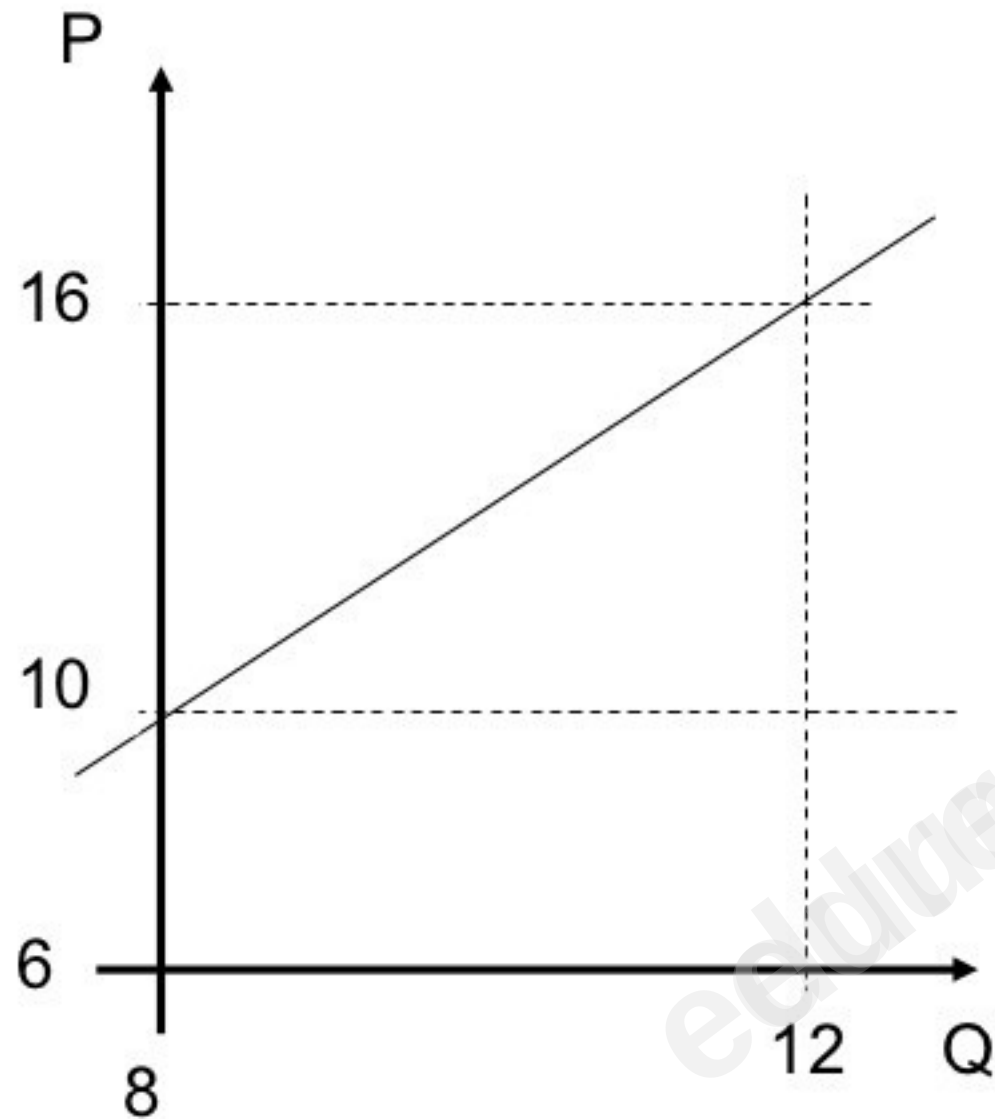
and

c = y-intercept

Note:

$$\text{x-intercept} = -c/m$$

Calculating the y-intercept



Graphs do not always show the y-intercept.

To calculate this intercept:

1. Measure the gradient, m

In this case, $m = 1.5$

2. Choose an x-y co-ordinate from any point on the straight line. e.g. (12, 16)

3. Substitute these into: $y = mx + c$,
with (P = y and Q = x)

In this case $16 = (1.5 \times 12) + c$

$$16 = 18 + c$$

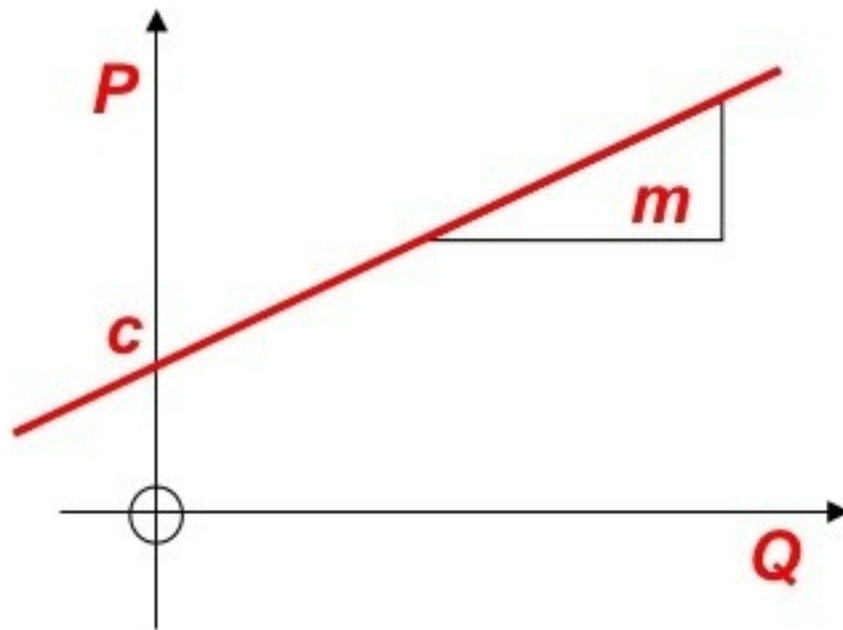
$$c = 16 - 18$$

$$c = \text{y-intercept} = -2$$

Linear relationships

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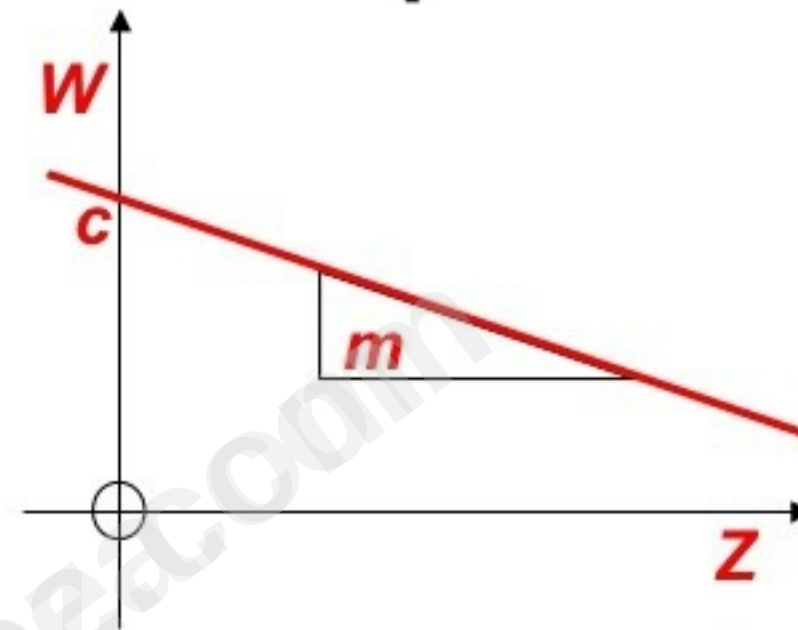
<https://britishstudentroom-b430a.web.app/>



Quantity P increases linearly with quantity Q .

This can be expressed by the equation: $P = mQ + c$

In this case, the gradient m is **POSITIVE**.



Quantity W decreases linearly with quantity Z .

This can be expressed by the equation: $W = mZ + c$

In this case, the gradient m is **NEGATIVE**.

Note: In neither case should the word 'proportional' be used as neither line passes through the origin.

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Questions

1. Quantity **P** is related to quantity **Q** by the equation:
 $P = 5Q + 7$. If a graph of **P** against **Q** was plotted what would be the gradient and y-intercept?
 $m = + 5; c = + 7$
2. Quantity **J** is related to quantity **K** by the equation:
 $J - 6 = K / 3$. If a graph of **J** against **K** was plotted what would be the gradient and y-intercept?
 $m = + 0.33; c = + 6$
3. Quantity **W** is related to quantity **V** by the equation:
 $V + 4W = 3$. If a graph of **W** against **V** was plotted what would be the gradient and x-intercept?
 $m = - 0.25; x\text{-intercept} = + 3; (c = + 0.75)$

Direct proportion

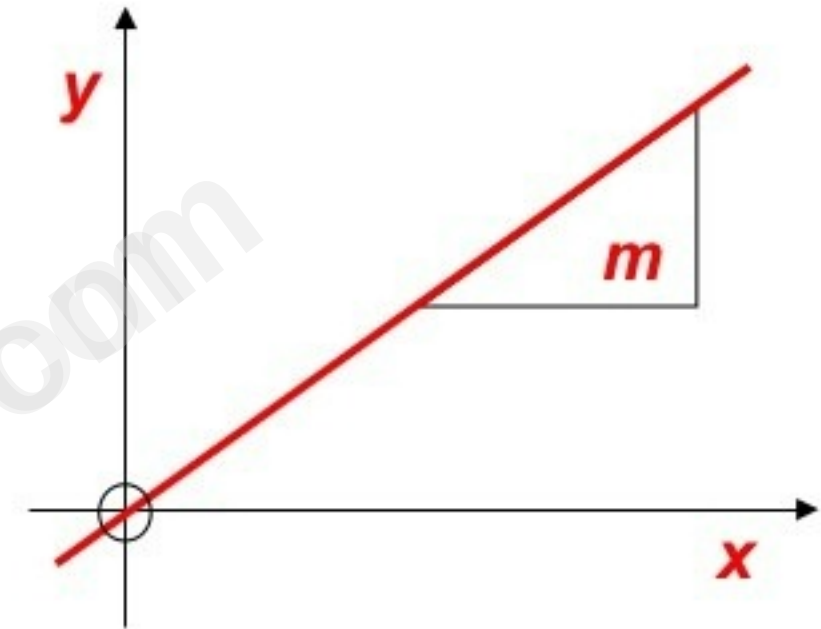
Physical quantities are directly proportional to each other if when one of them is doubled the other will also double.

A graph of two quantities that are directly proportional to each other will be:

- a straight line
- **AND** pass through the origin

The general equation of the straight line in this case is: $y = mx$, in this case, $c = 0$

Note: The word '**direct**' is sometimes not written.



Inverse proportion

Physical quantities are inversely proportional to each other if when one of them is doubled the other will halve.

A graph of two quantities that are inversely proportional to each other will be:

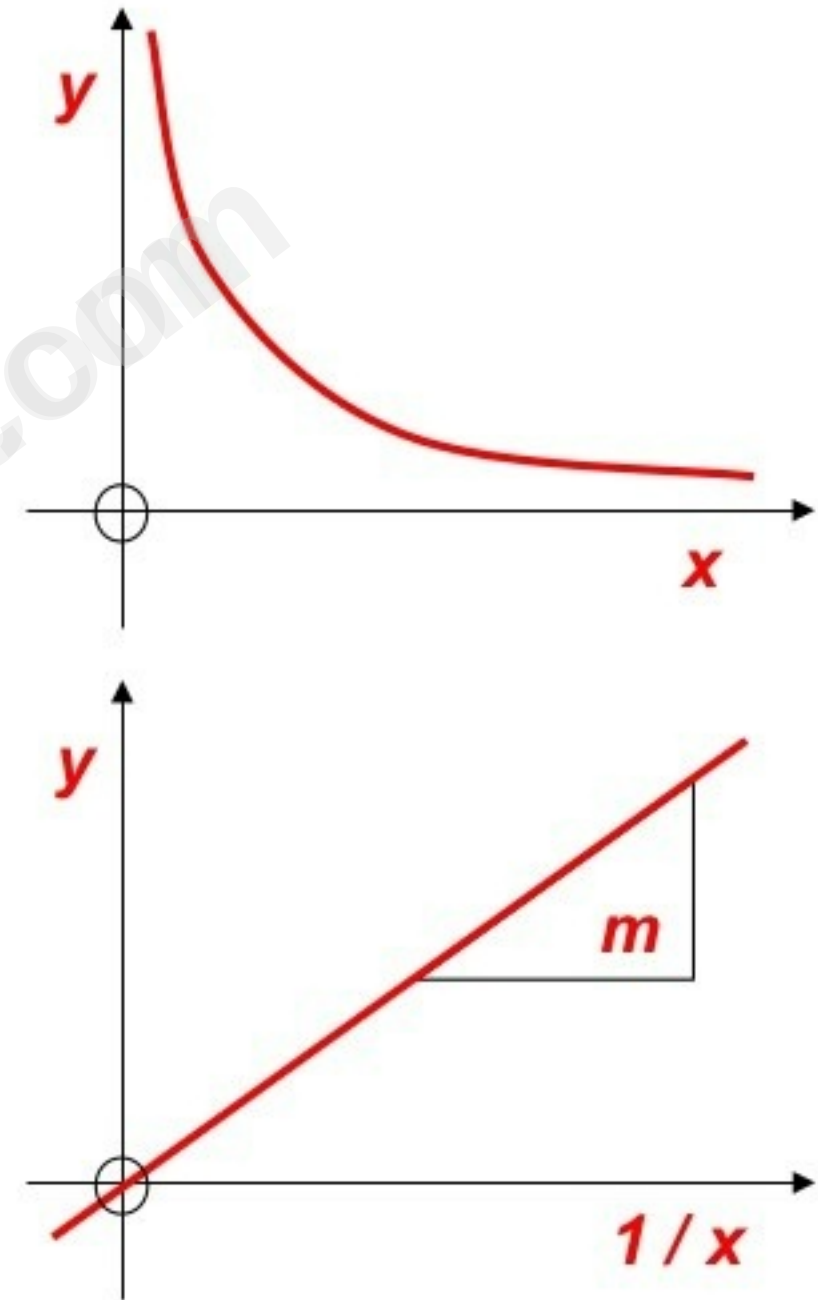
- a rectangular hyperbola
- has no y- or x-intercept

Inverse proportion can be verified by drawing a graph of y against $1/x$.

This should be:

- a straight line
- **AND** pass through the origin

The general equation of the straight line in this case is: $y = m / x$



Systematic error

Systematic error is error of measurement due to readings that systematically differ from the true reading and follow a pattern or trend or bias.

Example: **Suppose a measurement should be 567cm**

Readings showing **systematic error**: 585cm; 584cm; 583cm; 584cm

Systematic error is often caused by poor measurement technique or by using incorrectly calibrated instruments.

Calculating a mean value (584cm) does not eliminate systematic error.

Zero error is a common cause of systematic error. This occurs when an instrument does not read zero when it should do so. The measurement examples above may have been caused by a zero error of about + 17 cm.

Random error

Random error is error of measurement due to readings that vary randomly with no recognisable pattern or trend or bias.

Example: **Suppose a measurement should be 567cm**

Readings showing **random error** only: 569cm; 568cm; 564cm; 566cm

Random error is unavoidable but can be minimalised by using a consistent measurement technique and the best possible measuring instruments.

Calculating a mean value (567cm) will reduce the effect of random error.

An object is known to have a mass of exactly 1kg. It has its mass measured on four different occasions. Complete the table below by stating whether or not the readings indicated show small or large systematic or random error.

readings / kg	systematic	random
1.05; 0.95; 1.02		
1.29; 1.30; 1.28		
1.20; 0.85; 1.05		
1.05; 1.35; 1.16		

Range of measurements

Range is equal to the difference between the highest and lowest reading

Readings: 45g; 44g; 44g; 47g; 46g; 45g

Range: = 47g – 44g
= 3g

Mean value $\langle x \rangle$

Mean value calculated by adding the readings together and dividing by the number of readings.

Readings: 45g; 44g; 44g; 47g; 46g; 45g

Mean value of mass $\langle m \rangle$:

$$= (45+44+44+47+46+45) / 6$$

$$\langle m \rangle = 45.2 \text{ g}$$

Uncertainty or probable error

The uncertainty (or probable error) in the mean value of a measurement is half the range expressed as a $\pm$ value

Example: If mean mass is 45.2g and the range is 3g then:

The probable error (uncertainty) is $\pm 1.5\text{g}$

Uncertainty in a single reading OR when measurements do not vary

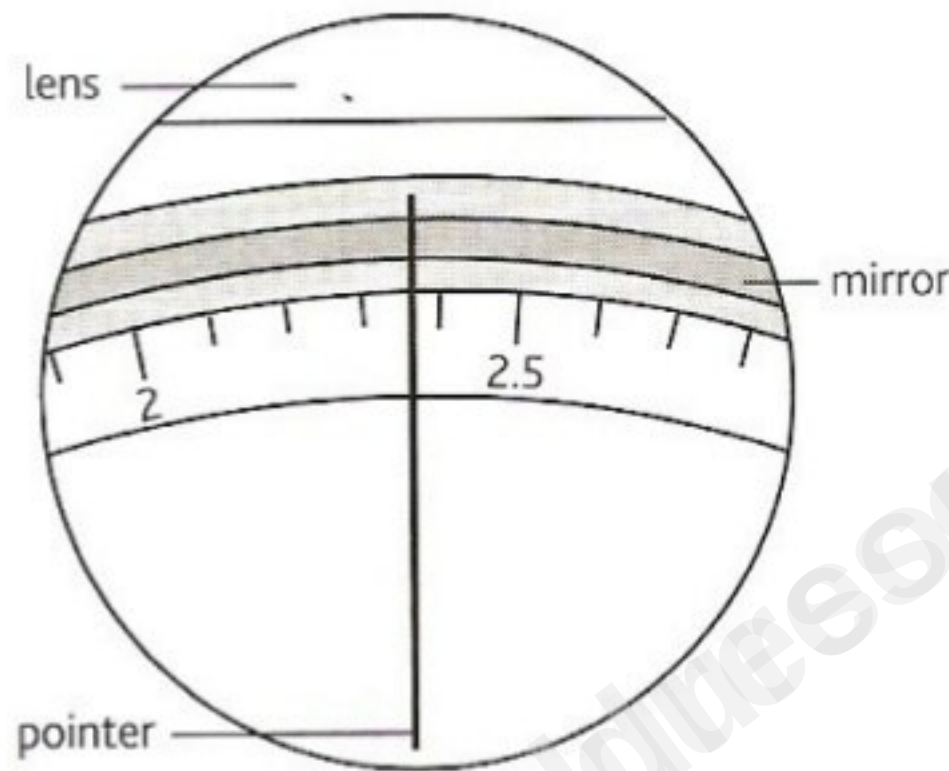


Figure 2 Magnifying a scale

- The probable error is equal to the precision in reading the instrument
- For the scale opposite this would be:
 - ± 0.1 without the magnifying glass
 - ± 0.02 perhaps with the magnifying glass

Percentage uncertainty

percentage uncertainty = probable error x 100%

measurement

Example: Calculate the % uncertainty the mass measurement $45 \pm 2\text{g}$

percentage uncertainty = 2g x 100%

45g

= 4.44 %

Combining percentage uncertainties

1. Products (multiplication)

Add the percentage uncertainties together.

Example:

Calculate the percentage uncertainty in force causing a mass of $50\text{kg} \pm 10\%$ to accelerate by $20\text{ ms}^{-2} \pm 5\%$.

$$**F = ma**$$

Hence force = $1000\text{N} \pm 15\%$ (10% plus 5%)

2. Quotients (division)

Add the percentage uncertainties together.

Example:

Calculate the percentage uncertainty in the density of a material of mass $300\text{g} \pm 5\%$ and volume $60\text{cm}^3 \pm 2\%$.

$$D = M / V$$

Hence density = $5.0 \text{ gcm}^{-3} \pm 7\%$ (5% plus 2%)

3. Powers

Multiply the percentage uncertainty by the number of the power.

Example:

Calculate the percentage uncertainty in the volume of a cube of side, $L = 4.0\text{cm} \pm 2\%$.

$\text{Volume} = L^3$

$\text{Volume} = 64\text{cm}^3 \pm 6\% \quad (2\% \times 3)$

Significant figures and uncertainty

The percentage uncertainty in a measurement or calculation determines the number of significant figures to be used.

Example:

mass = $4.52\text{g} \pm 10\%$

$\pm 10\%$ of 4.52g is $\pm 0.452\text{g}$

The uncertainty should be quoted to 1sf only. i.e. $\pm 0.5\text{g}$

The quantity value (4.52) should be quoted to the same decimal places as the 1sf uncertainty value. i.e. '4.5'

The mass value will now be quoted to only 2sf.

mass = $4.5 \pm 0.5\text{g}$

Conclusion reliability and uncertainty

The smaller the percentage uncertainty the more reliable is a conclusion.

Example: The average speed of a car is measured using two different methods:

(a) manually with a stop-watch

– distance $100 \pm 0.5\text{m}$; time $12.2 \pm 0.5\text{s}$

(b) automatically using a set of light gates

– distance $10 \pm 0.5\text{cm}$; time $1.31 \pm 0.01\text{s}$

Which method gives the more reliable answer?

Percentage uncertainties:

- (a) stop-watch – distance $\pm 0.5\%$; time $\pm 4\%$
- (b) light gates – distance $\pm 5\%$; time $\pm 0.8\%$

Total percentage uncertainties:

- (a) stop-watch: $\pm 4.5\%$
- (b) light gates: $\pm 5.8\%$

Evaluation:

The stop-watch method has the lower overall percentage uncertainty and so is the more reliable method.

The light gate method would be much better if a larger distance was used.

Planning procedures

Usually the final part of a written ISA paper is a question involving the planning of a procedure, usually related to an ISA experiment, to test a hypothesis.

Example:

In an ISA experiment a marble was rolled down a slope. With the slope angle kept constant the time taken by the marble was measured for different distances down the slope. The average speed of the marble was then measured using the equation, $\text{speed} = \text{distance} \div \text{time}$.

Question:

Describe a procedure for measuring how the average speed varies with slope angle. [5 marks]

Answer:

Any five of:

- measure the angle of a slope using a **protractor**
- release the marble from the **same distance** up the slope
- start the **stop-watch** on marble release stop the stop-watch once the marble reaches the end of the slope
- repeat **timing**
- calculate the **average** time
- measure the distance the marble rolls using a **metre ruler**
- calculate average speed using: **$\text{speed} = \text{distance} \div \text{time}$**
- repeat the above for different **slope angles**

Internet Links

- **Equation Grapher** - PhET - Learn about graphing polynomials. The shape of the curve changes as the constants are adjusted. View the curves for the individual terms (e.g. $y=bx$) to see how they add to generate the polynomial curve.

eduresourceza.com

Notes from Breithaupt pages 219 to 220, 223 to 225 & 233

1. Define in the context of recording measurements, and give examples of, what is meant by: (a) reliable; (b) valid; (c) range; (d) mean value; (e) systematic error; (f) random error; (g) zero error; (h) uncertainty; (i) accuracy; (j) precision and (k) linearity
2. What determines the precision in (a) a single reading and (b) multiple readings?
3. Define percentage uncertainty.
4. Two measurements $P = 2.0 \pm 0.1$ and $Q = 4.0 \pm 0.4$ are obtained. Determine the uncertainty (probable error) in: (a) $P \times Q$; (b) Q / P ; (c) P^3 ; (d) $\sqrt{Q}$.
5. Measure the area of a piece of A4 paper and state the probable error (or uncertainty) in your answer.
6. State the number 1230.0456 to (a) 6 sf, (b) 3 sf and (c) 0 sf.

Notes from Breithaupt pages 238 & 239

1. Copy figure 2 on page 238 and define the terms of the equation of a straight line graph.
2. Copy figure 1 on page 238 and explain how it shows the direct proportionality relationship between the two quantities.
3. Draw figures 3, 4 & 5 and explain how these graphs relate to the equation **$y = mx + c$** .
4. How can straight line graphs be used to solve simultaneous equations?
5. Try the summary questions on page 239