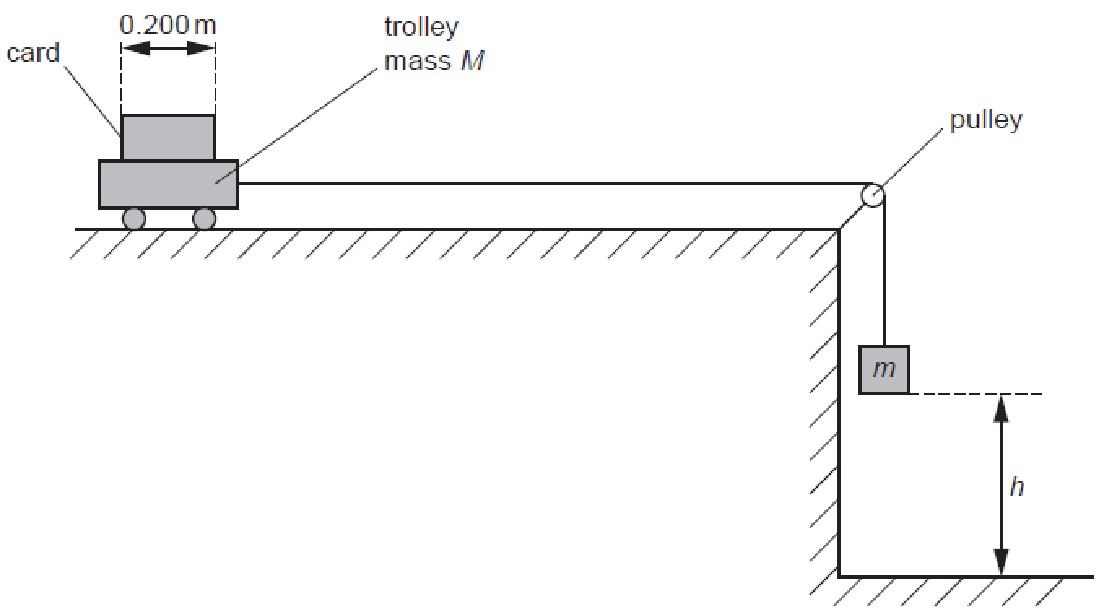
SALTUS GRAMMAR SCHOOL

AP Physics



Unit 18 – Experimental Physics

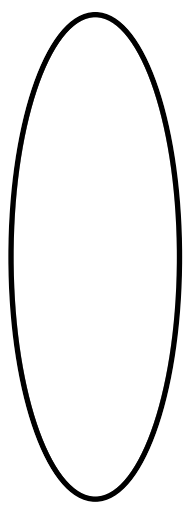
Name: ....

Date: ....

Summary

The aim of this unit is to gain an understanding of how to do science experiments. Although this is mainly geared towards physics concepts and problems, the same methods can be applied across every aspect of science. Comprehension, explaining, planning, investigating and data analysis are strongly emphasised, along with tips for problem solving. Most of these problems and questions have been sourced from UK A-Level exam papers. It is expected that at least one question on the new style AP exams will be of a similar nature.

Key Equations



Data Analysis

In science we often investiagte how one variable affects another. Usually the variable that is controlled (the independent variable) is recorded on the left hand column in a table and on the x-axis in a graph, while the one that is measured (the dependent variable) is recorded in the right hand column and on the y-axis of the graph. Very often, these variables are not directly proportional so the graph is not linear. Curves are ok to show a general pattern but not useful to determine an exact relationship. Therefore, we often "linearise" the data in order to produce a straight-line graph that we can easily measure the gradient of and area underneath. These values are often important as they relate to variables in the experiment that were fixed as constants.

The general mathematical equation for a linear graph is:

$$y = mx + c$$

Top tip: if you ever have a square root in an equation it is ALWAYS easier to square the entire equaton to get rid of it.

e.g. Measuring how the KE of an object varies with its velocity.

We know that $KE = \frac{1}{2}mv^2$, so let $x = v$ and $y = KE$. In this case the graph becomes linear if we change the x variable to v^2 instead of v.

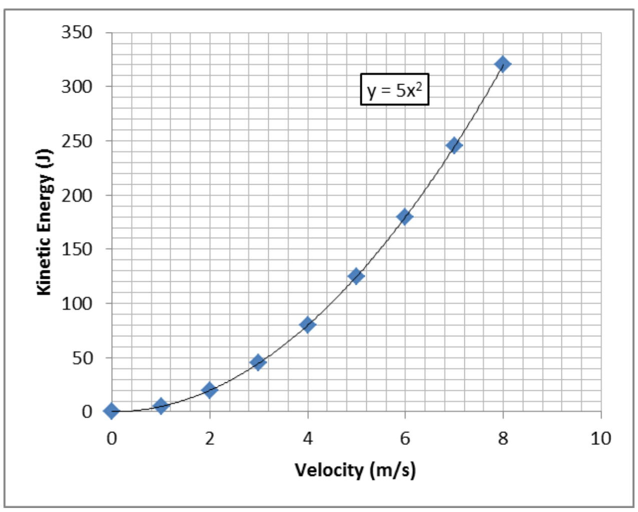


Fig 1: Plotting the raw data produces a curve.

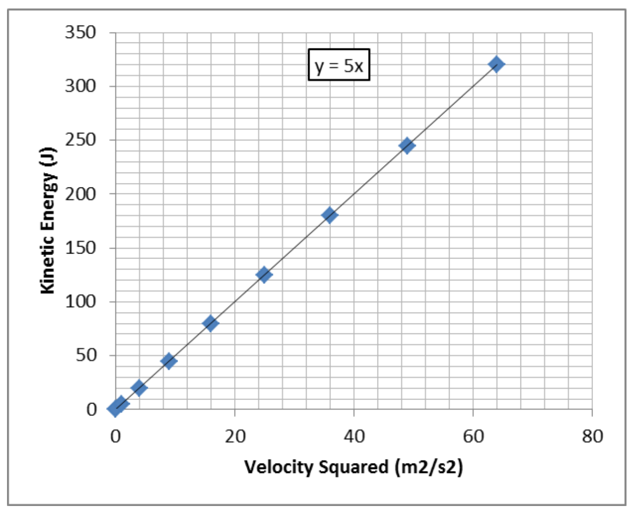


Fig 2: Plotting KE against v2 produces a linear graph, from which the gradient (m/2) can be easily determined.

For the examples below, state which variables should be plotted, including on which axis, and what the gradient represents.

1. $A = \pi r^2$ Area of a circle (variables *r* and *A*)

2. $V = \frac{4}{3}\pi r^3$ Volume of a sphere (variables: *r* and *V*)

3. $v = \sqrt{2gh}$ Speed of a falling object (variables: *h* and *v*)

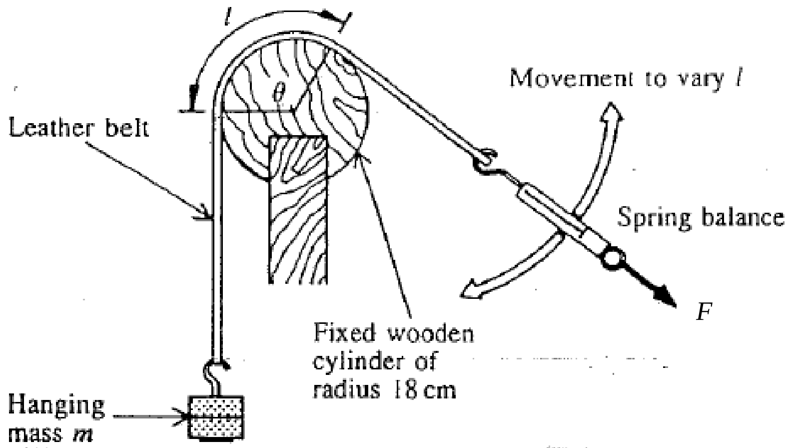
4. $T = {}^{1}/_{f}$ Relationship between period and frequency (variables: *f* and *T*)

5. $F = \frac{mv^2}{r}$ Centripetal force (variables: *r* and *v*)

6. $F = \frac{GMm}{r^2}$ Universal gravitation (variables: *r* and *F*)

7. $T = 2\pi\sqrt{\frac{l}{g}}$ Period of pendulum (variables: *l* and *T*)

1. The apparatus shown was set up to investigate the friction between a leather belt and a fixed wooden surface. In the position shown the spring balance waa pulled until the leather belt began to slip around the wooden cylinder. The force, *F*, at which this happened and the length, *l*, of the belt in contact with the wooden cylinder were recorded.



The spring balance was then moved to various positions as indicated in the diagram in order to vary *l*, and a series of reading of *l* and *F* were obtained.

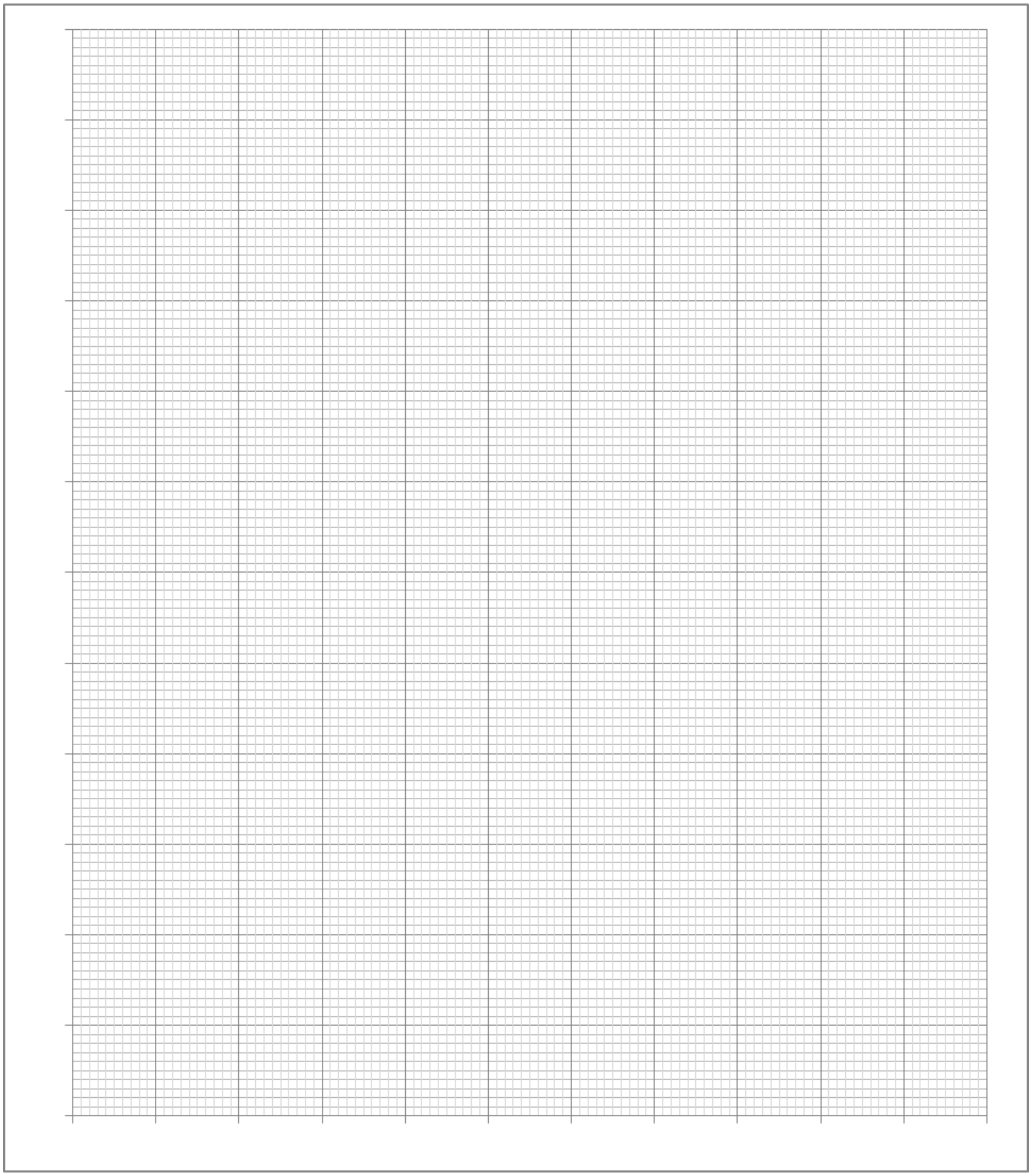
l **(cm)**	18.9	25.2	31.5	35.1	41.4	46.8	51.3	56.7
F **(N)**	12.0	13.3	14.6	15.7	17.3	18.6	20.4	22.1

A student is told that the predicted relationship is $F = mge^{\mu\theta}$, where *mg* is the weight of the hanging mass and θ is the angle as shown on the diagram.

The angle θ is given in radians by l/r, where *r* is the radius of the wooden cylinder (18 cm). The constant μ is called the coefficient of friction.

a) Calculate values of θ in radians and draw up a table of values of θ and $\ln(F)$

b) Plot a graph of $\ln(F)$ against θ.



c) Use the equation above and your graph to deduce values for the mass, m, and the coefficient of friction, μ. Explain your reasoning.

2. A number of identical cells are used in a range of different applications. In each case a small constant current, *I*, gradually transfers all the energy from the cell to the circuit components

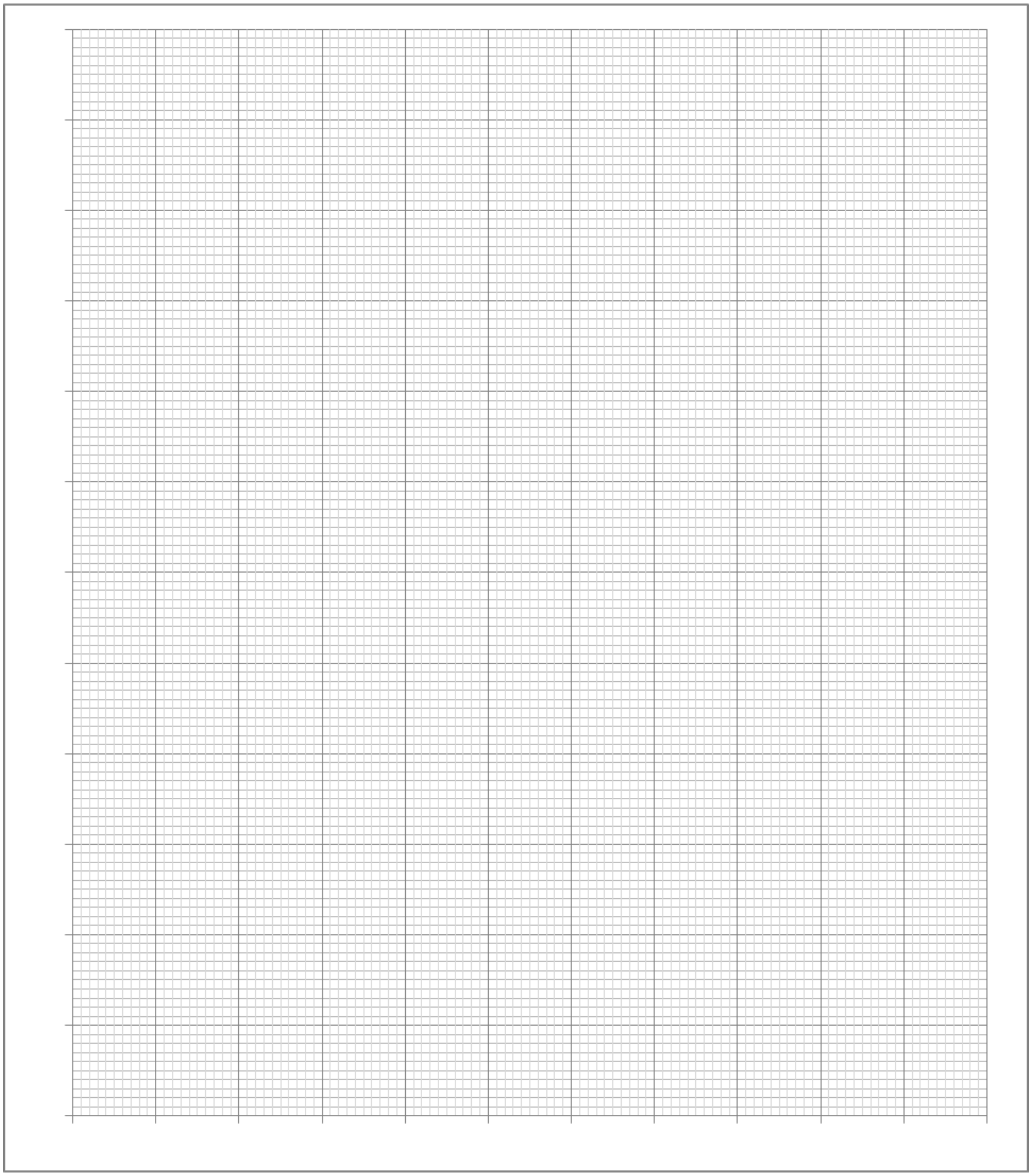
The total discharge time, *t*, is different in each application. The current, *I*, is measure in each casse and the following data is recorded.

***I* (mA)**	1.0	2.0	3.0	4.0	6.0	8.0	10.0
***t* (days)**	25	11	6.7	4.8	2.9	2.0	1.5

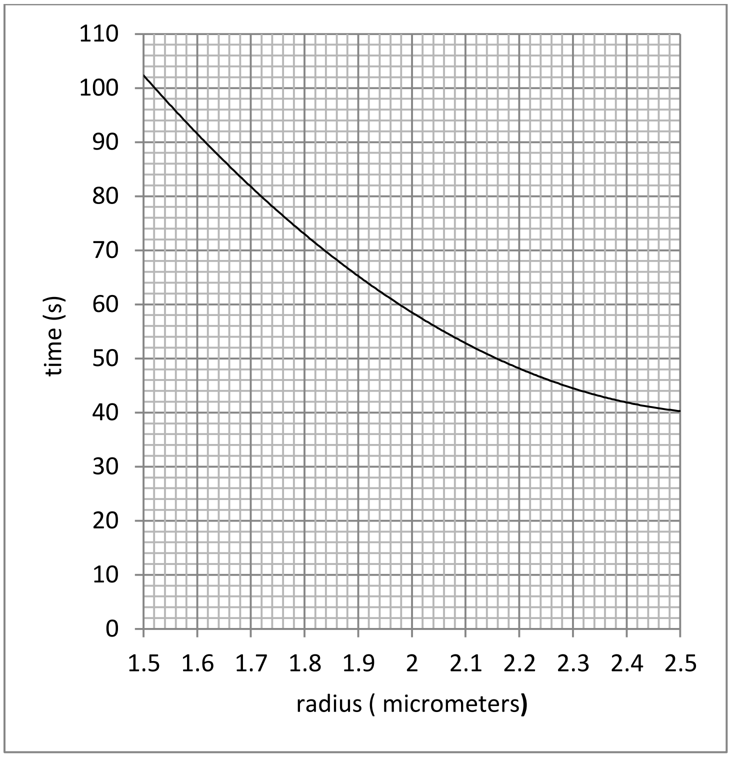
a) It is suggested that *I* and *t* are related by a power law of the form $I = kt^n$, where *k* and *n* are constants. Draw up a table of values and plot a graph to test this relationship.

b) From your graph, deduce values for *n* and *k*.

c) Explain your calculations. Comment on your value for *n*.



2. When scent is sprayed from a fine nozzle, very small liquid drops only a few micrometers across are produced. In still air these drops form a cloud which sinks with constant speed very slowly to the ground. The graph below shows the time, *t*, it takes a drop of radius, *r*, to fall 1.00 cm in air under still conditions.



a) Explain how you would test this graphical data to see if the relationship between *t* and *r* is:

i) $t \propto \frac{1}{r}$

ii) $t \propto e^{-kr}$, where *k* = constant

Do not perform these tests, simply state what you would do and explain how you would interpret the results of each test.

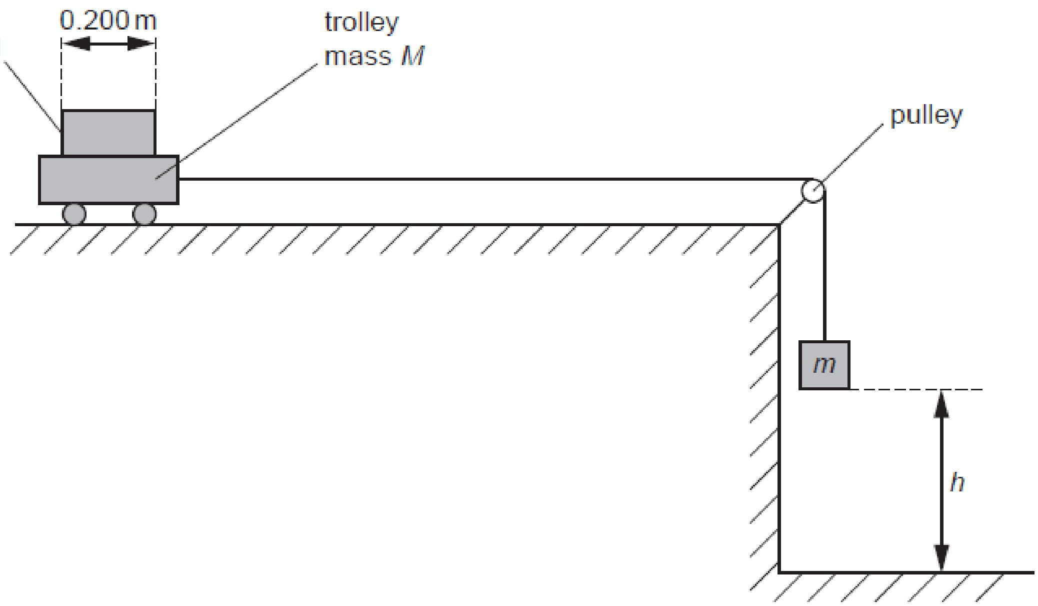
b) It is suggested that the relationship between t and r is $t \propto \frac{1}{r^2}$.

Prepare a table of values of t and r from the graph. Add values of $\frac{1}{r^2}$ to your table.

Draw a graph of t against $\frac{1}{r^2}$.

Comment on the validity of the suggestion.

3. A student is investigating how a mass attached to a trolley affects the motion of the trolley. The trolley is a attached to a mass, *m*, by a string passing over a pulley as shown below.



A piece of card of length 0.200 m is fixed to the trolley. The mass, *M*, of the trolley and the card is 0.800 kg. The mass, *m*, is released and falls through a fixed height, *h*, accelerating the trolley. When the mass, *m*, hits the ground, the trolley continues to move with constant velocity, *v*.

This velocity, *v*, is determined by measuring the time, *t*, for the card to pass fully through a light gate connected to a timer.

It is suggested that *v* and *m* are related by the equation

$$mg = (m + M)\frac{v^2}{2h}$$

Where *g* is the acceleration of free fall.

a) A graph is plotted of v^2 on the *y*-axis against $\frac{m}{(m+M)}$ on the *x*-axis. Express the gradient in terms of *g*.

Gradient = ………………………

b) Values of m and t are given below:

m (kg)	t (x 10^{-3} s)	$\frac{m}{(m+M)}$	v (m/s)	v^2 (m^2/s^2)
0.1	174			
0.2	132			
0.3	112			
0.4	102			
0.5	95			
0.6	90			

Complete the table.

c) i) Plot a graph of v^2 against $m/(m + M)$.

ii) Draw a line of best fit on your graph.

iii) Determine the gradient of the line of best fit.

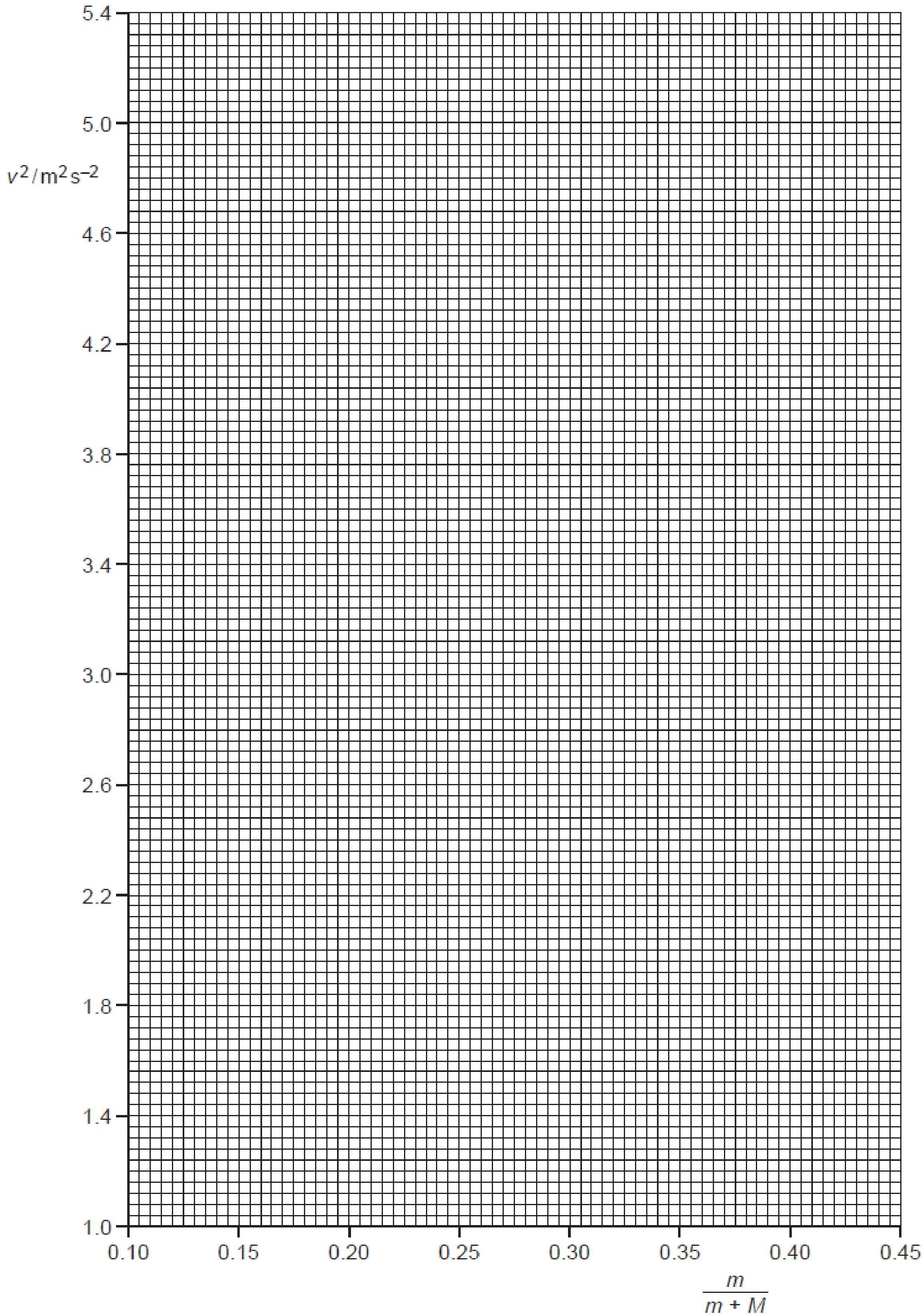
Gradient = …………………………

d) In this experiment h = 0.60 m. Using your answer to c) iii), determine the value of g.

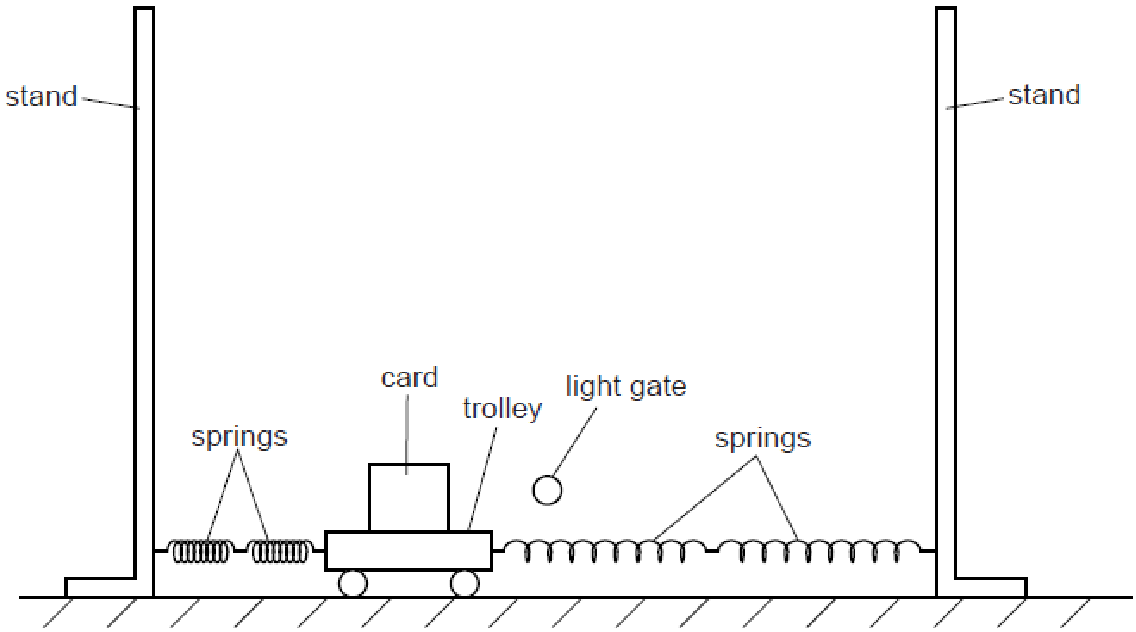
g = ………………….. m/s^2.

e) A 1.0 kg mass is added to the trolley and the experiment is repeated using the same range of values of m as in b). Determine the largest value of the velocity that the trolley will achieve, using the relationship given and your answer to d).

v = ………………… m/s


5.4
5.0
v^2 / $m^2 s^{-2}$
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
$\frac{m}{m + M}$

4. A trolley is attached to springs as shown below. When the trolley is displaced and then released, the trolley oscillates.



A student investigates how the maximum speed, v, of the trolley varies with the total mass, M, of the trolley.

The maximum speed is determined using the time, t, taken for the card to pass through a light gate connected to an electronic timer. The length of the card is 5.0 cm.

It is suggested that v and M are related by the equation:

$$v = A\sqrt{\frac{k}{M}}$$

where A is the initial displacement and k is the spring constant of the springs.

a) A graph is plotted of v^2 on the y-axis against $1/M$ on the x-axis. Determine an expression for the gradient in terms of A and k.

Gradient = ...

b) Values of M and t are given below:

M (kg)	t (s)	$1/M$ (kg^{-1})	v^2 (m^2/s^2)
0.75	0.046		
1.25	0.058		
1.75	0.068		
2.25	0.078		
2.75	0.086		
3.25	0.092		

Complete the table.

c) Plot a graph of v^2 against $1/M$. Include a line of best fit

d) Determine the gradient of the line of best fit.

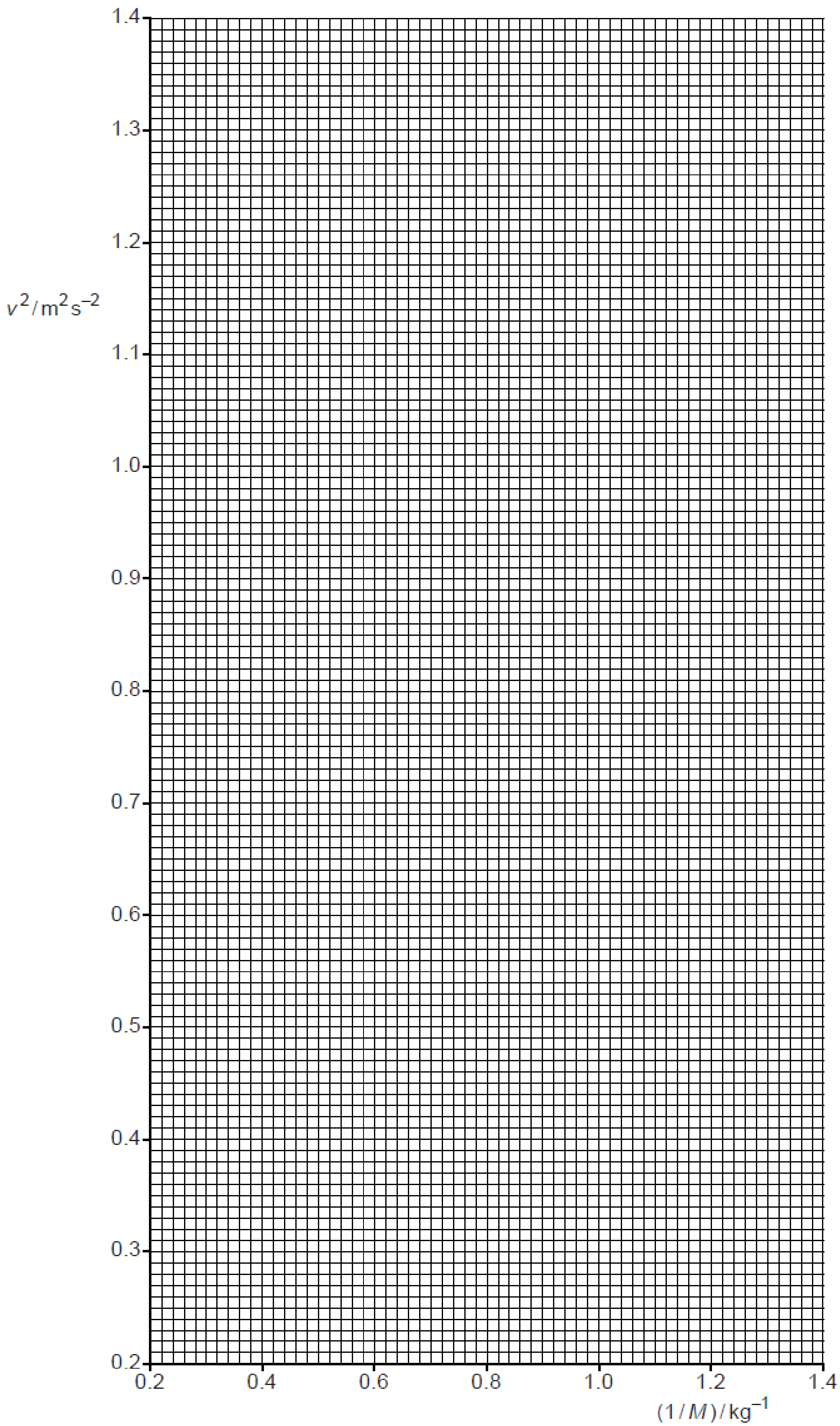
Gradient = ...

e) The value of A = 0.20 m. Using your answer to d), determine a value for the spring constant k.

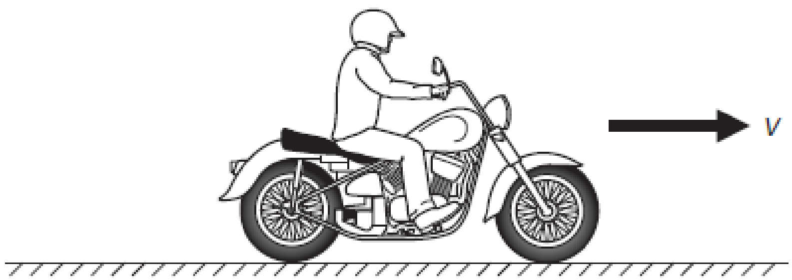
k = ...

f) The experiment is repeated using the same springs and a trolley with a total mass = 0.75 kg. The initial displacement is 0.10 m. Determine the maximum speed expected using your value of k.

v = ... m/s


1.4
1.3
1.2
v2 / m2 s–2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.2
0.4
0.6
0.8
1.0
1.2
1.4
(1 / M) / kg–1

5. A student is investigating the stopping distance for a bike with high-performance brakes. A rider riding the bike on a test track is recorded on film.



The stopping distance d is measured for different speeds v.

It is suggested that v and d are related by the equation:

$$d = \frac{v^2}{2a} + vt$$

Where a is the deceleration of the bike and t is the reaction time of the rider.

a) Use your knowledge of kinematics to derive this equation.

b) A graph is plotted of d/v on the y-axis against v on the x-axis. Determine the expressions for the gradient AND the y-intercept in terms of a and t.

Gradient = ...

y-intercept = ...

c) Values of v and d are given below:

v (m/s)	**d (m)**	
10	13.0	
15	24.5	
20	39.5	
25	57.5	
30	79.0	
35	103.0	

Complete the table with the calculated values of d/v. Include the units.

d) Plot a graph of d/v against v. Draw a line of best fit.

e) Determine the gradient of the line of best fit. Include the units.

Gradient = ...

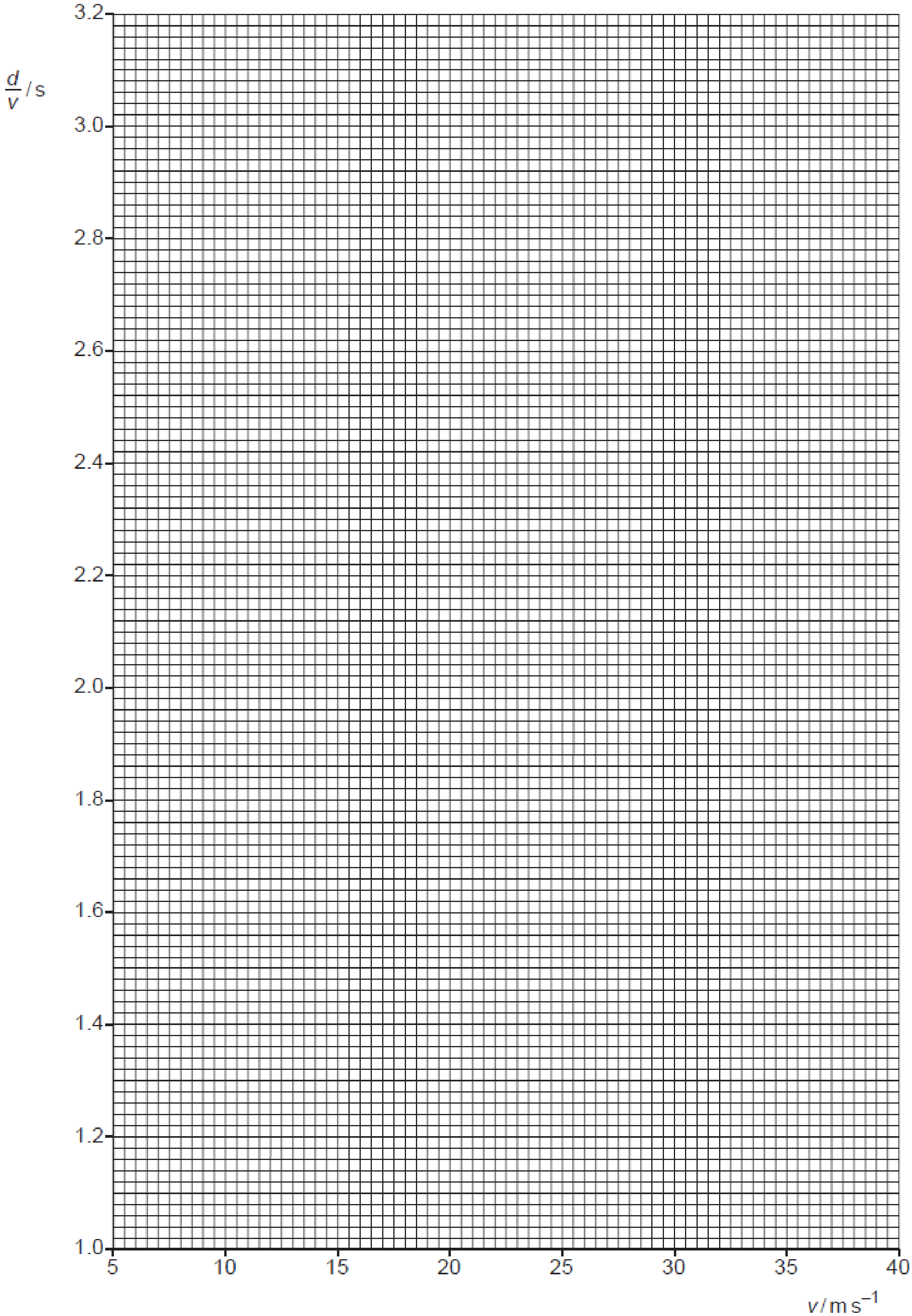
f) Determine the y-intercept of the line of best fit. Include the units.

y-intercept = ...

g) Using your answers above, determine values for a and t. Include units.

a = ...

t = ...



$\frac{d}{v}$ / s
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
5
10
15
20
25
30
35
40
v / m s^{-1}

Planning Investigations

1. A student wishes to determine the resistivity of aluminium. The resistivity of a conductor is defined as:

$$\rho = \frac{RA}{l}$$

for a conductor of resistance *R*, cross-sectional area *A* and length *l*.

The typical dimensions of a strip of aluminium of lengths *c, d* and *t* are shown below. The resistivity of aluminium is about 10^{-8} Ωm.

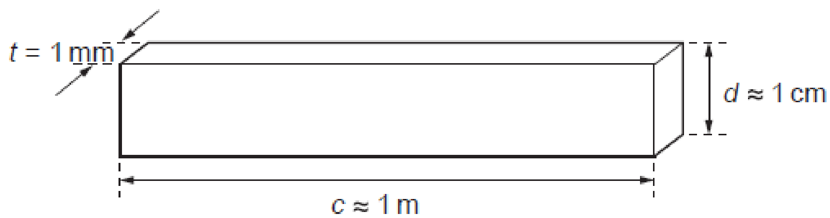


Fig. 1.1 (not to scale)

Design a laboratory experiment to determine the resistivity of aluminium using this strip. The usual school apparatus is available, including a metal cutter.

You should draw a diagram, in the space available, showing the arrangement of your equipment. In your account you should pay particular attention to:

a) The procedure to be followed (the method),
b) The measurements to be taken,
c) The control of the variables,
d) The analysis of the data,
e) Any safety precautions that need to be taken.

(15 points)

Diagram

2. Two students are having a adiscussion about an experiment in which the air inside a bell jar is gradually removed. The sound of a ringing bell inside the jar is heard to decrease in volume during this process.

One student suggests that the frequency, f, of the sound wave and the pressure, p, are related by the equation:

$$f = kp^2$$

where k is a constant.

Design a laboratory experiment to test the relationship between f and p and determine a value for the constant, k. The usual school apparatus is available.

You should draw a diagram, in the space available, showing the arrangement of your equipment. In your account you should pay particular attention to:

a) The procedure to be followed (the method),
b) The measurements to be taken,
c) The control of the variables,
d) The analysis of the data,
e) Any safety precautions that need to be taken.

(15 points)

Diagram

3. A student is investigating how the resistance of a nichrome wire varies with temperature.

It is suggested that:

$$R = R_o(1 + \alpha T)$$

where R_o is the resistance at 0°C, α is a constant and T is the temperature measured in °C.

Design a laboratory experiment to test the relationship between T and R and determine the value of a.

You should draw a diagram, in the space available, showing the arrangement of your equipment. In your account you should pay particular attention to:

a) The procedure to be followed (the method),
b) The measurements to be taken,
c) The control of the variables,
d) The analysis of the data,
e) Any safety precautions that need to be taken.

(15 points)

Diagram

AP Physics I – Research Projects

The new AP syllabus specifies a great deal of emphasis on problem solving skills, dealing with a variety of physical science concepts, variables and experimental work. This leads to research, which is a major part of both science and engineering. You are to undertake a large research project. Each has the potential of involving a lot of work. Use of data loggers is encouraged. As one question on your final exam will be practical-based, this project will count for 25% of your Mock Exam grade.
It is expected that the whole project is likely to run to 10 pages, once background, theory, methods, data, analysis and conclusions are included. (Max sensible font 12 pt – embed graphs etc)

1. Motion of a bungee jumper. (energy, oscillations, dynamics, kinematics. Note: best to model with springs, rather than rubber bands)

2. Investigation into the best method to measure *g*. (dynamics and kinematics)

3. Investigating the factors that affect the terminal velocity of a ball bearing falling through honey. (energy, kinematics, dynamics, fluids, thermal physics)

4. Investigation of the factors that affect the speed of a cylinder rolling down a slope. (dynamics, energy and rotational mechanics)

5. Investigation into the operation of bicycle gearing. (dynamics, energy, torque, rotational mechanics)

Cambridge A-Level Examiner's Guide to Practical Work

This guide refers to the general marking principles in question 1 of the physics practical examination. The sections are divided up into (broadly) measurements, presentation of results and graphical work.

Measurement and observation.

The number of observations to be made (usually six) is almost always indicated on the question paper. This is to prevent candidates from spending too much time taking readings and not allowing enough time for the graphical work and the analysis. Six readings are usually required for a linear trend and nine (or more) for a curved trend. Candidates are not penalised for taking more than the suggested number of readings.
If they do, however, it is expected that all these observations will be plotted on the graph grid.

The range over which the readings are to be taken is almost always specified in the question paper. It is expected that candidates will use sensible intervals between each reading in this range. The range is usually given in such a way so that candidates should not find it difficult to decide what values they should choose. For example, if a quantity d was to be measured, the question 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 (intervals are fine)

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

Not acceptable (first three readings and last two readings are too close together)

Repeated Readings.

It is expected that candidates will repeat readings and calculate 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. 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.

Quality of results.

One mark is sometimes 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.

Significant figures.

Candidates are often asked to explain why they have given a calculated quantity to a specific number of 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:

(a) Vague statements such as 'it increases the accuracy of the experiment'.

(b) 'I am going to plot a graph, so I will give my answers to 2 sig. figs.'

(c) 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 make the error in (c). 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 accuracy 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.

i.e. 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 <u>except</u> 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 accuracy 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.

Estimation of uncertainty and percentage uncertainty.

In some papers candidates are 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 will be half the range. The expression

Percentage uncertainty = uncertainty/average value x 100

should be used.

If single readings have been taken then the uncertainty should be half of the smallest interval on the measuring instrument (assuming no zero error). However, this is not always the case. A good example would be a stopwatch. 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
0.4 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.

Description of an observation.

Candidates may be asked to describe something which they see during an experiment. Diagrams are a particularly useful aid in this respect.

Explanation of how a measurement is made/evaluationof procedure

If the method of making a particular measurement is unusual or difficult, candidates may be asked to explain how they performed the measurement. Again, diagrams are useful, and can save time. The last section of question two in both papers is entirely devoted to evaluation. Candidates would be advised to concentrate on the difficulties which they encountered in actually doing the experiment, and how these difficulties may be overcome (perhaps using more sophisticated equipment). Many candidates just tend to describe what they have done (i.e. the procedure) and do not evaluate the procedure.

Presentation of results.

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

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'. This is because a logarithm is a power, and therefore has no unit. Thus the logarithm of a length *l* measured in centimetres using a base of ten should be written as lg (*l*/cm) since *l*/cm is a dimensionless quantity.

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 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, since 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, since 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 half a degree it is unreasonable to give temperatures which indicate that a precision of one hundredth of a degree have been achieved.

□ /^{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 □ - 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).

Significant figures in calculated quantities.

Calculated quantities should be given to the same number of significant figures as the measured quantity of least accuracy. 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 (2 Ω) or four (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) to three significant figures.

20T/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.

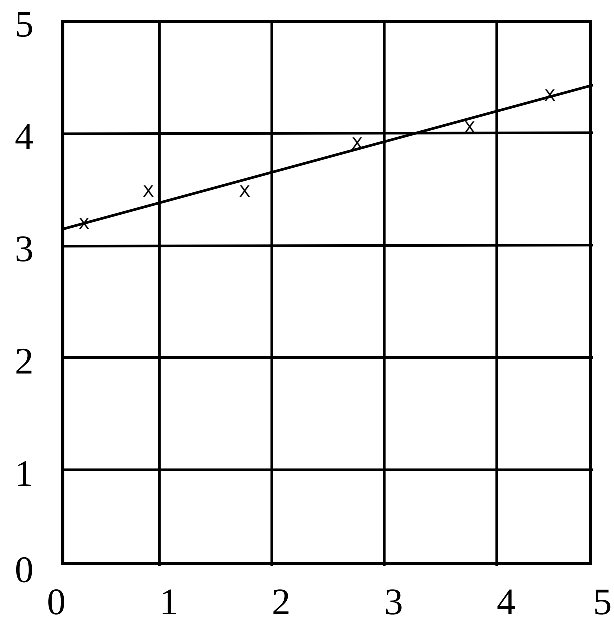
Graphical work.

Credit for graphical work usually falls into five categories:

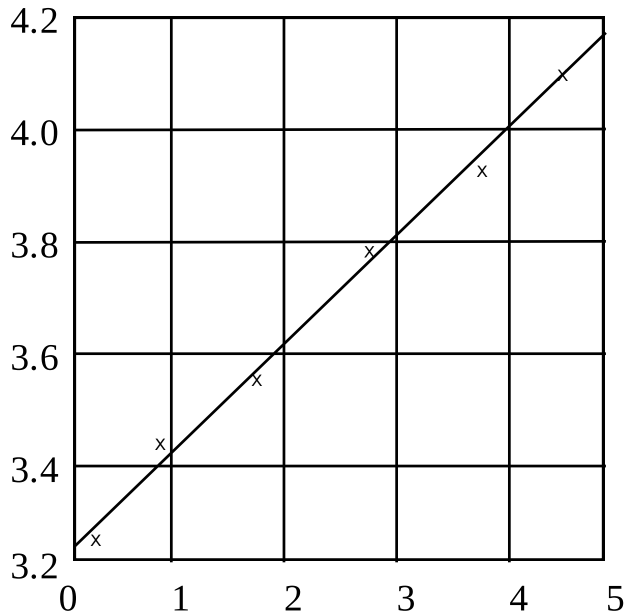
- Choice of scale
- Plotting of points
- Line of best fit
- Calculation of gradient
- Determination of the *y*-intercept

Choice of scales.

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



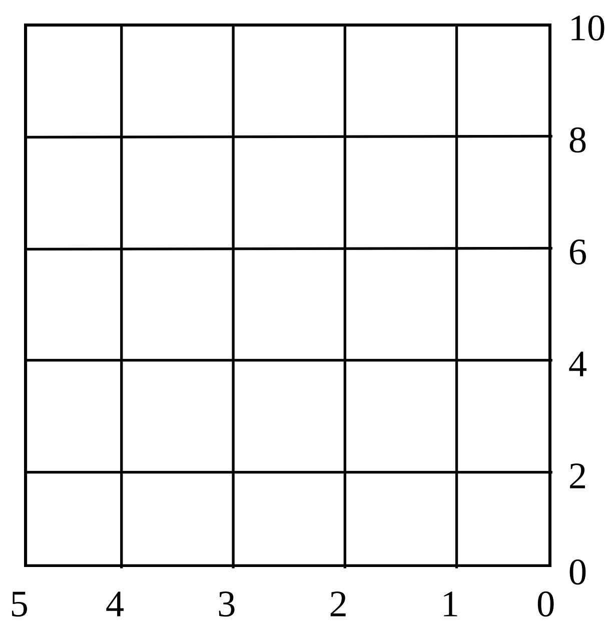
Not acceptable (scale in the *y*-direction is compressed)



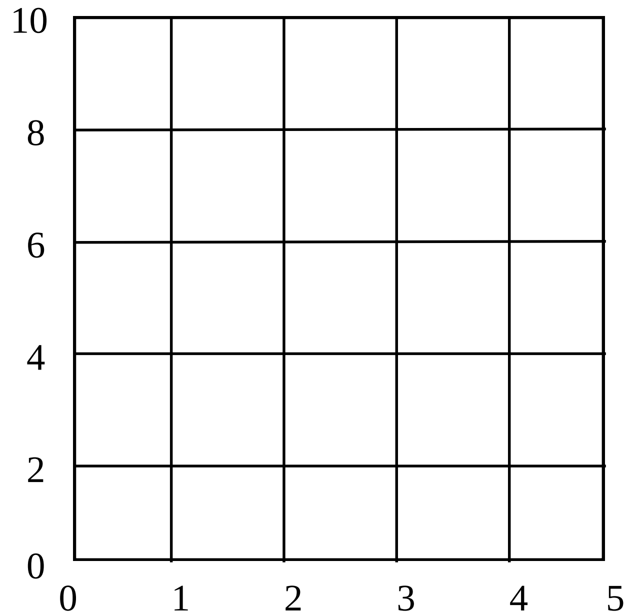
Acceptable (points fill more than half the graph grid in both the *x* and *y* directions).

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

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



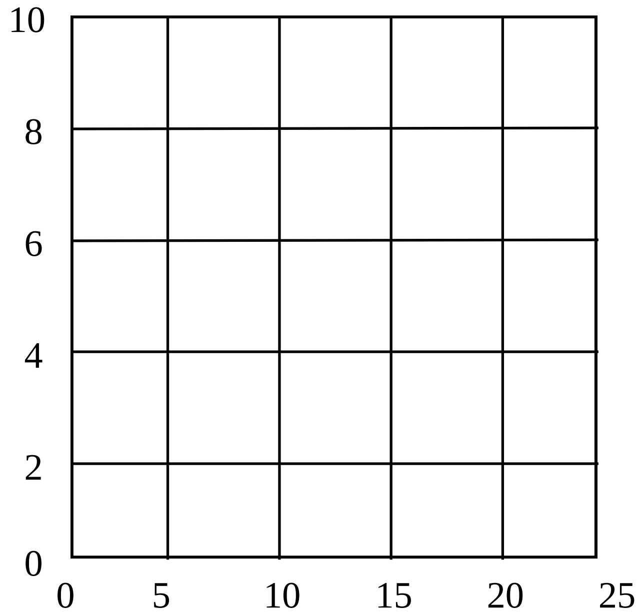
Not acceptable (unconventional scale direction).



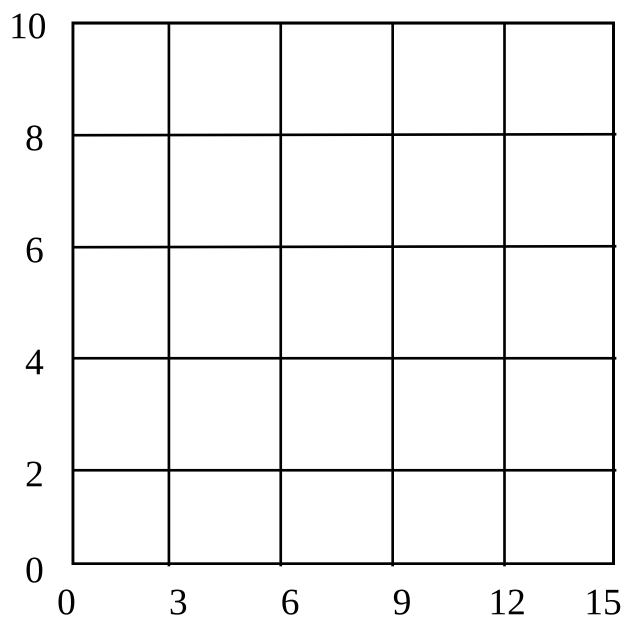
Acceptable (conventional scale direction)

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

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



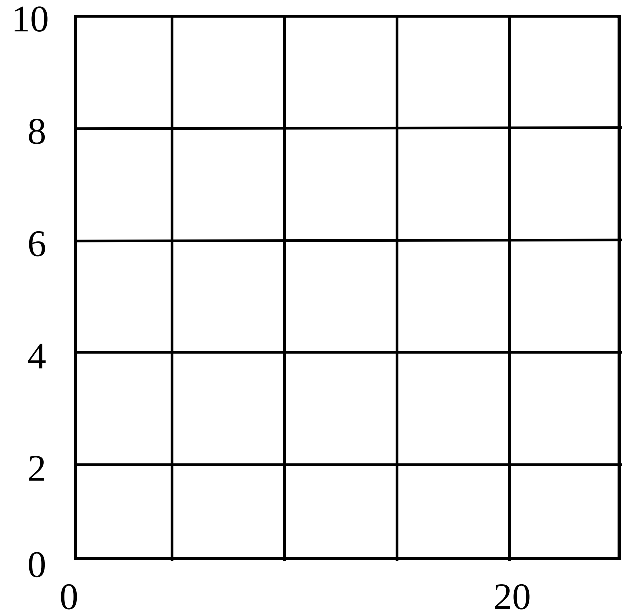
Acceptable scale divisions.



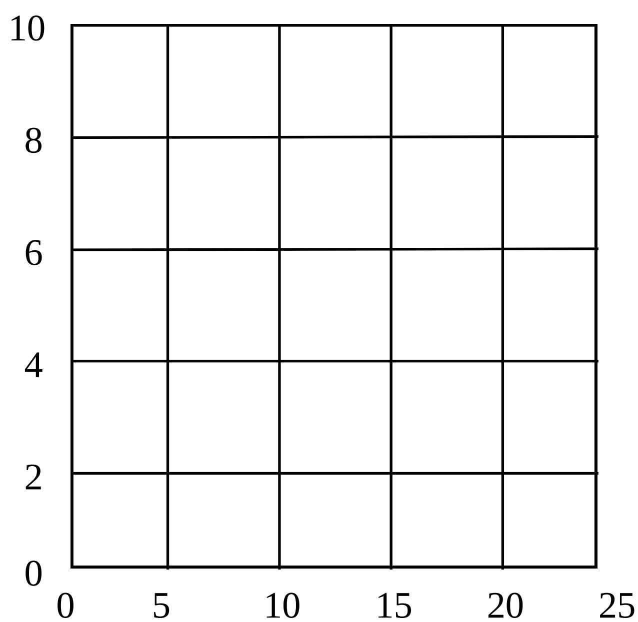
Not acceptable. Awkward scale on the *x*-axis. Other examples are 6:10, 7:10 and 8.319:10 !!)

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).

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

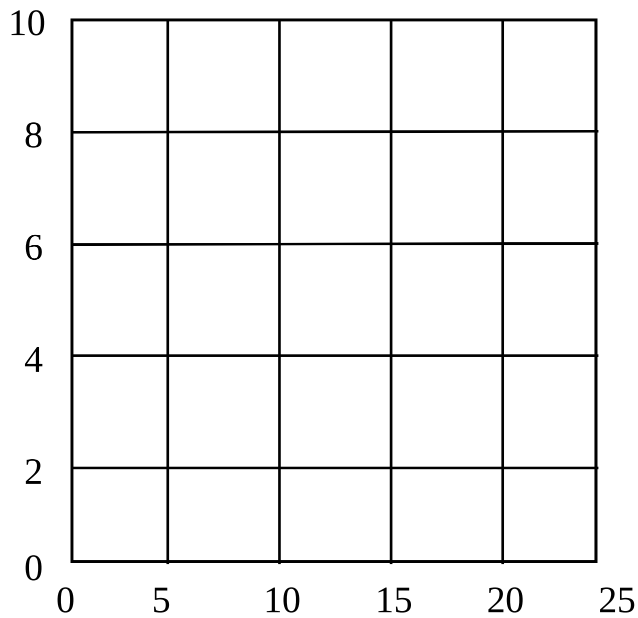


Not acceptable (too many large squares with no label)

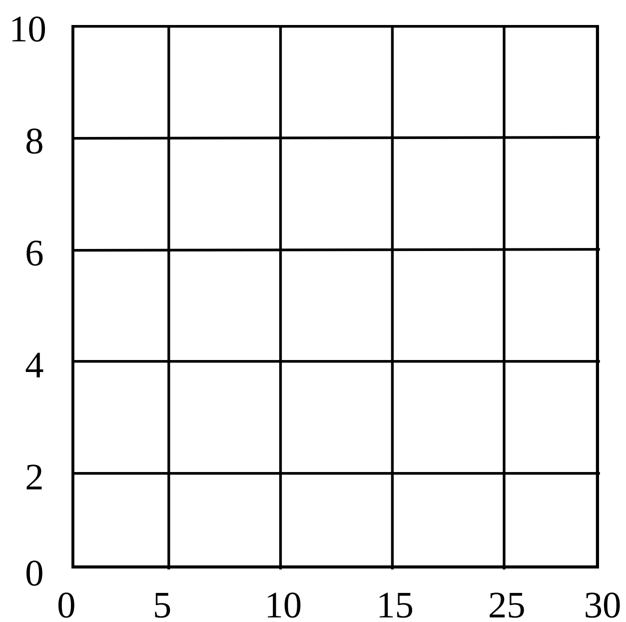


Acceptable (scales have regular labels)

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



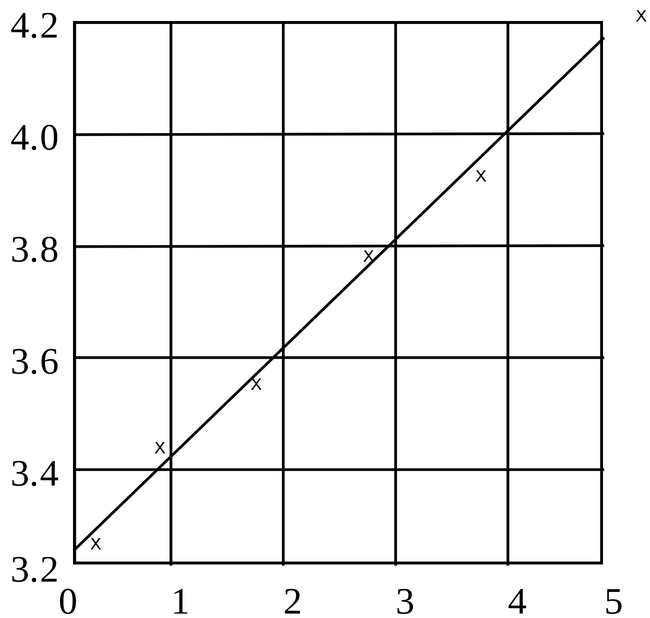
Acceptable. Scale labelling is regular



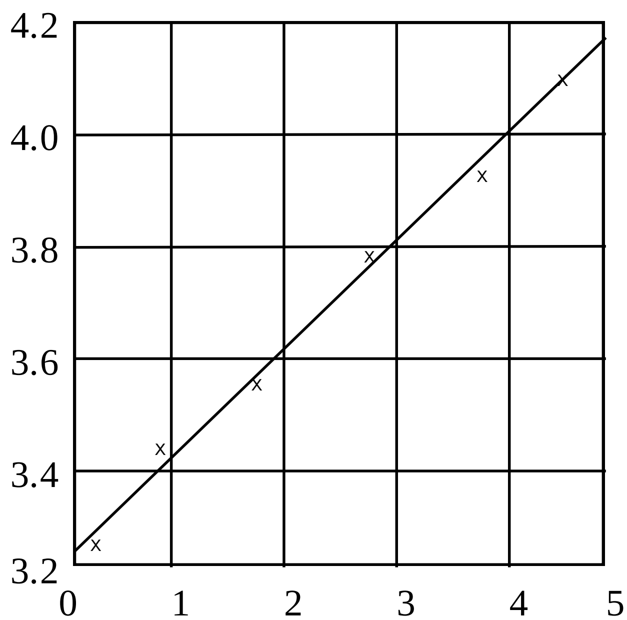
Not acceptable (non-linear scale on the *x*-axis).

Plotting of points.

1. 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 (last point has been plotted in the margin area).



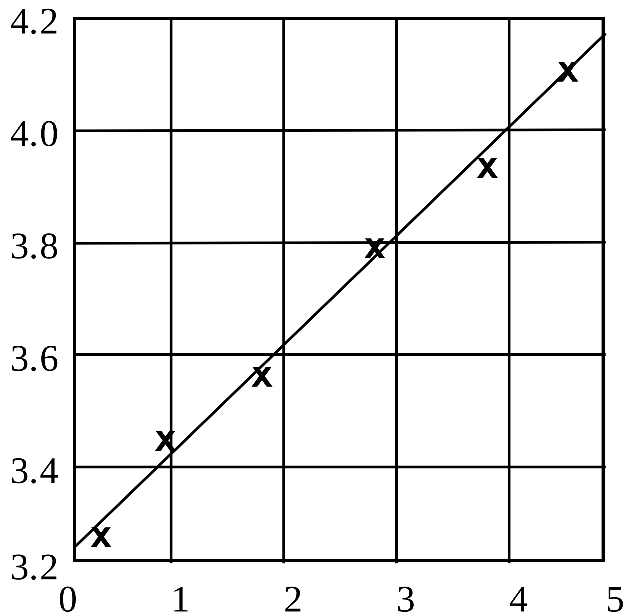
Acceptable (all plotted points are on the graph grid).

2. It is expected that all observations will be plotted (e.g. if ten observations have been made then it is expected that there will be ten plots).

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

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

5. 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.

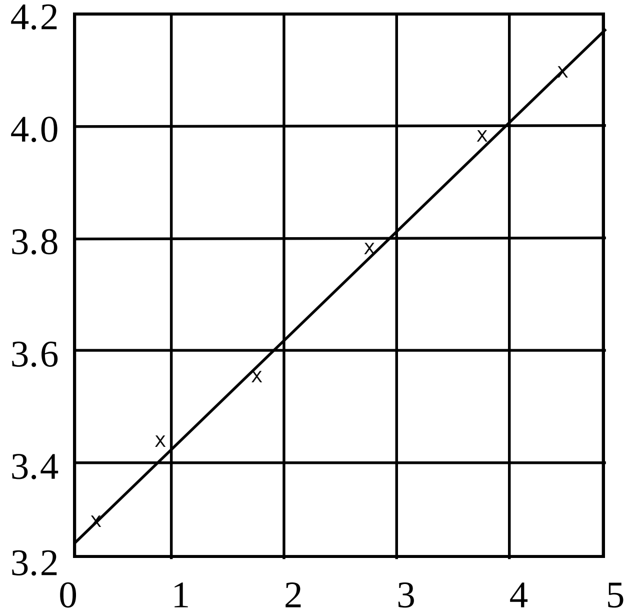


Thick plots not acceptable

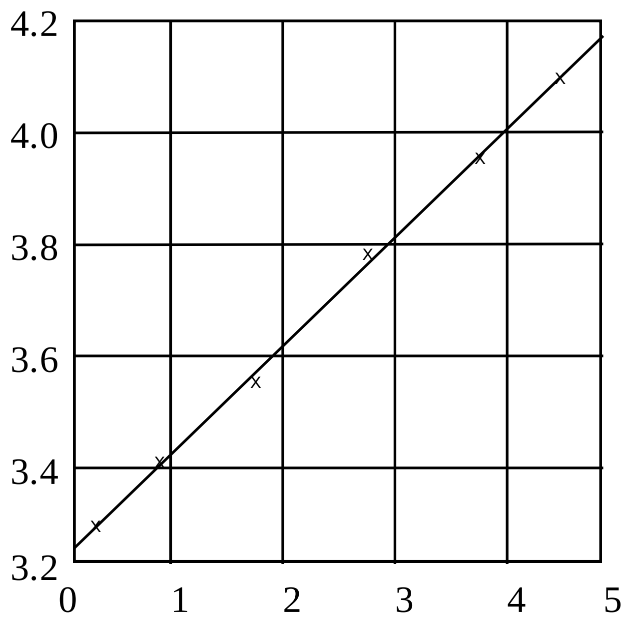
Line (or curve) of best fit.

1. There must be at least five plots on the graph grid for a 'best fit' mark to be awarded. Four plots on the grid (or fewer) cannot score this mark.

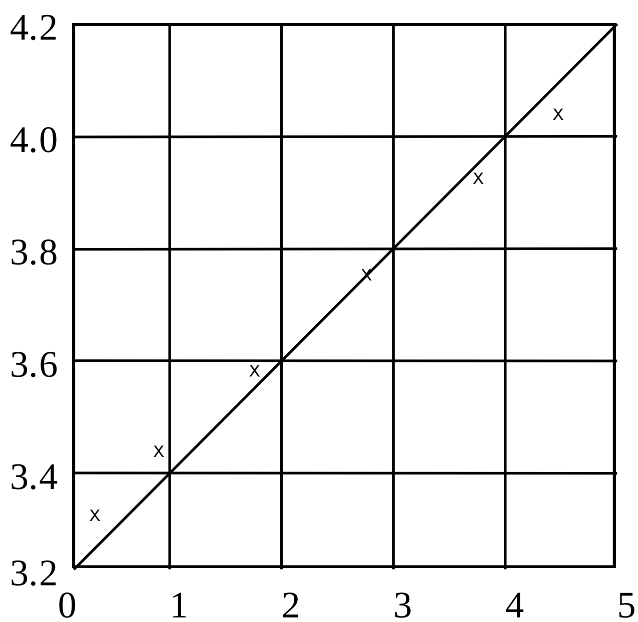
2. There must be a reasonable balance of points about the line. It is often felt that candidates would do better if they were able to use a clear plastic rule so that points can be seen which are on both sides of the line as it is being drawn.



Not acceptable (too many points above the line)

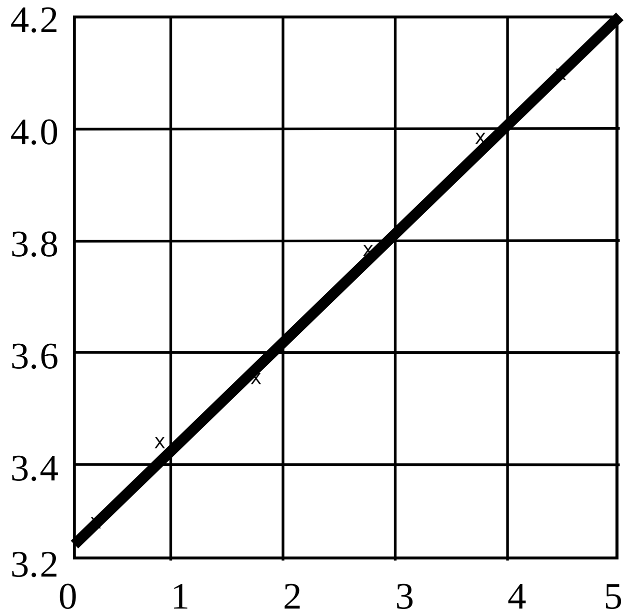


Acceptable balance of points about the line.

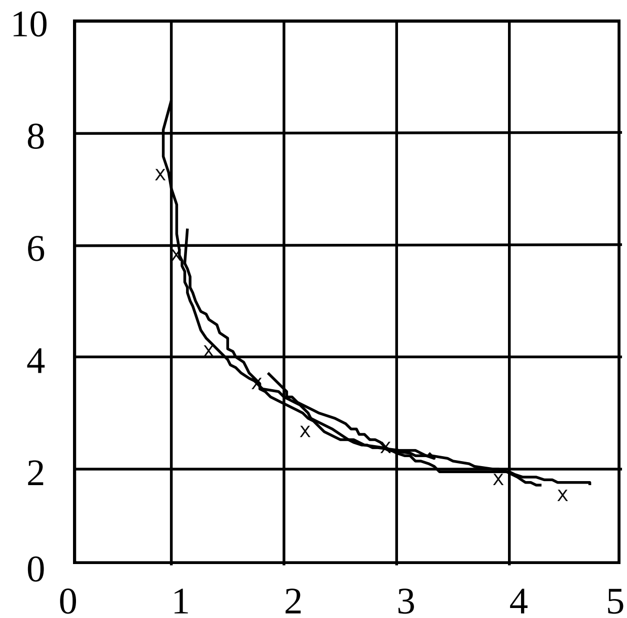


Not acceptable (forced line through the origin)

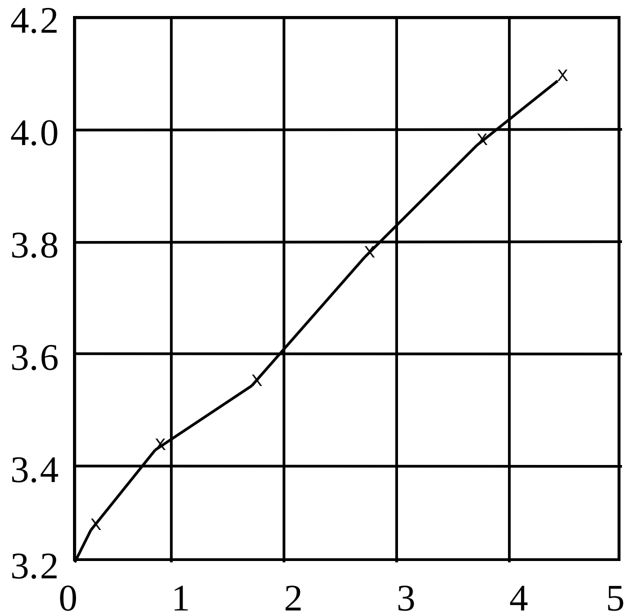
3. The line must be thin and clear. Thick/hairy/point-to-point/kinked lines are not credited.



Not acceptable (thick line)



Not acceptable (hairy).

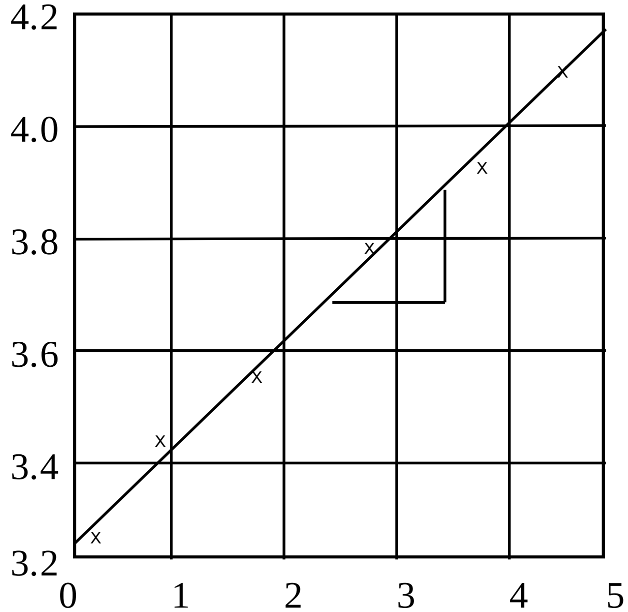


Not acceptable (point-to-point)

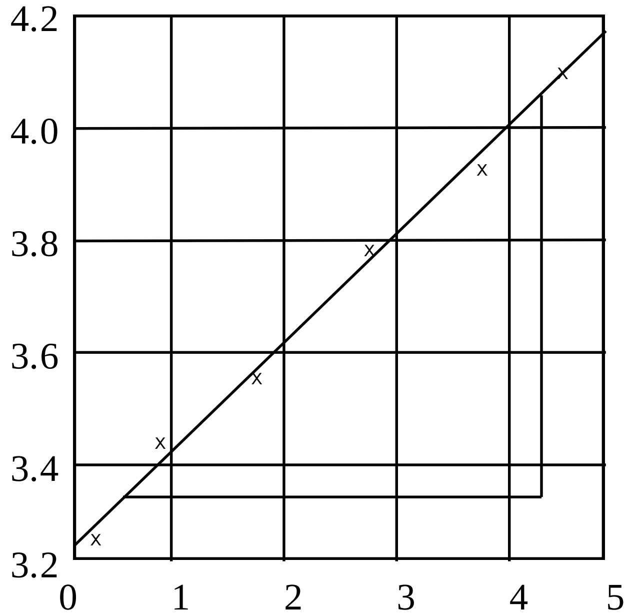
Measurement of Gradient.

1. All the working must be shown. A 'bald' value for the gradient will 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.

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



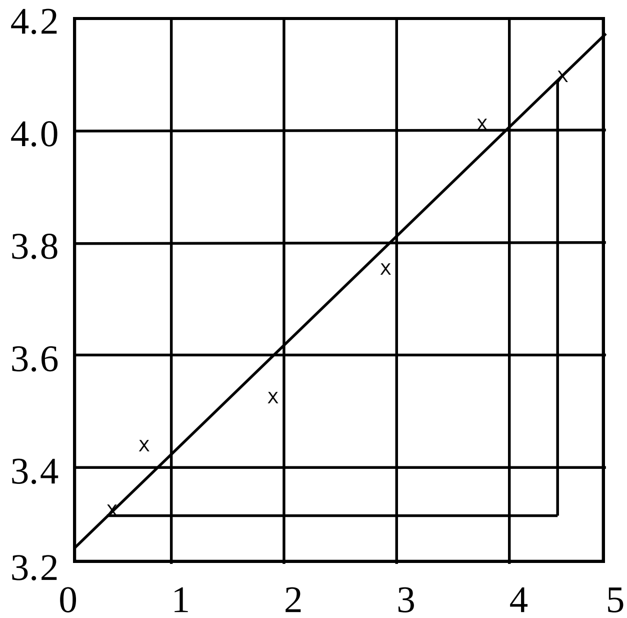
Not acceptable (triangle used is too small).



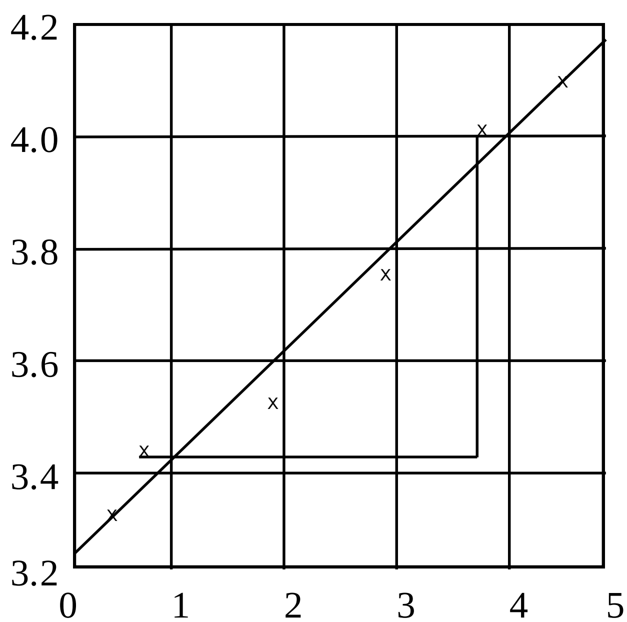
Acceptable (large triangle used)

3. The value of □ x and □ y 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).

4. 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)

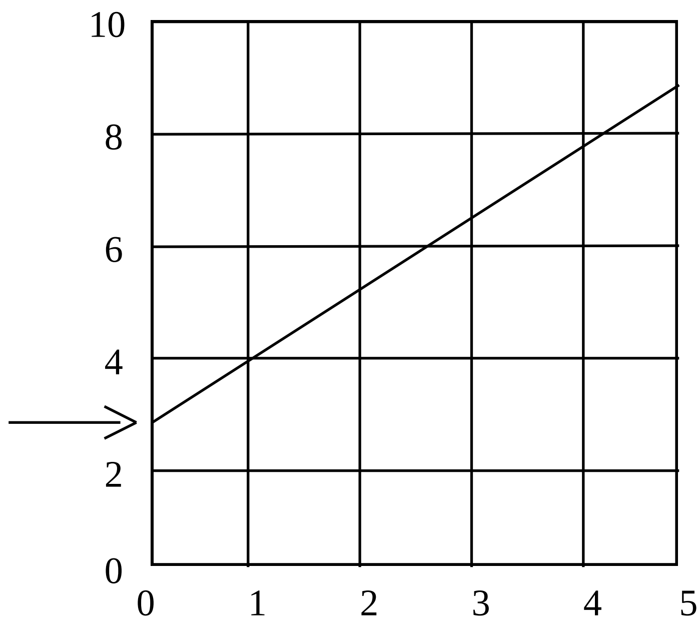


Not acceptable (data points used which do not lie on the line of best fit)

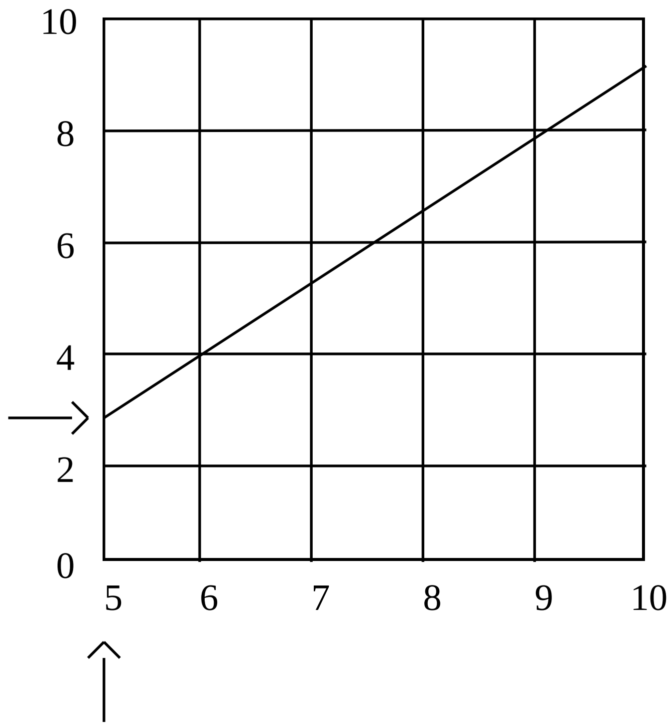
5. A gradient value has no unit since it is a ratio of two numbers from the graph.

Intercept.

1. 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 (value taken from the line $x = 0$)



Not acceptable (y-intercept found from the line x = 5)

It is expected that candidates will be able to use the equation of a straight line to calculate 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.

Guidelines for Writing a Good Lab Report

Every lab report will consist of the following components:

1. **Title page** – The title page must contain the title of the experiment, the names of experimenter, the date the experiment was performed and the date the report was submitted.
2. **Objectives (or Purpose)** – a brief sentence or two that describe the purpose of the experiment. This should be similar to that provided in your lab manual, however, written in your own words.
3. **Theory** – a brief summary of the relevant principles behind the experiment. This section should contain any equations you will need to analyse the data. Again, do not just re-write the information in the lab manual, explain the principles involved in your own words.
4. **Apparatus** – a list of all the equipment needed to conduct the experiment.
5. **Procedure** – a list of the steps required to conduct the experiment. This should be brief, and not a re-write of the manual. It should describe what was measured and how it was measured. If you took any special precautions not mentioned in the lab manual, or deviated in any way from the manual, you should describe what you did along with a justification. There could be extra marks for particularly innovative ideas!
6. **Data** – summarise your findings in tables. Often, the lab manual will have tables for you to fill as you acquire the data. These can be excellent guides for the format to be used in representing your data in tables in the lab report. All data must be shown, and it should be reported neatly.
7. **Sample calculations** – showing the method of obtaining the results. Show all intermediate steps of calculations needed to reach the final results. However, if the experiment requires several computations of the same type, only one of each type need be shown in the report. All calculations must have the appropriate units indicated.
8. **Graphs** – in many cases, data should also be shown in graphical form. Graphical analysis can be particularly useful in demonstrating mathematical relationships between physical quantities measured, and may be required for the complete numerical analysis of the data. The proper format for graphs will be reviewed in the lab.
9. **Questions** – many of the experiments have questions at the end of the procedure, which are intended to stimulate thought and to guide the student in interpreting the experimental results. These questions may either be answered one by one, in a section entitled 'Questions', or they may be answered, in discussion style, within the text of the section entitled 'Conclusions'.
10. **Conclusions** – when all the calculations have been made and curves plotted, you should study the results and draw some conclusions concerning what relationships are indicated by the data, and what physical principles are demonstrated. In particular, you should also report the final numerical results within the conclusions. For example, if the objective was to measure the acceleration due to gravity, you would report that this quantity was found to have an experimental value of _______ (with the appropriate units, and uncertainty if

requested). You should then also state the 'accepted' value of this quantity, thereby comparing your value with the tabulated one. You should also discuss some of the factors present in the laboratory that may be sources of error in the procedure. See class notes regarding the types of factors to consider.

The mark of a good lab report is careful and rigorous consideration of the procedure, data, and underlying principles. Really think hard about all aspects of the results in terms of what they mean. You will do well if you demonstrate that you understand what was done and why, and what your results indicate.