**Maths for Chemists Information Sheets**

Use pages 260-267 of your textbook to help you as well.

**MS 0.0 Recognise and make use of appropriate units in calculations**

Each equation will have standard units. Sometimes the data that you are given will not be in the standard units and you will need to convert the value to the correct units before performing the calculation.

**Temperature**

This can be measured in either °C or K. 0°C is equivalent to 273K.

**°C to K**: Add 273.

**K to °C**: Subtract 273.

**Pressure**

This can be measured in either Pa, kPa or atmospheres.

1kPa = 1000Pa 1 atmosphere = 100,000Pa

**kPa to Pa**: multiply by 1000

**Pa to kPa**: divide by 1000

**Pa to atmospheres**: Divide by 100,000

**Atmospheres to Pa**: Multiply by 100,000

**kPa to atmospheres**: Divide by 100

**Atmospheres to kPa:** Multiply by 100

**Volume**

1dm3 = 1000cm3 1m3 = 1000dm3

 **cm3 to m3**: divide by 1,000,000

**cm3 to dm3**: divide by 1000

**m3 to dm3**: multiply by 1000

**m3 to cm3**: multiply by 1,000,000

**dm3 to cm3**: multiply by 1000

**Mass**

1kg = 1000g

**kg to g**: multiply by 1000

**g to kg**: divide by 1000

**MS 0.1 Recognise and use expressions in decimal, ordinary and standard form**

Standard Form is used a lot in Maths and Science as a convenient way of writing very large, or very small numbers.

We will deal with large numbers first:

We can break down large numbers into two numbers:

500 = 5 x 100 = 5 x102

5000 = 5 x 1000 = 5 x 103

50000 = 5 x 10000 = 5 x 104

This becomes more useful as the numbers get larger.

The standard form number does not have to be a whole number.

For example:

550 = 5.5 x 100 = 5.5 x102

5550 = 5.55 x 1000 = 5.55 x 103

54800 = 5.48 x 10000 = 5.48 x 104

This is called standard form.

Standard form is:

(A number between 1 and 10) x a power of ten

The power of ten can be positive (for a large number) or negative (for a small number).

For small numbers, you need to understand negative powers of ten.

0.1 = 10-1

0.01 = 10-2

0.001 =10-3

Using the same method as we used for the larger numbers:

0.7 = 7 x 10-1

0.07 = 7 x10-2

0.007 = 7 x 10-3

Note that when you change numbers from ordinary to standard form, you should always keep the number of significant figures the same.

750000

0.0234

0.0067

0.00000000234

**MS 0.2 Use ratios, fractions and percentages**

A ratio compares values. It says how much of one thing there is compared to another thing.

For example, the ratio of your chemistry lessons is 3:2 because you have 3 lessons with one teacher and 2 with another.

Ratios can be simplified by dividing each part by the highest common factor.

For example in a class of 15 boys and 10 girls, both numbers can be divided by 5, so the ratio of boys to girls is 3:2 rather than 15:10.

For ratios with more than 2 parts, all of them need to be divided by the same number.

For example, if the number of different hair colours in a classroom was 3:12:6:9 then the highest common factor is 3 so the ratio becomes 1:4:2:3

Ratios can be converted to percentages.

For example, a 1:1 of boys to girls would be 50% boys and 50% girls.

To do this conversion add up all of the numbers together and then divide 100 by this number. Then multiply each ratio by this number.

For example,

A 2:3 ratio of boys to girls

2 + 3 = 5

100 divided by 5 = 20

2x 20 = 40% (boys)

3 x 20 = 60% (girls)

So 2:3 would be 40% boys and 60% girls.

To convert percentages to ratios simply divide each percentage by the highest common factor.

To convert fractions to percentages divide the top number by the bottom number and multiply by 100.

To convert percentages to fractions:

Write down the percent divided by 100

If the percent is not a whole number the multiply both top and bottom by 10 for every number after the decimal point.

Simplify the fraction by dividing both the top and the bottom number by the highest common factor.

For example 12.5 % = 12.5 / 100

This becomes 125 / 1000

The highest common factor is 125, so the fraction becomes 1/8

To convert ratios to fractions:

Add up all of the numbers in the ratio. This will give you the number that goes on the bottom of the fraction.

To get the fraction, divide the ratio by the number on the bottom.

If necessary, simplify the fraction.

For example 2:4

2 + 4 = 6 so the number on the bottom of each fraction is 6.

This gives 2/6 and 4/6

However each of these has a common factor of 2

So 2/6 becomes 1/3 and 4/6 becomes 2/3

**MS 0.3 Estimate results**

Most of the time in Chemistry we seek to find a definitive answer. However, sometimes it can be useful to estimate the effect of change.

The best example of this that you will meet in AS and A Level Chemistry is the general rule that ‘the rate of reaction will double for every increase in temperature of 10K’.

So, if a reaction took 90 seconds to complete at room temperature (293K) then an increase of 10K to 303K would mean that the reaction would be complete in 45 seconds.

It is important to remember that this is only an approximation and will not work for every chemical reaction. For example, if the reaction in question had a multistep mechanism and one of the steps was reversible and exothermic in the forward reaction then the rate of reaction might not increase by as much as expected or might even decrease. Conversely, a reaction involving free radicals might increase more than expected.

**MS 0.4 Use calculators to find and use power, exponential and logarithmic functions**

The power of a number means how many times that number is multiplied by itself.

So, 22 = 2 x 2 = 4

23 = 2 x 2 x 2 = 8

24 = 2 x 2 x 2 x2 = 16

There is a button on your calculator which can do this.

**Logarithms**

Given the equation  and being asked to find the unknown letter x, this question simply means “What power of 2 gives us 8”

The answer is of course 3 as .

This type of equation is known as an ‘**EXPONENTIAL EQUATION**’ as the unknown letter **IS** the power.

So if we were asked to solve  then what does x would be 4

Suppose we have to solve , we have a problem, as x is not a whole number. We could use trial and error but there must be a better way.

There is, we use **LOGARITHMS.**

DEFINITION OF A LOGARITHM

If we are given  where  is the base,

  is the power

  is the number

then

 “The logarithm of a number to a given base is the power to

 which the base must be raised to give the number.”

Any positive number except 1 can be used as the base.

So we have

 

**MS1.1 Use an appropriate number of significant figures**

When we use our calculators to work out a number it is not usually appropriate to record the figure exactly how it is written on the calculator. You will have to choose how many significant figures to record your answer to.

If you are using experimental data in your calculation then the answer should be recorded to the same number of significant figures as the original data with the **least** number of significant figures.

For example, if we were asked to calculate P from PV =nRT given the following data: V = 1.276m3 (4 sig figs), R = 8.31Jmol-1K-1 (3 sig figs), T = 297.05K (5 sig figs) then the pressure should be recorded to 3 significant figures.

Remember when we round to significant figures we start counting as soon as we reach a number that is not zero.

Example 1

Round 14.786548 to 2 significant figures

From the left the first number is 1. The second number is 4. However, we also need to look at the third number. This is 7. Since this is closer to 10 than 0 the 4 needs to be rounded up to a 5.

So 14.786548 to 2 significant figures is 15.

Example 2

Round 1.643 to 2 significant figures.

From the left the first two numbers are 1.6. The third number is 4, which is less than 5, so the 6 remains a six (i.e. the number is rounded down).

So 1.643 to 2 significant figures is 1.6.

Example 3

Round 0.056579

From the left the first two numbers, which are not zero, are 0.056. The third number is a 5 so the second digit is rounded up to a 7.

So 0.056579 to 2 significant figures is 0.057.

**MS1.2 Find arithmetic means**

To find the mean of a series of data points, simply add all of the numbers in the list together then divide by how many numbers there are in the list.

For example 1, 4 ,4 ,4 ,2 ,9 ,4

1st add the numbers together 1+4+4+4+2+9+4 = 28

2nd divide the answer by how many numbers are in the list 28 ÷ 7 = 4

So the mean is 4.

It is important that the mean is recorded to the same number of decimal places as the original data.

If the data is experimental data then normally we will exclude any anomalies, for example in titrations. Given the following data:

25.1, 24.6, 24.5, 24.5

The 25.1 is clearly an anomaly and should be excluded when we calculate the mean.

Weighted means

Sometimes you will be asked to calculate a weighted mean. This where some values are given more weight than others when the average (mean) is calculated.

In this case the weighted mean = sum of (values x weight) / sum of all the weights

This is easier to think about if we use an average.

For example, Simon wants to buy a Chemistry Revision Guide to help him with his A level Chemistry. He looks at all three guide and rates them out of ten for each of these categories.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Textbook A | Textbook B | Textbook C |
| Cost | 5 | 2 | 10 |
| Clearness of diagrams | 6 | 7 | 9 |
| Number of example questions | 9 | 5 | 3 |
| Clearness of writing | 7 | 7 | 5 |
| Mean | 6.75 | 5.25 | 6.75 |

Using a ‘normal’ mean, Simon gets the same rating for Textbook A and textbook C.

However, Simon thinks that the most important factors when choosing his textbook are the clearness of the writing and the number of example questions.

He gives each factor a percentage of importance:

|  |  |  |  |
| --- | --- | --- | --- |
|  | Textbook A | Textbook B | Textbook C |
|  | Rating | Weighted rating (% x rating) | Rating | Weighted rating (% x rating) | Rating | Weighted rating (% x rating) |
| Cost (10%) | 5 | 50 | 2 | 20 | 10 | 100 |
| Clearness of diagrams (20%) | 6 | 120 | 7 | 140 | 9 | 180 |
| Number of example questions (30%) | 9 | 270 | 5 | 150 | 3 | 90 |
| Clearness of writing (40%) | 7 | 280 | 7 | 280 | 5 | 200 |
| Sum of wx |  | 720 |  | 590 |  | 570 |
| Weighted mean (wx / 100) |  | 7.2 |  | 5.9 |  | 5.7 |

From this weighted average, Simon can see that Textbook A is the best textbook for him to buy. Textbook C, which was joint first when all of the factors had the same weighting, is actually the textbook with the worst rating now.

**MS 1.3 Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined**

Every measurement has some inherent uncertainty.

The uncertainty in a measurement using a particular instrument is no smaller than plus or minus half of the smallest division or greater. For example, a temperature measured with a thermometer is likely to have an uncertainty of ±0.5 °C if the graduations are 1 °C apart.

Measurements are often written with the uncertainty. An example of this would be to write a voltage was (2.40 ± 0.01) V.

**Measuring length**

When measuring length, two uncertainties must be included: the uncertainty of the placement of the zero of the ruler and the uncertainty of the point the measurement is taken from.

As both ends of the ruler have a ±0.5 scale division uncertainty, the measurement will have an uncertainty of ±1 division.

For most rulers, this will mean that the uncertainty in a measurement of length will be ±1 mm.

There are some occasions where the resolution of the instrument is not the limiting factor in the uncertainty in a measurement.

Best practice is to write down the full reading and then to write to a fewer significant figures when the uncertainty has been estimated.

Examples:

A stop watch has a resolution of hundredths of a second, but the uncertainty in the measurement is more likely to be due to the reaction time of the experimenter. Here, you should write the full reading on the stop watch (eg 12.20 s) and reduce this to 12 s later.

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

 **Multiple instances of readings**

Some methods of measuring involve the use of multiple instances in order to reduce the uncertainty. For example measuring the thickness of several sheets of paper together rather than one sheet, or timing several swings of a pendulum. The uncertainty of each measurement will be the uncertainty of the whole measurement divided by the number of sheets or swings. This method works because the percentage uncertainty on the time for a single swing is the same as the percentage uncertainty for the time taken for multiple swings.

For example:

Time taken for a pendulum to swing 10 times: (5.1 ± 0.1) s

Mean time taken for one swing: (0.51 ± 0.01) s

Repeated measurements

If measurements are repeated, the uncertainty can be calculated by finding half the range of the measured values.

For example:

Distance/m 1.23 1.32 1.27 1.22

1.32 – 1.22 = 0.10 so Mean distance: (1.26 ± 0.05) m

**Percentage uncertainties**

The percentage uncertainty in a measurement can be calculated using: percentage uncertainty = (uncertainty / value) x 100%

The percentage uncertainty in a repeated measurement can be calculated using:

percentage uncertainty = (uncertainty / mean value) x 100%

**Uncertainties in Titrations**

Titration is a special case where a number of factors are involved in the uncertainties in the measurement.

You should carry out a rough titration to determine the amount of titrant needed. This is to speed up the process of carrying out multiple samples. The value of this titre should be ignored in subsequent calculations.

In titrations one single titre is never sufficient. The experiment is usually done until there are at least two titres that are concordant ie within a certain allowable range, often 0.10 cm3. These values are then averaged.

For example:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Titration** | **Rough** | **1** | **2** | **3** |
| **Final reading** | 24.20 | 47.40 | 24.10 | 47.35 |
| **Initial reading** | 0.35 | 24.20 | 0.65 | 24.10 |
| **Titre / cm3** | 23.85 | 23.20 | 23.45 | 23.25 |

Here, titres 1 and 3 are within the allowable range of 0.10 cm3 so are averaged to 23.23 cm3.

Unlike in some Biology experiments (where anomalous results are always included unless there is good reason not to), in Chemistry it is assumed that repeats in a titration should be concordant. If they are not then there is likely to have been some experimental error. For example the wrong volume of solution added from the burette, the wrong amount of solution measuring the pipette or the end point might have been misjudged.

The total error in a titre is caused by three factors:

|  |  |
| --- | --- |
| **Error** | **Uncertainty** |
| Reading the burette at the start of the titration | Half a division = ±0.05 cm3 |
| Reading the burette at the end of the titration | Half a division = ±0.05 cm3 |
| Judging the end point to within one drop | Volume of a drop = ± 0.05 cm3 |
| **Total**  | ± **0.15 cm3** |

This will, of course, depend on the glassware used, as some burettes are calibrated to a higher accuracy than others.

**Uncertainties from gradients**

To find the uncertainty in a gradient, two lines should be drawn on the graph. One should be the “best” line of best fit. The second line should be the steepest or shallowest gradient line of best fit possible from the data. The gradient of each line should then be found.

The uncertainty in the gradient is found by:

 ×

Note the modulus bars meaning that this percentage will always be positive.

Best gradient

Worst gradient could be either:

or:

or

Shallowest gradient possible

In the same way, the percentage uncertainty in the y-intercept can be found:

Combining uncertainties

Percentage uncertainties should be combined using the following rules:

|  |  |  |
| --- | --- | --- |
| **Combination** | **Operation** | **Example** |
| **Adding or subtracting values** | Add the absolute uncertaintiesΔa = Δb + Δc | Initial volume in burette = 3.40 ± 0.05 cm3Final volume in burette = 28.50 ± 0.05 cm3Titre = 25.10 ± 0.10 cm3 |
| **Multiplying values** | Add the percentage uncertaintiesεa = εb + εc | Mass = 50.0 ± 0.1 g Temperature rise (T) = 10.9 ± 0.1 oCPercentage uncertainty in mass = 0.20%Percentage uncertainty in T = 0.92 %Heat change = 2278 JPercentage uncertainty in heat change = 1.12 %Absolute uncertainty in heat change = ± 26 J(Note – the uncertainty in specific heat is taken to be zero) |
| **Dividing values** | Add the percentage uncertaintiesεa = εb + εc | Mass of salt in solution= 100 ± 0.1 gVolume of solution = 250 ± 0.5 cm3Percentage uncertainty in mass = 0.1 %Percentage uncertainty in volume = 0.2 %Concentration of solution = 0.400 g cm–3Percentage uncertainty of concentration = 0.3 %Absolute uncertainty of concentration = ± 0.0012 g cm–3 |
| **Power rules** | Multiply the percentage uncertainty by the powerεa = c × εb | Concentration of H+ ions = 0.150 ± 0.001 mol dm–3rate of reaction = *k*[H+]2 = 0.207 mol dm–3 s–1(Note – the uncertainty in *k* is taken as zero and its value in this reaction is 0.920 dm6 mol–2 s–1)Percentage uncertainty in concentration = 0.67 %Percentage uncertainty in rate = 1.33 %Absolute uncertainty in rate = ± 0.003 mol dm–3 s–1  |

Note: Absolute uncertainties (denoted by Δ) have the same units as the quantity. Percentage uncertainties (denoted by ε) have no units. Uncertainties in trigonometric and logarithmic functions will not be tested in A-level exams.

**MS 2.1 Understand and use the symbols =, <, <<, >, >> ~** 

You should be familiar with the following symbols from GCSE Maths:

|  |  |
| --- | --- |
|  | directly proportional to |
|  | reversible reaction (both forward and backward reaction occur) |
| = | Equals  |
| > | greater than |
| < | less than |
| ~ | approximately |
| << | much less than |
| >> | much greater than |

**MS 2.3 Substitute numerical values into algebraic equations using appropriate units for physical quantities**

You need to be able to substitute numbers into an equation (either one you are given, or more likely, one that you have learnt).

For example, you might be asked to use one of the following equations:

Number of moles = mass/Mr

Concentration = n/v (if v is in dm3)

q=mcΔT

Before you substitute any values in, you need to convert all of the values into the appropriate units (This has already been covered in MS 0.0)

**MS 2.4 Solve algebraic equations**

In order to calculate values using equations you will often have to rearrange the equation to make the quantity you are being asked to calculate the subject of the equation

To rearrange an equation successfully you need to understand that whatever you do to one side of the equation, you also need to do to the other side of the equation.

For example,

PV = nRT

If we wish to make V the subject of this equation, it is currently multiplied by P, so to isolate V we need to divide both sides by P.

This gives PV/P = nRT / P

This simplifies to V = nRT / P

If we wish to make T the subject, it is currently multiplied by n and R, so to isolate T we need to divide both sides by n and R.

So PV / nR = nRT / nR

This simplifies to PV /nR = T

**MS 2.5 Use logarithm in relation to quantities that range over several orders of magnitude**

You have already learnt how to use your calculator to calculate logarithms. You will need to use these in A2 Chemistry to calculate the pH of solutions.

pH = -log10[H+]

**MS 3.1 Translate information between graphical, numerical and algebraic forms**

You will need to translate graphical data into the equation of a straight line.

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

Δy

Δx

Δy

Δx

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.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| x | y | √y | y2 | y3 |
| 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 |

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

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

The straightest graph is y against x2, suggesting that the relationship between x and y is

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=Axn, 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

This can be rearranged into

So a graph of against should be a straight line, with a gradient of and a y-intercept of

**MS 3.2 Plot two variables from experimental or other data**

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 sometimes take the place of data points where appropriate.

Scales and origins

You should attempt to spread the data points on a graph as far as possible without resorting to scales that are difficult to deal with. You 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 **plotted points** 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. You 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. You should ask yourself 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 some systematic error in the experiment. This would be a good source of discussion in an evaluation.

Dealing with anomalous results

At GCSE, you were probably taught to automatically ignore anomalous results. At A-level you need to 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, you should ask if the conditions the experiment took place under had changed (for example at a different temperature). Finally, you 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.

**MS3.3 Determine the slope and intercept of a linear graph**

The intercept of a graph is where the line crosses the y axis. It is the value of y when x = 0. Sometimes you will need to extrapolate (extend) the line of best fit in order to record the value of the intercept.

The slope, otherwise known as the gradient, of the graph is a measure of how steep the slope is. It is measured by drawing a triangle from the line and working out the change in the y value and the change in the x value.

Gradient = change in y / change in x

A positive gradient means that as x increases, y also increases. This is shown in the graph below.



A negative gradient means that as x increases, y decreases. This is shown in the graph below.



The unit of the gradient can be worked out by dividing the unit of the y axis by the unit of the x axis.

For example in a graph of concentration (y axis) by time (x axis), the units of concentration are moldm-3 and the units of time are seconds, so the units of the gradient would be moldm-3s-1

**MS 3.4 Calculate the rate of change from a graph showing a linear relationship**

For a linear relationship, the rate of change can be calculated from a graph by calculating the gradient of the line in exactly the same way as we have discussed in 3.3.

**MS 3.5 Draw and use the slope of a tangent to a curve as the measure of rate of change**

For a graph which shows a non-linear relationship (i.e. the line is a curve rather than a straight line) the gradient is different at different points on the graph. We can estimate the gradient at a given point by drawing a tangent to the curve and determining the gradient of the tangent. A tangent is a straight line which just touches the curve at the given point.

For example, to calculate the gradient of the curve at x=2:

The dotted line shows the tangent at x=2.

