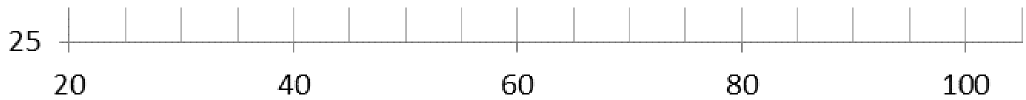
Graphing

Graphing skills can be assessed both in written papers for the A-level grade and by the teacher during the assessment of the endorsement. Students should recognise that the type of graph that they draw should be based on an understanding of the data they are using and the intended analysis of the data. The rules below are guidelines which will vary according to the specific circumstances.

Labelling axes

Axes should always be labelled with the quantity being measured and the units. These should be separated with a forward slash mark:

time / seconds



length / mm

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

Data points

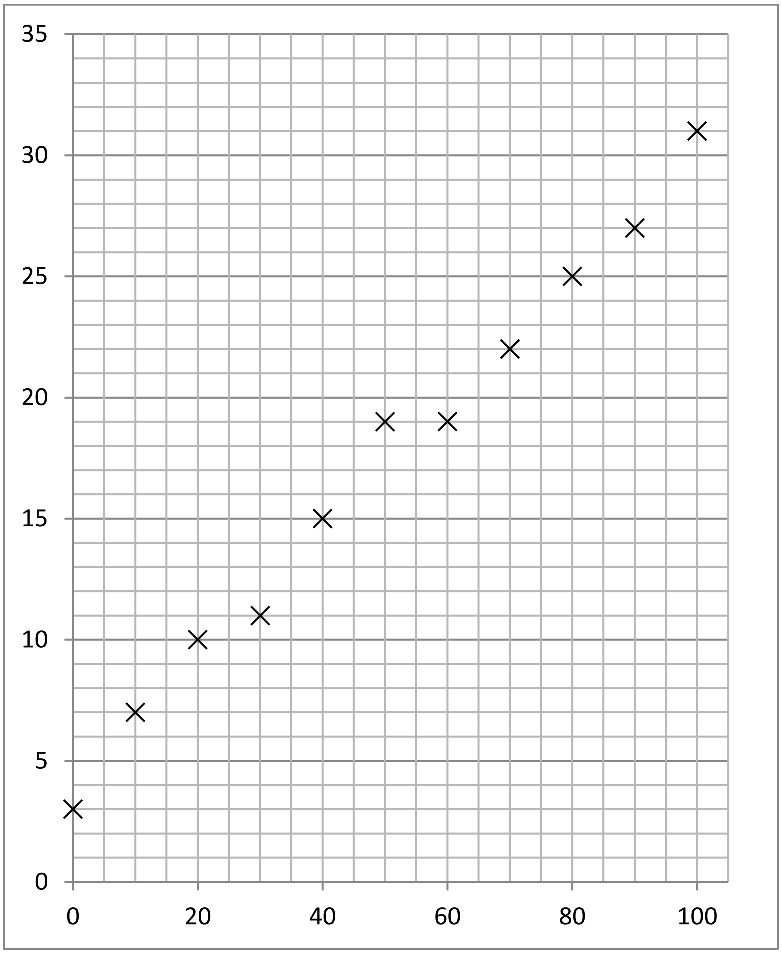
Data points should be marked with a cross. Both × and + marks are acceptable, but care should be taken that data points can be seen against the grid.

Error bars can take the place of data points where appropriate.

Scales and origins

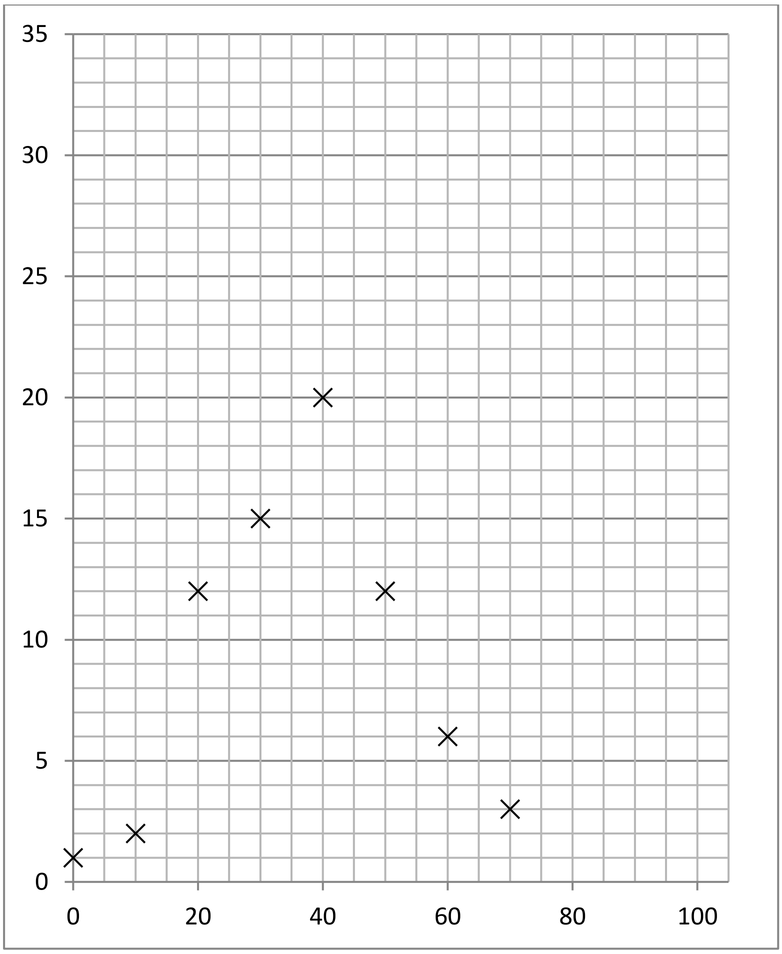
Students should attempt to spread the data points on a graph as far as possible without resorting to scales that are difficult to deal with. Students should consider:

- the maximum and minimum values of each variable
- the size of the graph paper
- whether 0.0 should be included as a data point
- how to draw the axes without using difficult scale markings (eg multiples of 3, 7, 11 etc)
- In exams, the plots should cover **at least half** of the grid supplied for the graph.

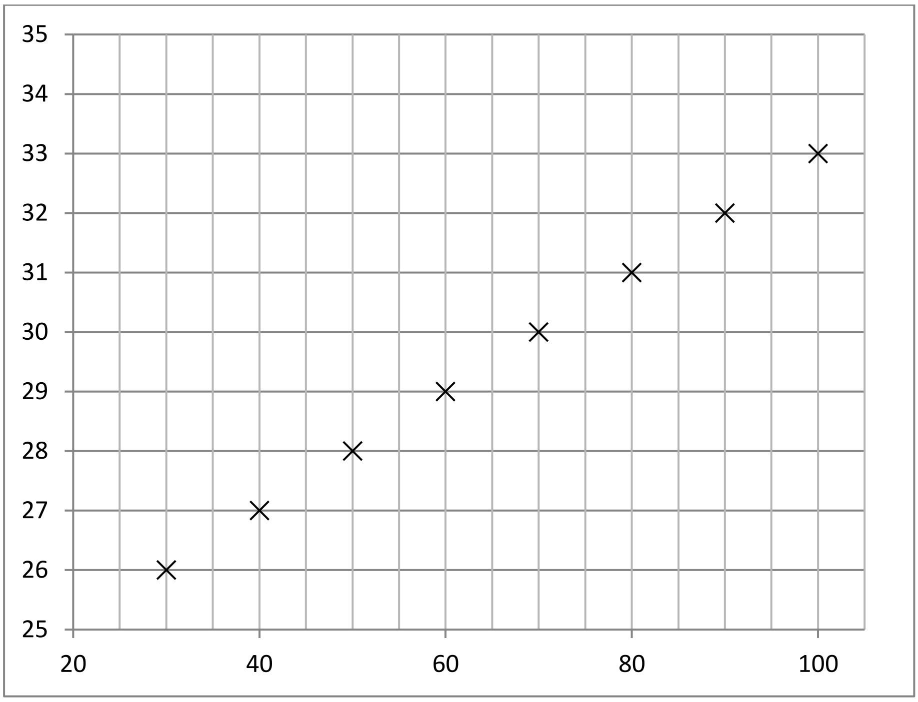


This graph has well-spaced marking points and the data fills the paper.

Each point is marked with a cross (so points can be seen even when a line of best fit is drawn).



This graph is on the limit of acceptability. The points do not quite fill the page, but to spread them further would result in the use of awkward scales.



At first glance, this graph is well drawn and has spread the data out sensibly. However, if the graph were to later be used to extrapolate the line, the lack of appropriate space could cause problems. Increasing the axes to ensure sufficient room is available is a skill that requires practice and may take a couple of attempts.

Lines 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 have an underlying equation that it is following (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?

There is no definitive way of determining where a line of best fit should be drawn. 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. Graphing programs can sometimes help, but tend to use algorithms that make assumptions about the data that may not be appropriate.

Lines of best fit should be continuous and drawn with 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 suggest some systematic error in the experiment. This would be a good source of discussion in an evaluation.

Dealing with anomalous results

At GCSE, students are often taught to automatically ignore anomalous results. At A-level students should think carefully about what could have caused the unexpected result - for example, if a different experimenter carried out the experiment, similarly, if a different solution was used or a different measuring device. Alternatively, the student should ask if the conditions the experiment took place under had changed (for example at a different temperature). Finally, they can evaluate about whether the anomalous result was the result of an accident or experimental error. In the case where the reason for an anomalous result occurring can be identified, the result should be ignored. In presenting results graphically, anomalous points should be plotted but ignored when the line of best fit is being decided.

Anomalous results should also be ignored where results are expected to be the same (for example in a titration in chemistry).

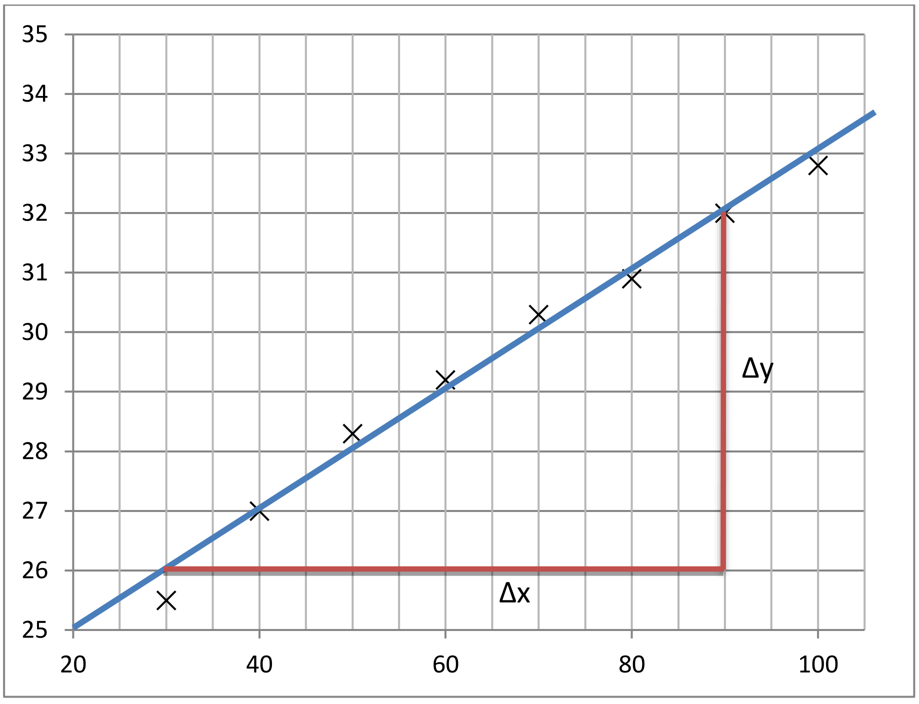
Where there is no obvious error and no expectation that results should be the same, anomalous results should be included. This will reduce the possibility that a key point is being overlooked.

Please note: when recording results it is important that all data are included. Anomalous results should only be ignored at the data analysis stage.

It is best practice whenever an anomalous result is identified for the experiment to be repeated. This highlights the need to tabulate and even graph results as an experiment is carried out.

Measuring gradients

When finding the gradient of a line of best fit, students should show their working by drawing a triangle on the line. The hypotenuse of the triangle should be at least half as big as the line of best fit.



The line of best fit here has an equal number of points on both sides. It is not too wide so points can be seen under it.
The gradient triangle has been drawn so the hypotenuse includes more than half of the line.
In addition, it starts and ends on points where the line of best fit crosses grid lines so the points can be read easily (this is not always possible).

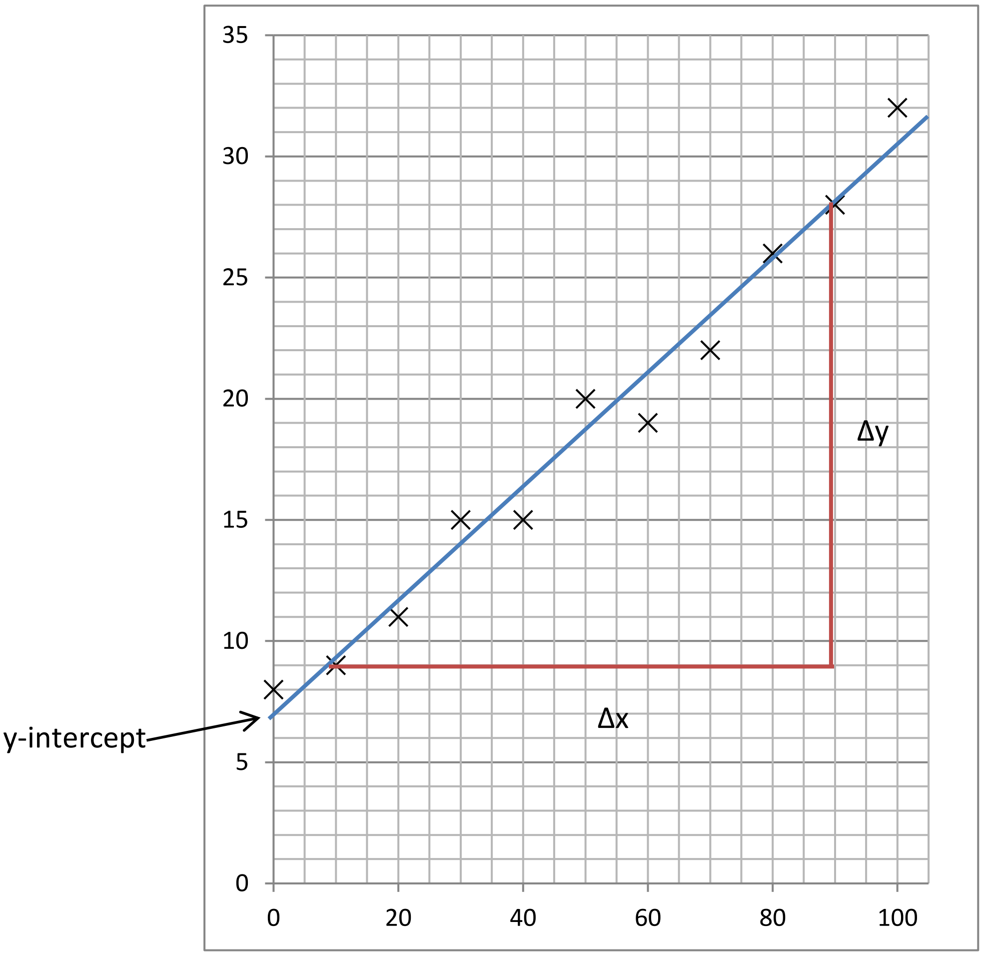
$$gradient = \frac{\Delta y}{\Delta x}$$

The equation of a straight line

Students should be able to translate graphical data into the equation of a straight line.

$$y = mx + c$$

Where y is the dependent variable, m is the gradient, x is the independent variable and c is the y-intercept.



Δy = 28 – 9 = 19 Δx = 90 – 10 = 80 gradient = 19 / 80 = 0.24 (2 sf) y-intercept = 7.0 equation of line: y = 0.24 x + 7.0

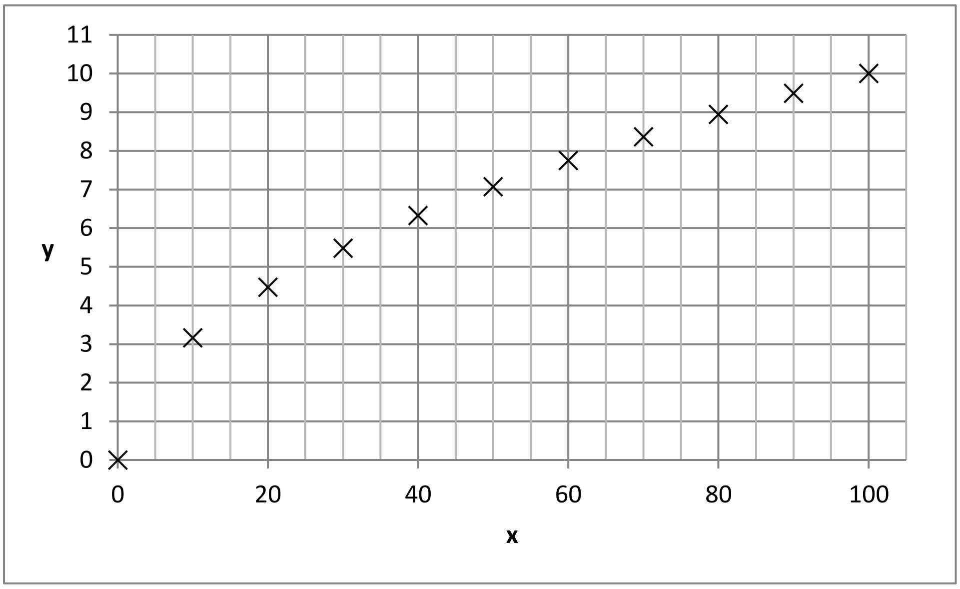
Testing relationships

Sometimes it is not clear what the relationship between two variables is. A quick way to find a possible relationship is to manipulate the data to form a straight line graph from the data by changing the variable plotted on each axis.

For example:

- **Raw data and graph**

x	y
0	0.00
10	3.16
20	4.47
30	5.48
40	6.32
50	7.07
60	7.75
70	8.37
80	8.94
90	9.49
100	10.00

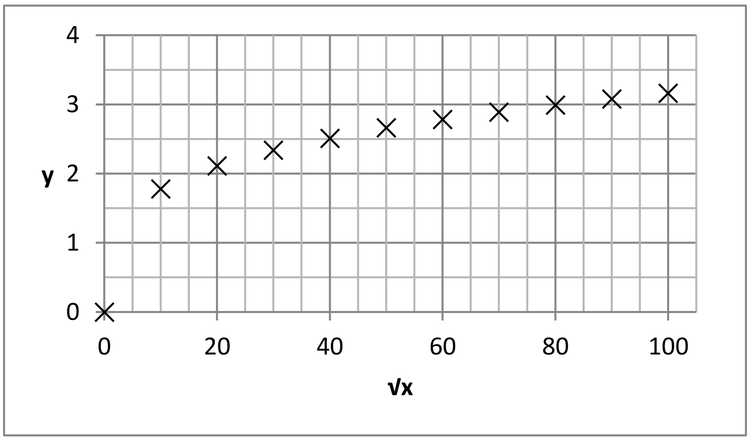


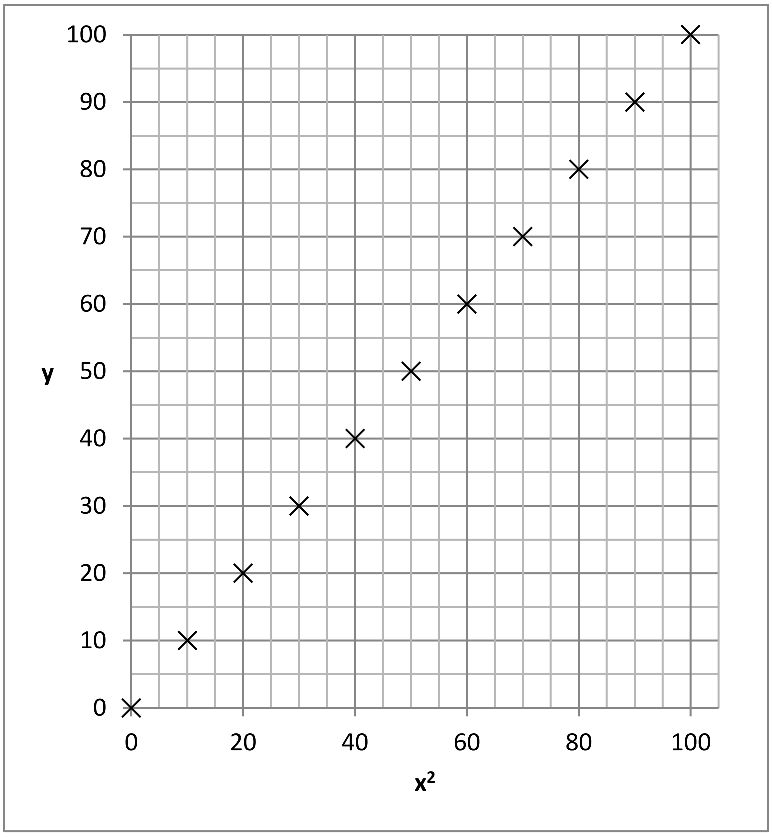
This is clearly not a straight line graph. The relationship between x and y is not clear.

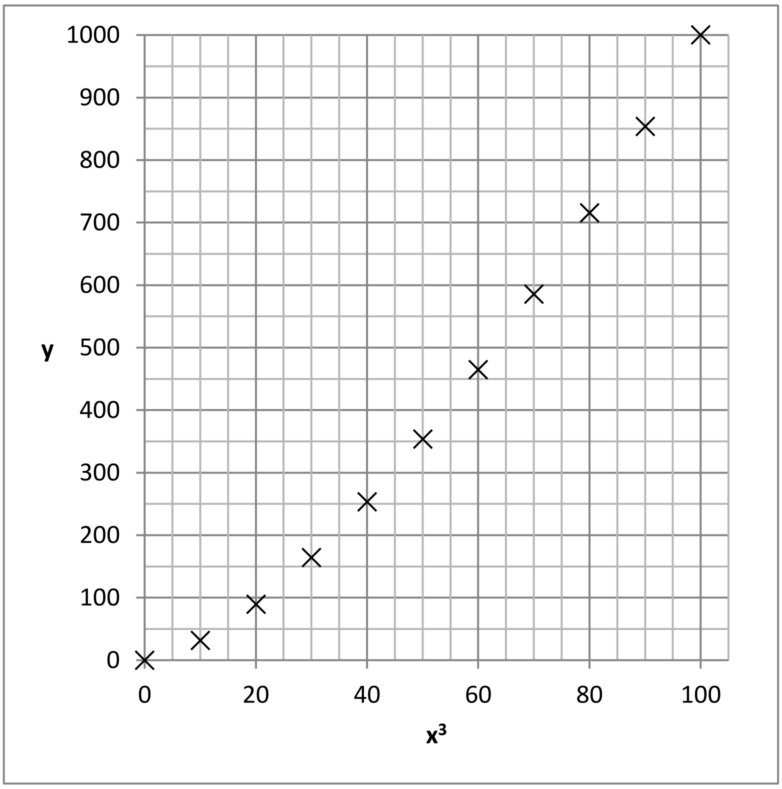
- **Manipulated data and graphs**

A series of different graphs can be drawn from these data. The one that is closest to a straight line is a good candidate for the relationship between x and y.

x	y	√y	y^2	y^3
0	0.00	0.00	0.00	0.00
10	3.16	1.78	10.00	32
20	4.47	2.11	20.00	89
30	5.48	2.34	30.00	160
40	6.32	2.51	40.00	250
50	7.07	2.66	50.00	350
60	7.75	2.78	60.00	470
70	8.37	2.89	70.00	590
80	8.94	2.99	80.00	720
90	9.49	3.08	90.00	850
100	10.00	3.16	100.00	1000







This is an idealised set of data to illustrate the point.

The straightest graph is y against x^2, suggesting that the relationship between x and y is

$$y \propto x^2$$

More complex relationships

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

Example one: 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(n).

The gradient of this graph will be n, with the y intercept log(A).

Example two

The equation that relates the rate constant of a reaction to temperature is

$$k = Ae^{-\frac{E_a}{RT}}$$

This can be rearranged into

$$\ln(k) = -\frac{E_a}{R}\left(\frac{1}{T}\right) + lnA$$

So a graph of $\ln(k)$ against $\left(\frac{1}{T}\right)$should be a straight line, with a gradient of$-\frac{E_a}{R}$ and a y-intercept of lnA