INTERNATIONAL GCSE

Biology, Chemistry, Physics and Human Biology (2017)

Guidance on using practical terminology

Pearson Edexcel International GCSE in Science

Use of practical terminology in International GCSE Sciences

Contents

Introduction

The use of terminology within practical and experimental work in science is a complicated issue. Definitions of terms can vary between different sources, and the same terms are used inter-changeably (but with different meanings) in planning investigations, using apparatus, and making measurements. There are also issues with student understanding, as many words such as 'accuracy' and 'precision' have everyday meanings outside the laboratory. All of these factors contribute to some confusion in this area!

The *Association for Science Education* has produced a helpful guide (*Language of Measurement*) which aims to bring consistency to the meanings of terminology in practical science. This is a useful guide, although some of the terminology is different to that which has been used for International GCSE in the past. When it comes to questions asked in International GCSE exams, we are less interested in students learning strict definitions of terms, and more interested in students appreciating – and critically evaluating – data collected and experimental methods.

This Guide, therefore, does not aim to give formal definitions for terminology used in practical science. Instead, it illustrates the terminology by using it within the context of experimental and investigative work. Using terminology within the context of practical scenarios will, it is hoped, give students and teachers a better 'feel' for the terms used. The Guide considers four different aspects of practical science:

- Planning investigations
- Using apparatus
- Making measurements
- Presenting and analysing data

There is also an Appendix giving guidance on graph drawing for International GCSE Sciences.

It is also worth noting that, because of the issues surrounding consistency of understanding of practical terminology, question paper writers often write questions in ways that avoid words such as 'accuracy' and 'precision'. However, as students will frequently use this terminology in answers, it is important that there is a common understanding of their meaning.

Planning investigations

When planning an investigation, it is important to consider the different factors, or **variables**, which can be altered in order to bring about a change. During an investigation, one variable is altered (**independent variable**); and the effect on another variable (**dependent variable**) is measured. Other variables which may affect the results of the investigation are kept constant or **controlled**.

An investigation where variables that may affect the outcome are all controlled – except the independent variable – is referred to as a **fair test**. Controlling variables will improve the **validity** of the data in an investigation. This is because the investigation is more likely to measure what it was designed to measure, as changes in other variables will be less likely to affect the investigation.

The term **valid** is also often used to describe an investigation with the variables suitably controlled, as well as the conclusion that is drawn from this type of investigation.

Using apparatus

A variety of apparatus can be used to collect individual **readings** or **measurements** which make up the set of **data** for an experiment or investigation.

When selecting apparatus, it is important to consider how the choice made can affect the data collected. For example, temperature could be measured with a thermometer with **graduations** (scale markings) which are 1°C apart, or ones that are 0.5°C apart; and a volume of 25cm^3 could be measured using a measuring cylinder, or a pipette. Using apparatus with finer graduations is more likely to produce data that is **precise** (due to a smaller spread) – but may also give a final result that is more **accurate**. The term **precise** has been extended in previous International GCSE specifications to apply to the apparatus itself e.g. a thermometer with 0.5°C graduations is more precise than one with 1°C graduations. Although this does not agree with the ASE guidance (where the recommended terminology is that the apparatus has a 'greater resolution'), it may still be encountered in International GCSE papers and resources.

Many pieces of apparatus are adjusted or **calibrated** before use. Calibration may involve making sure that the apparatus gives the correct reading for a known reference object e.g. a balance shows the correct mass for a reference object of known mass. More often, the apparatus is adjusted so that the measuring **scale** is set to zero before measurements are taken. When measuring the mass of an object, a balance that is set to zero before taking a measurement is described as being **tared**.

When reading the scale on a piece of apparatus, it is often possible to take a reading between the graduations. For example, a burette is graduated in 0.1 cm^3 divisions, but is always read to the nearest 0.05 cm^3. This is probably not possible if the scale is already finely divided e.g. a millimetre scale on a ruler.

When reading any scale, care should be taken not to view the scale at an angle. This avoids introducing errors due to **parallax**.

For measurements of time, it is worth noting that human reaction time is around one-third of a second, so the recording of a time to the nearest 0.01 s is difficult to justify, even with a digital stop clock. It is sufficient to record times to no greater precision (or resolution) that the nearest 0.1 s. Indeed, for most practical purposes, recording time to the nearest 0.5 s will be more than adequate.

Making measurements

It is important that the data collected allows a person doing an experiment to be confident about the conclusions made. Data is therefore collected over a **range** of values for the independent variable. This prevents making a conclusion that is only true under for a limited range of values.

It is also good practice to **repeat** measurements during an investigation, as this helps to identify and reduce potential errors. When measurements are repeated, the term **precision** is used to describe how closely-grouped the individual readings are. Remember that precise data, which may show excellent consistency, may not necessarily be in line with the correct value! In Chemistry – especially in titrations – readings which achieve a particular level of precision are described as **concordant** (for International GCSE Chemistry, this is typically titre values within 0.20 cm^3 of each other).

There are two ways in which an experiment can be repeated to collect further data. The first method is for the person doing the experiment to repeat it using the same method, and under the same conditions. Data collected by this method is **repeatable** if it shows the same pattern as the original experiment. The second way is for a different person to follow the method to repeat the experiment separately – this is likely to involve different apparatus and reaction conditions. Data collected by this method is **reproducible** if it shows the same pattern as the original experiment. International GCSE does not distinguish between these two different methods of repeating measurements, and uses the term **reliability** to cover both. At this level, the expectation is that students understand that the reliability of data – and, by extension, of an experimental method – is improved by repeating measurements (and removing **anomalies**) by either method.

When data is collected there will be occasions when some of the data does not fit the expected pattern. Data collected when an experiment is repeated will often show some variation in the repeat measurements taken at one set of conditions. This variation in the data may be the result of some form of experimental **error**.

Data which does not fit the expected pattern is usually considered to be **anomalous**. In some cases, **anomalies** are spotted in data and are removed before the data is processed e.g. if voltage is measured across the same resistor as 5.0 V, 5.1 V, 4.9 V and 12.6V then the final reading is removed before calculating the average voltage as 5.0 V. In other cases, an anomalous point may not be evident until the data is processed and presented. This will be seen most frequently in a graph, where an anomalous point does not fit the **line of best fit**.

Remember that, when using living organisms in Biology, variation in the data may be due to experimental error, but could also be the result of natural biological variation in organisms. Biologists will often keep data collected from living organisms, that appears to be anomalous, in order to show this natural variation.

Presenting and analysing data

In practical work, students are expected to collect data in a suitable **table**. A data table should have headings showing the variables being measured, along with the **units** for these measurements. Data should be presented in numerical order within the table and should also be given to a consistent number of **decimal places**.

When data is processed in a table, the result of any calculation should be given to the same number of **significant figures** as the lowest number of significant figures in the data processed. For example: a student takes measurements in a circuit of 8.0 V and 2.15 A, and records these in a table. The table also shows a value for resistance, calculated from these data – this should be given to 2 sf i.e 3.7 Ω.

Within examination papers, **units** in tables and graphs will be presented in the written-out format: *temperature in °C*. The exception to this will be when percentages are used: these will be shown in brackets i.e. *percentage (%)*. Note that compound units will usually be given in the format "N / m" or "Newtons per metre" rather than "N m^{-1}".

Students should be familiar with the use of a **tally** when showing data in a table. This includes the use of the appropriate symbol to show a group of five counts.

Repeated data is usually processed by taking the **mean (average)** of the readings – taking into account any **anomalous** readings when doing so. (See previous section). When calculating a **mean**, it is worth remembering the measuring scale used, and the scale on the axis of any graph being plotted. For example, consider an experiment where a student uses a ruler to measure a distance. The measurements are repeated to give values of 93 mm, 91 mm and 87 mm. Quoting the mean distance as 90 mm, rather than 90.33 mm reflects the scale being used (which has been used to measure to the nearest mm) and, more important, is more likely to fit the scale of the graph axes more neatly. It is perfectly acceptable, however, to give the mean of a set of date to one more significant figure than the collected data.

A **graph** is often plotted to show the relationship between the variables in an investigation, with a **line of best fit** used to show this relationship. Note that the line of best fit not be straight: it may be a curve – and sometimes more than one line may be needed to show the relationship. Exam questions clearly indicate to students the nature of the line of best fit that is expected. Where the line of best fit is a straight line, passing through the **origin**, the variables are **directly proportional** to each other. Other straight lines show a **linear relationship** between the variables.

When analysing the data collected in an investigation, it may be useful to compare the data – or the final result – with that printed in a standard reference book, or data source. The data book value will usually be considered to be the **true value**. Collected data would be considered **accurate** if it is in close agreement to that true value.

In most investigations, **accuracy** will be affected by many factors. The control of variables, the use of measuring apparatus with finer scale graduations, and the process of repeating measurements and removing anomalies may all affect the accuracy of the final result.

There will be a number of reasons why data collected in an experimental procedure may not allow an accurate result to be calculated. All measuring instruments have a small degree of **uncertainty**: this will vary between different instruments. For example, the uncertainty when using a pipette is less than the uncertainty when using a measuring cylinder. Other errors may result from the experimental procedure used e.g. heat loss when measuring a change in temperature; or from an error in the experimenter's method e.g. handling losses when using chemical substances. Note that exam questions always require a specific error to be identified – errors and anomalies should not simply be attributed to avoidable clumsiness on the part of the experimenter!

Although beyond the scope of the International GCSE, students may like to know that experimental errors fall into two types: **systematic errors** and **random errors**. A **systematic error** usually arises because of the apparatus used, or a consistent issue with the collection technique. For example, using measuring apparatus that has not been **calibrated**, or taking readings from a position that is affected by **parallax** would both be examples of systematic errors. A **random error**, as the name suggests, usually arises because of inconsistent decisions taken in the experiment. The most common will be incorrectly estimating a reading which falls between two divisions on a measuring scale; but may also occur if, for example, an electrical supply to a circuit varies slightly in the voltage supplied during an investigation.

Very able students may realise that **systematic errors** can be hard to spot. All measurements are equally affected, so the data may be both precise and free from anomalies – but the final answer will not be accurate. Data affected by **random errors** will be more likely to show anomalies and lack precision – but different random errors may cancel out to give a final answer which appears to be accurate!

APPENDIX - Guidance for drawing graphs

- Use pencil (HB) for drawing graphs.
- The data plotted on the graph should take up more than half of the graph paper used – so choose your scales with this in mind!
- Make sure that your scale is easy to use. For example, choosing a scale where the large grid squares read: 0, 7, 14, 21, 28… will make it very difficult to plot data corresponding to a reading of 6, 8 or 12 units.
- Axes must be linear. If (0, 0) is not being shown (because it is not a point, or because the range to be plotted is far from zero), then it is better to start the axes at a number other than zero, rather than to start at (0, 0) and show a break in the axis.
- Axes should be labelled – exam papers will use this format: "Force in N".
- Normally, the independent variable is plotted on the x-axis and the dependent variable on the y-axis, but note that this is not always the case. Some graphs are drawn with the axes the "wrong way round", especially if the gradient then comes out with a particular value or unit that is signficant.
- Points can be shown by a simple dot – but an open 'o', an 'x' or a '+' are better, as they are much clearer and can still be seen once a best fit line is drawn.
- Most graphs will be scatter graphs. There are some exceptions to this:
    - a bar chart or histogram can be drawn to represent frequency for data sets e.g. the number of different types of organisms found in a habitat,
    - a bar chart can also be used to represent discrete data e.g. to show the boiling point of each member of the halogen Group in the Periodic Table,
    - our "*Guide to Maths for Scientists*" gives further detail on bar charts and histograms, but a good rule of thumb is that if the x-axis shows non-continuous data, then the data is shown as a bar chart, with bars of equal width which do not touch. If the variable on the x-axis shows continuous data, then the data may be shown as a histogram, where the bars do touch.
- The line of best fit should go through, or close to, all points, except any anomalous ones. It may be useful to consider if the line should go through the origin, assuming that the axes used go down to (0, 0). Indeed, the failure of a graph that should go through the origin to do so once plotted may give some idea of the size of experimental errors!
- Note that, in Biology, exam questions will usually simply ask for the points on graphs to be joined with straight lines. Biology is also the most likely science to ask for more than one data set to be shown on the same axes. In this situation, a key should be given, or the lines labelled to indicate which shows each data set.
- If a gradient is being calculated, the points selected for the calculation should be far apart i.e. using a large gradient triangle.