OCR
Oxford Cambridge and RSA

GCSE (9-1) Physics A & B

AS and A Level Physics A & B

## Language of Measurement in context

The purpose of this exemplar investigation is to illustrate the use of the language of measurement terms in the context of a Physics practical activity. Measurement terms in bold are defined further in the glossary.

The balancing of a rod

This resource is adapted from one of the GCE legacy practical tasks available on OCR interchange.[1]

In this experiment, a student investigates the balance of a metal rod to determine a value for the mass M of the rod.
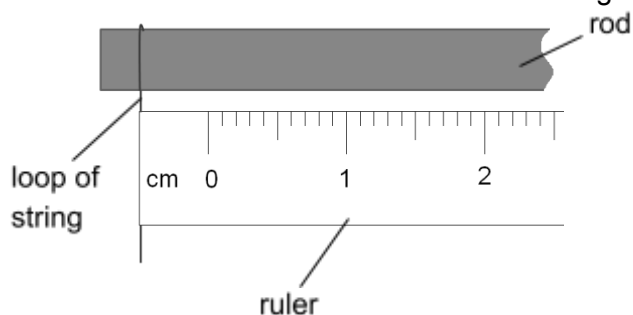
The experimental set up is shown in **Fig. 1**.
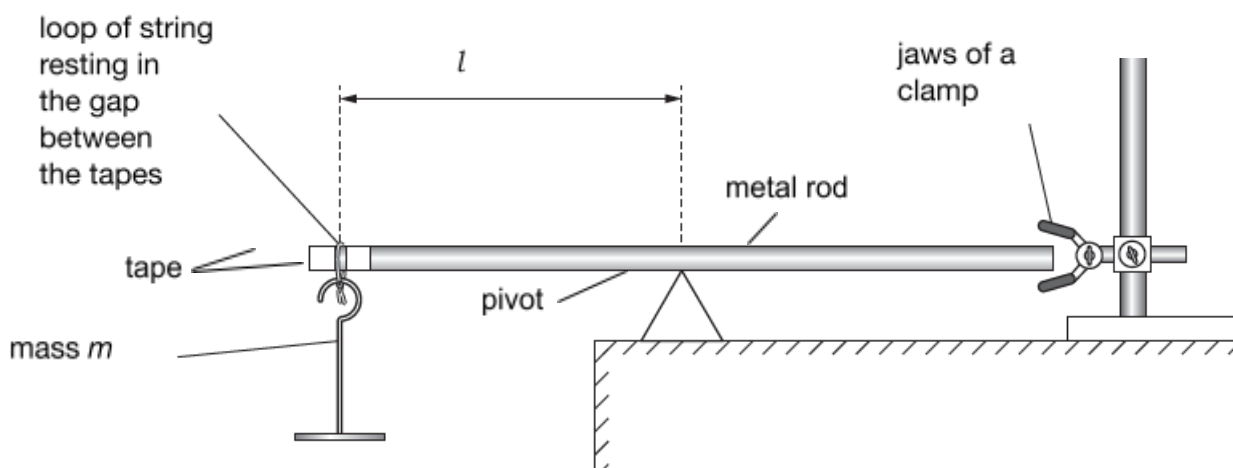
Fig. 1

The distance l when the rod is balanced is measured from the loop of string to the pivot as the mass m suspended from the rod is varied.

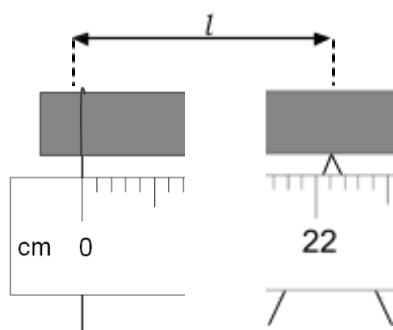The student makes a mistake when taking the measurement of l as shown in **Fig. 2**.

Fig. 2

Here a **systematic error** has been introduced when measuring the length l with a ruler. The student has not measured from the loop of string using the zero mark on the ruler.

Random error is always present in a measurement. Calculating the mean for repeat measurements can reduce the effect of random error.

The student now measures distance l correctly from the loop to the pivot, as shown in **Fig. 3**.

The distance measured is 22.1 cm or 0.221 m.

When using apparatus with an analogue graduated scale, the absolute **uncertainty** in a single measurement is typically taken to be ± half the smallest graduation, in this case ±0.5 mm.

The overall absolute uncertainty in any distance measured with a ruler involves two measurements.

overall absolute uncertainty = 2 × 0.5 mm = ±1 mm. [2]

distance l = 0.221 ± 0.001 m

Fig. 3

In this experiment there are other factors that can contribute to uncertainty in the measured value of l other than the uncertainty associated with the ruler scale.

For each value of m, the measurement of l is taken three times and the mean length l_{ave} and the value of $(1/l_{ave})$ is calculated. The results are in the table.

Mass m is the **independent variable**. Length l is the **dependent variable**. In general, the independent variable would be recorded in the first column, then the dependent variable to the right and processed data to the far right

m/kg	l_1/m	l_2/m	l_3/m	l_{ave}/m	$(1/l_{ave})$/m^{-1}
0.100	0.263	0.260	0.259	0.261	3.84
0.150	0.248	0.249	0.251	0.249	4.01
0.200	0.236	0.233	0.232	0.234	4.28
0.250	0.219	0.220	0.223	0.221	4.53
0.350	0.196	0.198	0.236	0.197	5.08

The length measurements are given to the nearest mm. 1 mm is the **resolution** of a standard 30 cm ruler.

An **anomalous result (outlier)** is identified here. The measurement can be repeated or excluded from the calculation of the mean length.

The repeated measurements of l are frequently close together for each value of m. We can say the **precision** of the measurements is good although there is some variation.

The measurements of l by the student here for each value of m are produced under similar conditions by the same student and are closely clustered. We can say the measurements have good **repeatability**.

m/kg	l_1/m	l_2/m	l_3/m
0.150	0.248	0.249	0.251

The **range** of values of l for each value of m is also an indication of the **uncertainty** in the measurement which takes in to account other factors than just the uncertainty associated with the ruler scale.

The student plots a graph of m (y-axis) against $\frac{1}{l}$ (x-axis) and draws a **line of best fit**.

His teacher says the intercept of the line with the y-axis can be used to determine a value for the mass M of the rod.

The student determines an experimental value for the mass M of the rod.

$$M = 0.648 \text{ kg}$$

The mass of the rod when measured on an electronic balance is 0.626 kg. This is the true value for the mass of the rod (note: this assumes that the balance is both accurate and calibrated).

Does the student's experiment give an **accurate** value for the mass of the rod?

$$\text{percentage difference} = \frac{experimental\ value - true\ value}{true\ value} \times 100$$

$$= \frac{0.648\ kg - 0.626\ kg}{0.626\ kg} \times 100 = 3.51\ \%$$

A measurement result is considered **accurate** if it is close to the true/accepted value.

The percentage difference between the student's experimental result and the true/accepted value for the mass of the rod is only 3.51%.

The student concludes that the value for the experimental value of the mass of the rod is **accurate** because its value is close enough to the true/accepted value of the mass of the rod.

The student's teacher carried out the experiment at home with their own apparatus. The teacher found that the value of their experimental value for the mass of the rod differed by 14.6% from the true value.

A measurement result is considered **reproducible** if similar results are obtained using different groups, methods or equipment. Here we can say that the measurement results do **not** have good reproducibility (based on only two experiments).

Notes

[1] This resource is in the style of a GCE practical but many of the terms apply to both GCE and GCSE. The specification defines the content of the assessments.

[2] We are aware that some textbooks do not give a consistent message regarding the treatment of uncertainties associated with measuring instruments. For GCE Physics A and Physics B we will therefore allow both half the resolution as the absolute uncertainty for a measuring instrument and the resolution itself as the absolute uncertainty.

Independent variable

The value of the independent variable m is changed to measure and record its effect on the dependent variable l. The value of the independent variable is not affected by other variables.

Dependent variable

The value of the dependent variable, l changes as the student changes the value of the independent variable m.

Control variables

Other variables, such as temperature, are controlled to ensure that they don't affect the value of the dependent variable l.

Precision

Repeat measurements that are closely clustered are precise. If there is a lot of variation, they are not precise.

Taking repeat measurements and calculating the mean reduces the effect of random error.

Investigating the mass of a rod

string loop resting in the gap between the tapes

jaws of a clamp

l

mass hanger

pivot

table
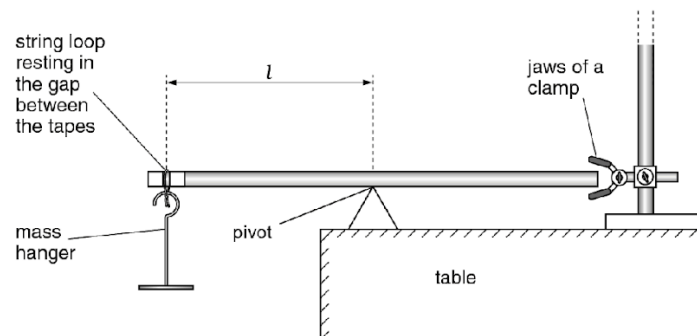
Method

1. Suspend a 0.100 kg mass m at the end of the metal rod. Adjust the position of the pivot to balance the rod.
2. Record the mass m suspended at a distance l from the pivot.
3. Use a ruler to measure the length l from the loop of string to the pivot. Record this value.
4. Repeat the measurement of l twice more and calculate the mean value l_{ave}. Record your results in a table.
5. Repeat the experiment for different values of m until you have at least 5 sets of values for l_{ave}.
6. Plot a graph of m against $1/l_{ave}$. Draw a line of best fit.
7. The mass of the rod is determined from the y-intercept of the line. This value can be compared with the true value for the mass of the rod, obtained using an accurate balance. This allows the accuracy of the experiment to be determined.

Uncertainty

The uncertainty in a single ruler reading is ±0.5 mm. Measuring distance involves two readings, one at either end, so the total uncertainty of the measurement is ±1 mm. The range of values obtained can also be used to estimate the uncertainty in a measurement.

Repeatability

If the repeat measurements of l are **precise** we can say they have good repeatability as they are produced under the same conditions by the same person.

Best fit line

Drawing a line of best fit represents the best estimate of the relationship between m and $1/l_{ave}$. Here, the y-axis intercept can be used to determine an estimate for the mass of the rod.

Accuracy

The accuracy of the experimental value of the rod can be judged by comparing it to the 'true' value. If the two agree closely we can say the experimental value is accurate. Improving the experimental procedure and apparatus can also increase accuracy.

Science

Glossary of terms

Term	Definition	Notes
accuracy	a measurement result is considered accurate if it is judged to be close to the true/acceptable value	Accuracy is a property of a single result. Random and systematic errors can affect accuracy.
anomaly (outlier)	value in a set of results that is judged not to be part of the inherent variation	Calculate the mean without the anomaly if you suspect an anomaly due to an error or due to different conditions. If you identify an anomaly during the practical, then consider repeating the measurement. In **Maths**, you may use the term 'outlier'.
control variable	variables other than the independent and dependent variables which are kept the same	These are quantities or conditions that are kept the same in a practical. Changes in these conditions could affect the validity of your method and results.
dependent variable	variable which is measured whenever there is a change in the independent variable	The dependent variable are recorded as either numerical values with units (quantitative) or in the form of descriptive comments (qualitative).
independent variable	variable which is deliberately changed by the person in the planning of a practical activity	The independent variable is recorded in the first column of a results table. The dependent variable is recorded to the right with processed data in the far right columns. In a graph, the independent variable is usually plotted on the *x*-axis with the dependent variable on the *y*-axis.
line of best fit	a line drawn on a graph that passes as close as possible to the data points. It represents the best estimate of the underlying relationship between the variables.	A line of best fit can be a straight line or a curve. This differs from **GCSE Maths**, where a line of best fit is always a straight line.
precision	a quality denoting the closeness of agreement between measured values obtained by repeated measurements	Precision refers to more than one value. Precise results are clustered together. You can only determine if your results are precise by repeating the measurement. Reducing the effect of random errors improves precision. A systematic error does not affect precision, as it is the same error each time. You may have precise results with a systematic error, but not accurate results.
random error	error in a measurement due to small uncontrollable effects	We can't correct random errors, but we can reduce their effect by making more measurements and calculating the mean. Random errors contribute to uncertainty.

Term	Definition	Notes
range (of a variable)	the maximum and minimum values of the independent or dependent variables	In **Maths** the range is the difference between the biggest and smallest value of a variable.
repeatability	precision obtained when measurement results are produced in one laboratory, by a single operator, using the same conditions, over a short timescale	A measurement is repeatable when repetition under the same conditions gives similar results. Anomalous results can be identified by repeating the measurement. However, never discard data simply because it does not correspond with expectations.
reproducibility	precision obtained when measurement results are produced by different laboratories and therefore by different operators using different pieces of equipment	A measurement is reproducible when similar results are produced by different groups or different equipment or altered methods. If the results are reproducible then you can be confident in the quality of the result.
resolution	smallest change in the input quantity being measured by a measuring instrument that gives a perceptible change in the reading of the measuring instrument	For example, the resolution of a ruler is 1 mm and the resolution of a burette is $0.1 \, cm^3$. It is not correct to describe equipment with a higher resolution as being more precise, as precision is a property of repeated results.
systematic error	error due to the measured value differing from the true value by the same amount each time	Methods or equipment may introduce systematic errors, producing consistent errors in results. Using the same equipment each time avoids introducing more systematic errors. Calibrating equipment where appropriate reduces systematic errors. A **zero error** is when the measuring device indicates a value when the quantity being measured is zero. Systematic errors contribute to uncertainty.
uncertainty	interval within which the true value can be expected to lie, with a given level of confidence or probability	Uncertainties depend on a range of factors, including systematic and random errors. Analogue apparatus typically have an uncertainty of ± half the smallest graduation. The uncertainty of the digital apparatus is ± the resolution of the apparatus.
validity (of an experiment)	suitability of the method used to answer the question being asked	To ensure validity, identify control variables and keep them constant to avoid affecting the dependent variables. In the case of field studies there are naturally changing variables. Ensure the control variables are as similar as possible when repeating.