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Overview of A-level H2 Physics Practical Work

1. Instructional Objectives:

The practical programme at A-levels aims to enhance students' experience in practical work and to inculcate in students good habits in experimental techniques and experimental report-writing.

The syllabus (GCE A-Level H2 PHYSICS Syllabus 9749) specifies that candidates should be able to:

- follow a detailed set or sequence of instructions and use techniques, apparatus and materials safely and effectively;
- make observations and measurements with due regard for precision and accuracy;
- record observations, measurements, methods and techniques with due regard for precision, accuracy and units;
- interpret and evaluate observations and experimental data;
- Identify a problem, design and plan investigations, evaluate methods and techniques, and suggest possible improvements.

Paper 4 (2 h 30 min, 55 marks)

This paper will assess appropriate aspects of objectives C1 to C5 in the following skill areas:

- Planning (P)
- Manipulation, measurement and observation (MMO)
- Presentation of data and observations (PDO)
- Analysis, conclusions and evaluation (ACE)

The assessment of Planning (P) will have a weighting of 5%. The assessment of skill areas MMO, PDO and ACE will have a weighting of 15%.

The assessment of PDO and ACE may also include questions on data-analysis which do not require practical equipment and apparatus. Candidates would be allocated a specified time for access to apparatus and materials of specific questions (See Appendix).

Candidates will not be permitted to refer to books and laboratory notebooks during the assessment.

2. Things to Bring For Lab Session

Please ensure that you have the following items for every lab session:

1. 30 cm long, transparent rule
2. flexible curve; (French curve, if you prefer)
3. graph paper
4. writing pad
5. sharp 2B pencil
6. dark blue or black pens (smudge free ball-point pens are preferred)
7. scientific calculator or graphic calculator (of approved model)
8. mathematical set (including protractor, set square, etc.)

You may also find it useful to have

1. markers of different colours,
2. scissors
3. scotch tape

3 Standard Operating Procedures

1. Before the experiment,
   - Be seated in the laboratory according to your index number.
   - To ensure your workbench is uncluttered and ready for experimental setups, leave your belongings under the bench.
2. During the experiment,
   - Be thoughtful and follow the procedures to carry out the experiment.
   - Exercise proper care and observe all safety precautions for all practical work.
   - Horseplay is prohibited.
3. After the experiment,
   - Return all apparatus back to their original places.
   - Ensure that all work areas are clean.
   - Collect all your belongings before leaving.

4 General Laboratory Safety Regulations

Good common sense is needed for safety in a laboratory. It is expected that each student will work in a responsible manner and exercise discipline and good judgement.

1. Students must not enter or work in laboratories unless a teacher is present.
2. Laboratory storerooms and preparation rooms are out of bounds to all students.
3. Long hair should be tied back to avoid any interference with laboratory work.
4. Eating and drinking are prohibited in laboratories.
5. Students should always work thoughtfully and purposefully. Practical jokes and other acts of carelessness are strictly prohibited.
6. Students should seek clarification from the teacher if instructions for an experiment are not thoroughly understood. Students should not proceed with an experiment if in doubt.
7. Safety goggles must be worn whenever there is any risk of injury to the eyes.
8. Protective gloves and clothing must be worn when handling hazardous materials.
9. Hands must always be thoroughly washed before leaving the laboratory, regardless of whether or not gloves are worn.
10. Equipment used to handle or transfer hazardous materials must be inspected for leaks, cracks and other forms of damage before use.
11. Damaged equipment, breakages, accidents and spillage should be immediately reported to the teacher.
12. Electrical wirings must be kept away from naked flames and heaters. Areas around electrical equipment should be kept dry and where appropriate, kept far from water.
13. Unlabelled chemicals should not be used. Unlabelled containers should be reported to the teacher.
14. Chemicals or other materials must never be tasted unless specifically directed by the teacher.
15. Students should not take apparatus or chemicals out of the laboratory without the permission of a teacher.
16. Unauthorised experiments are prohibited.
17. Pipetting should always be carried out using a pipette aid and never by mouth.
18. Sharp objects (such as needles, razors or pins) should not be discarded in waste-bins or trash bags. Instead, a sturdy container should be used for sharp waste objects.

In Case of Injuries:

1. Minor injury – cuts and burns

   - First Aid Box is located at the front notice board.
   - Inform Teacher / Lab Staff.
   - Record in the Injury Report Book beside First Aid Box.

2. Major Injury
   - Give first aid at once.
   - Inform Teacher / Lab Staff.

In Case of Fire

1. Fire extinguisher and fire blankets are located at front of the lab.

When to Evacuate

1. When there is gas leakage.
2. When the fire alarm goes off.

Emergency Numbers:

- Kong Chian Admin Block : 64683955
- College Reception : 64683956

5. Proper and Safe Use of General Physics Laboratory equipment

Use of Heat and Chemicals:

- Never heat flammable substances.
- Never leave a flame unattended.
- Do not play with fire.
- Use Styrofoam cup to collect hot water.
- Do not touch the hot water urns with bare hands.

Mechanical safety:

- Be extra vigilant when dealing with equipment with pointed or sharp edges.
- Handle heavy objects with care.
- When using the retort stand, ensure that the base is secured by using a brick or G-clamp so that your apparatus would not topple.

- Electrical Safety:
- Switches or Electrical cables must never be handled with wet hands.
- Do not use any electrical appliance with exposed wires, report to teachers immediately.
- Do not insert anything into the power socket on the student bench.
- Always make sure all capacitors are discharged (using a grounded cable with an insulating handle) before touching high voltage leads or the "inside" of any equipment even after it has been turned off. Capacitors inside equipment can hold charge for many hours after the equipment has been turned off.
- Ensure electrical circuits are connected properly to avoid short circuit. Do not short-circuit batteries and ammeters.
- Obtain permission before operating any equipment connected to the mains.

Laser Safety:

- Never look into any laser beam, no matter how low-power or "eye-safe" you may think it is.
- Always wear safety goggles if instructed by your tutor.
- The most common injury using lasers is eye injury resulting from scattered laser light reflected off mountings, sides of mirrors or from the "shiny" surface of a table. The best way to avoid these injuries is to always wear your goggles and never lower your head to the level of the laser beam. The laser beam should always be at or below chest level.
- Always use "beam stops" to intercept laser beams. Do not allow them to propagate through the laboratory. Never walk through a laser beam. Some laser beams of only a few watts can burn a hole through a shirt in only a few seconds.
- If you suspect that you have suffered an eye injury, notify your tutor immediately. Your ability to recover from an eye injury decreases the longer you wait.

A The basics of performing experiments

1. Read the instructions to understand **the aims, principles and procedures** before setting up the experiment.

2. **Collect and check** all the apparatus as listed.

3. **Decide on the most efficient order of work** where possible.

   E.g. if you need hot water bath in an experiment, you should start heating the water and carry on with your other preparations while the water is being heated.

4. You are expected to be able to **assemble the apparatus without help. Arrange your experiment such that data can be easily collected.**

   E.g. position the metre rule such that you can read the scale conveniently. Give yourself sufficient room on the bench for your written work. Ensure that all apparatus are firmly secured or supported to ensure reliable readings obtained and prevent accidents due to unstable setups.

5. **Read the instruments to the correct precision.** Ascertain the smallest division on the scale, and check that the reading taken is sensible with correct precision.

6. **Repeat readings where necessary.** Other than checking the reproducibility of the results, random errors can be reduced by taking average of repeated readings using the same apparatus. Systematic errors may sometimes be reduced or identified by using different apparatus and procedures. When taking repeated readings, it is often advisable to take measurement in one direction and repeat in a reverse direction.

   E.g. we measure the extensions of vertical spring mass by first loading masses, then take repeated measurements by unloading masses; this is to check that the spring is extended within the limit of proportionality.

7. **Be honest in taking readings.** Do not decide in advance what you are going to find for a particular reading. By all means, **check that the reading is approximately what you expect** – it is a good way of avoiding mistakes, but if you presume that there is an established pattern in the data you are recording and then slavishly follow it, you may miss any real change or anomaly in the pattern.

8. Fit your data to a linear graph where appropriate. It allows you to easily verify the relationship between the variables indicated, or determine unknown constants.

B Uncertainties

B1 Sources of uncertainties

In performing practical work, learners should be aware that uncertainties are inherent in any measurement. Any measuring apparatus used has an associated uncertainty.

The important question to ask is whether an experimenter can be confident that the true value lies in the range that is predicted by the uncertainty that is quoted. Good experimental design will attempt to reduce the uncertainty in the outcome of an experiment. The experimenter will design experiments and procedures that produce the least uncertainty and to provide a realistic uncertainty for the outcome.

In assessing uncertainty, there are a number of issues that have to be considered. These include

- the resolution of the instrument used
- the manufacturer's tolerance on instruments
- the judgments that are made by the experimenter
- the procedures adopted (eg repeated readings)

Numerical questions will look at a number of these factors. Often, the resolution will be the guiding factor in assessing a numerical uncertainty. There may be further questions that would require candidate to evaluate arrangements and procedures. Students could be asked how particular procedures would affect uncertainties and how they could be reduced by different apparatus design or procedure.

A combination of the above factors means that there can be no hard and fast rules about the actual uncertainty in a measurement. What we can assess from an instrument's resolution is the **minimum** possible uncertainty. Only the experimenter can assess the other factors based on the arrangement and use of the apparatus and a rigorous experimenter would draw attention to these factors and take them into account.

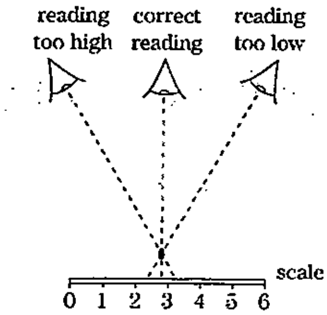
Examples:

- A stopwatch has a resolution of 0.01 s (or even 0.001s), however the operator's reaction time is significantly longer, increasing the total uncertainty in the measurement.
- A light gate measures time with the same resolution of 0.01s, but has a significantly lower total uncertainty as it eliminates the reaction time.

- If a student measures the length of a piece of wire, it is very difficult to hold the wire completely straight against the ruler. The uncertainty in the measurement is likely to be higher than the ±1 mm uncertainty of the ruler. Depending on the number of "kinks" in the wire, the uncertainty could be reasonably judged to be nearer ± 2 or 3 mm.

The uncertainty of the reading from digital voltmeters and ammeters depends on the electronics and is not strictly the last figure in the readout. Manufacturers usually quote the percentage uncertainties for the different ranges. Unless otherwise stated it may be assumed that ±0.5 in the least significant digit is to be the uncertainty in the measurement. This would generally be rounded up to ±1 of the least significant digit when quoting the value and the uncertainty together. For example (5.21 ±0.01) V. If the reading fluctuates, then it may be necessary to take a number of readings and do a mean and range calculation.

B2 Reducing uncertainties

Example	Good practice to reduce uncertainty
zero error on an instrument	Where there is a zero error, the meter should be adjusted to zero or, if this not possible, the zero error should be noted in your account and all recorded readings should then be adjusted.
a parallax error 	1. have the scale as close as possible to the pointer 2. view the scale normally (i.e. so your line of sight is perpendicular to the scale.) The scales on some meters are fitted with a small plane mirror to help to view the scale normally. When the image of the pointer in the mirror is hidden behind the pointer, then the scale is being viewed correctly and the reading can be taken (see Figure 1.8). Similarly, a small plane mirror may be used to assist with reading a metre rule, as illustrated in Figure 1.9.
Timing oscillations	1. Check for zero error on the stopwatch. 2. Count sufficient oscillations so that the time is greater than about ten seconds (twenty seconds is even better as this further reduces percentage uncertainty). For example: Time taken for a pendulum to swing 10 times: (5.1 ± 0.1) s Mean time taken for one swing: (0.51 ± 0.01) s 3. Stop and then restart the oscillations - there may be a systematic error due to the wrong mode of oscillation (e.g. oscillations not in one plane for a simple pendulum). 4. Repeat the timing of the oscillations. At least two timings should be made.
Measuring the diameter of a wire	1. Check the micrometer for any zero error. 2. Measure the diameter at several positions along the length of the wire (to allow for tapering). 3. Measurements along the length of the wire should be taken spirally (to check for circular cross-section)

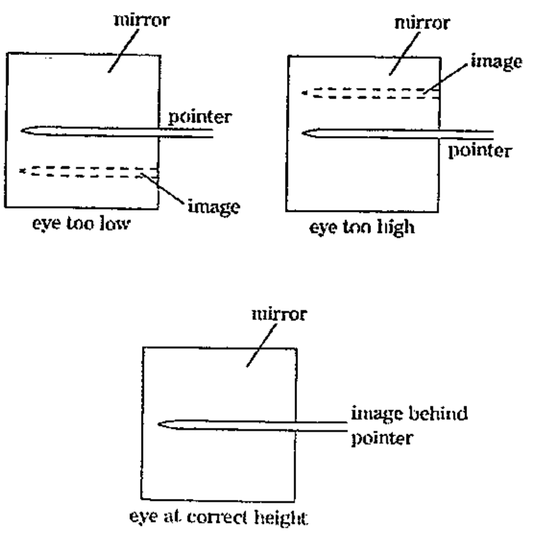


Figure 1.8 Use of a plane mirror

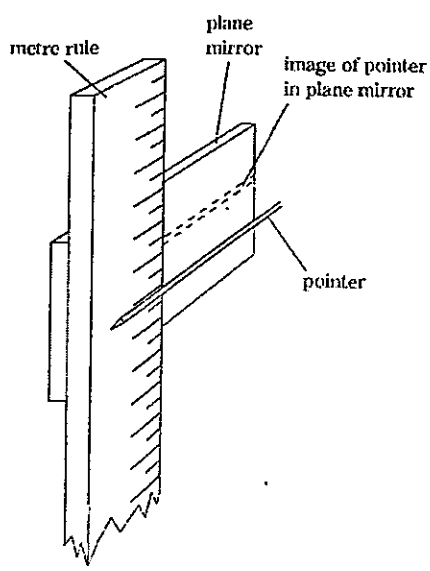


Figure 1.9 Using a plane mirror with a metre rule

C Recording Measurements

C1 Data Type

Data can be divided into two types:

(i) **raw** data – data that you measure using instruments and record during an experiment.

(ii) **derived** data – data that is calculated or derived from the raw readings.

C2 Raw data - Recording measurements

When using a digital measuring device (such as a modern top pan balance or ammeter), record *all* the digits shown.

When using a non-digital device (such as a ruler or a measurement cylinder), record to the precision of the instrument used for the measurement.

Precision of common laboratory equipment:

Equipment	Unit	Precision	Possible last digits
Ruler	m	±0.001	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
Vernier Callipers	m	±0.0001 ±0.00005	0, 1, 2, 3, 4, 5, 6, 7, 8, 9 0, 5
Micrometer screw gauge	m	±0.00001	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
Stopwatch	s	±0.1*	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
Thermometer	°C	±0.5	0, 5

* the stopwatch can actually display higher precision, but we take into account errors due to human reaction time when starting and stopping the stopwatch.

D Presentation of results

D1 Tables

The following guidelines should be followed when presenting results in tables.

- Think ahead so that there are space for all the columns. All raw data in a single table with ruled lines and border. (See Fig. 1)
- Independent variable (IV) in the first column; dependent variable (DV) in columns to the right (for quantitative observations) OR descriptive comments in columns to the right (for qualitative observations).
- Processed data (e.g. means, rates, standard deviations) in columns to the far right.
- No calculations in the table, only calculated values.
- Each column headed with informative description (for qualitative data) or physical quantity **and** correct units (for quantitative data); units separated from physical quantity using a solidus (slash).
- No units in the body of the table, only in the column headings.
- At least 6 sets of readings for a straight line graph and at least of 8 sets of readings for non-linear graph.
- The range of IV data must be sufficiently wide and readings well distributed over the range.
- It is also expected that all readings should be repeated as appropriate.
- Raw data recorded to a number of decimal places appropriate to the resolution of the measuring equipment.
- All raw data of the same type recorded to the same number of decimal places, and show repeated measurements where appropriate.
- Processed data recorded to the same sig figs or up to one significant figure more than the raw data.

Further notes

- <u>Data that are constant</u> throughout the experiment can be <u>recorded above the table.</u>
- Construct the table prior to taking any readings and record the readings in pen immediately into the prepared table as you take measurements during the experiment.

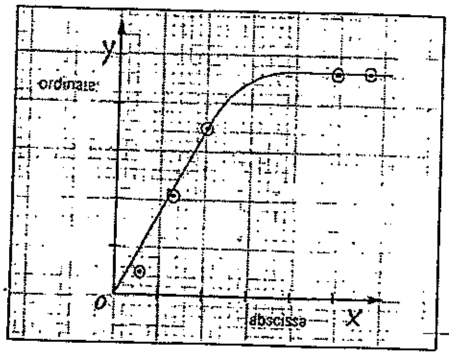
  Do not waste time copying and erasing your rough work. Errors may easily occur during transcription.
- It is a good practice to collect data at the extreme values before starting the experiment, to maximise the range of data to be collected.
- Leave additional space for additional lines or columns in your table in case you have additional data you need to collect or further compute.

  Always be prepared to take extra readings *after* you have plotted a graph to determine the shape of the graph more accurately.

M /kg	x /m	y /m	$y-x$ /m	
0.100				
0.200				
0.300				
0.400				
0.500				
0.600				
0.700				

(Hutchings, 1990)

A table should have plenty of space for extra columns and extra lines.



Questions to ponder

The graph on the left was drawn by a student who had not planned his experiment very well. Think about these questions.

1. Do you think that sufficient points have been taken? Explain.
2. Why should you always plot a graph before taking the apparatus apart?

Table headings

It is important to keep a record of data whilst carrying out practical work. It is expected that all table column (or row) headings will consist of a quantity and a unit.
The quantity may be represented by a symbol or written in words, with units indicated using a forward slash "/" before the unit. When in print, quantities are represented with a symbol in italics, while units are upright, and a "/" in between. For example: *T* / °C

pd / V	Current / A
2.0	0.15
4.0	0.31
6.0	0.45

OR

V / V	*I* / A
2.0	0.15
4.0	0.31
6.0	0.45

Unconventional symbols should be clearly defined before the table. For example, "*N*: number of oscillations"

The unit should always be written in the index form, e.g. use m s^{-2} and NOT m / s^2, to avoid confusions.

It is good practice to draw a table before an experiment commences and then enter data straight into the table. This can sometimes lead to data points being in the wrong order. For example, when investigating the electrical characteristics of a component by plotting an *I* – *V* curve, a student may initially decide to take current readings at pd values of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 V . On discovering a more significant change in current between 1.5 and 2.0 V, the student might decide to take further readings at 1.6, 1.7, 1.8, 1.9 V to investigate this part of the characteristics in more detail. Whilst this is perfectly acceptable, it is generally a good idea to make a fair copy of the table in ascending order of pd to enable patterns to be spotted more easily. Reordered tables should follow the original data if using a lab book.

It is also expected that the independent variable is the left hand column in a table, with the following columns showing the dependent variables. These should be headed in similar ways to measured variables. The body of the table should not contain units.

Consistency of presentation of raw data

All raw readings of a particular quantity should, where possible, be recorded to the same number of decimal places. These should be consistent with the precision of the apparatus used to make the measurement or the uncertainty in measurement. For example, a length of string measured to be 60 cm using a ruler with mm graduations should be recorded as 600 mm, 60.0 cm or 0.600 m, and **not** just 60 cm.

Tabulating logarithmic values

The logarithm of a quantity can only be taken if a quantity has no units. Therefore, the quantity is divided by an initial value or its unit before taking the logarithm. The resulting logarithm then has no units.

However, it is important to be clear about which unit the quantity had to start with. The logarithm of a distance in km will be very different from the logarithm of the same distance in mm.

These should be included in tables in the following way:

time / s	log (time / s)
2.3	0.36
3.5	0.54
5.6	0.75

Trigonometric functions

Angles have dimensionless units, the heading can be θ /° or θ /rad. When you take sine, cosine or tangent of an angle, the result is a dimensionless number. The heading can simply be sin θ , cos θ, tan θ .

Always check that you are using the correct mode in your calculator as the results of sinθ in degree and sinθ in radian can be very different.

Example: Planning a typical table of results

$$T = \frac{t_1 + t_2}{2N}$$

L / cm	no. of oscillations, N / s	time for N oscillations /s		T / s	T^2 / s^2
		t_1	t_2		

In this table, besides L and t that are measured directly, a column for the number of oscillations is added to allow flexibility in the oscillation experiment[1].

Readings of t have been repeated (to give t_1 and t_2). The average time, t_{av} is optional. However, we state the formula to determine period above the T column. The column for the calculated quantity T^2 comes about by linearising[2] the given relationship to be investigated, and reaching the conclusion that the straight graph to be plotted is one of T^2 against L.

If the range of L is known, the six sets of L values can be pre-planned. The column of L values are to be expressed to the precision of a ruler that is 0.1 cm. See next section for detail.

[1] Instead of fixing the number of oscillations to 20, it is more sensible to ensure that the time taken for the oscillations to be 20 s or more to lower the percentage uncertainty. There is uncertainty when measuring both the start time and also the stopping time, resulting from the experimenter's reflex time (as much as 0.2 s each, i.e. totalling 0.4 s). The percentage uncertainty which this 0.4 s represents decreases as the total time measured increases. Try carry out simple error calculations to discover, for example, the effect of a human reaction time of 0.2 seconds on timings of 2 s, 20 s and 200 s.

[2] Read p. 23-27 on linearization skills.

E Decimal place (d.p.) or significant figures (s.f.)

E1 For Raw data:

All **raw readings** are usually recorded to the **precision of the instrument**, i.e. **d.p.**

For example, if you use a metre rule to measure length of two centimetres, the precision of the metre rule is ± 1 mm = ± 0.1 cm, hence then the length must be recorded as "2.0 cm" and not "2 cm".

If the same instrument (with same scaling) is used to measure a quantity, all the values of that quantity should be expressed to the same precision (i.e. d.p.). Hence, if one measurement of length is given to the nearest millimetre, then all lengths measured using the same instrument must be given to the nearest millimetre too.

Exceptions to the rule

A stopwatch can have an instrument precision of ± 0.001 s, however as there is a human reaction time of approximately 0.2 s to 0.5 s, it does not make sense to record the timings to ± 0.001 s precision (3 d.p.). Hence we usually record the stopwatch reading to 1 d.p. in seconds.

E2 For Processed data:

The result of a calculation that involves measured quantities cannot be more certain than the least certain of the information that is used.

So the result should contain the same number of s.f. / d.p. as the measurement that has the smallest number of s.f. / d.p. , depending on the arithmetic used in the calculations.[3]

A common mistake by students is to simply copy down the final answer from the display of a calculator. This often has far more significant figures than the measurements justify.

E3 Rounding off

When rounding off a number that has more significant figures than are justified (as in the example above), if the last figure is between 5 and 9 inclusive round up; if it is between 0 and 4 inclusive round down.

For example, the number 3.5099 rounded to:

4 sig figs is 3.510
3 sig figs is 3.51
2 sig figs is 3.5
1 sig fig is 4

Notice that when rounding you only look at the one figure beyond the number of figures to which you are rounding, i.e. to round to three sig fig you only look at the fourth figure.

[3] The rules for determining the no. of significant figures to record a derived reading is based on rough approximations of uncertainties. In general, we use these rules as error analysis can be too time consuming for daily practical lessons.

How do we know the number of significant figures?

When rounding 228.5 to 2 significant figures, an incorrect approach would be to round to 230.

When seen in isolation, it would be impossible to know whether the final zero in 230 is significant (and the value to 3 sig figs) or insignificant (and the value to 2 sig figs).

In such cases, standard form should be used and is unambiguous:

- 2.3×10^2 is to 2 sig figs
- 2.30×10^2 is to 3 sig figs

When to round off?

It is important to be careful when rounding off in a calculation with two or more steps.

- Rounding off should be left until the very end of the calculation.
- Rounding off after each step, and using this rounded figure as the starting figure for the next step, is likely to make a difference to the final answer. This introduces a **rounding error**.

Learners often introduce rounding errors in multi-step calculations.

E4 d.p. / s.f. Rules

- **Addition and Subtraction**

  the no. of d.p. of the calculated value should be equal to the least no. of the d.p.

  E.g. 2.5 + 3.212

  The calculator gives 5.712

  Since 2.5 has 1 d.p. and 3.212 has 3 d.p., the final sum should be given to the least no. of d.p.,

  2.5 + 3.212 = 5.7 (1.dp.) not 6 or 5.712

- **Multiplication, Division, Trigonometry etc.**

  the number of significant figures in the calculated value should be equal to the least number of s.f. in the raw data.

  E.g.

  The resistance of a resistor is determined by measuring the potential difference and current. The voltmeter reads 12.0 V and the ammeter 1.3 mA.

  The resistance can be found using $R = V/I$.

  Using a calculator the resistance is then $12.0/(1.3 \times 10^{-3}) = 9.2307\ k\Omega$.

  Since the least certain measurement (the current) is only to 2 sig figs, the answer should also be quoted to 2 s.f..

Therefore, the resistance to the correct number of *sig figs* is R = 9.2 kΩ

It should be noted however, that if this figure is to be used in subsequent calculations then the rounding off should not be applied until the final answer has been obtained.

For example, the resistor is used in a circuit to determine the capacitance of a capacitor. The circuit was found to have a time constant τ = RC = 0.31 s

Using the calculator value of 9.2307 kΩ

- C = 3.3584 × 10^{-5} F
- rounding to 2 sig figs gives C = 3.36 × 10^{-5} F (correct)

Using the rounded value of 9.2 kΩ to determine the capacitance

- C = 3.3696 × 10^{-5} F
- rounding to 2 sig figs gives C = 3.37 × 10^{-5} F and we have a 'rounding error'.

- **Logarithms**

Significant figures in logarithmic quantities often pose difficulties for learners.

When calculating logarithm (log_{10} or lg) or natural log (ln) of a number, the digit to the left of the decimal point is not 'significant' in relation to the precision of the data. It fulfils the same role as × 10^n in the standard notation, which is also not considered part of the number of significant figures.

To illustrate, observe the values in the table below. All values for x are given to 3 sig figs.

x	lg(x)
2.53	0.403
25.3	1.403
253	2.403
2.53 × 10^6	6.403
2.52 × 10^6	6.401
2.54 × 10^6	6.405

Only the digits to the right of the decimal point (including zeros) should be counted as significant figures.

It can be seen that changes the last figure in the value of x will change the third decimal place in the value of log(x). Therefore it would be sensible to quote log(x) to three decimal places if the values of x are correct to three significant figures.

Hence **when you take lg or ln of a number with *N* s.f., the results should have *N* d.p.**

Using a calculator, lg (111.7) = 2.048053

111.7 is a 4 sig fig, so the final answer should be expressed as 2.0481 (4 d.p.).

- **Multiple Mathematical Operations**

  When calculations involve both of these types of operations, the rules must be followed in the same order as the operations, **rounding only occurs at the last step of the calculation.**

  2dp 4dp ↗ 2dp → 2sf

  For example, let us look at $\frac{(0.43 + 0.0804)}{(0.009800)}$ = 52.08163265 (calculator value)

  ↘ 4sf

  Step 1. The addition is done first. 0.43 + 0.0804 = 0.5104

  Following the rule for addition, the final answer should have 2 d.p. (i.e. 0.51) and so is 2 s.f. (As rounding is the last step, so we still use 0.5104 for the next step.)

  Step 2. Division is done next. 0.5104 / 0.009800 = 52.08163265 (calculator value)

  Following the rule for division, the sum of the numerator should be a 2 s.f. number (see Step 1) and the denominator is a 4 s.f. figure.

  Choosing the lower s.f. the final answer should be recorded as a 2 s.f. number i.e. 52.

E5 Other Points to Note in Tabulating Data

When a reading has many zeros before or after the decimal point, you should write it in ***standard form...***

x^2 / cm^2
0.00220
0.00100
0.00098

⇒

x^2 / cm^2
2.20×10^{-3}
1.00×10^{-3}
0.98×10^{-3}

or move the common multiple into the heading:

x^2 / cm^2
0.00220
0.00100
0.00098

⇒

x^2 / $\times 10^{-3}$ cm^2
2.20
1.00
0.98

F Errors in procedure

The accuracy of a final result also depends on the procedure used. For example, in a calorimetry experiment, the measurement of a temperature change may be precise but there may be large heat losses to the surroundings which affect the accuracy of the overall result.

When determining the acceleration of free fall g by dropping objects, ignoring air resistance may significantly affect the accuracy. Compare dropping an inflated balloon and a stone of a similar shape and volume from the same height: air resistance will cause the balloon to fall much slower than the stone. The value for g found with the balloon will thus have a much lower accuracy than the one found using the stone.

Anomalous readings

Anomalies are values in a set of results which are judged not to be part of the variation caused by random uncertainty. An anomaly is displayed as an outlier (a plotted point that does not follow the trend set by the rest of the points) on a graph.

If a piece of data was produced due to a failure in the experimental procedure, or by human error, it would be justifiable to remove it before analysing the data. For example if a time lapse measurement is clearly different to the other readings taken for that particular data point it might be judged as being an outlier and should be ignored when the mean time is calculated.

However, data must never be discarded simply because it does not correspond with expectation. Anomalies in data may be an indication of a new trend. For instance the spring force is no longer proportional to the spring extension beyond the limit of proportionality.

It is best practice whenever an anomalous result is identified for the experiment to be repeated. Chances are it could be due to the experimenter's error in plotting or in data collection. This highlights the need to tabulate and graph results as an experiment is carried out.

Tackling practical exam questions on anomalies

This question is commonly asked in practical exams where a given relationship is investigated:

"Comment on any anomalous data or results that you may have obtained. Explain your answer."

Scenario 1: There is no anomaly on the graph

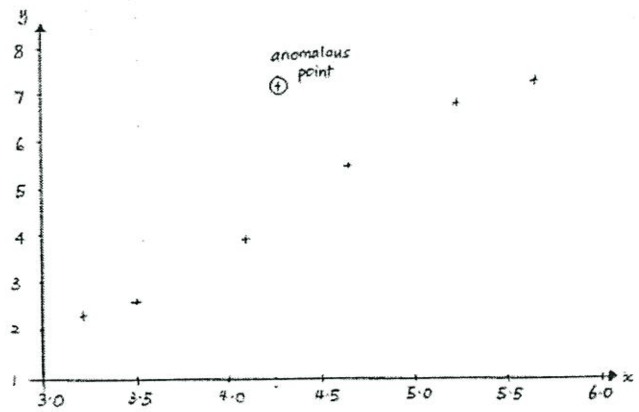
Answer:

There is no anomalous data as no data point deviates significantly from the linear trend set by all the data points. All data points are evenly scattered **about** the best fit line.

Note: If you observe that the line passes through or very close to, the majority of plotted points, you may add it on to your answer.

Scenario 2: There is an anomalous point on the graph

For example



Identify the anomalous point by circling the anomalous point on the graph and label it as "anomalous point" as shown. Read off the coordinates, say (X,Y).

Answer:

(X,Y) is an anomalous point since it **deviates significantly** from the linear trend set by the other data points.

Note that only one anomalous point is accepted.

G Percentage Difference

Learners may be asked to determine the difference between experimental values and accepted values. 'Experimental values' are those that are derived from measurement or calculation, whereas 'accepted' or 'theoretical' values are values that are accepted by the scientific community. The percentage difference between an experimental and accepted value is determined as follows:

$$\text{percentage difference} = \frac{\text{experimental value - accepted value}}{\text{accepted value}} \times 100\%$$

In many cases there will be no 'accepted value', especially since most experiments are performed to find out something 'new'. However it is considered good practice when developing a new experiment to first try to perform a measurement that does have an accepted value the result can be compared to. The scientist can then assess if their experiment is accurate.

H Units

Records of measurements should always include the relevant units. There are 7 SI base units, all other units are derived from the 7 base units. Practicals and other assessed work may require the derivation of units by the learner.

I Graphing

☆ at least 6 points (planning- 10 points)

A graph is a powerful means of providing a visual picture of the experimental results. A well-presented graph will enable the reader to obtain an accurate interpretation of the results easily. Hence it is an important component in any experiment.

Specifically, a graph serves to:

- display the relationship between two variables;
- verify the relationship between two variables;
- show at which point a particular relationship ceases to be true, e.g. when a linear function becomes a non-linear function;
- help determine the constants in the equation relating the two variables;
- improve the accuracy of the experiment by averaging the random errors of the data points; and
- identify possible presence of systematic errors.

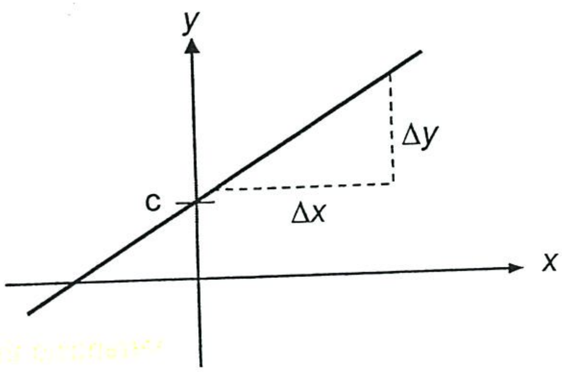
I1 Graph Analysis

1.1 Linear Relationship

A straight-line graph is represented algebraically by an equation of the form:

$$y = mx + c, \qquad \text{where } c \neq 0$$

where m is the gradient and c is the y-intercept of the graph.

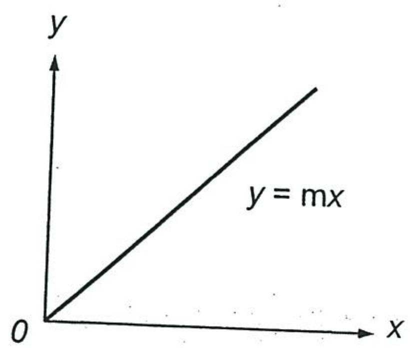


$$m = \frac{\Delta y}{\Delta x}$$

Graph of y against x

1.2 Proportional Relationship

If the straight line cuts the origin, the y-intercept c = 0.



Graph of y against x

The equation

$$y = mx + c$$

becomes

$$y = mx$$

This is a proportional relationship. It means that 'y is proportional to x'.

Proportional relationship is reserved for the case when c = 0.

If a straight-line graph is obtained when y is plotted against x, we should say that 'y is linearly related to x'. In other words, proportional relationship implies a linear graph, but a linear graph need not necessarily imply a proportional relationship.

1.3 Non-linear Relationships

It is very common that the relationship between two quantities x and y is non-linear, and plotting a graph of y against x produces a curve.

These graphs reveal less useful information than linear graphs. However, the slope may be a useful quantity. For example, the slope of a displacement-time graph gives the instantaneous velocity. To find the slope at a point on the curve is to find the gradient of the tangent to the curve at that point.

Linearisation - Converting a Curved Graph into a Straight Line

Graphs can be used to analyse more complex relationships by rearranging the equation into a form similar to $y = mx+c$.

In fact, linearization of equation should be done before planning the table, so that you know the processed data required (i.e. x and y) for plotting the straight line graph.

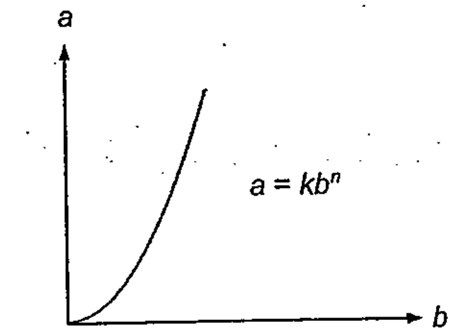
The following are some common non-linear relationships that we often encounter in Physics and respective ways to linearise them to gather more useful data.

(a) Power Relationship

Given

$$a = kb^n,$$

where a, b are variables and k, n are constants. n can either be a positive or negative real number.



Graph of a against b

To obtain a linear relationship of the form y = mx + c, we take logarithms on both sides of the equation to give:

$$a = kb^n$$

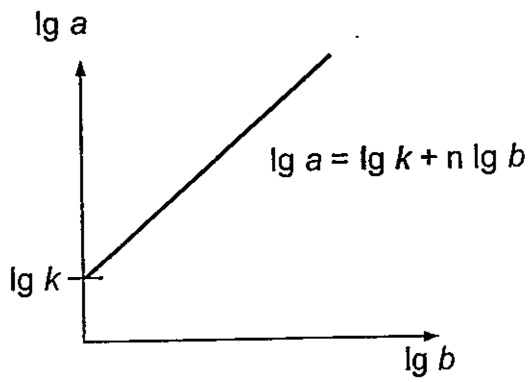
$$\lg a = \lg (k\,b^n)$$

$$\lg a = \lg k + \lg b^n$$

$$\boxed{\lg a = \lg k + n\ \lg b}$$

$$y \quad = \quad c \quad + \quad m \quad x$$

Plotting lg a against lg b, a straight line will be obtained with gradient n and vertical-intercept lg k.



Graph of lg a against lg b

(b) Exponential Relationship

$$a = A\,e^{Bb}$$

or $$a = A\exp(Bb),$$

where *a and b are variables*, and A and B are constants

To obtain a linear relationship of the form $y = mx + c$, we take logarithms to base e on both sides of the equation to give:

$$a = A\,e^{Bb}$$

$$\ln a = \ln(A\,e^{Bb})$$

$$\ln a = \ln A + \ln e^{Bb}$$

$$\underbrace{\ln a}_{y} = \underbrace{\ln A}_{c} + \underbrace{B}_{m}\,\underbrace{b}_{x}$$

$y = c + m\,x$

Plotting ln *a* against *b* will obtain a straight line with gradient *B* and vertical-intercept ln *A*.

(c) Inversely Proportional relationship

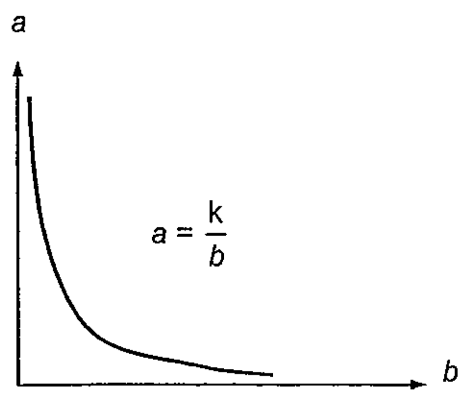
For an equation

$$a = \frac{k}{b}$$

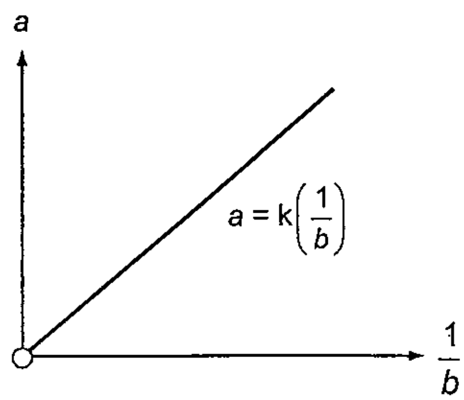
where *a* is the dependent variable
b is the independent variable
k is a constant

The equation will give a curve when we plot *a* against *b*.

Plotting *a* against 1/*b* will obtain a straight line with gradient k.



Graph of *a* vs *b*



Graph of *a* vs 1/*b*

Linearization Example 1

When water is displaced by an amount l in a U tube, the time period, T, varies with the following relationship: $T = 2\pi\sqrt{\frac{l}{2g}}$

This could be used to find g, the acceleration due to gravity.

- Take measurements of T and l.
- Rearrange the equation to become linear: $T^2 = 4\pi^2 \frac{l}{2g}$
- Calculate T^2 for each value of l.
- By re-writing the equation as: $T^2 = \frac{4\pi^2}{2g} l$

  it becomes clear that a graph of T^2 against l will be linear with a gradient of $\frac{4\pi^2}{2g}$.
- Calculate the gradient (m) by drawing a triangle on the graph.
- Find g by rearranging the equation $m = \frac{4\pi^2}{2g}$ into $g = \frac{4\pi^2}{2m} = \frac{2\pi^2}{m}$

Example 2: testing power laws

A relationship is known to be of the form $y = Ax^n$, but n is unknown.
Measurements of y and x are taken.

A graph is plotted with log(y) plotted against log(x).

The gradient of this graph will be n, with the y intercept log(A), as log(y) = n(log(x)) + log(A)

Example 3

The equation that relates the pd, V, across a capacitor, C, as it discharges through a resistor, R, over a period of time, t.

$$V = V_0 e^{-\frac{t}{RC}} \quad \text{where } V_0 = \text{pd across capacitor at } t = 0$$

This can be rearranged into $\ln V = -\frac{t}{RC} + \ln V_0$

So a graph of $\ln V$ against t should be a straight line, with a gradient of $-\frac{1}{RC}$ and a y-intercept of $\ln V_0$

I2 Guidelines for Graphing

The following general guidelines should be followed when presenting data in graphs. This section provides background information on the following graphical skills assessed both in the written and practical examinations.

- choice of scale (1, 2, 5)
- plotting of points
- line of best fit
- calculation of gradient
- determination of the y-intercept.

Everything on the graph paper should be written in **2B pencil**, and **no calculations should be done on the graph paper.**

Scales and origins

Students should attempt to spread the data points on a graph as far as possible without resorting to scales that are difficult to deal with. Students should consider:

- the maximum and minimum values of each variable
- the orientation of the graph paper (portrait or landscape)
- how to draw the axes without using difficult scale markings (awkward ratios such as eg multiples of 3, 6, 7, 9 squares per unit should be avoided)
- the plots should cover **at least half of the grid** supplied for the graph. This may mean that the origin is not included, i.e. the point (0,0) is not shown on the page.

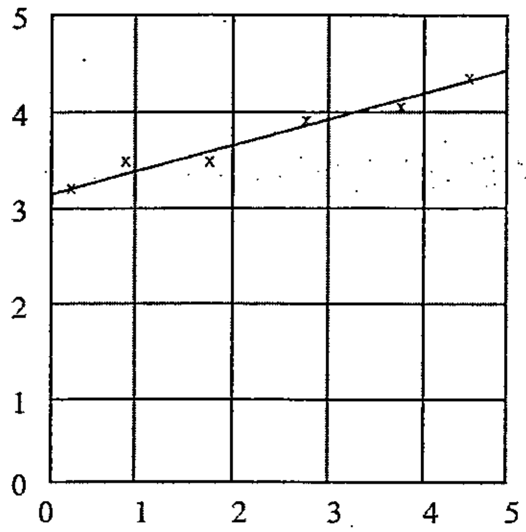
Please note that in this section, many generic graphs are used to illustrate the points made.

Students producing such graphs on the basis of real practical work or in examination questions would be expected to add in axes labels and units.

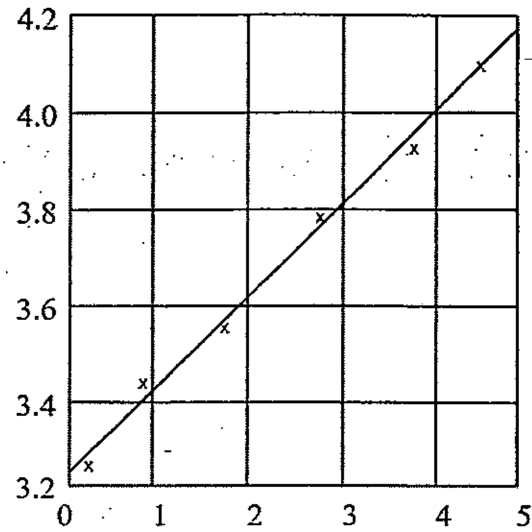
Choice of scale

Scales should be chosen so that the plotted points occupy at least half the graph grid in both the x and y directions.

You can always orientate your graph either as a portrait or landscape.



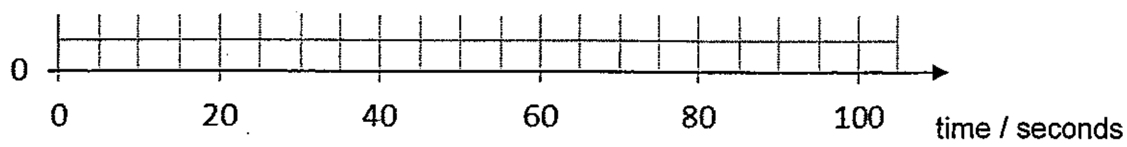
Not acceptable - scale in the *y*-direction is compressed

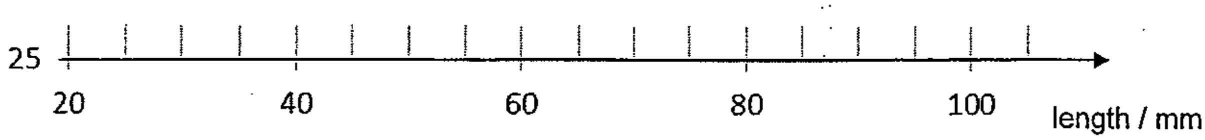


Acceptable - points fill more than half the graph grid in both the *x* and *y* directions

As far as possible, the dependent variable should be plotted on the vertical axis, while the term containing the independent variable should be plotted on the horizontal axis.

Axes should always be labelled the same way as the column headings in the table of results, with the quantity being measured and the units, separated with a forward slash (solidus). For example:

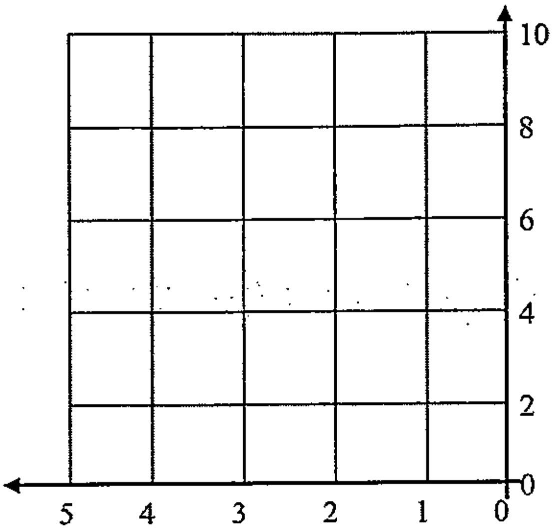




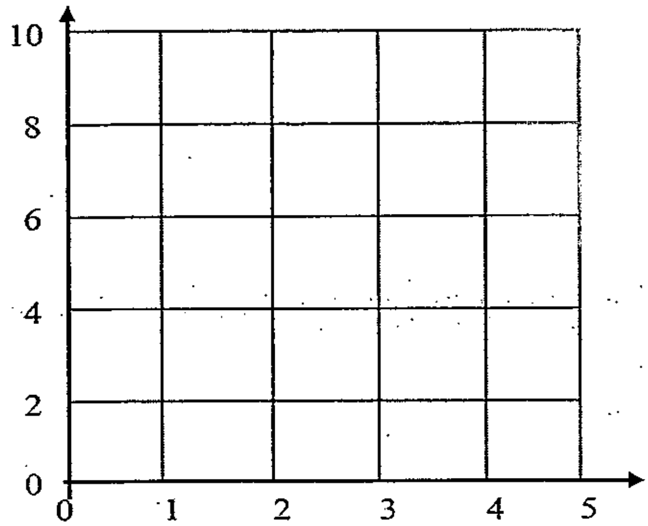
Axes should not be labelled with the units on each scale marking.

Graph axes

The scale direction must be conventional (i.e. numbers increasing from left to right).

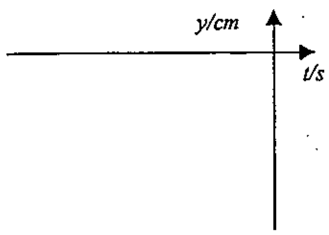


Not acceptable - unconventional scale direction



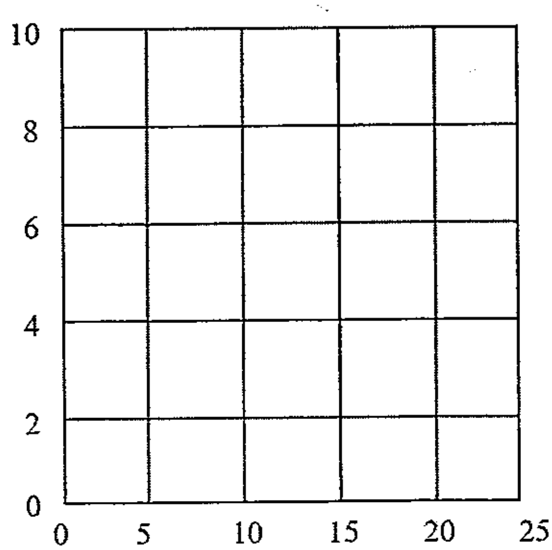
Acceptable - conventional scale direction

This problem often occurs when scales are used with negative numbers.
Learners are encouraged to choose scales that are easy to work with.

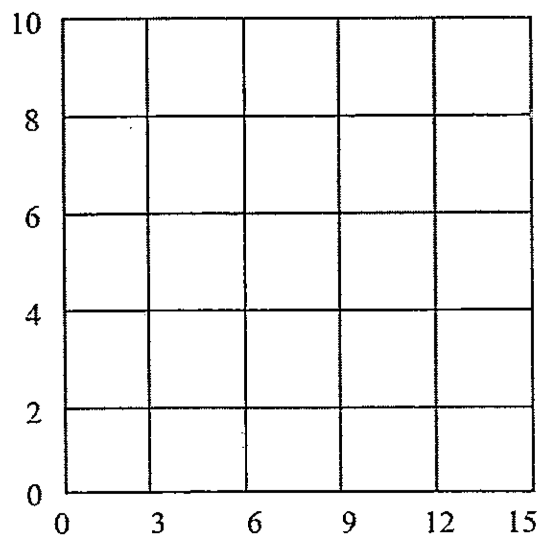


For example, the axes should be drawn as shown on the left when the data on both the vertical and horizontal axes are negative.

Graph Scales



Acceptable scale divisions.



Not acceptable - awkward scale on the *x*-axis.

Learners who choose awkward scales in examinations often lose marks for plotting points (as they cannot read the scales correctly) and calculation of gradient (Δx and Δy often misread – again because of poor choice of scale).

Plan the scales carefully before plotting the points the graph.
Remember you can use the graph paper both in portrait or landscape format to fit the scales that spread the data points to occupy at least half the graph grid in both the x and y directions.

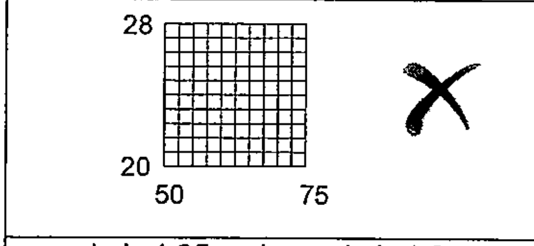
Scales chosen must be convenient to plot and read.

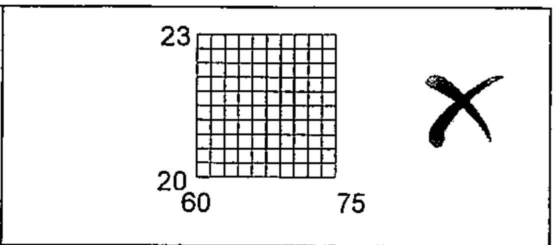
Examples of convenient scales are 1:1 (1 two-cm square is used to represent 1 unit), 1:2, 1:5 and 1:10. Avoid inconvenient scales such as 1:4, 1:8 or 1:25. Never ever use odd scales like 1:3, 1:7 etc.

To further illustrate the point,

Consider the following odd scales.

Plot the point (64, 23.3) on the scales below to the accuracy of ½ a small square.



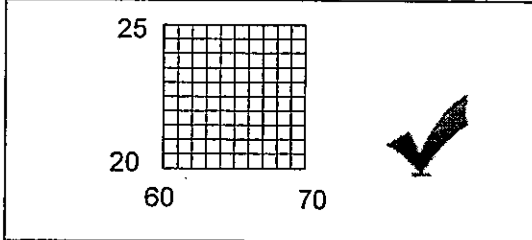


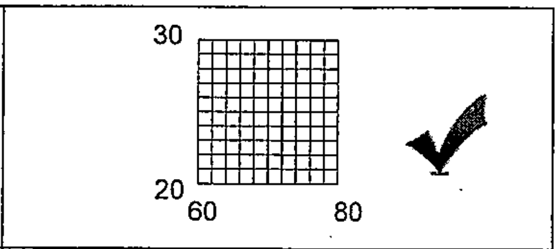
x-scale is 1:25 and y-scale is 1:8	x-scale is 1:15 and y-scale is 1:3

Notice that it is more difficult to plot the point accurately, especially if you were not using a calculator.

Now consider the following convenient scales

plot the same point (64, 23.3) on the following scales to ½-small-square accuracy:



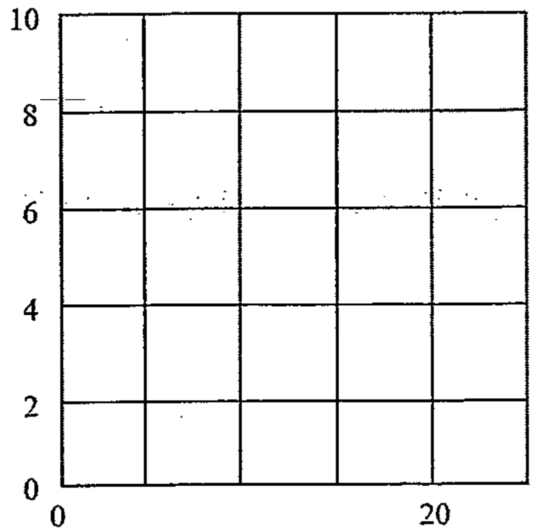


x-scale is 1:10 and y-scale is 1:5	x-scale is 1:20 and y-scale is 1:10

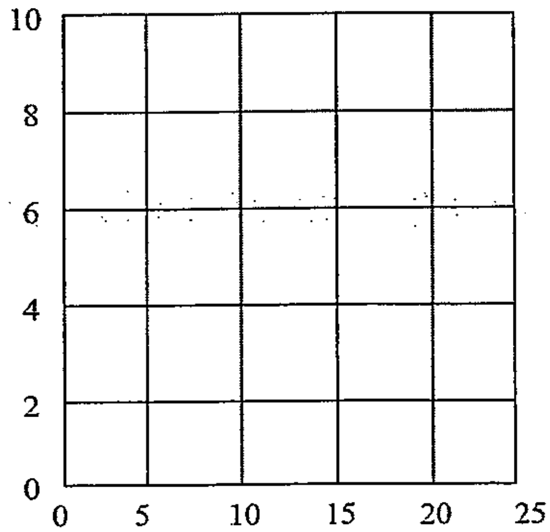
Is it now easier to plot? In fact, convenient scales allow you to do your plotting accurately even without using a calculator!

More on Scales

Scales should be labelled reasonably frequently (i.e. there should not be more than three large squares between each scale label on either axis). Recommended standard is tick mark and numerical label at every 2 cm intervals.

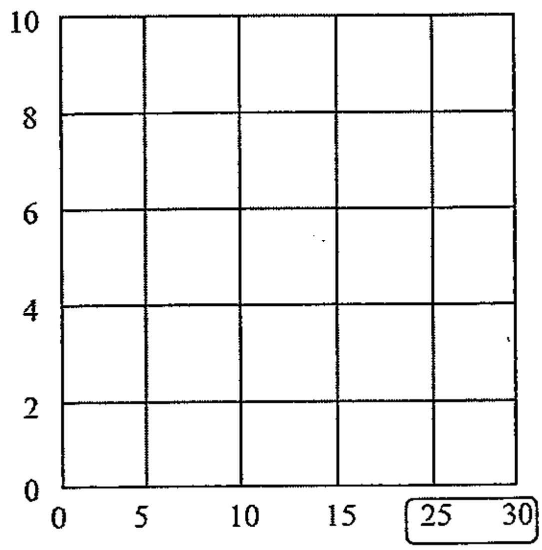


Not acceptable - too many large squares with no label

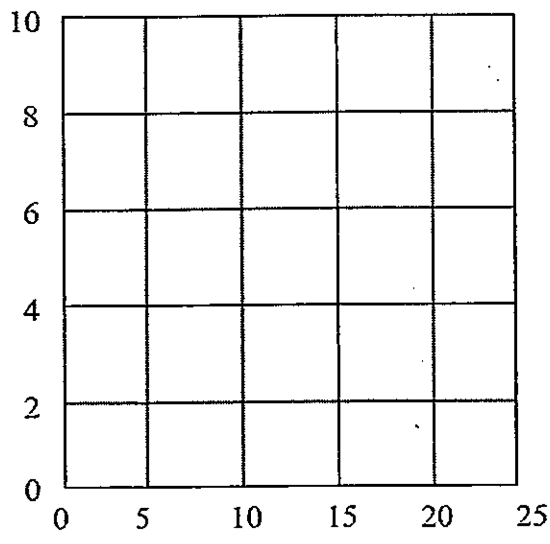


Acceptable - scales have regular labels

There should be no 'holes' or missing labels in the scale.

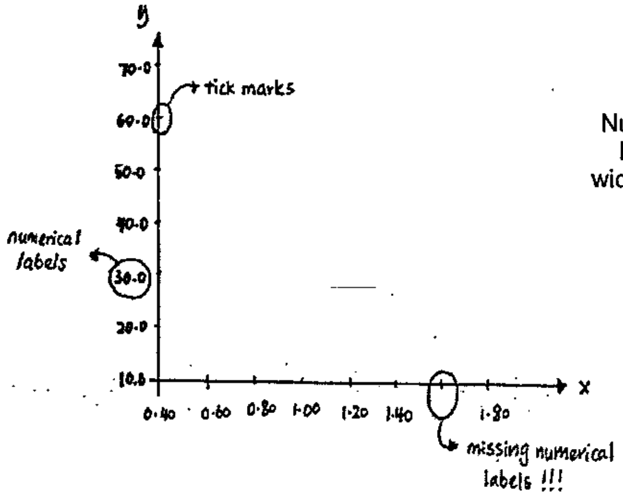


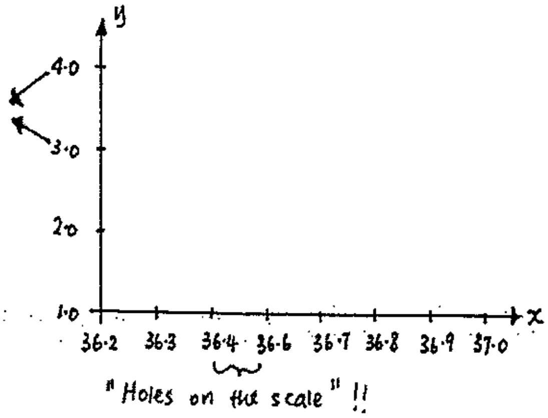
Not acceptable - non-linear scale on the *x*-axis



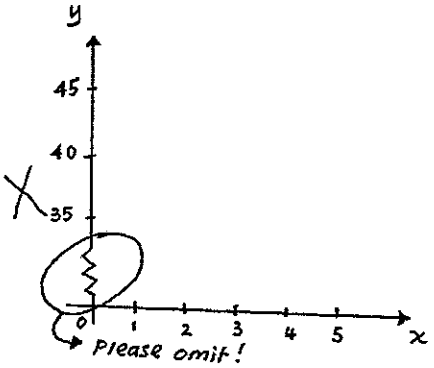
Acceptable - scale labelling is regular

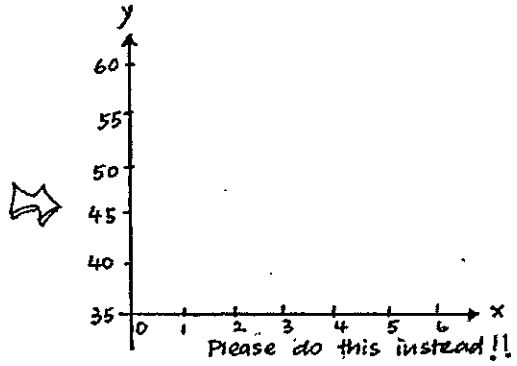
More negative examples





It is not necessary to start an axis at zero, but do not draw "zigzags" on the axes.



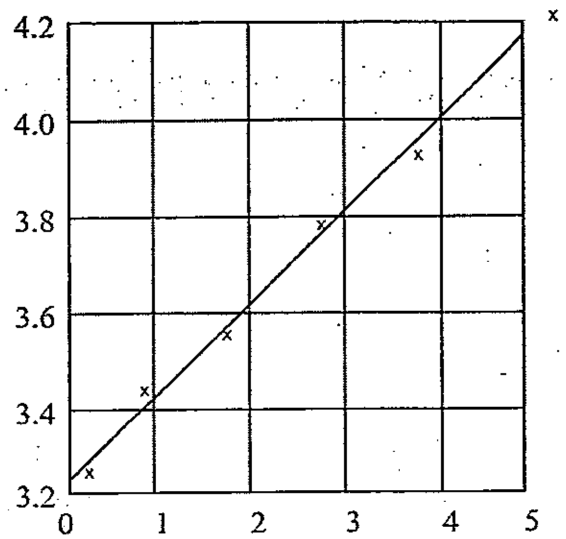


You **do not need to start either axes from zero,** even if you require the y-intercept, as the intercept can always be determined from the *gradient* and another point on the best fit line using $y = mx + c$.

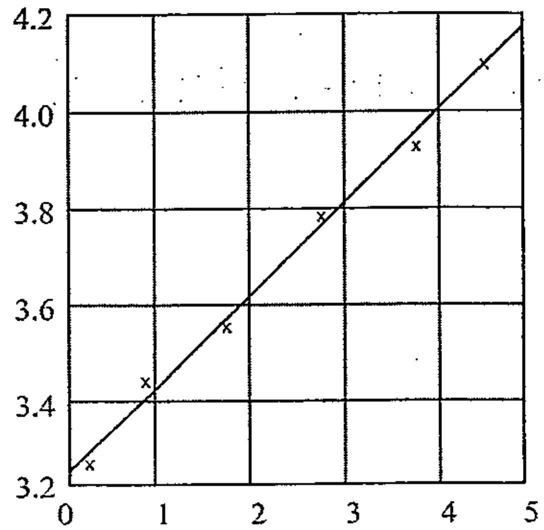
Plotting of points

Data points should be marked with a cross (×, or +) or an encircled dot (⊙ , NOT thick dot •) using a sharp 2B pencil, but care should be taken that data points can be seen against the grid.

Plots in the margin area are not allowed, and will be ignored in examinations. Sometimes weaker candidates (realising they have made a poor choice of scale) will attempt to draw a series of lines in the margin area so that they can plot the 'extra' point in the margin area. This is considered to be bad practice and would not be credited.



Not acceptable - the last point has been plotted in the margin area



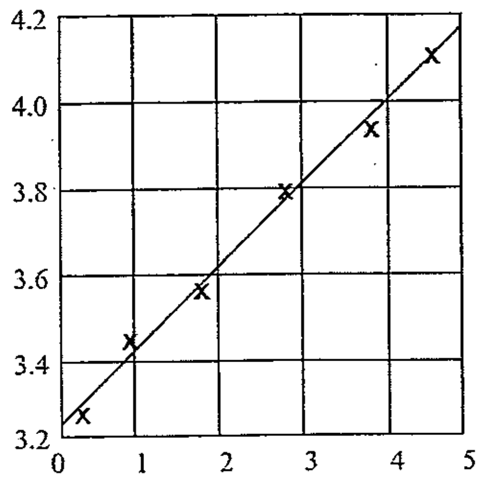
Acceptable - all plotted points are on the graph grid

It is expected that all observations will be plotted (e.g. if six observations have been made then it is expected that there will be six plots, including anomalous point).

Plotted points must be accurate to half a small square.

Plots must be clear (and not obscured by the line of best fit or other working).

Thick plots are not acceptable. If it cannot be judged whether a plot is accurate to half a small square (because the plot is too thick) then the plotting mark will not be awarded.



Thick plots not acceptable

Line (or curve) of best fit

Lines of best fit should be drawn when appropriate. Students should consider the following when deciding where to draw a line of best fit:

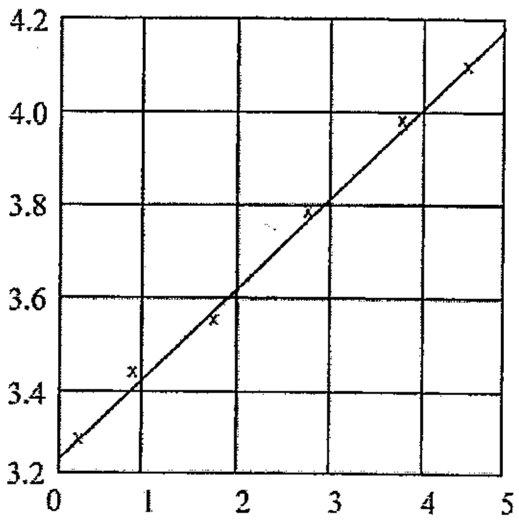
- Are the data likely to be following an underlying equation (for example, a relationship governed by a physical law)? This will help decide if the line should be straight or curved.
- Are there any anomalous results? Ignore the point which you identified as anomalous and take into account the remaining points for best fit.

There is no definitive way of determining where a line of best fit should be drawn. There must be a reasonable balance of points about the line. A good rule of thumb is to make sure that there are as many points on one side of the line as the other. Often the line should pass through, or very close to, the majority of plotted points. It is often felt that candidates would do better if they were able to use a clear plastic rule so that points can be seen which are on both sides of the line as it is being drawn.

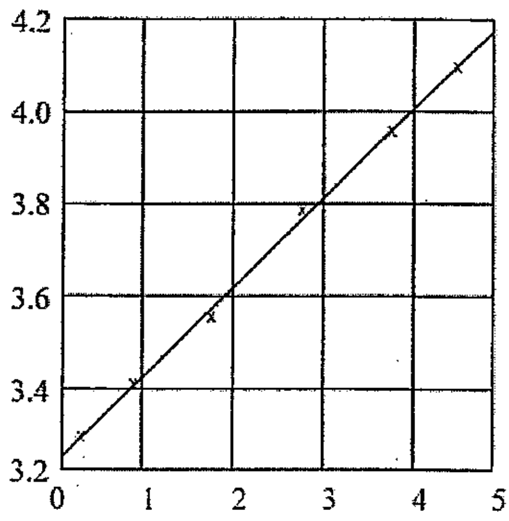
A more advanced way of assessment of best fit is to check that the sum of the perpendicular distance of points on one side ≈ the sum of perpendicular distance of points on the other side.

Lines of best fit should be continuous and drawn as a thin pencil that does not obscure the points below and does not add uncertainty to the measurement of gradient of the line.

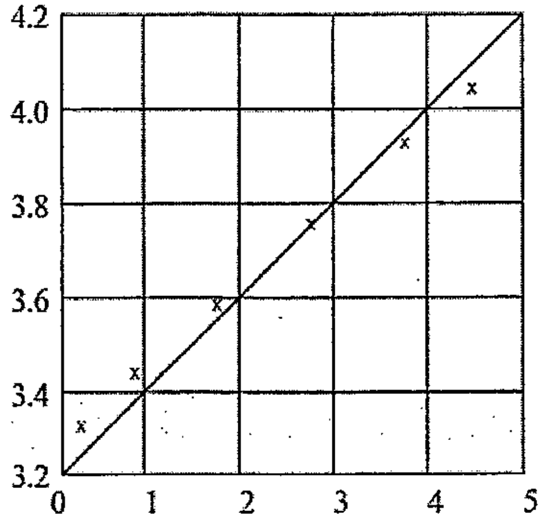
Not all lines of best fit go through the origin. Students should ask themselves whether a 0 in the independent variable is likely to produce a 0 in the dependent variable. This can provide an extra and more certain point through which a line must pass. A line of best fit that is expected to pass through (0,0), but does not, would imply some systematic error in the experiment. This would be a good source of discussion in an evaluation.



Not acceptable - too many points above the line



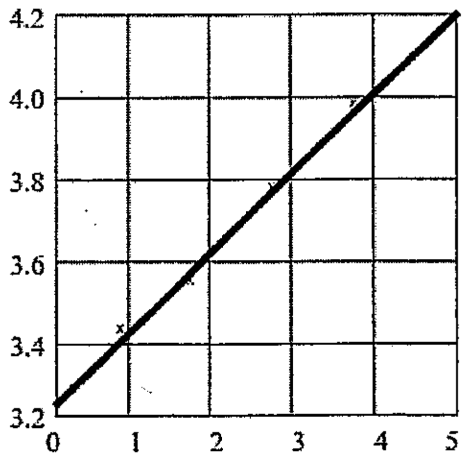
Acceptable balance of points about the line



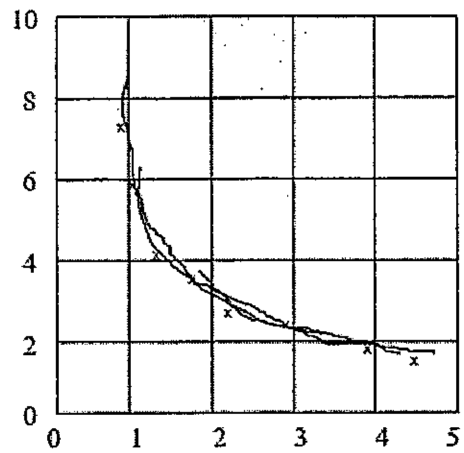
Not acceptable - forced line through the origin (not appropriate in this instance)

Excluding (0, 3.2) and turning the line clockwise about the centre, all points can be closer to the best fit.

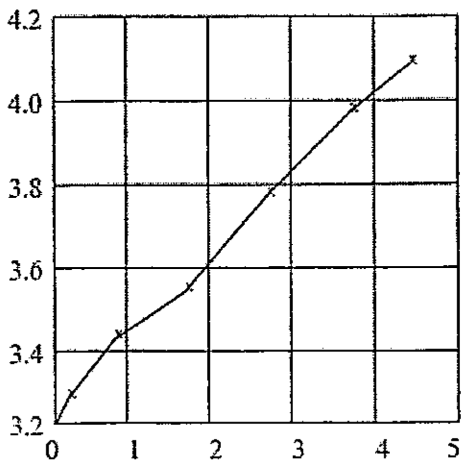
The line must be thin and clear. Thick/hairy/point-to-point/kinked lines are not credited. To draw in the best fit line in a single stroke, a 30-cm transparent ruler is essential.



Not acceptable - thick line



Not acceptable - 'hairy' curve



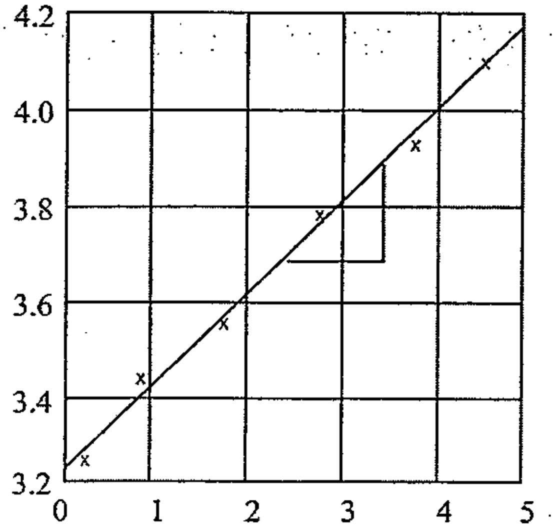
Not acceptable – joining point-to-point

Determining gradients

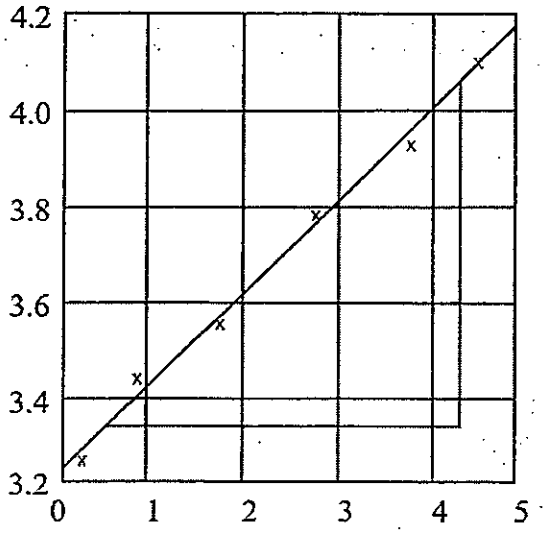
All the working must be shown. A 'bald' value for the gradient may not be credited. It is helpful to both candidates and examiners if the triangle used to find the gradient were to be drawn on the graph grid and the co-ordinates of the vertices clearly labelled.

Choose 2 convenient points along the best fit (e.g. lie on grid intersection), for ease of reading.

The length of the hypotenuse of the triangle should be greater than half the length of the line which has been drawn.



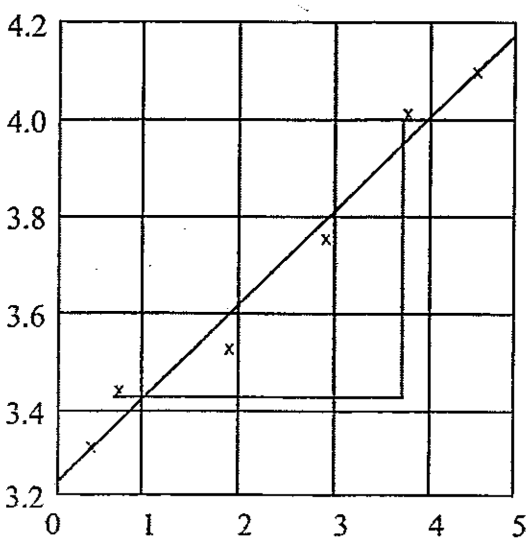
Not acceptable - the 'triangle' used is too small



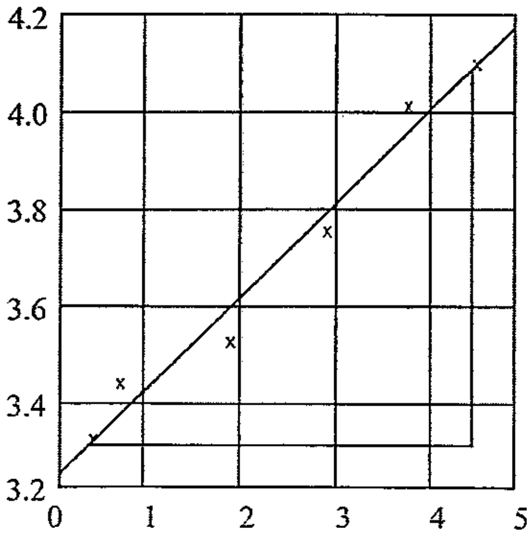
Acceptable – a large 'triangle' used

The values of Δx and Δy must be given to an accuracy of at least one small square (i.e. the 'read-off' values must be accurate to half a small square).

If plots are used which have been taken from the table of results then they must lie on the line of best fit (to within half a small square).



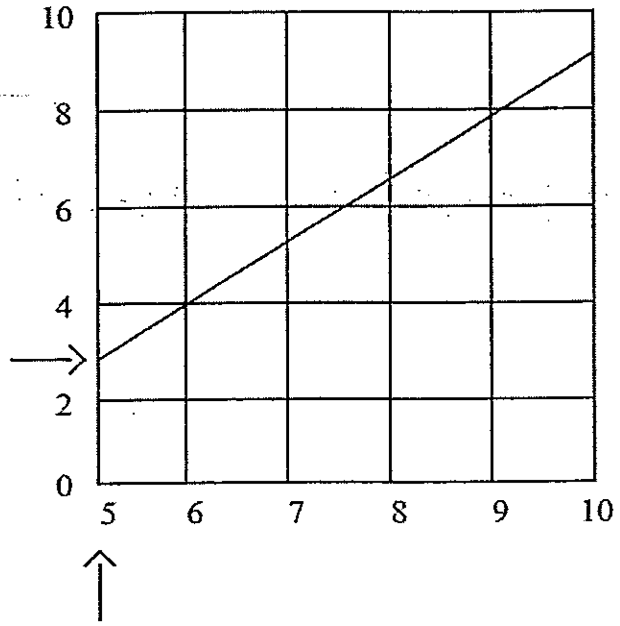
Not acceptable - the data points used which do not lie on the line of best fit



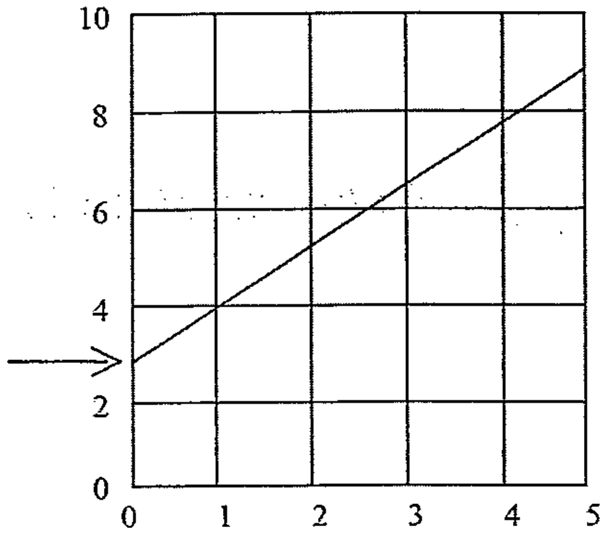
Acceptable - plots on line

Intercept

The y-intercept must be read from an axis where x = 0. It is often the case that candidates will choose scales so that the plotted points fill the graph grid (as they should do) but then go on to read the y-intercept from a line other than x = 0.



Wrong!! – the y-intercept is found from the line $x = 5$



Acceptable – the value taken from the line $x = 0$

Alternatively, the intercept value can be calculated, recognising that a straight-line graph has the basic formula y = mx + c. Substituting the gradient value and a set of coordinates on the line of best fit and solving the equation will give the intercept.

I3 Drawing Conclusions

Many of the graphs we draw are straight line graphs, and the most common conclusions we can draw from the straight line graphs are *gradient* and *y-intercept*.

1.1 Determining the Gradient of a straight line – Step-by-Step Example

A straight line graph is described by the equation $y = mx + c$, where m is the gradient of the graph.

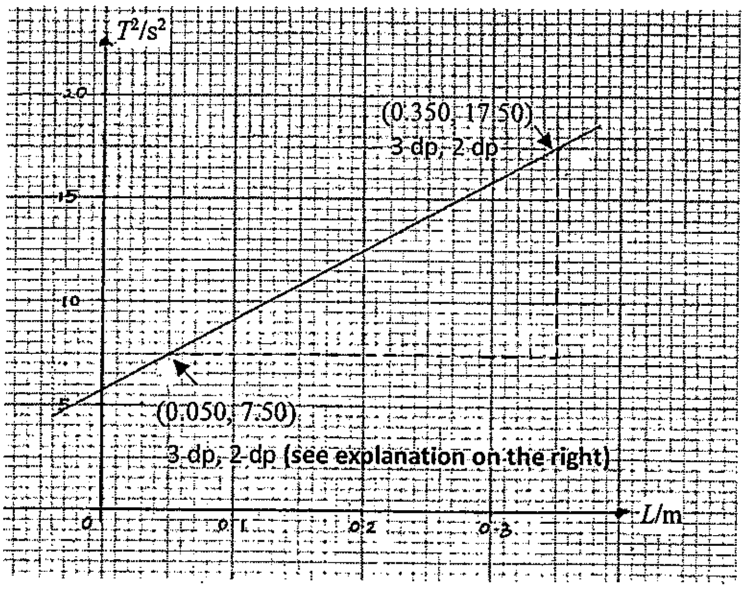
The gradient can be found using the coordinates of the vertices, (x_1, y_1) and (x_2, y_2), of a gradient triangle:

$$Gradient = \frac{y_2 - y_1}{x_2 - x_1}$$

The specific steps to determining the gradient and how the working is to be presented are illustrated in the example below:

Consider the following graph:

Given that the equation to verify is $T^2 = n\,L + k$



Step 1: Draw the gradient triangle.

- Gradient triangle must be sufficiently large so that hypotenuse is more than ½ the graph paper.
- Gradient triangle should be drawn with **dotted lines.**

Step 2: Label gradient coordinates of the gradient triangle neatly on graph.

- Do not put in extraneous markings on the vertices.
- Gradient coordinates should be **recorded to accuracy of ½ square:**
- Consider the x-ordinates (T^2 / s^2):
  - 10 small divisions 0.1
  - ½ square – 0.1 / 20 = 0.005
  - All x-values should be read to ±0.005, 3 dp
- Consider the y-ordinates (L / m):
  - 10 small divisions – 5
  - ½ square – 5 / 20 = 0.25
  - All y-values should be read to ±0.25, 2 dp

Step 3: Compute gradient using the equation: $Gradient = \frac{y_2 - y_1}{x_2 - x_1}$

- **All working** for the gradient has to be **shown clearly on the answer script**. (Not on the graph paper!).
- Copy the coordinates into the working including all the zeros in the decimals.
- Apply the s.f. rules to determine the appropriate s.f. to express the final answer in.
- Determine the units of the final answer.

(See details below.)

Hence, gradient $= \dfrac{17.50-7.50}{0.350-0.050}$ → Numerator: 2 d.p. – 2.d.p. ⇒ 2 d.p.; Denominator: 3 d.p. – 3.d.p. ⇒ 3 d.p.

$= \dfrac{10.00}{0.300}$ → $\dfrac{4\text{ s.f.}}{3\text{ s.f.}} \rightarrow$ 3 s.f. (least no. of s.f.)

$= 33.3$

Thus n = 33.3 s^2 m^{-1} → n value with correct unit

Note: the gradient does not carry unit as it is purely a numerical value. However, the corresponding unknown constant does carry a unit.

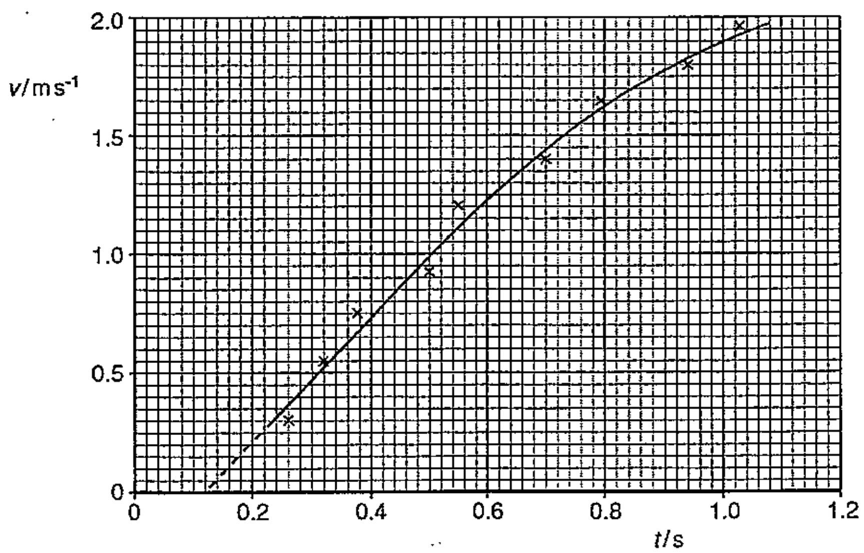
Always refer to the original equation (especially if the linearised equation carries logarithmic terms), being a homogenous equation, all the terms on both sides of the equation must have the same units. Analyse and determine the units of the unknown constant.

1.2 Gradient at a Point on the Curve

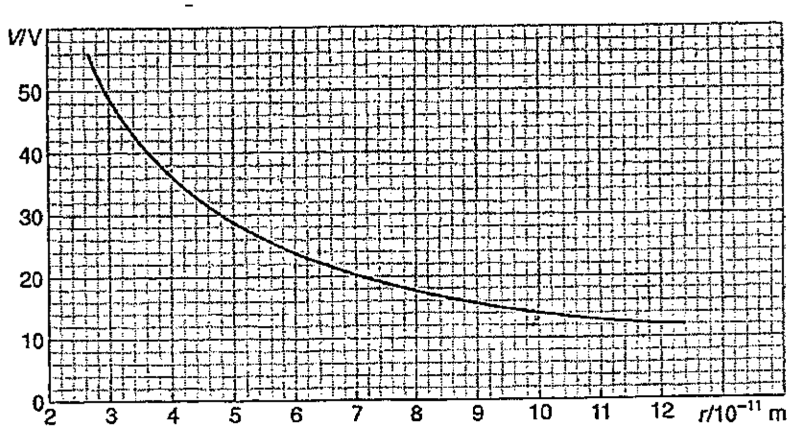
If the gradient at a point of a curve is required, the tangent line must first be drawn at the point, before determining the gradient of the tangent.

Exercise: Can you draw the tangent line for the following two curves?

(a) Sketch the tangent line for the following curve at t = 0.8 s.



(b) Sketch the tangent line for the following curve at $r = 5.0 \times 10^{-11}$ m.



2 Determining the y-intercept Step-by-Step

- The *y-intercept* is the value at which the curve cuts the *y*-axis (i.e. *y*-coordinate when $x = 0$). **Hence, it can be read off the graph if the *x*-axis begins at zero.**
- However, if the inclusion of $x = 0$ in the graph means that all points are plotted on a small area of the graph, then it is not sensible to include the origin in the graph.

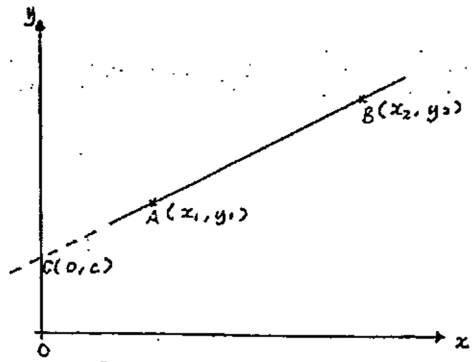
The intercept should then be determined from calculations.

Method 1:

Let c be the *y*-intercept of the graph:

Gradient of CB = Gradient of AB

$$\Rightarrow \frac{y_2 - c}{x_2 - 0} = \frac{y_2 - y_1}{x_2 - x_1}$$



Method 2 (preferred):

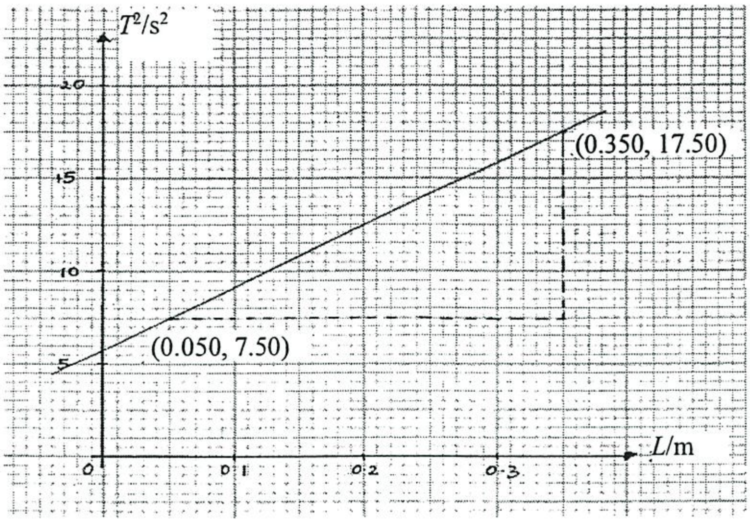
Suppose gradient, m has already been determined.

Then you can substitute the value of gradient and the coordinates of a point on the line, say (x_1, y_1) into the linearised equation ($y = mx + c$).

- <u>**Note**</u>
  - If the y-intercept is read from the graph, it must be read to half the smallest square, i.e. to the **correct number of d.p. (precision) allowed by the scale of the graph.**
  - If the *y*-intercept is calculated, then **its s.f. must follow the s.f. of the coordinates used.** Subsequent values calculated from the *y*-intercept should also be expressed to the same s.f.
  - To save time, use one of the points that were used to determine the gradient.

Using the same example on p. 34, we illustrate three possible methods in determining the *y*-intercept of the graph. Do take note of how the answers are to be presented in a write-up as well.

Given that the equation to verify is $T^2 = n\,L + k$



Method 1: Read off from the graph

In this case, the x-axis MUST start from zero, then the vertical intercept is a true intercept. Hence, the *y*-intercept can be read off from the graph.

From the graph, *y*-intercept = 5.75 → *y*-axis ½ square: 0.25. Value read to ½ square.

Thus k = 5.75 s^2 → Unit same as T^2

Method 2: Calculate from gradient and one point using $y = mx + c$.

(a point on the best fit line

Using gradient, n = 33.3 s^2 m^{-1} and (0.050, 7.50):

$k = T^2 - n\,L$

= (7.50) - (33.3)(0.050) → (33.3)(0.50) → (3 s.f.)(2 s.f.) → 2 s.f. → 1.7(1d.p.)
7.50 – 1.7
→ (2 d.p.) – (1 d.p.)
→ 1 d.p. (least)

= 5.8 s^2 → Correct unit

Method 3: Calculate from $\frac{y_2 - c}{x_2 - 0} = \frac{y_2 - y_1}{x_2 - x_1}$ in this case $\frac{T_2^2 - k}{L_2 - 0} = \frac{T_2^2 - T_1^2}{L_2 - L_1}$

Using (0.050, 5.50) and (0.350, 17.50),

$$\frac{17.50 - k}{0.350 - 0.000} = \frac{17.50 - 7.50}{0.350 - 0.050}$$

$$\Rightarrow \quad k = 17.50 - 0.350\left(\frac{17.50 - 7.50}{0.350 - 0.050}\right)$$

→ $0.350(\frac{17.50 - 7.50}{0.350 - 0.050}) \rightarrow (3 \text{ s.f.})(\frac{4 \text{ s.f.}}{3 \text{ s.f.}}) \rightarrow 3 \text{ s.f.} \rightarrow 11.7(1 \text{ d.p.})$

= 5.8 s^2 → Correct unit

2 Qualitative Conclusion

For most straight line graphs, after the gradient and intercept are found, you will be asked to determine the constants in the relationship given in the question.

a. **Working** for obtaining these constants from the gradients and *y*-intercepts must be **clearly shown**.

b. Credit is awarded only when the **units of the constants** are correct.

c. The **significant figures of the constants** must also be correct.

d. Write a statement to comment on the validity of the given relationships if the question asks for it.

Some examples:

"The straight line graph obtained suggests that the relationship $\frac{1}{T^2} = \frac{k}{x^3} + c$ *is valid, with* $k = 1.23\ m^3s^{-2}$ *and* $c = -0.985\ s^{-2}$*."*

– This statement is used when you expect to plot a straight line graph with a certain gradient and *y*-intercept, and you have determined both quantities.

"Since the graph of y^2 *vs. x is a* ***straight line graph passing through the origin****,* y^2 *is directly proportional to x."*

– This statement is used when you expect to plot a straight line graph with a certain gradient, passing through the origin, and have determined both the gradient and y-intercept (at the origin).

"Since the graph of y^2 *vs. x is a straight line graph,* y^2 *is linearly related to x."*

– This statement is used when you expect to plot a straight line graph of certain gradient, but have NOT found y-intercept.

"From my graph, R is only linearly related to A from A = 0.00 m^2 *to 0.30* m^3*."*

– This statement is used when you expect to plot a straight line graph, but the graph is only linear for a limited range of values.

Note:

A straight line graph only suggests a linear relationship between the *y-variable* and *x-variable*. For one variable to be ***directly proportional*** to the other, a straight line graph passing through the origin (i.e. *y-intercept* = 0) must be obtained.

J Evaluating an Experiment Qualitatively

Generally in evaluating an experiment qualitatively you should make comments on the following:

- **Possible sources of errors** encountered in the experiment and **how these errors may affect** the experiment.
- **Experimental precautions** that should be taken to ensure reliability of results.

To aid us in our brainstorming for the above points you may consider the following areas in the experiment:

- **Physics principles** that form the basis of the experiment and **any assumptions** made in forming the hypothesis,
- **Variables** to be measured. This includes the control, the dependent, and the independent variables. They can be both raw and derived variables.
- **Procedures.** Lastly, read through the experimental procedure and set up to scan for additional points that need to be taken care.

Some Points to Note:

- In general, the errors and improvements expected to be written are supposed to be significant ones unique to the experiment.
  - They **should not be errors due to inadequacy of the experimenter.** They should also not be improvements that the experimenter could have carried out during the experiment.
    - e.g. "I did not stir the water when collecting the temperature readings so there could be variations in temperature depending on where I put the thermometer." ×INCORRECT!!!!
    - e.g. "The fan was not switched off causing the oscillations of the pendulum to be unstable and therefore resulting in variations of the period collected." ×INCORRECT!!!!
  - They **should not be generic improvements**
    - e.g. "collect 3 sets of readings for each and take average to reduce random error."

- Try to **write about different aspects of the experiment** and not dwell on errors pertaining to just the measurement of one variable.

The figure below gives an overview of how to evaluate an experiment qualitatively.