10 Helpful Guide on Practical Skills

This guide is designed to provide helpful tips on the qualitative, quantitative and evaluative tasks for the AS and A2 Practical Skills. It is envisaged that the guide will promote a better understanding of what examiners expect from the candidates. There is particular focus on measurements, presentation of results, graphical work and analysis of results.

Measurements

1. Measurement and observation

The minimum number of observations to be made is usually six for most tasks. This will prevent candidates from spending too much time taking readings and not allowing enough time for the graphical work and the analysis. Six (or more) readings are usually required for a linear trend or nine for a curved trend. Candidates will not be penalised for taking more than the six observations. However, taking fewer than six observations may lead to a penalty. It is expected that **all** observations will be plotted on the graph grid.

The range over which the readings are to be taken may be specified in the task. It is expected that candidates will use sensible intervals between each reading in this range. For example, if a quantity *d* was to be measured, the task may instruct candidates in the following way '... for values of *d* in the range 15 cm < *d* < 75 cm measure the time for ... until you have six sets of readings for *d* and *t* ...', in which case a sensible interval would be 10 cm.

d / cm	*t* / s
20.0	
30.0	
40.0	
50.0	
60.0	
70.0	

Acceptable - the intervals are fine

d / cm	*t* / s
20.0	
22.0	
26.0	
44.0	
68.0	
70.0	

Not acceptable - the first three readings and last two readings are too close together

2. Repeated readings

It is expected that candidates will repeat readings and determine an average. All **raw readings** should be recorded. Many weaker candidates only record a final average value and not the raw values from which it was derived. In consideration of the time limits for the assessments, it is only necessary to repeat readings so that **two** sets of values are obtained. Again, the reason for this is to avoid too much time being spent taking readings from the apparatus.

3. Quality of results

Some marks may be reserved for the candidates who have done the experiment carefully. This is usually judged by the *scatter of points* about a line of best fit.

4. Significant figures

Many candidates use an appropriate number of significant figures in a calculated quantity, but often do not understand why. In their explanation it is expected that the number of significant figures in the final calculated quantity will be related to the number of significant figures in the raw data which has been used in the calculation.

Common errors made by weaker candidates include:

- Vague statements such as 'it increases the accuracy of the experiment'.
- 'I am going to plot a graph, so I will give my answers to 2 sig. figs.'
- Confusion between significant figures and decimal places (e.g. 'I have given x to two decimal places so x^3 should be given to two decimal places').

Many candidates confuse significant figures (sf) and decimal places (dp). It may be helpful to these candidates if increased guidance could be given. Often it is helpful to consider pairs of values such as those shown in the table below:

x	x^3
6.52	277.17
6.53	278.45
6.54	279.73

Too many sf in the values of x^3 (5 sf values from 3 sf data)

Clearly both sets of values for x and x^3 are given to two decimal places. However, values of x^3 are given to five significant figures, which is not justified from the precision of the values of x. Changing the third significant figure in the value for x (2, 3 or 4) changes the third significant figure in the value of x^3 (7, 8 and 9). Hence the values for x^3 should only be quoted to three significant figures (to be consistent with the values of x from which they were derived).

x	x^3
6.52	277
6.53	278
6.54	280

sf in values of x^3 are correct (3 sf values from 3 sf data)

Similar difficulties apply when large numbers are involved. Consider the case of a voltmeter having a resistance of 50 000 Ω. It is unclear as to whether this value is correct to one, two, three, four or five significant figures. In this case candidates would find it helpful to be encouraged to use scientific notation or multiplying prefixes to indicate how many significant figures are intended to be shown.

For example:

.
R = 50 000 Ω (could be 1, 2, 3, 4 or 5 sf)
$R = 5 \times 10^4$ Ω (1 sf)
$R = 5.0 \times 10^4$ Ω (2 sf, 1 dp)
$R = 5.00 \times 10^4$ Ω (3 sf, 2 dp)
R = 50 kΩ (2 sf)
R = 50.0 kΩ (3 sf, 1 dp)

Candidates would benefit from using any of the forms above **except** the first one in order to make it clear how many significant figures they intend to give.

Significant figures in logarithmic quantities are also not well understood by candidates. Often it is not appreciated that the characteristic is a place value and is not 'significant' in relation to the precision of the data. The following set of values could be used to illustrate this. All the values of x have been given to 3 significant figures.

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

Clearly the characteristic must be given, but it can be seen that changing the last figure in the value of x will change the third decimal place in the value of lg x. Therefore it would be sensible in this case to quote lg x to three decimal places if the values of x are correct to three significant figures.

Presentation of results

Presentation of results is dealt within three main areas; column headings, consistency of raw readings and significant figures in calculated quantities. Procedures for dealing with these are as follows:

1. Column headings

It is expected that **all** column headings will consist of a quantity **and** a unit.

The quantity may be represented by a symbol or written in words. There must be some kind of distinguishing notation between the quantity and the unit. Candidates should be encouraged to use solidus notation, but a variety of other notations are accepted. For example, a length *L* measured in centimetres may be represented as follows:

L /cm, *L*(cm), *L*in cm, and $\frac{L}{\text{cm}}$

are all **acceptable** as column headings.

If the distinguishing notation between a quantity and its unit are not clear then credit will not be given. Examples of this are show below:

L cm, L_{cm}, $\frac{L}{\text{cm}}$ or just 'cm'

are **not** acceptable.

Units relating to quantities where the logarithm has been found should appear in brackets after the 'log'. The logarithm of a quantity has no unit. It is recommended that the logarithm of a length *L* measured in centimetres using a base of ten should be written as lg (*L*/cm).

2. Consistency of presentation of raw data

All the raw readings of a particular quantity should be recorded to the same number of decimal places. These should be consistent with the apparatus used to make the measurement. In the example shown below a rule with a millimetre scale has been used to make a measurement of length. We may expect all the readings of length *L* therefore to be given to the nearest millimetre, even if a value is a whole number of centimetres.

L / cm	*t* / s
2	
3.7	
4.9	
5.9	
6.3	

Not acceptable - the first reading is to the nearest cm and all the others are to the nearest mm.

L / cm	*t* / s
2.0	
3.7	
4.9	
5.9	
6.3	

Acceptable - all the raw readings have been given to the same degree of precision

Candidates are sometimes tempted to 'increase the accuracy of the experiment' by adding extra zeros to the readings. This makes the readings inconsistent with the apparatus used in measuring that particular quantity. In the case of a thermometer which can measure to a precision of about a degree ($\pm$ 1 ^{0}C) it is unreasonable to give temperatures which indicate that a precision of one hundredth of a degree have been achieved.

θ / ^{O}C	*t* / s
22.00	
35.50	
47.00	
58.50	
77.00	
89.50	

Not acceptable - too many dp in the values of θ - not achievable with a mercury-in-glass thermometer

Candidates sometimes go the other way and do not record enough decimal places (e.g. length values which are recorded to the nearest centimetre when a rule with a scale in millimetres is used to make the measurement).

3. Significant figures in calculated quantities

Calculated quantities should be given to the same number of significant figures as the measured quantity of least precision. Consider the table of readings below:

V / V	*I* / A	*R* / Ω
3.0	1.43	2.1
4.0	1.57	2.5
5.0	1.99	2.5
6.0	2.45	2.4
7.0	3.02	2.3

If values of *V* and *I* are measured to two and three significant figures respectively, we would expect *R* to be given to two significant figures. This is because a value of

V = 3.1 V in the first row of figures would give *R* = 2.2 Ω (i.e. changing the second significant figure in the value of *V* will change the second significant figure in the value of *R*).

Three significant figures would be *acceptable* for *R*, but **not** one significant figure (e.g: 2 Ω) or four significant figure (2.098 Ω).

The exception to this rule is when candidates use stopwatches reading to 0.01 s. Candidates cannot measure to this accuracy although many will record readings directly from the stopwatch. Therefore in this case it would be acceptable for candidates to round down to the nearest tenth of a second and give values of a calculated quantity (e.g. period *T*) to three significant figures.

20*T* / s	*T* / s
10.49	0.525
14.31	0.716
17.69	0.885
24.88	1.24
29.61	1.48
33.02	1.65

Acceptable. Note that some values of *T* are to three dp and others are to two dp, but all the values of *T* are to 3 sf

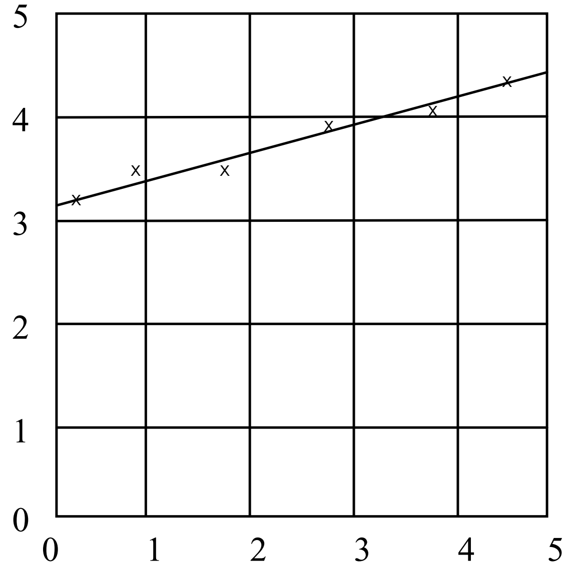
Graphical work

Credit for graphical work usually may often fall into five categories:

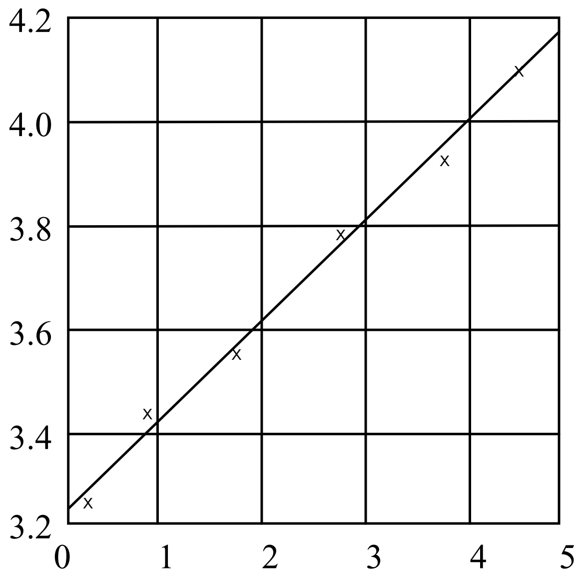
- Choice of scale
- Plotting of points
- Line of best fit
- Calculation of gradient
- Determination of the *y*-intercept

1. Choice of scales

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



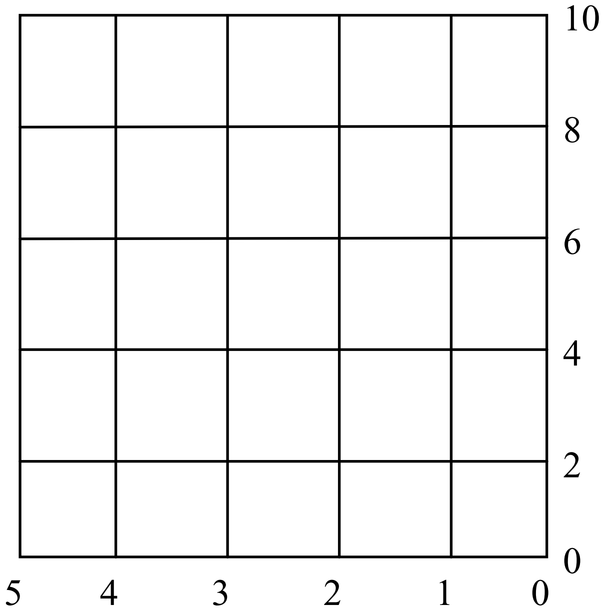
Not acceptable - scale in the *y*-direction is compressed



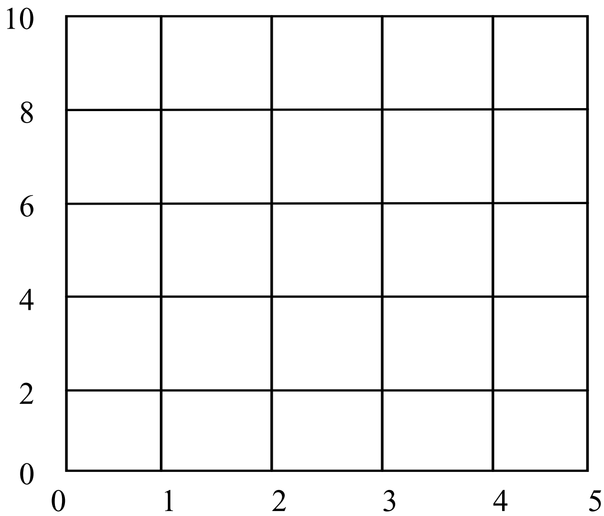
Acceptable - points fill more than half the graph grid in both the *x* and *y* directions

b. It is expected that each axis will be labelled with the quantity which is being plotted.

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



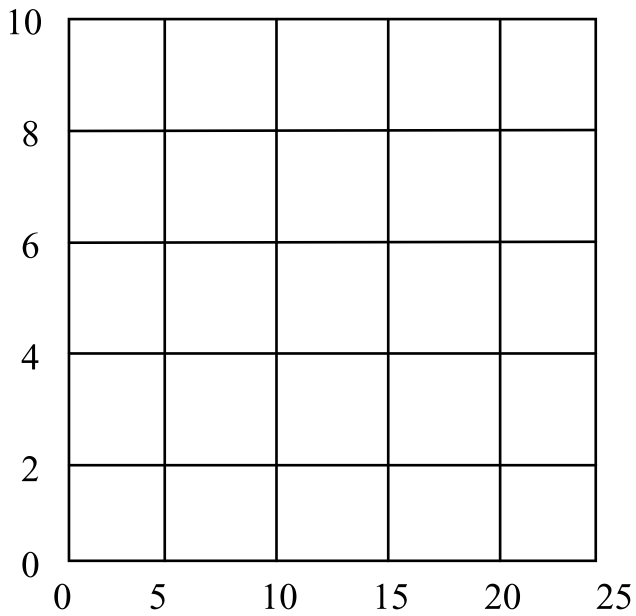
Not acceptable - unconventional scale direction



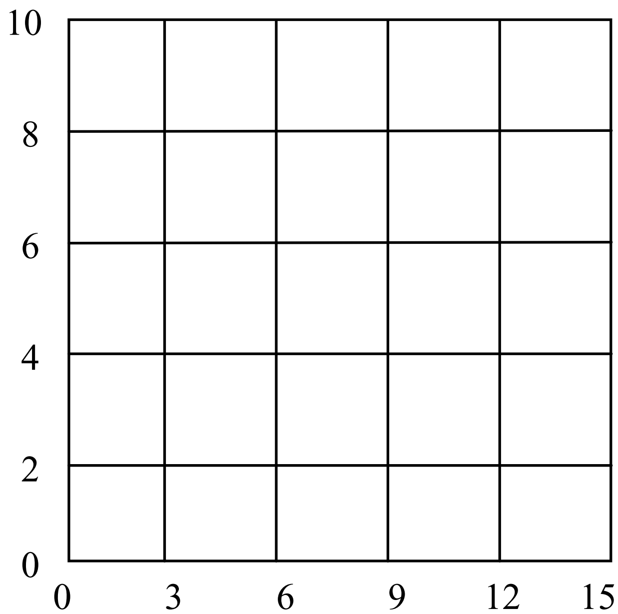
Acceptable - conventional scale direction

This problem often occurs when scales are used with negative numbers.

d. Candidates should be encouraged to choose scales that are easy to work with.



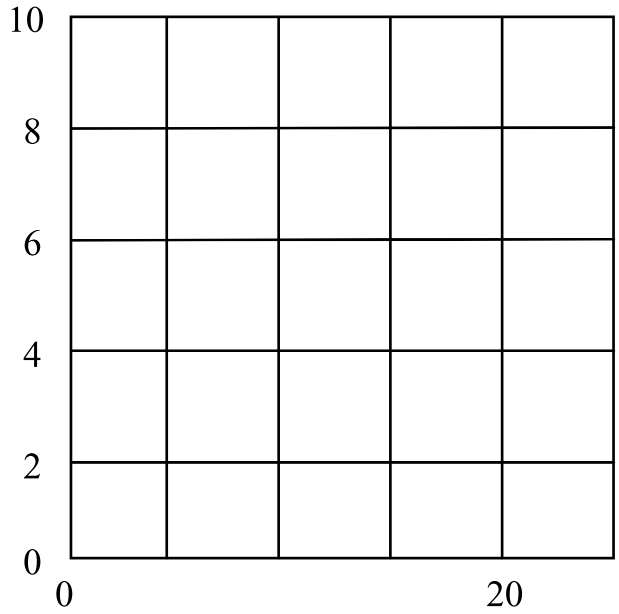
Acceptable scale divisions.



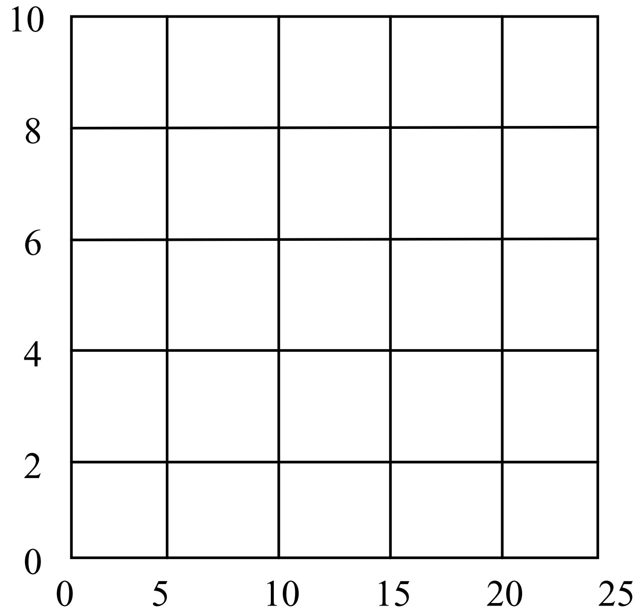
Not acceptable - awkward scale on the *x*-axis.

Candidates who choose awkward scales 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).

e. Scales should be labelled reasonably frequently (i.e. there should not be more than three large squares between each scale label on either axis).

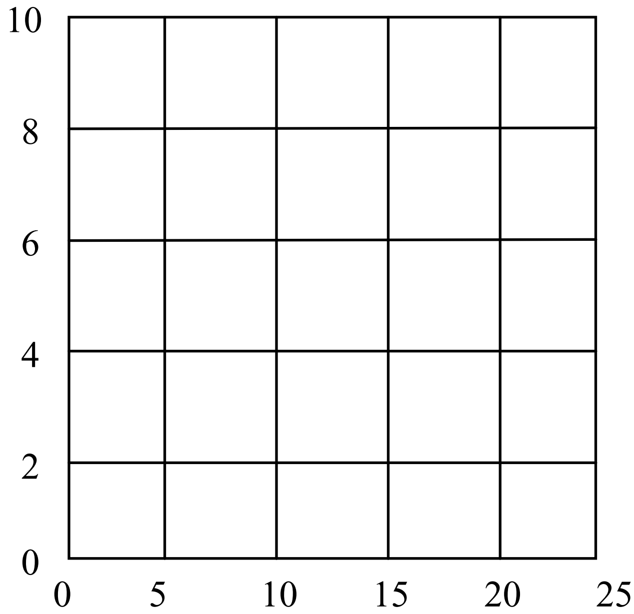


Not acceptable - too many large squares with no label

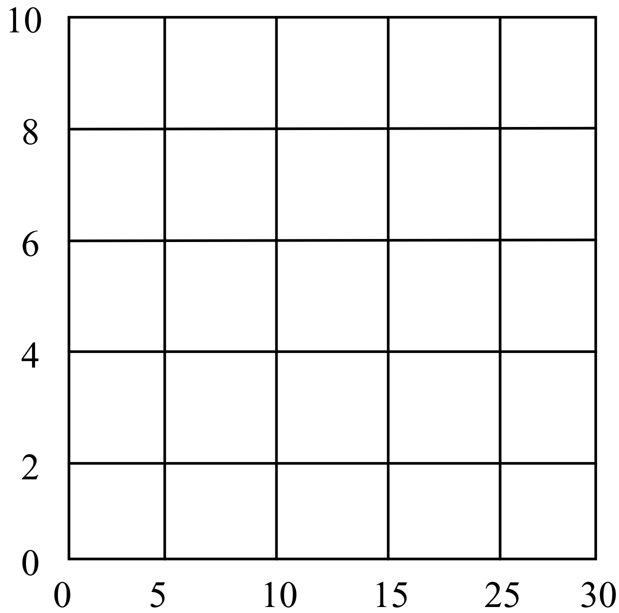


Acceptable - scales have regular labels

f. There should be no 'holes' in the scale.



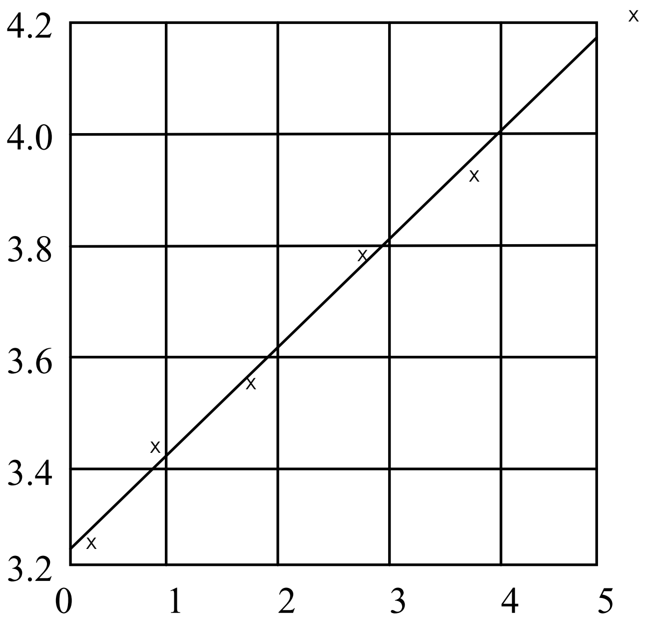
Acceptable - scale labelling is regular



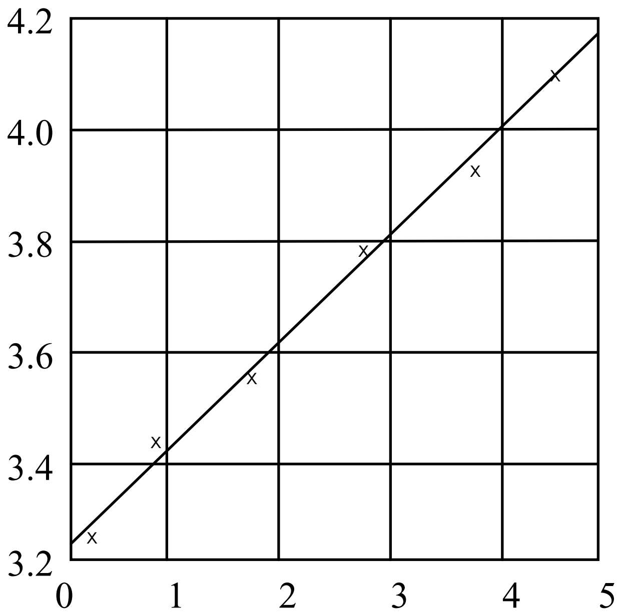
Not acceptable - non-linear scale on the *x*-axis

2. Plotting of points

a. Plots in the margin area are not allowed. Candidates would find it helpful to be told that any plots in the margin area will be ignored. Sometimes weaker candidates (realising that 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 will not be credited.



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



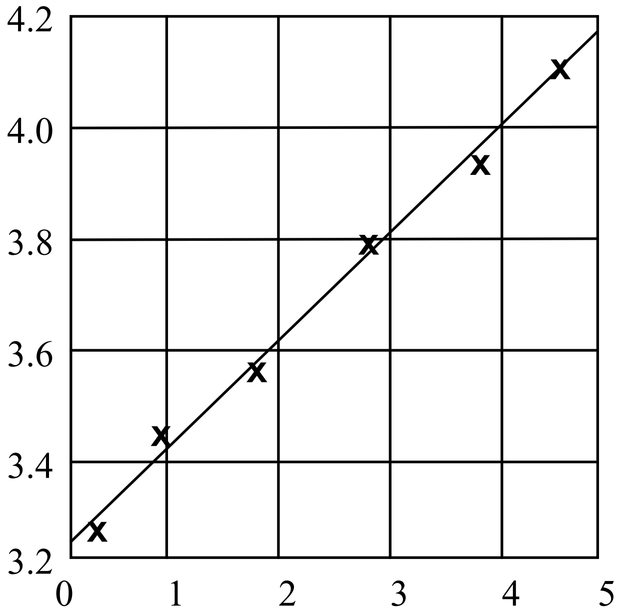
Acceptable - all plotted points are on the graph grid

b. 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).

c. Plotted points must be accurate to half a small square.

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

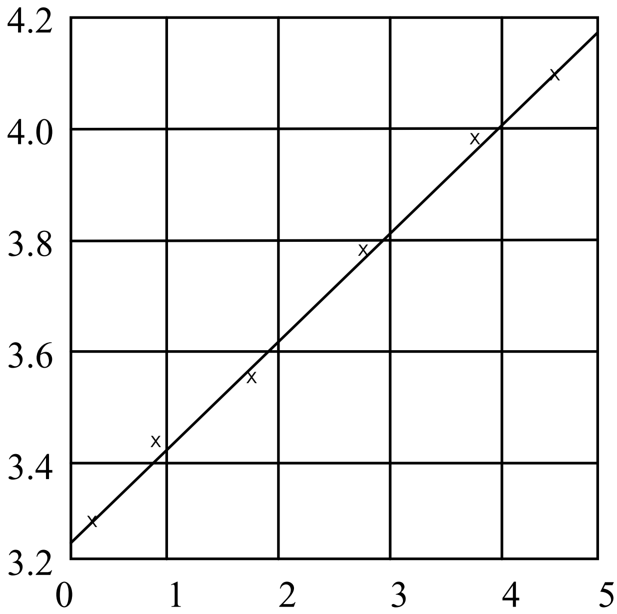
e. Thick plots are not acceptable. If it cannot be judged whether a plot is accurate to half a small square (because the plot is too thick) then the plotting mark will not be awarded.



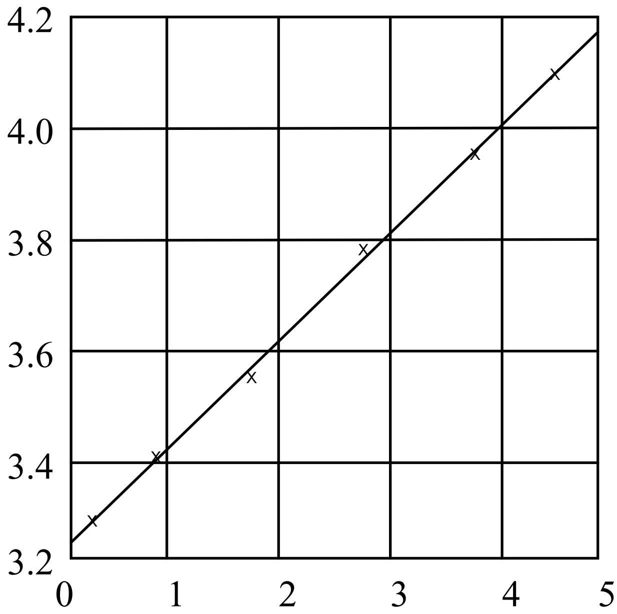
Thick plots not acceptable

3. Line (or curve) of best fit

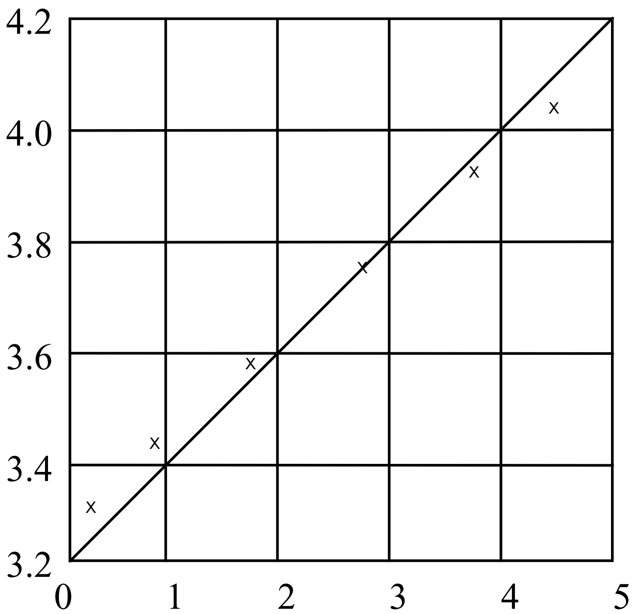
a. There must be a reasonable balance of points about the line. It is often felt that candidates would do better if they were able to use a clear plastic rule so that points can be seen which are on both sides of the line as it is being drawn.



Not acceptable - too many points above the line

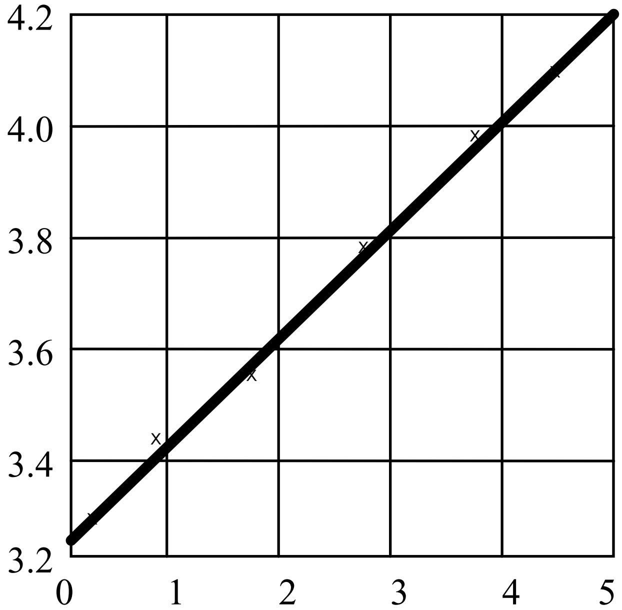


Acceptable balance of points about the line

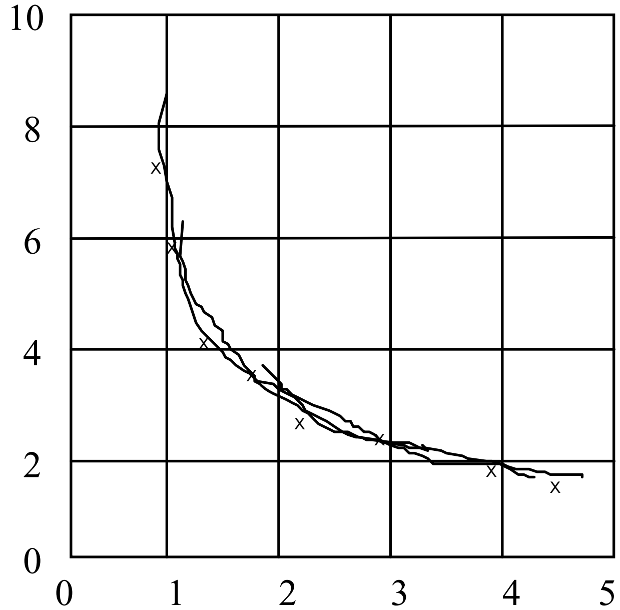


Not acceptable - forced line through the origin

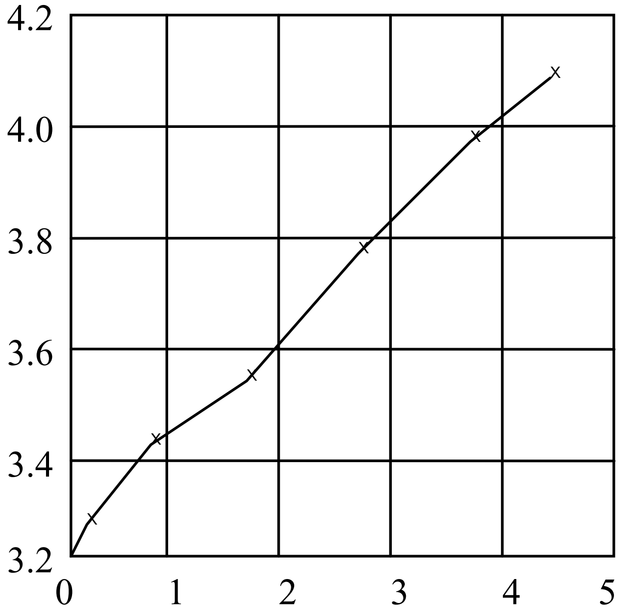
b. The line must be thin and clear. Thick/hairy/point-to-point/kinked lines are not credited.



Not acceptable - thick line



Not acceptable - 'hairy' curve

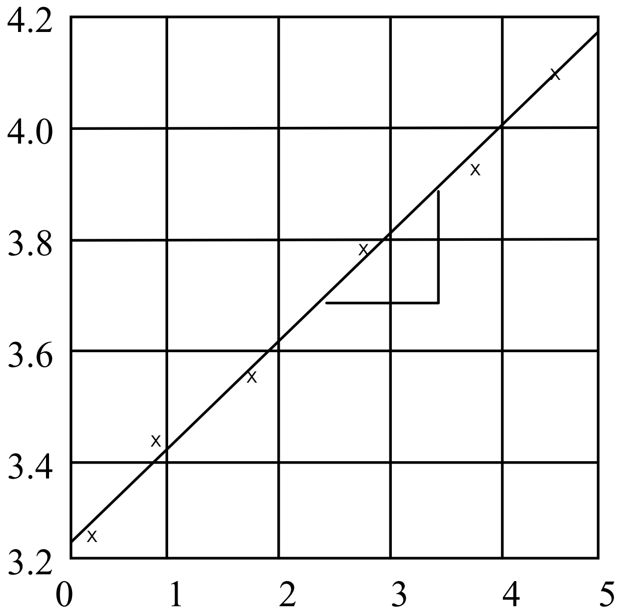


Not acceptable – joining point-to-point

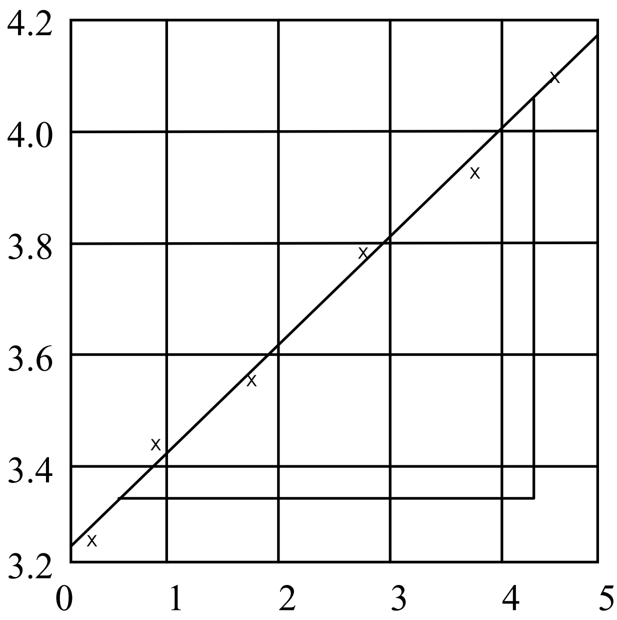
3. Determining gradients

a. 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.

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



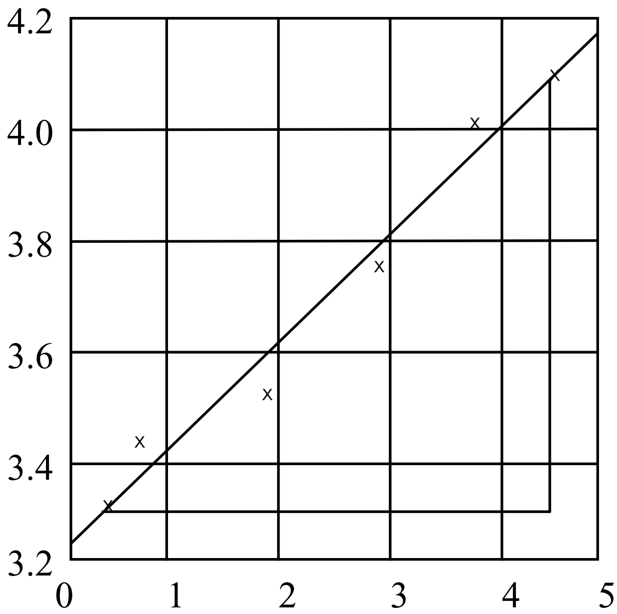
Not acceptable - the ‘triangle’ used is too small



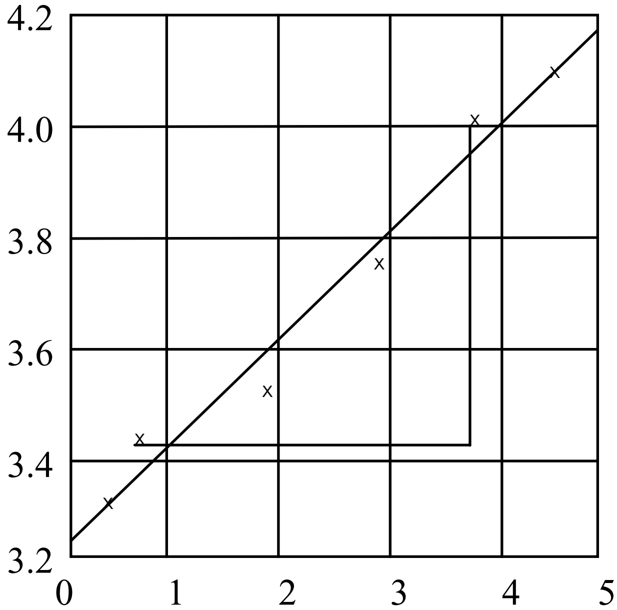
Acceptable – a large ‘triangle’ used

c. The value 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).

d. 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).



Acceptable - plots on line

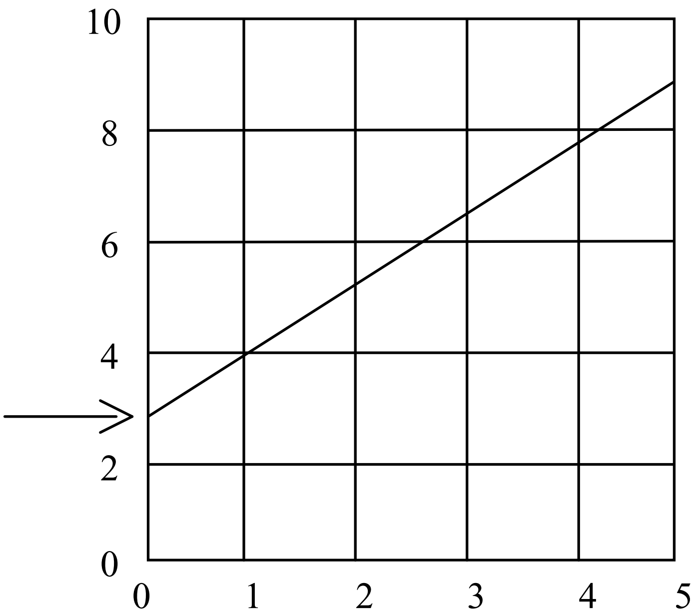


Not acceptable - the data points used which do not lie on the line of best fit

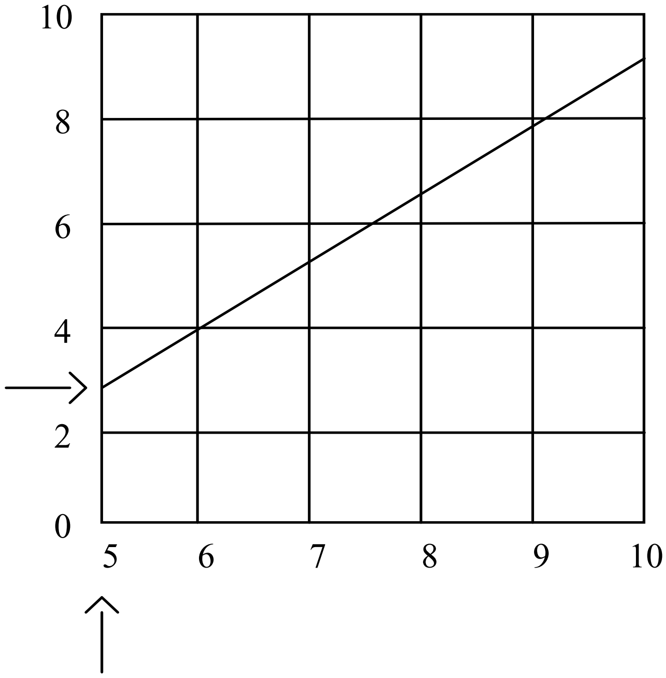
e. A gradient value has no unit since it is a ratio of two numbers from the graph

5. Intercept

a. 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 $x = 0$.



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



Not acceptable – the *y*-intercept is found from the line *x* = 5

b. It is expected that candidates will be able to use the equation of a straight line ($y = mx + c$) to determine the *y*-intercept if the choice of scale is such that it is not possible to take a direct reading from the *y*-axis when *x* = 0. In this case it is expected that a pair of *x* and *y* values from the line of best fit (together with a gradient value) will be substituted into the equation *y* = *mx* + *c* to give a value for the *y*-intercept.

Uncertainties

1. Percentage uncertainty

In the evaluative tasks candidates may be asked to calculate a simple percentage uncertainty or state the uncertainty in a measurement. When repeated readings have been done then it is expected that the uncertainty in the measured quantity will be half the range. The expression

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{average value}} \times 100\%$$

should be used.

If *single* readings have been taken then the uncertainty should be the smallest interval or division on the measuring instrument. Consider the example below.

Example: A metre rule is used to measure the length of a book.

uncertainty in the measuring instrument (the ruler) = ± 1mm

length = (295 ± 1) mm

The percentage uncertainty in the length is

$$\% \text{ uncertainty} = \pm \frac{1}{295} \times 100 = \pm 0.34\%$$

Determining the uncertainty in time measurements using a stopwatch raises a few issues. Almost all stopwatches will give times to one hundredth of a second, but candidates clearly cannot operate the watch to this accuracy. Human reaction time will give errors of (typically) 0.1 s to 0.6 s, which are reasonable estimates of the uncertainty.

Similar ideas apply to measurement of length, where parallax errors may make it difficult for candidates to measure a length to the accuracy of the rule used.

2. The rules for determining percentage uncertainties

A key assessment objective of the evaluative tasks is going to be determining the final uncertainty in a quantity. Here are some useful rules:

- If $y = ab$

  Rule: % uncertainty in *y* = % uncertainty in *a* + % uncertainty in *b*

- $y = \frac{a}{b}$ (For example when determining the gradient of a line)

  Rule: % uncertainty in *y* = % uncertainty in *a* + % uncertainty in *b*

- $y = a^2$

  Rule: % uncertainty in *y* = 2 $\times$ % uncertainty in *a*

3. Determining the uncertainty in the gradient using maximum and minimum gradients

Candidates may determine the uncertainty in the gradient by drawing lines of maximum and minimum gradients through their scattered data points. What happens when there is little scatter of the data points? This is when candidates may draw *error bars*.

The uncertainty in the gradient can be determined as follows:

a. Error bars may be added to each plotted point if the data points are not too scattered.

b. Draw a best fit line through the scattered points (or through the error bars). The worst acceptable line is then drawn. This will either be the *steepest* or *shallowest* line.

c Determine the gradient of the best fit line and the gradient of the worst acceptable line.

d Uncertainty = |gradient of best fit line – gradient of worst acceptable line|.

e The percentage uncertainty in the gradient can be determined as follows:

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{gradient of best fit line}} \times 100\%$$

4. Determining the uncertainty in the *y*-intercept using maximum and minimum gradients

Candidates may determine the uncertainty in the *y*-intercept by using lines of maximum and/or minimum gradients through their scattered data points. What happens when there is little scatter of the data points? This is again when candidates may draw *error bars*.

a. Error bars may be added to each plotted point if the data points are not too scattered.

b. Draw a best fit line through the scattered points (or through the error bars). The worst acceptable line is then drawn. This will either be the *steepest* or *shallowest* line.

c Determine the *y*-intercept of the worst acceptable line and the *y*-intercept of the best fit line.

d Uncertainty = |*y*-intercept of best fit line – *y*-intercept of worst acceptable line|.

e The percentage uncertainty in the *y*-intercept can be determined as follows:

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{y\text{ - intercept}} \times 100\% .$$

5. Understanding the terms accuracy and precision

Candidates generally have a poor comprehension of the terms **accuracy** and **precision**. These are often used to mean the same thing. Candidates are strongly advised to use these two important terms with great care when evaluating their experimental procedures.

An experiment is **accurate** when the measured quantity has a value *very close to the accepted value*. For example an experimental value for the acceleration of free fall of 9.78 m s^{-2} is much more *accurate* than an experimental value of 9.05 m s^{-2}.

The term **precision** is linked to the *spread of the data* or the *percentage uncertainty* in a measurement. A precise experiment has a smaller the *spread in the data* or the smaller the *uncertainty*. Hence, an experiment with an acceleration of free fall of

(9.05 ± 0.05) m s^{-2} is much more *precise* than an experiment with (9.78 ± 1.20) m s^{-2}; but the latter is much more *accurate*.