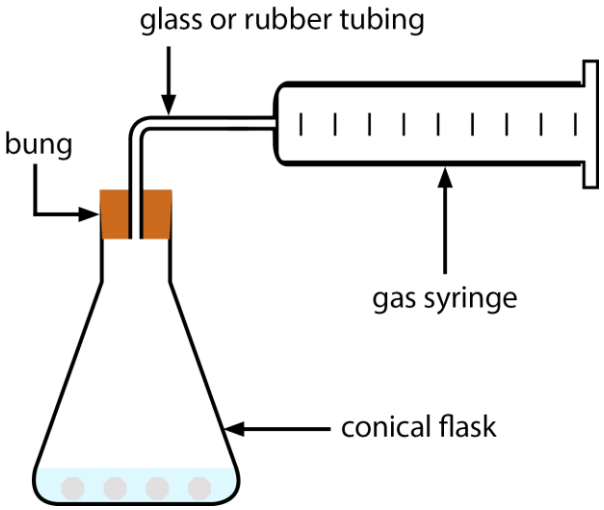
GCSE (9-1) Chemistry A & B

AS and A Level Chemistry 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 Chemistry practical activity. Measurement terms in bold are fully defined in the glossary.

Determining the rate of a reaction



This practical investigates the rate of the reaction between calcium carbonate and hydrochloric acid. The volume of gas produced by the reaction is measured and used to monitor the rate of the reaction.

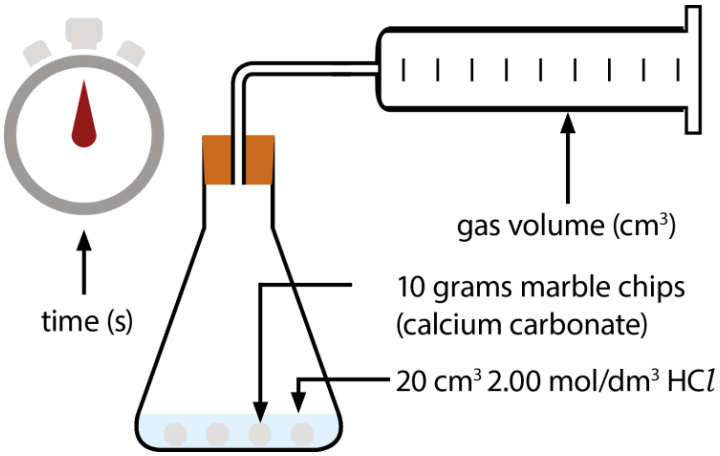
The volume and concentration of the hydrochloric acid used ensures that the acid is used up (so the calcium carbonate is in excess).

Before starting their investigation, the student identifies the variables involved:

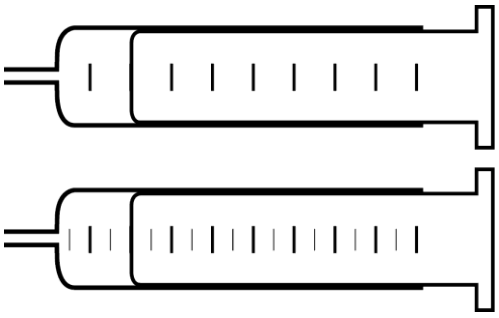
For this practical, the mass of marble chips and the volume and concentration of hydrochloric acid are **control variables** (kept the same).

The **independent variable** is time (changes during the practical).

The gas volume is the **dependent variable** (measured during the practical).



To collect the gas produced, the student has to choose from two gas syringes:

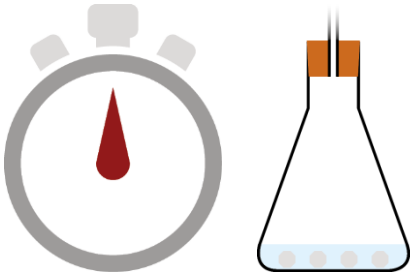


The bottom gas syringe has more graduations than the top syringe, so it can measure smaller changes. We can say it has a higher **resolution**.

Precision is used in reference to repeated measurement values, and shouldn't be used instead of **resolution**.

The student identifies some potential sources of **random error** in their experiment:

Some gas may escape before the student places the bung in the conical flask at the start of the procedure. There may also be a delay between them noting a time on the stopwatch and making a measurement.



The student then records their results.

Time (s)	Volume of gas (cm^3)			Mean (cm^3)
	Test 1	Test 2	Test 3	
0	0	0	0	0
10	6	7	7	6.7
20	12	13	19	12.5
30	19	19	20	19.3
40	24	26	26	25.3
50	29	32	31	30.7
60	34	36	35	35.0
70	38	40	39	39.0
80	41	43	42	42.0
90	45	46	45	45.3

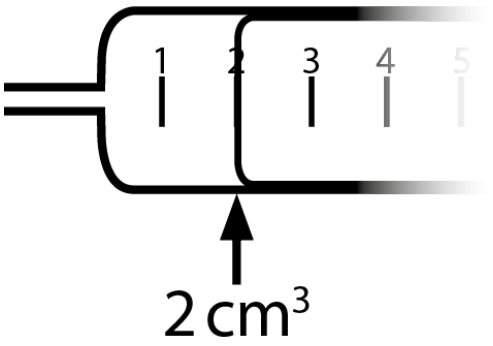
Repeated test values usually differ slightly due to **random error**. Averaging repeat measurements reduces the effect of random error.

An **anomalous** result can be ignored. Repeat the test or exclude the result from the mean calculation.

Repeated measurements that are close together can be described as **precise**.

The repeated measurements of gas volume, obtained by the same student using the same method, are close together for each value of time. We can say that they have good **repeatability**. If we wanted to know if the results are **reproducible** we'd need to see if similar results are obtained using different students, methods or equipment. The term 'reliable' shouldn't be used, as its meaning is unclear.

After recording their results, the student calculates the uncertainty in each measurement.



When using apparatus with an analogue graduated scale, we assume that the **uncertainty** in a single measurement is plus or minus half the smallest graduation. For the gas syringe shown to the left, the uncertainty is ±0.5 cm^3.

In cases where a measurement value comes from two readings (for example, a burette), we double the uncertainty value to reflect this.

The student wants to know how the volume of gas produced by the end of their experiment compares to the volume of gas predicted by the reaction equation and quantities used.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

20 cm^3 of 2.00 mol/dm^3 hydrochloric acid contains 0.010 moles of HCl
Complete reaction would form 0.0050 moles of CO_2
0.0050 moles of CO_2 has a volume of 120 cm^3
The final experimental volume of CO_2 was 55cm^3

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

$$= \frac{55\ cm^3 - 120\ cm^3}{120\ cm^3} \times 100$$

$$= 54\%$$

A result is **accurate** if it is close to the true value.

The percentage difference between the student's experimental result and the calculated value for the volume of gas produced is very high. The student concludes that the final volume of gas at the end of their experiment is not an accurate value.

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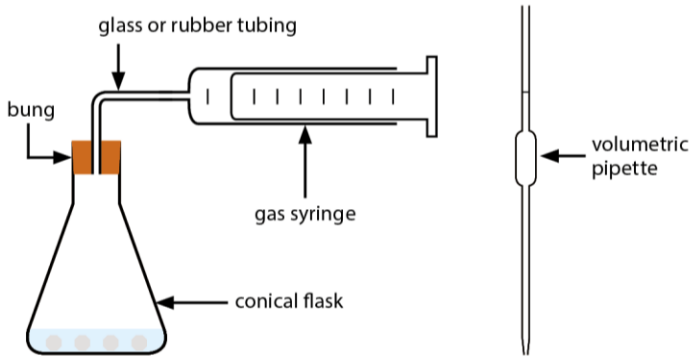
Determining rate of a reaction from volume of gas produced



$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

Method

1. 10 grams of marble chips are weighed and placed in a Buchner flask. The side-arm of the Buchner flask is connected to a piece of rubber tubing which is then connected to a gas syringe.
2. 20 cm^3 of 2.00 mol dm^{-3} $HCl(aq)$ are measured using a pipette.
3. The acid is poured into the Buchner flask. A bung is placed in the top of the Buchner flask, and the initial volume of gas in the gas syringe is recorded.
4. The volume of gas in the gas syringe is recorded every ten seconds until the volume remains constant.
5. The procedure is repeated to gain additional sets of results.

Control variable

The same initial mass is used when the procedure is repeated.

Accuracy

It's easier to read the scale of gas syringe than it is to read the scale of a measuring cylinder if the gas was collected over water. The readings are likely to be more accurate.

However, the accuracy of the results could still be affected by random or systematic errors.

Control variable

The same concentration and volume of HCl is used for repeats.

Dependent variable

The variable that's measured.

Independent variable

The time changes during the procedure as measurements are made.

Accuracy

Using a volumetric pipette to measure volumes is more accurate than using a measuring cylinder.

Random error

The volume of gas that escapes between the timer starting and the bung being placed in the flask is is a source of random error.

Systematic error

Problems with apparatus calibration can introduce a systematic error. These are consistent, repeatable errors associated with equipment.

Random error

The time between reading the time and taking the gas syringe reading is another source of random error in this procedure.

Precision

Repeating results allows precision to be determined. Just repeating results does not improve accuracy.

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 reduce 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 is recorded as either numerical values with units (quantitative) or in the form of descriptive comments (qualitative).
independent variable	variable which is deliberately changed or selected 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 more confident in the quality of the results.
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 have an uncertainty of ± half the smallest graduation. The uncertainty of digital apparatus is ± the resolution of the apparatus. The A Level Practical Skills handbooks contain further guidance on uncertainties.
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 field studies there are naturally changing variables. Ensure the control variables are as similar as possible when repeating.

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