MATHEMATICAL SKILLS

Arithmetic and numerical computation

- Recognise and make use of appropriate units in calculations.
- Recognise and use expressions in decimal and standard form.
- Use ratios, fractions and percentages.
- Estimate Results.
- Use a calculator to use power, exponential and logarithm functions
- Use calculators to handle sin x, cos x and tan x when x is expressed in radians or degrees

Handling Data

- Use an appropriate number of significant figures.
- Find arithmetic means.
- Understand simple probability.
- Make order of magnitude calculations.
- *Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers (advanced).*

Algebra

- Understand and use the symbols $= \; < \; \ll \; > \; \gg \; \propto \; \approx \; \Delta$.
- Substitute numerical values into algebraic equations using appropriate units for physical quantities.
- Solve algebraic equations, including quadratics.
- Use logarithms in context with quantities that range over several orders of magnitude.

Graphs

- Translate information between graphical, numerical, and algebraic forms.
- Plot two variables from experimental or other data on a lin-lin, log-lin, or log-log scale.
- Understand that y=mx+c (or equivalent) represents a linear relationship.
- Determine the slope and intercept of a linear graph.
- Calculate rate of change from a linear graph (y=mx+c).
- Draw and use the slope of a tangent as a measure of a rate of change.
- Distinguish between instantaneous and average rate of change.
- Understand the possible physical significance of the area between the curve and the x-axis and be able to calculate or estimate it by graphical methods as appropriate.
- Apply the contexts underlying calculus (but without using the explicit use of derivatives and integrals) by solving equations involving rates of change using a graphical or spreadsheet approach.
- Interpret logarithmic plots.
- Use logarithmic plots to determine exponential and power law relationships.
- Sketch relationships.

Geometry and Trigonometry

- Use angles in regular 2D structure.
- Visualise and represent 2D forms.
- Calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres.
- Use Pythagoras's Theorem and the angle sum of a triangle.
- Use sin, cos and tan in physical problems.
- Use of small angle approximations for sin, cos and tan.
- Understand the relationship between degrees and radians and translate from one to another.

PROCESSING DATA

Definitions of key terms used in science 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 to check if it has been calibrated correctly.

Data
Information, either qualitative or quantitative, that has been collected.

Errors
See also uncertainties.

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

Measurement error
The difference between a measured value and the true value.

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. Example: a positive or negative reading when the jaws of a vernier calliper are closed.

Evidence
Data which has 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 m would give an interval of 10 cm.

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; important in ensuring that any pattern is detected.
For example a range of distances may be quoted as either: 'from 10 cm 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; e.g. 'the temperature is 20°C ± 2°C, *at a level of confidence of 95%' (advanced).*

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, e.g. names of plants or types of material.
>
> ***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 (e.g. 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. white mice, brown mice, grey mice).

Tabulating data

Tables should have ruled lines and a border.

For quantitative observations: independent variables should be written in the first column and dependent variables in columns to the right.
For qualitative observations: independent variables in the first column and descriptive comments in columns to the right.

Processed data, such as means and rates, should be put in columns to the far right.

A table does not contain calculations, only calculated values.

No units in the body of the table, only in the column headings

Raw data should be recorded to a number of decimal places appropriate to the resolution of the measuring equipment.

All raw data of the same type should be recorded to the same number of decimal places.

Tables should have clear headings with units indicated using a forward slash (solidus) before the unit (recommended) or with the unit within brackets.
Examples: Time / s; Temperature / °C; Current / mA OR Time (s), Temperature (°C); Current (mA).

Note: 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 time in microseconds will be very different from the logarithm of the same time in seconds. So, it is necessary to take this in account in tables in the following way: Log (time/μs); Log (time/s)

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.
Given different conventions in different countries, decimal points and commas may be used according to the students' choice, as long as they do it consistently.

For example, a sample labelled as "0.1 mol.dm^3 NaOH" should not be recorded in a table of results as 0.10 mol.dm^{-3} NaOH.

Calculated quantities should be shown to the number of significant figures of the data with the least number of significant figures. One significant figure more or less should not normally be penalised. Significant figures of quantities involving logarithms should be treated with generosity.

Uncertainties

When doing experiments, students should be aware that uncertainties are inherent in any measurement. Any measuring device used has an associated uncertainty.
As a general rule, the uncertainty is often taken to be half a division on either side of the smallest unit on the scale you are using. However, the accuracy of measurements does also depend on the quality of the apparatus used, such as a balance, thermometer or glassware.

For example, a 1 cm^3 volumetric pipette class B will have an uncertainty of ± 0.015 cm^3 where a class A pipette will have an uncertainty of ± 0.007 cm^3

The uncertainty of a piece of glassware is usually marked on the glassware. Students should be able to calculate from this the percentage uncertainty in a given measurement.

Students should also be aware of the qualitative difference in uncertainty of different pieces of equipment. For example, if using a measuring cylinder, the smallest measuring cylinder for the volume to be measured should be chosen, as this will offer the lowest uncertainty. Measuring cylinders themselves have higher uncertainty than equipment such as burettes, volumetric pipettes and volumetric flasks.

Because of the variability, assessments will frequently state the absolute uncertainty in any measurement given to allow students to calculate the percentage uncertainty. If no information is given, the uncertainty in each reading should be taken as half a division on either side of the smallest unit.

For example:
unless otherwise stated, in every reading a

- thermometer graduated in divisions of 1 °C would have an uncertainty of ± 0.5 °C
- burette graduated in divisions of 0.1 cm^3 would have an uncertainty of ± 0.05 cm^3
- two-decimal place balance would have an uncertainty of ± 0.005 g.

Good experimental design will attempt to reduce the uncertainty in the outcome of an experiment. The experimenter will design experiments and procedures that produce the least uncertainty and to provide a realistic uncertainty for the outcome.

Students should be able to calculate absolute and percentage uncertainties.

Graphing

Choice of scales

Scales should be chosen so that the plotted points occupy as much as possible the graph grid in both the *x* and the *y* directions. Students should consider:

- the maximum and minimum values of each variable
- the size of the graph paper whether 0.0 should be included as a data point
- how to draw the axes without using difficult scale markings

Labelling axes

Axes should always be labelled with the quantity being measured and the units. Students should use de *x*-axis for the independent variables and the *y*-axis for the dependent ones.

Data points

Data points should be marked with a cross or a small dot. A cross has the convenience it stays visible when drawing a line of best fit.

Where appropriate error bars can replace data points.

Lines of best fit

A good rule of thumb to draw a line of best fit is to make sure the line passes through the majority of the plotted points and that there are as many points on one side of the line as the other. Anomalous data points should not taken in account.

Sources:

AS and A Level mathematical skills Physics A & B - ocr.org.uk
AS and A Level Practical skills Handbooks Biology, Chemistry, Physics - ocr.org.uk,
AS and A-Level Required practical handbooks Biology, Chemistry and Physics - AQA