Achievement Standard 91168 Carry out a practical physics investigation that leads to a non-linear mathematical relationship

Guidelines

What follows is an interpretation of the standard. It has not been approved by the NZQA.

Measurement and observation

The number of observations to be made should be atleast five and no more than seven (providing the practical experiment allows such a range). This is to prevent students from spending too much time taking readings and not allowing enough time for the graphical work and the analysis. Five to seven readings are usually required for a linear trend or for a curved trend. It is expected that all these observations will be plotted on the graph grid.

It is expected that students will use sensible intervals between each reading in this range. The range is usually given in such a way so that students 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 students in the following way '... for values of *d* in the range 15 cm < *d* < 75 cm measure the time for ... until you have five to seven 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)

The measurements should be – at the very least – over half the possible range.

Repeated Reading.

It is expected that students will repeat readings and calculate an average. All raw readings should be recorded. 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.

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/m	*t*/s
0.02	
0.037	
0.049	
0.059	
0.063	

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

l/m	*t*/s
0.020	
0.037	
0.049	
0.059	
0.063	

Acceptable, since all the raw readings have been given to the same degree of precision.

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

Temperature/^{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 *temperature* - not achievable with an alcohol-in-glass thermometer.

Students 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). Measurements are determined by the smallest scale division of each of the measuring instruments (e.g. a meter ruler can has scale divisions to the nearest millimetre so a length should be 0.710 m – but not 0.7105 which would imply estimation between the graduations or 0.71 m which would imply insufficient accuracy).

<u>Significant figures</u>

Significant figures in calculated quantities e.g. $length^2$ are not assessed at Level 2.

<u>Explanation of errors.</u>

You should be able to identify – and justify why - a variable needs to be controlled
There are several sources of errors in measurements. These include:

Averaging – where results have random errors. For example, almost all stopwatches will give times to one hundredth of a second, but students clearly cannot operate the watch to this accuracy. Human reaction time will give errors of (typically) 0.1 s to 0.4 s.

Parallax - the observer and/or the instrument placement apply to measurements such as length, where parallax errors may make it difficult for students to measure a length to the accuracy of the rule used.

Zero End correction – the instrument used to make a measurement may have a systematic error e.g. a meter ruler placed vertically on a bench will not measure from 0.00 m due to its manufacture.

Choice of scale – the measuring instrument may have more than one scale to select from. Where possible, the most accurate scale should always be used.

<u>Presentation of results.</u>

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:

<u>Column headings.</u>

It is expected that <u>all</u> column headings will consist of a quantity <u>and</u> 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. For example, a length *l* measured in meters may be represented as follows:

l/m, *l* (m), *l* in m 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}, or just 'cm' are not acceptable.

<u>Presentation of processed results.</u>

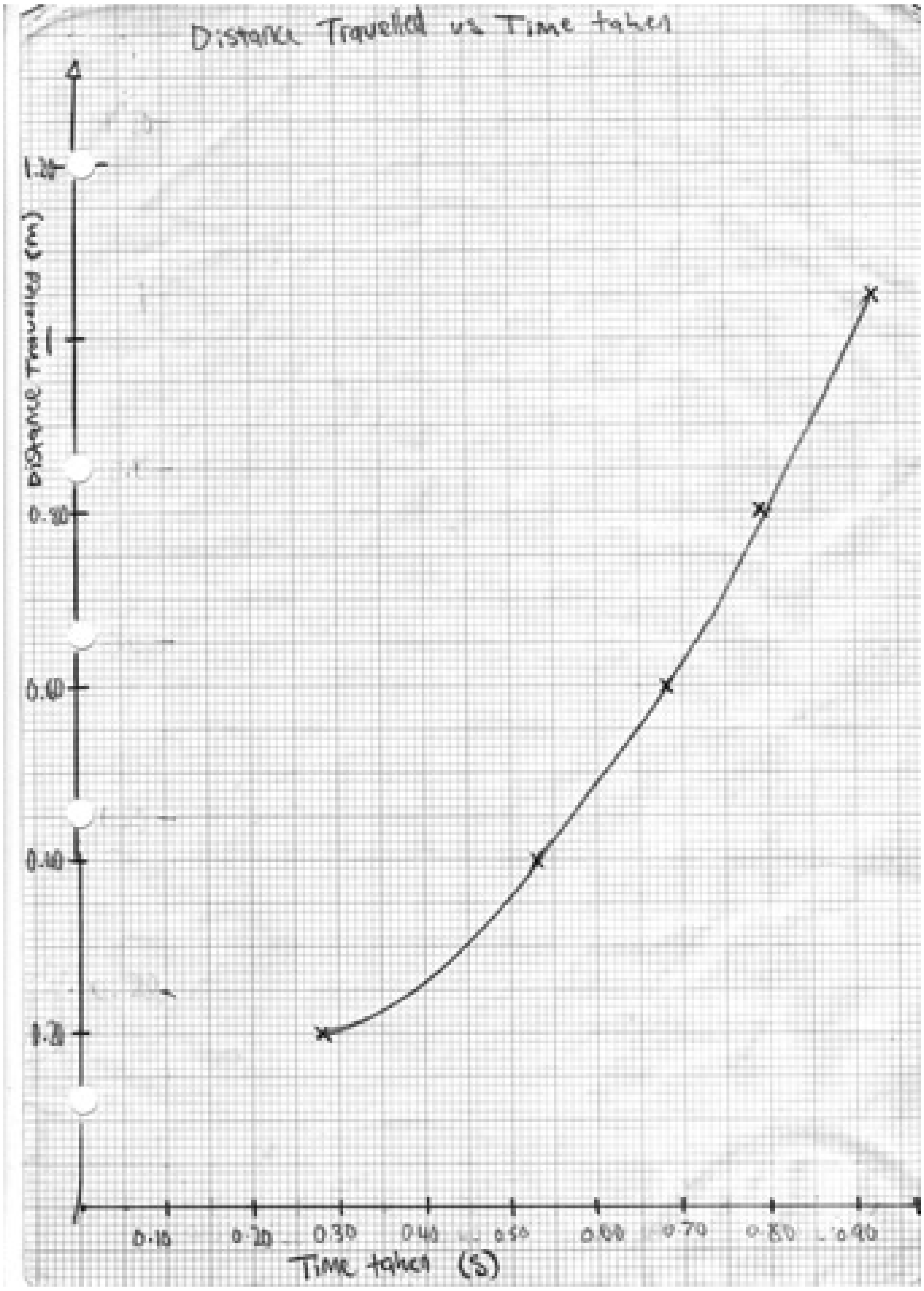
20*T*/s	*T*/s
10.49	0.525
14.31	0.716
17.69	0.885
24.88	1.24
29.61	1.48
33.02	1.65

Acceptable. Note that some values of *T* are to three dp and others are to two dp, but all the values of 20*T* are to 2 decimal places. Decimal places are not usually marked at level 2 in the processed data.

Graphical work

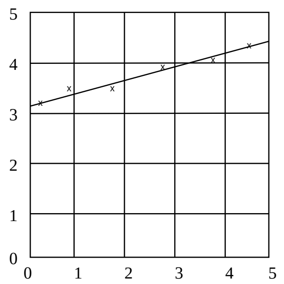
For this standard, it is likely that the assessment will require graphs to be hand plotted.

For example:

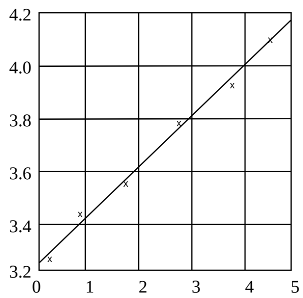


Choice of scales.

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



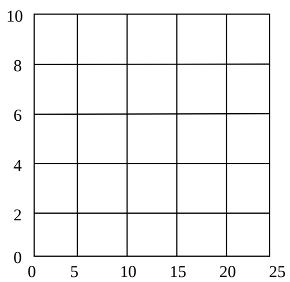
Not acceptable (scale in the *y*-direction is compressed)



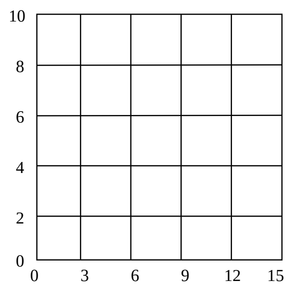
Acceptable (points fill more than half the graph grid in both the *x* and *y* directions).

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

You should choose scales that are easy to work with.



Acceptable scale divisions.

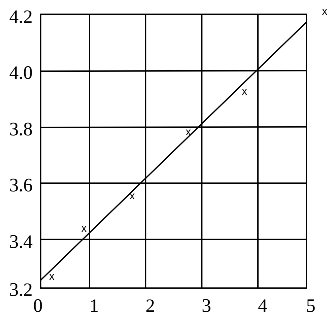


Not acceptable. Awkward scale on the *x*-axis.

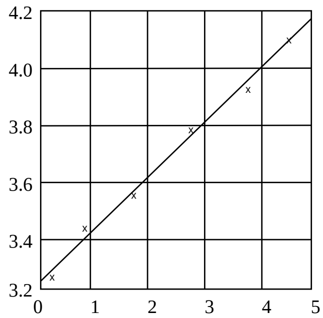
Other examples are 7s. If you choose awkward scales it is often a struggle to plot points (it is harder to read the scales correctly) and calculation of gradient (Δx and Δy may be misread - again because of poor choice of scale).

Plotting of points.

Plots in the margin area are not allowed.



Not acceptable (last point has been plotted in the margin area).

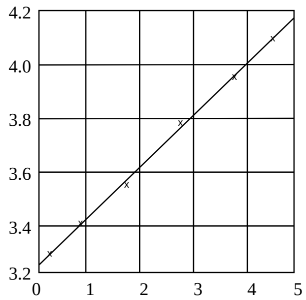


Acceptable (all plotted points are on the graph grid).

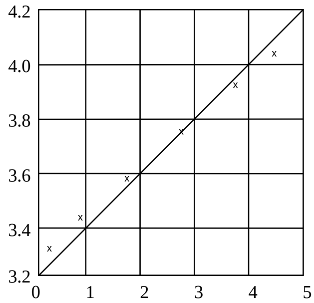
It is expected that all observations will be plotted (e.g. if ten observations have been made then it is expected that there will be ten plots).

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

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

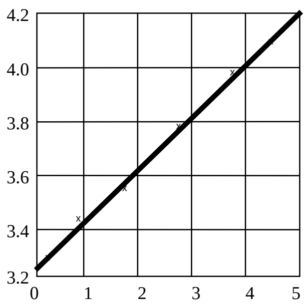


Acceptable balance of points about the line.

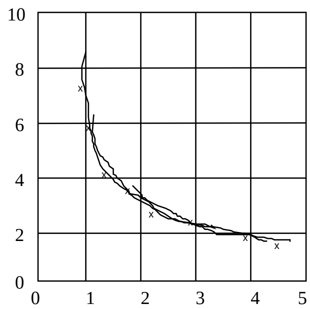


Not acceptable (forced line through the origin)

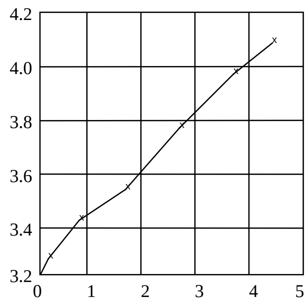
The line must be thin and clear. Thick/hairy/point-to-point/kinked lines are not acceptable.



Not acceptable (thick line)

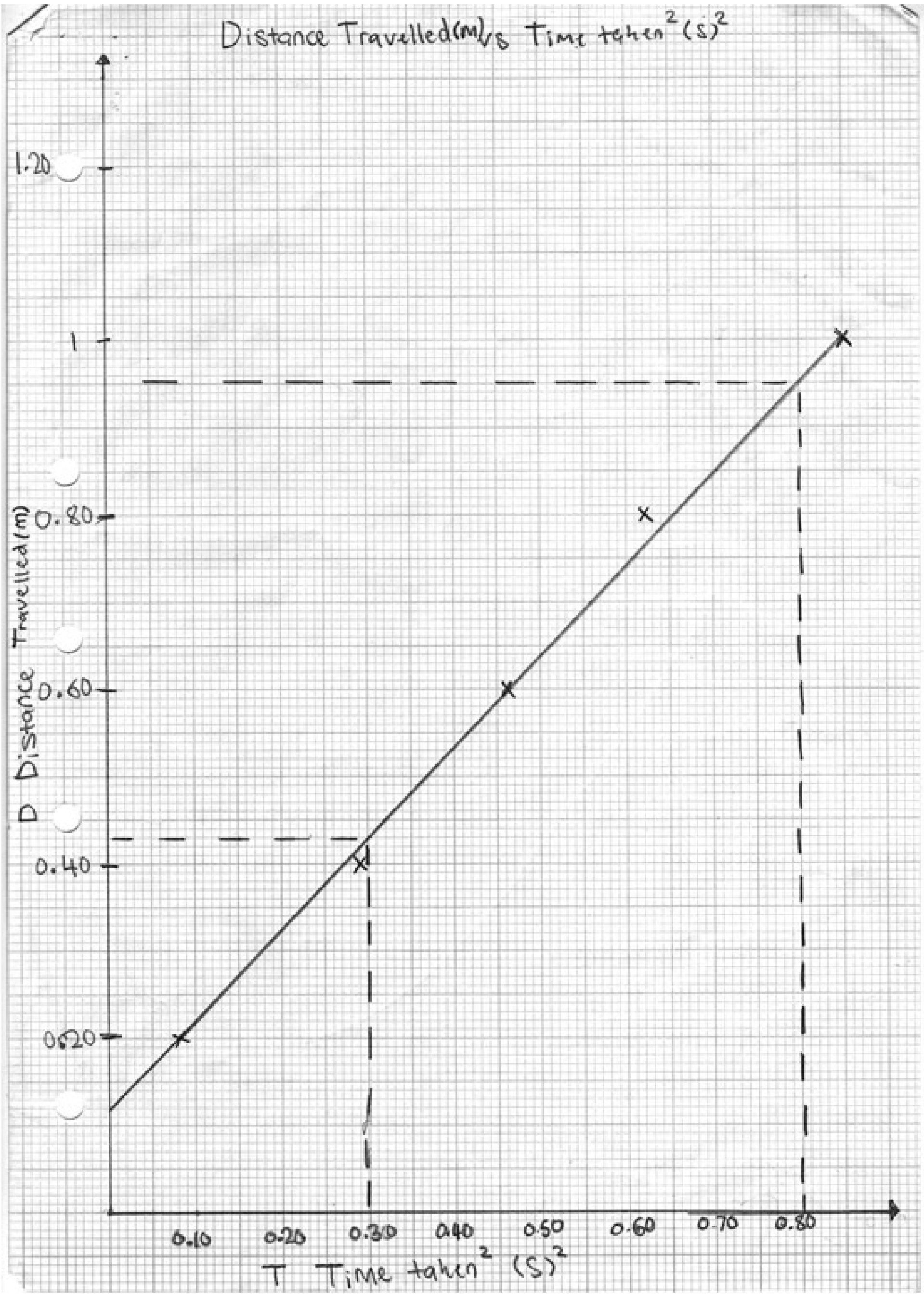


Not acceptable (hairy).



Not acceptable (joined the dots to make an animal)

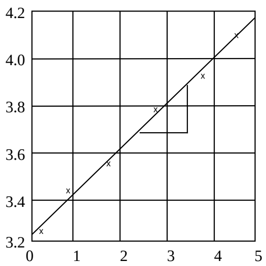
Line (or curve) of best fit.



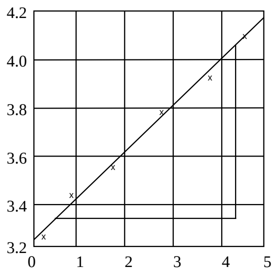
Measurement of Gradient.

All the working must be shown. A value for the gradient without workings will not be accepted. It is helpful to both students 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. If plots are used which have been taken from the table of results then they must lie on the line of best fit.

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

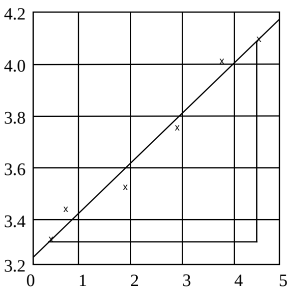


Not acceptable (triangle used is too small).

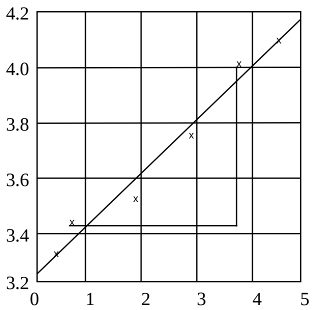


Acceptable (large triangle used)

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).



Acceptable (plots on line)

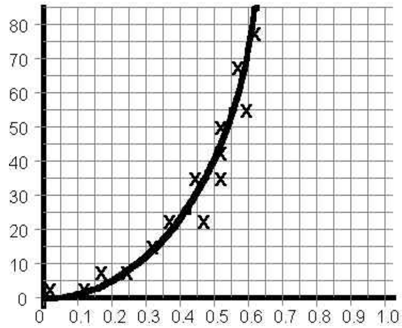


Not acceptable (data points used which do not lie on the line of best fit)

Relationships

You are expected to be able to describe the type of mathematical relationship that exists between the variables.

For the investigations you should be should be able to identify the type of relationship



and be able to convert one of the two variables by squaring, reciprocating, or inverse squaring.

You should be able to tabulate this data with suitable units.

l/m	*t*/s	t^2/s^2
0.020		
0.037		
0.049		
0.059		
0.063		

You should be able to plot a graph using this processed data (e.g. *l* versus t^2).

You will typically be supplied with the relationship and, if this is the case, you should be able to use the equation to determine what graph they would need to plot.

For example if you were are asked to investigate the relationship:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

By changing the length,l, and measuring the time period, T then a graph of T (y-axis) versus √l should produce a straight line graph with a gradient equal to 2π/√g that passes through the origin (based on $y = mx + c$)

You should be able to use the equation of a straight line to determine the mathematical relationship between the the experimental variable and the processed variable by substituting the two variables, the gradient and the y-intercept into the equation $y = mx + c$ to produce an equation such as $l = 9.8t^2 + 0$.

Critical Thinking

In your write up you may need to discuss critical issues such as:

Why there is a limit to either end of the value chosen for the independent variable

For example, in a pendulum experiment there is a lower limit to length of pendulum string that could be used since the time interval would be too short to measure without reaction time becoming a large factor compared to the time measured

A justification for why a variable needs to be controlled

For example, in a pendulum experiment, a change in the starting amplitude of swing (e.g. a mixture of little and big swings) introduces a second variable to the experiment.

A description of any difficulties encountered when making measurements and how these difficulties were overcome

For example, in a pendulum experiment, there are the time taken for one oscillation (particularly for small values of L) is short so multiple measurements e.g. 10T or 20T make it easier to measure one oscillation by reducing systematic errors associated with using a stopwatch.

The relationship between the findings and physics ideas

You may be asked to use the mathematical relationship to determine a physical constant (e.g. in a pendulum experiment, the acceleration due to gravity).
For example, in a pendulum experiment, you might be asked to use your graph and a supplied equation to estimate value for g. Your report might then compare your value of g with actual value of $9.8\ ms^{-2}$ and explain why values should correspond/possible reasons for variance if values do not correspond.
Both the mathematical relationship and the physical constant would typically be derived from the graph plotted and the gradient calculated.

Description of any unexpected results and a suggestion of how they could have been caused and/or the effect they had on the validity of the conclusion.

For example, outliers might be identified on your graph and you might discuss how these points were identified and ignored when plotting the line of best fit.