This handbook should be used, in conjunction with the specification and practical resources provided by the school, in order to build your practical competency and develop the skills needed for the written examination papers and to pass the practical endorsement.
1 Contents

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2 Guidance on using lab books

Students do not need to write up every practical that they do in detail. However, it is good practice to have a record of all they do. A lab book could contain this record. It is a student’s personal book and may contain a range of notes, tables, jottings, reminders of what went wrong, errors identified and other findings. It is a live document that can function as a learning journal.

Lab books are not a requirement of the CPAC endorsement or the AQA AS and A-level specifications in Biology, Chemistry or Physics. They are highly valued by colleagues in higher education and are an easy way for students to demonstrate their mastery of Competence 5 “Researches, references and reports”.

Each institution has its own rules on lab book usage. The following guidelines are an amalgam of guidelines from a selection of companies and universities that use lab books. They are designed to help students and teachers in preparing to use lab books for university but do not represent the only way that books could be used for A-level sciences. Teachers will wish to vary or ignore the following points to suit their purposes.

The purpose of a lab book

A lab book is a complete record of everything that has been done in the laboratory. As such it becomes important both to track progress of experiments, but also, in industry and universities, to prove who developed an idea or discovered something first.

A lab book is a:

- source of data that can be used later by the experimenter or others
- complete record of what has been done so that experiments could be understood or repeated by a competent scientist at some point in the future
- tool that supports sound thinking and helps experimenters to question their results to ensure that their interpretation is the same one that others would come to
- record of why experiments were done.

Type of book

A lab book is often a hard-backed book with bound pages. Spiral bound notebooks are not recommended as it is too easy to rip a page out and start again. It is generally advisable that a lab book has a cover that won’t disintegrate the moment it gets slightly wet.
Style

Notes should be recorded as experiments are taking place. They should not be a “neat” record written at a later date from scraps of paper. However, they should be written clearly, in legible writing and in language which can be understood by others.

Many lab books are used in industry as a source of data, and so should be written in indelible ink.

To ensure that an observer can be confident that all data are included when a lab book is examined, there should be no blank spaces. Mistakes should be crossed out and re-written. Numbers should not be overwritten, erased, nor should Tippex be used. Pencil should not be used for anything other than graphs and diagrams.

Each page should be dated

Worksheets, graphs, printed information, photographs and even flat “data” such as chromatograms or TLC plates can all be stuck into a lab book. They should not cover up any information so that photocopying the page shows all information in one go. Anything glued in should lie flat and not be folded.

Content

Generally, lab books will contain:

- title and date of experiment
- notes on what the objectives of the experiment
- notes on the method, including all details (eg temperatures, volumes, settings of pieces of equipment) with justification where necessary
- sketches of how equipment has been set up can be helpful. Photographs pasted in are also acceptable
- data and observations input to tables (or similar) while carrying out the experiment
- calculations – annotated to show thinking
- graphs and charts
- summary, discussions and conclusions
- cross-references to earlier data and references to external information.

This list and its order are not prescriptive. Many experiments change as they are set up and trials run. Often a method will be given, then some data, then a brief mention of changes that were necessary, then more data and so on.

3 Cross Board statement on CPAC

<table>
<thead>
<tr>
<th>Common Practical Assessment Criteria (CPAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The assessment of practical skills is a compulsory requirement of the course of study for A-level qualifications in biology, chemistry and physics. It will appear on all students’ certificates as a separately reported result, alongside the overall grade for the qualification. The arrangements for the assessment of practical skills are common to all awarding organisations. These arrangements include:</td>
</tr>
</tbody>
</table>

* * *
• A minimum of 12 practical activities to be carried out by each student which, together, meet the requirements of Appendices 5b (Practical skills identified for direct assessment and developed through teaching and learning) and 5c (Use of apparatus and techniques) from the prescribed subject content, published by the Department for Education. The required practical activities will be defined by each awarding organisation in their specification;
• Teachers will assess students using Common Practical Assessment Criteria (CPAC) issued jointly by the awarding organisations. The CPAC are based on the requirements of Appendices 5b and 5c of the subject content requirements published by the Department for Education, and define the minimum standard required for the achievement of a pass;
• Each student will keep an appropriate record of their practical work, including their assessed practical activities;
• Students who demonstrate the required standard across all the requirements of the CPAC will receive a ‘pass’ grade;
• There will be no separate assessment of practical skills for AS qualifications;
• Students will answer questions in the AS and A level examination papers that assess the requirements of Appendix 5a (Practical skills identified for indirect assessment and developed through teaching and learning) from the prescribed subject content, published by the Department for Education. These questions may draw on, or range beyond, the practical activities included in the specification.

In order to achieve a pass, students will need to:
• develop these competencies by carrying out a minimum of 12 practical activities, which allow acquisition of the techniques outlined in the requirements of the specification;
• consistently and routinely exhibit the competencies listed in the CPAC before the completion of the A-level course;
• keep an appropriate record of their practical work, including their assessed practical activities;
• be able to demonstrate and/or record independent evidence of their competency, including evidence of independent application of investigative approaches and methods to practical work.

The practical activities prescribed in the subject specification will provide opportunities for demonstrating competence in all the skills identified, together with the use of apparatus and techniques for each subject. However, students can also demonstrate these competencies in any additional practical activity undertaken throughout the course of study which covers the requirements of appendix 5c.

Students may work in groups but teachers who award a pass to their students need to be confident of individual students’ competence.
4 Practical competencies

<table>
<thead>
<tr>
<th>Competency</th>
<th>Practical mastery</th>
</tr>
</thead>
<tbody>
<tr>
<td>In order to achieve a pass, students will need to have met the following expectations.</td>
<td></td>
</tr>
<tr>
<td>Students will be expected to develop these competencies through the acquisition of the technical skills specified in Appendix 5 of the DfE subject content for each science subject Biology, Chemistry and Physics. Students can demonstrate these competencies in any practical activity undertaken throughout the course of study. The 12 practical activities prescribed in the subject specification, which cover the requirements of Appendix 5c, will provide opportunities for demonstrating competence in all the skills identified together with the use of apparatus and practical techniques for each subject.</td>
<td></td>
</tr>
<tr>
<td>Students may work in groups but must be able to demonstrate and record independent evidence of their competency. This must include evidence of independent application of investigative approaches and methods to practical work.</td>
<td></td>
</tr>
<tr>
<td>Teachers who award a pass to their students need to be confident that the student consistently and routinely exhibits the competencies listed below before completion of the A level course.</td>
<td></td>
</tr>
<tr>
<td>1. Follows written procedures</td>
<td>a. Correctly follows instructions to carry out experimental techniques or procedures.</td>
</tr>
<tr>
<td>2. Applies investigative approaches and methods when using instruments and equipment</td>
<td>a. Correctly uses appropriate instrumentation, apparatus and materials (including ICT) to carry out investigative activities, experimental techniques and procedures with minimal assistance or prompting.</td>
</tr>
<tr>
<td></td>
<td>b. Carries out techniques or procedures methodically, in sequence and in combination, identifying practical issues and making adjustments when necessary.</td>
</tr>
<tr>
<td></td>
<td>c. Identifies and controls significant quantitative variables where applicable, and plans approaches to take account of variables that cannot readily be controlled.</td>
</tr>
<tr>
<td></td>
<td>d. Selects appropriate equipment and measurement strategies in order to ensure suitably accurate results.</td>
</tr>
</tbody>
</table>
3. Safely uses a range of practical equipment and materials

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Identifies hazards and assesses risks associated with these hazards, making safety adjustments as necessary, when carrying out experimental techniques and procedures in the lab or field.</td>
</tr>
<tr>
<td>b.</td>
<td>Uses appropriate safety equipment and approaches to minimise risks with minimal prompting.</td>
</tr>
</tbody>
</table>

4. Makes and records observations

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Makes accurate observations relevant to the experimental or investigative procedure.</td>
</tr>
<tr>
<td>b.</td>
<td>Obtains accurate, precise and sufficient data for experimental and investigative procedures and records this methodically using appropriate units and conventions.</td>
</tr>
</tbody>
</table>

5. Researches, references and reports

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Uses appropriate software and/or tools to process data, carry out research and report findings.</td>
</tr>
<tr>
<td>b.</td>
<td>Cites sources of information demonstrating that research has taken place, supporting planning and conclusions.</td>
</tr>
</tbody>
</table>

## 5 Apparatus and techniques

*(Space Here Point 16)*

<table>
<thead>
<tr>
<th></th>
<th>apparatus and techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATa</td>
<td>use appropriate analogue apparatus to record a range of measurements (to include length/distance, temperature, pressure, force, angles, volume) and to interpolate between scale markings</td>
</tr>
<tr>
<td>ATb</td>
<td>use appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance, mass)</td>
</tr>
<tr>
<td>ATc</td>
<td>use methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiduciary marker, set square or plumb line</td>
</tr>
<tr>
<td>ATd</td>
<td>use stopwatch or light gates for timing</td>
</tr>
<tr>
<td>ATe</td>
<td>use calipers and micrometers for small distances, using digital or vernier scales</td>
</tr>
<tr>
<td>ATf</td>
<td>correctly construct circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important</td>
</tr>
<tr>
<td>ATg</td>
<td>design, construct and check circuits using DC power supplies, cells, and a range of circuit components</td>
</tr>
<tr>
<td>ATH</td>
<td>use signal generator and oscilloscope, including volts/division and time-base</td>
</tr>
<tr>
<td>ATi</td>
<td>generate and measure waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave/radio wave source</td>
</tr>
</tbody>
</table>
### 6  Physics required practicals (1-6 AS, 7-12 A2)

<table>
<thead>
<tr>
<th>Required activity</th>
<th>Apparatus and technique reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Investigation into the variation of the frequency of stationary waves on a string with length, tension and mass per unit length of the string</td>
<td>a, b, c, i</td>
</tr>
<tr>
<td>2  Investigation of interference effects to include the Young’s slit experiment and interference by a diffraction grating</td>
<td>a, j</td>
</tr>
<tr>
<td>3  Determination of $g$ by a free-fall method</td>
<td>a, c, d, k</td>
</tr>
<tr>
<td>4  Determination of the Young modulus by a simple method</td>
<td>a, c, e</td>
</tr>
<tr>
<td>5  Determination of resistivity of a wire using a micrometer, ammeter and voltmeter</td>
<td>a, b, e, f</td>
</tr>
<tr>
<td>6  Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of the cell with current in it</td>
<td>b, f, g</td>
</tr>
<tr>
<td>7  Investigation into simple harmonic motion using a mass-spring system and a simple pendulum</td>
<td>a, b, c, h, i</td>
</tr>
<tr>
<td>8  Investigation of Boyle’s (constant temperature) law and Charles’s (constant pressure) law for gas</td>
<td>a</td>
</tr>
<tr>
<td>9  Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant $RC$</td>
<td>b, f, g, h, k</td>
</tr>
<tr>
<td>10 Investigate how the force on a wire varies with flux density, current and length of wire using a top pan balance</td>
<td>a, b, f</td>
</tr>
<tr>
<td>11 Investigate, using a search coil and oscilloscope, the effect on magnetic flux linkage of varying the angle between a search coil and magnetic field direction</td>
<td>a, b, f, h</td>
</tr>
<tr>
<td>12 Investigation of the inverse-square law for gamma radiation</td>
<td>a, b, k, l</td>
</tr>
</tbody>
</table>

### 7  Practical skills to be assessed in written papers in AS physics

Overall, at least 15% of the marks for all AS level Physics courses will require the assessment of practical skills.

In order to be able to answer these questions, students need to have been taught, and to have acquired competence in, the appropriate areas of practical skills as indicated in the table of coverage below.

**Independent thinking**
PS1.1 Solve problems set in practical contexts
PS1.2 Apply scientific knowledge to practical contexts

**Use and application of scientific methods and practices**
PS2.1 Comment on experimental design and evaluate scientific methods
PS2.2 Present data in appropriate ways
PS2.3 Evaluate results and draw conclusions with reference to measurement uncertainties and errors
PS2.4 Identify variables including those that must be controlled

**Numeracy and the application of mathematical concepts in a practical context**
PS3.1 Plot and interpret graphs
PS3.2 Process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix for each science
PS3.3 Consider margins of error, accuracy and precision of data

**Instruments and equipment**
PS4.1 Know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

**AS required practical activities**
The following practicals must be carried out by all students taking this course. Written papers will assess knowledge and understanding of these, and the skills exemplified within each practical.

1. Investigation into the variation of the frequency of stationary waves on a string with length, tension and mass per unit length of the string.
2. Investigation of interference effects to include the Young’s slit experiment and interference by a diffraction grating.
3. Determination of g by a free-fall method.
4. Determination of the Young modulus by a simple method.
5. Determination of resistivity of a wire using a micrometer, ammeter and voltmeter.
6. Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal p.d of the cell with current in it.

8 **Practical skills to be assessed in written papers in A2 physics**

Overall, at least 15% of the marks for all A-level Physics courses will require the assessment of practical skills.
In order to be able to answer these questions, students need to have been taught, and to have acquired competence in, the appropriate areas of practical skills as indicated in the table of coverage below.

**Independent thinking**
PS1.1 Solve problems set in practical contexts
PS1.2 Apply scientific knowledge to practical contexts
8.3.2 **Use and application of scientific methods and practices**
PS2.1 Comment on experimental design and evaluate scientific methods
PS2.2 Present data in appropriate ways
PS2.3 Evaluate results and draw conclusions with reference to measurement uncertainties and errors
PS2.4 Identify variables including those that must be controlled
8.3.3 **Numeracy and the application of mathematical concepts in a practical context**
PS3.1 Plot and interpret graphs
PS3.2 Process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix for each science
PS3.3 Consider margins of error, accuracy and precision of data

8.3.4 Instruments and equipment
PS4.1 Know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

A-level required practical activities
The following practicals must be carried out by all students taking this course. Written papers will assess knowledge and understanding of these, and the skills exemplified within each practical.

Required activity apparatus
1 Investigation into the variation of the frequency of stationary waves on a string with length, tension and mass per unit length of the string.
2 Investigation of interference effects to include the Young’s slit experiment and interference by a diffraction grating.
3 Determination of $g$ by a free-fall method.
4 Determination of the Young modulus by a simple method.
5 Determination of resistivity of a wire using a micrometer, ammeter and voltmeter.
6 Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of the cell with current in it.
7 Investigation into simple harmonic motion using a mass–spring system and a simple pendulum.
8 Investigation of Boyle’s (constant temperature) law and Charles’s (constant pressure) law for a gas.
9 Investigation of the charge and discharge of capacitors. Analysis techniques should include log-linear plotting leading to a determination of the time constant $RC$.
10 Investigate the relationship between magnetic flux density, current and length of wire using a top pan balance.
11 Investigate the effect on magnetic flux density of varying the angle using a search coil and oscilloscope.
12 Investigation of the inverse-square law for gamma radiation.

9 Exam board guidance on practical techniques

A. Tabulating data

It is important to keep a record of data whilst carrying out practical work. Tables should have clear headings with units indicated using a forward slash before the unit.

<table>
<thead>
<tr>
<th>pd / V</th>
<th>Current / A</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>0.15</td>
</tr>
<tr>
<td>4.0</td>
<td>0.31</td>
</tr>
<tr>
<td>6.0</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Although using a forward slash is the standard format, other formats are generally acceptable. For example:
It is good practice to draw a table before an experiment commences and then enter data straight into the table. This can sometimes lead to data points being in the wrong order. For example, when investigating the electrical characteristics of a component by plotting an I – V curve, a student may initially decide to take current readings at pd values of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 V. On discovering a more significant change in current between 1.5 and 2.0 V, the student might decide to take further readings at 1.6, 1.7, 1.8, 1.9 V to investigate this part of the characteristics in more detail. Whilst this is perfectly acceptable, it is generally a good idea to make a fair copy of the table in ascending order of pd to enable patterns to be spotted more easily. Reordered tables should follow the original data if using a lab book, data should not be noted down in rough before it is written up.

It is also expected that the independent variable is the left hand column in a table, with the following columns showing the dependent variables. These should be headed in similar ways to measured variables. The body of the table should not contain units.

### Tabulating logarithmic values

When the logarithm is taken of a physical quantity, the resulting value has no unit. However, it is important to be clear about which unit the quantity had to start with. The logarithm of a distance in km will be very different from the logarithm of the same distance in mm.

These should be included in tables in the following way:

<table>
<thead>
<tr>
<th>Reading number</th>
<th>time / s</th>
<th>log (time/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.3</td>
<td>0.36</td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>0.54</td>
</tr>
<tr>
<td>3</td>
<td>5.6</td>
<td>0.75</td>
</tr>
</tbody>
</table>

### B. Significant figures

Data should be written in tables to the same number of significant figures. This number should be determined by the resolution of the device being used to measure the data or the uncertainty in measurement. For example, a length of string measured to be 60 cm using a ruler with mm graduations should be recorded as 600 mm, 60.0 cm or 0.600 m, and NOT just 60 cm. Similarly a resistor value quoted by the manufacturer as 56kΩ, 5% tolerance should NOT be recorded as 56.0 kΩ.
There is sometimes confusion over the number of significant figures when readings cross multiples of 10. Changing the number of decimal places across a power of ten retains the number of significant figures **but changes the accuracy**. The same number of decimal places should therefore generally be used, as illustrated below.

| 0.97  | 99.7 |
| 0.98  | 99.8 |
| 0.99  | 99.9 |
| 1.00  | 100.0 |
| 1.10  | 101.0 |

It is good practice to write down all digits showing on a digital meter.

Calculated quantities should be shown to the number of significant figures of the data with the least number of significant figures.

Example:

Calculate the size of an object if the magnification of a photo is ×25 and it is measured to be 24.6 mm on the photo.

\[
\text{size of real object} = \frac{\text{size of image}}{\text{magnification}}
\]

\[
\text{size of real object} = \frac{24.6 \times 10^{-3}}{25}
\]

\[
\text{size of real object} = 9.8 \times 10^{-4}
\]

Note that the size of the real object can only be quoted to two significant figures as the magnification is only quoted to two significant figures.

### C. Uncertainties

Students should know that 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.

Students should be aware that measurements are often written with the uncertainty. An example of this would be to write a voltage was (2.40 ± 0.005) 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.

**Other factors**

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, the student should write the full reading on the stop watch (e.g. 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:

<table>
<thead>
<tr>
<th>Repeat</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance/m</td>
<td>1.23</td>
<td>1.32</td>
<td>1.27</td>
<td>1.22</td>
</tr>
</tbody>
</table>

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

Percentage uncertainties

The percentage uncertainty in a measurement can be calculated using:

\[
\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{value}} \times 100\%
\]

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

\[
\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{mean value}} \times 100\%
\]

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:

\[
\text{percentage uncertainty} = \frac{|\text{best gradient} - \text{worst gradient}|}{\text{best gradient}} \times 100\%
\]

Note the modulus bars meaning that this percentage will always be positive.
In the same way, the percentage uncertainty in the y-intercept can be found:

$$\text{percentage uncertainty} = \left| \frac{\text{best } y \text{ intercept} - \text{worst } y \text{ intercept}}{\text{best } y \text{ intercept}} \right| \times 100\%$$

Combining uncertainties

Percentage uncertainties should be combined using the following rules:

<table>
<thead>
<tr>
<th>Combination</th>
<th>Operation</th>
<th>Example</th>
</tr>
</thead>
</table>
| Adding or subtracting values  $$a = b + c$$ | Add the absolute uncertainties $$\Delta a = \Delta b + \Delta c$$ | Object distance, $$u = (5.0 \pm 0.1) \text{ cm}$$  
Image distance, $$v = (7.2 \pm 0.1) \text{ cm}$$  
Difference $$(v - u) = (2.2 \pm 0.2) \text{ cm}$$ |
| Multiplying values  $$a = b \times c$$ | Add the percentage uncertainties $$\varepsilon a = \varepsilon b + \varepsilon c$$ | Voltage = $$(15.20 \pm 0.1) \text{ V}$$  
Current = $$(0.51 \pm 0.01) \text{ A}$$  
Percentage uncertainty in voltage = 0.7% |
<table>
<thead>
<tr>
<th>Dividing values</th>
<th>Power rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a = \frac{b}{c} )</td>
<td>( a = b^c )</td>
</tr>
<tr>
<td>Add the percentage uncertainties</td>
<td>Multiply the percentage uncertainty by the power</td>
</tr>
<tr>
<td>( \varepsilon_a = \varepsilon_b + \varepsilon_c )</td>
<td>( \varepsilon_a = c \times \varepsilon_b )</td>
</tr>
</tbody>
</table>

| Mass of object = \((30.2 \pm 0.1)\) g |
| Volume of object = \((18.0 \pm 0.5)\) cm³ |
| Percentage uncertainty in mass of object = 0.3% |
| Percentage uncertainty in volume = 2.8% |
| Density = \(\frac{30.2}{18.0}\) g cm⁻³ |
| Percentage uncertainty in density = 3.1% |
| Absolute uncertainty in density = ± 0.05 g cm⁻³ |

| Radius of circle = \((6.0 \pm 0.1)\) cm |
| Percentage uncertainty in radius = 1.6% |
| Area of circle = \(\pi r^2 = 20.7\) cm² |
| Percentage uncertainty in area = 3.2% |
| Absolute uncertainty = ± 0.7 cm² |

(Note – the uncertainty in \(\pi\) is taken to be zero)

Note: Absolute uncertainties (denoted by \(\Delta\)) have the same units as the quantity.

Percentage uncertainties (denoted by \(\varepsilon\)) have no units.

Uncertainties in trigonometric and logarithmic functions will not be tested in A-level exams.

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

**Data points**

Data points should be marked with a cross. Both $\times$ and $\oplus$ 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
- whether they will be attempting to calculate the equation of a line, therefore needing the $y$ intercept (Physics only)
- 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 calculate the equation of the line, the lack of a y-intercept could cause problems. Increasing the axes to ensure all points are spread out but the y-intercept is also included 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?
- Are there uncertainties in the measurements? The line of best fit should fall within error bars if drawn.

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 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, 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.

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.

\[ \text{gradient} = \frac{\Delta y}{\Delta x} \]

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.
\[ \Delta y = 28 - 9 = 19 \]
\[ \Delta x = 90 - 10 = 80 \]
gradient = \( \frac{19}{80} = 0.24 \) (2 sf)
y-intercept = 7.0
equation of line:
y = 0.24x + 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**

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>3.16</td>
</tr>
<tr>
<td>20</td>
<td>4.47</td>
</tr>
<tr>
<td>30</td>
<td>5.48</td>
</tr>
<tr>
<td>40</td>
<td>6.32</td>
</tr>
<tr>
<td>50</td>
<td>7.07</td>
</tr>
<tr>
<td>60</td>
<td>7.75</td>
</tr>
<tr>
<td>70</td>
<td>8.37</td>
</tr>
<tr>
<td>80</td>
<td>8.94</td>
</tr>
<tr>
<td>90</td>
<td>9.49</td>
</tr>
<tr>
<td>100</td>
<td>10.00</td>
</tr>
</tbody>
</table>

  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.

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>\sqrt{y}</th>
<th>y^2</th>
<th>y^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>3.16</td>
<td>1.78</td>
<td>10.00</td>
<td>32</td>
</tr>
</tbody>
</table>
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

When water is displaced by an amount $l$ in a U tube, the time period, $T$, varies with the following relationship:

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

This could be used to find $g$, the acceleration due to gravity.

- Take measurements of $T$ and $l$.
- Rearrange the equation to become linear:

$$T^2 = 4\pi^2 \frac{l}{2g}$$

- Calculate $T^2$ for each value of $l$.
- By re-writing the equation as:

$$T^2 = \frac{4\pi^2}{2g} l$$

it becomes clear that a graph of $T^2$ against $l$ will be linear with a gradient of $\frac{4\pi^2}{2g}$.

- Calculate the gradient ($m$) by drawing a triangle on the graph.
Find g by rearranging the equation \( m = \frac{4\pi^2}{2g} \) into \( g = \frac{4\pi^2}{2} m \).

**Example two:** 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 three**

The equation that relates the pd, \( V \), across a capacitor, \( C \), as it discharges through a resistor, \( R \), over a period of time, \( t \).

\[
V = V_0 e^{-\frac{t}{RC}}
\]

Where \( V_0 = \text{pd across capacitor at } t = 0 \)

This can be rearranged into

\[
\ln V = -\frac{t}{RC} + \ln V_0
\]

So a graph of \( \ln V \) against \( t \) should be a straight line, with a gradient of \(-\frac{1}{RC}\) and a \( y \)-intercept of \( \ln V_0 \).

**E. Glossary of terms**

The following subject specific vocabulary provides definitions of key terms used in AQA’s AS and A-level Biology, Chemistry and Physics specifications.

**Accuracy**

A measurement result is considered accurate if it is judged to be close to the true value.

**Calibration**

Marking a scale on a measuring instrument.

This involves establishing the relationship between indications of a measuring instrument and standard or reference quantity values, which must be applied.

For example, placing a thermometer in melting ice to see whether it reads 0°C, in order to check if it has been calibrated correctly.

**Data**

Information, either qualitative or quantitative, that have been collected.

**Errors**

See also uncertainties.
**Measurement error**
The difference between a measured value and the true value.

**Anomalies**
These are values in a set of results which are judged not to be part of the variation caused by random uncertainty.

**Random error**
These cause readings to be spread about the true value, due to results varying in an unpredictable way from one measurement to the next.
Random errors are present when any measurement is made, and cannot be corrected. The effect of random errors can be reduced by making more measurements and calculating a new mean.

**Systematic error**
These cause readings to differ from the true value by a consistent amount each time a measurement is made.
Sources of systematic error can include the environment, methods of observation or instruments used.
Systematic errors cannot be dealt with by simple repeats. If a systematic error is suspected, the data collection should be repeated using a different technique or a different set of equipment, and the results compared.

**Zero error**
Any indication that a measuring system gives a false reading when the true value of a measured quantity is zero, eg the needle on an ammeter failing to return to zero when no current flows.
A zero error may result in a systematic uncertainty.

**Evidence**
Data that have been shown to be valid.

**Fair test**
A fair test is one in which only the independent variable has been allowed to affect the dependent variable.

**Hypothesis**
A proposal intended to explain certain facts or observations.

**Interval**
The quantity between readings e.g. a set of 11 readings equally spaced over a distance of 1 metre would give an interval of 10 centimetres.

**Precision**
Precise measurements are ones in which there is very little spread about the mean value.
Precision depends only on the extent of random errors – it gives no indication of how close results are to the true value.

**Prediction**
A prediction is a statement suggesting what will happen in the future, based on observation, experience or a hypothesis.

**Range**
The maximum and minimum values of the independent or dependent variables;
For example a range of distances may be quoted as either:
'From 10cm to 50 cm' or
'From 50 cm to 10 cm'
Repeatable
A measurement is repeatable if the original experimenter repeats the investigation using same method and equipment and obtains the same results.

Reproducible
A measurement is reproducible if the investigation is repeated by another person, or by using different equipment or techniques, and the same results are obtained.

Resolution
This is the smallest change in the quantity being measured (input) of a measuring instrument that gives a perceptible change in the reading.

Sketch graph
A line graph, not necessarily on a grid, that shows the general shape of the relationship between two variables. It will not have any points plotted and although the axes should be labelled they may not be scaled.

True value
This is the value that would be obtained in an ideal measurement.

Uncertainty
The interval within which the true value can be expected to lie, with a given level of confidence or probability eg “the temperature is 20 °C ± 2 °C, at a level of confidence of 95 %”.

Validity
Suitability of the investigative procedure to answer the question being asked. For example, an investigation to find out if the rate of a chemical reaction depended upon the concentration of one of the reactants would not be a valid procedure if the temperature of the reactants was not controlled.

Valid conclusion
A conclusion supported by valid data, obtained from an appropriate experimental design and based on sound reasoning.

Variables
These are physical, chemical or biological quantities or characteristics.

Categoric variables
Categoric variables have values that are labels eg names of plants or types of material or reading at week 1, reading at week 2 etc.

Continuous variables
Continuous variables can have values (called a quantity) that can be given a magnitude either by counting (as in the case of the number of shrimp) or by measurement (eg light intensity, flow rate etc).

Control variables
A control variable is one which may, in addition to the independent variable, affect the outcome of the investigation and therefore has to be kept constant or at least monitored.

Dependent variables
The dependent variable is the variable of which the value is measured for each and every change in the independent variable.
**Independent variables**

The independent variable is the variable for which values are changed or selected by the investigator.

**Nominal variables**

A nominal variable is a type of categoric variable where there is no ordering of categories (e.g., red flowers, pink flowers, blue flowers).

### 10 Mathematical requirements for practical

In order to be able to develop their skills, knowledge and understanding in physics, students need to have been taught, and to have acquired competence in, the appropriate areas of mathematics as indicated in the table of coverage below.

Overall, at least 40% of the marks in assessments for physics will require the use of mathematical skills. These skills will be applied in the context of physics A-level and will be at least the standard of higher tier GCSE mathematics.

The following tables illustrate where these mathematical skills may be developed during teaching or could be assessed. Those shown in bold type would only be tested in the full A-level course. This list of examples is not exhaustive. These skills could be developed or assessed in other areas of specification content. Other areas where these skills could be developed have been exemplified throughout the specifications.

#### 1. Arithmetic and numerical computation

**MS 0.1 Recognise and make use of appropriate units in calculations**

Students may be tested on their ability to:

- identify the correct units for physical properties such as m s\(^{-1}\), the unit for velocity
- convert between units with different prefixes e.g., cm\(^3\) to m\(^3\)

**MS 0.2 Recognise and use expressions in decimal and standard form**

Students may be tested on their ability to:

- use physical constants expressed in standard form such as \(c = 3.00 \times 10^8\) m s\(^{-1}\)

**MS 0.3 Use ratios, fractions and percentages**

Students may be tested on their ability to:

- calculate efficiency of devices
- calculate percentage uncertainties in measurements

**MS 0.4 Estimate results**

Students may be tested on their ability to:

- estimate the effect of changing experimental parameters on measurable values

**MS 0.5 Use calculators to find and use power, exponential and logarithmic functions**

Students may be tested on their ability to:

- solve for unknowns in decay problems such as

\[ N = N_0 e^{-kt} \]

**MS 0.6 Use calculators to handle sin x, cos x, tan x when x is expressed in degrees or radians**

Students may be tested on their ability to:

- calculate the direction of resultant vectors

#### 2. Handling data

**MS 1.1 Use an appropriate number of significant figures**

Students may be tested on their ability to:

- report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures
- understand that calculated results can only be reported to the limits of the least accurate measurement

**MS 1.2 Find arithmetic means**
Students may be tested on their ability to:
• calculate a mean value for repeated experimental readings

**MS 1.3 Understand simple probability**
Students may be tested on their ability to:
• understand probability in the context of radioactive decay

**MS 1.4 Make order of magnitude calculations**
Students may be tested on their ability to:
• evaluate equations with variables expressed in different orders of magnitude

**MS 1.5 Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers**
Students may be tested on their ability to:
• determine the uncertainty where two readings for length need to be added together

### 3. Algebra

**MS 2.1 Understand and use the symbols: =, <, <<, >>, >, ∝, ≈, Δ**
Students may be tested on their ability to:
• recognise the significance of the symbols in the expression $F \propto \Delta p/\Delta t$

**MS 2.2 Change the subject of an equation, including non-linear equations**
Students may be tested on their ability to:
• rearrange $E = mc^2$ to make $m$ the subject

**MS 2.3 Substitute numerical values into algebraic equations using appropriate units for physical quantities**
Students may be tested on their ability to:
• calculate the momentum $p$ of an object by substituting the values for mass $m$ and velocity $v$ into the equation $p = mv$

**MS 2.4 Solve algebraic equations, including quadratic equations**
Students may be tested on their ability to:
• solve kinematic equations for constant acceleration such as $v = u + at$ and $s = ut + \frac{1}{2}at^2$

**MS 2.5 Use logarithms in relation to quantities that range over several orders of magnitude**
Students may be tested on their ability to:
• recognise and interpret real world

### 6.4 Graphs

**MS 3.1 Translate information between graphical, numerical and algebraic forms**
Students may be tested on their ability to:
• calculate Young modulus for materials using stress–strain graphs

**MS 3.2 Plot two variables from experimental or other data**
Students may be tested on their ability to:
• plot graphs of extension of a wire against force applied

**MS 3.3 Understand that $y = mx + c$ represents a linear relationship**
Students may be tested on their ability to:
• rearrange and compare $v = u + at$ with $y = mx + c$ for velocity–time graph in constant acceleration problems

**MS 3.4 Determine the slope and intercept of a linear graph**
Students may be tested on their ability to:
• read off and interpret intercept point from a graph e.g. the initial velocity in a velocity–time graph

**MS 3.5 Calculate rate of change from a graph showing a linear relationship**
Students may be tested on their ability to:
• calculate acceleration from a linear velocity–time graph

**MS 3.6 Draw and use the slope of a tangent to a curve as a measure of rate of change**
Students may be tested on their ability to:
• draw a tangent to the curve of a displacement– time graph and use the gradient to approximate the velocity at a specific time

**MS 3.7 Distinguish between instantaneous rate of change and average rate of change**
Students may be tested on their ability to:
• understand that the gradient of the tangent of a displacement–time graph gives the velocity at a point in time which is a different measure to the average velocity

MS 3.8 Understand the possible physical significance of the area between a curve and the x axis and be able to calculate it or estimate it by graphical methods as appropriate

Students may be tested on their ability to:
• recognise that for a capacitor the area under a voltage–charge graph is equivalent to the energy stored

MS 3.9 Apply the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, e.g.

\[ \frac{\Delta y}{\Delta x} = \lambda x \] using a graphical method or spreadsheet modelling

Students may be tested on their ability to:
• determine \( g \) from distance-time plot for projectile motion

MS 3.10 Interpret logarithmic plots Students may be tested on their ability to:
• obtain time constant for capacitor discharge by interpreting plot of \( \log V \) against time

Use logarithmic plots to test exponential and power law variations

Students may be tested on their ability to:
• use logarithmic plots with decay law of radioactivity / charging and discharging of a capacitor

MS 3.12 Sketch relationships which are modelled by

\[ y = \frac{k}{x}, \quad y = kx^2, \quad y = \frac{k}{x^2}, \quad y = kx, \]
\[ y = \sin x, \quad y = \cos x, \quad y = e^{+x}, \quad \text{and} \]
\[ y = \sin^2 x, \quad y = \cos^2 x \]

as applied to physical relationships

Students may be tested on their ability to:
• sketch relationships between pressure and volume for an ideal gas

5. Geometry and trigonometry

MS 4.1 Use angles in regular 2D and 3D structures

Students may be tested on their ability to:
• interpret force diagrams to solve problems

MS 4.2 Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects

Students may be tested on their ability to:
• draw force diagrams to solve mechanics problems

MS 4.3 Calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres

Students may be tested on their ability to:
• calculate the area of the cross-section to work out the resistance of a conductor given its length and resistivity

MS 4.4 Use Pythagoras' theorem, and the angle sum of a triangle

Students may be tested on their ability to:
• calculate the magnitude of a resultant vector, resolving forces into components to solve problems

MS 4.5 Use sin, cos and tan in physical problems

Students may be tested on their ability to:
• resolve forces into components

MS 4.6 Use of small angle approximations including \( \sin \theta \approx \theta \), \( \tan \theta \approx \theta \), \( \cos \theta \approx 1 \) for small \( \theta \) where appropriate

Students may be tested on their ability to:
• calculate fringe separations in interference patterns

MS 4.7 Understand the relationship between degrees and radians and translate from one to the other

Students may be tested on their ability to:
• convert angle in degrees to angle in radians