Chemical measurements and uncertainty

4.3.1.4 · Quantitative chemistry · revision notes

Every measurement has some uncertainty. You need to calculate the mean of repeat results, use the range to estimate the uncertainty of the mean, and use uncertainties to compare results. These skills come up in practical and data questions on both papers.

Key facts

- Mean = total of results ÷ number of results (leave out anomalies)
- Range = highest − lowest
- Uncertainty = ± range ÷ 2
- Write results as mean ± uncertainty, with a unit
- Precise = little spread about the mean
- Accurate = close to the true value
- Resolution = smallest change an instrument can measure
- Repeatable = same person and method; reproducible = different person, method or equipment

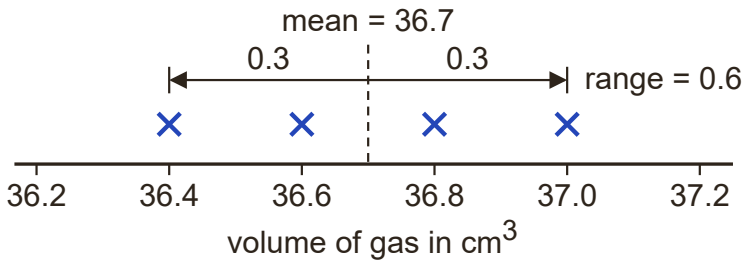
Notes

Uncertainty in measurements

- Whenever a measurement is made there is always some **uncertainty** about the result. Repeating it usually gives slightly different values.
- Causes include the **resolution** of the instrument (the smallest change it can show, e.g. a balance that reads to 0.01 g) and random errors, such as judging exactly when a colour changes.
- Repeating measurements and calculating a mean reduces the effect of random errors.

Mean, range and uncertainty

- Mean = sum of the results ÷ number of results. Leave out any **anomalous** results.
- Range = highest value − lowest value of the results you used.
- Uncertainty = ± (range ÷ 2). The true value is likely to lie between mean − uncertainty and mean + uncertainty.
- Worked example: gas volumes of 36.4, 37.0, 36.6 and 36.8 cm^3. Mean = 146.8 ÷ 4 = 36.7 cm^3. Range = 37.0 − 36.4 = 0.6 cm^3. Uncertainty = ± 0.3 cm^3. Result: 36.7 ± 0.3 cm^3.

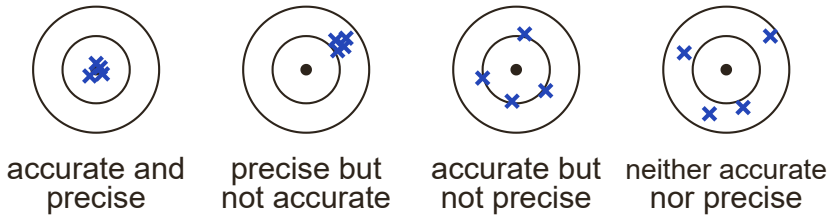


Result: 36.7 ± 0.3 cm^3. The uncertainty is half the range, measured either side of the mean.

- Give the mean and the uncertainty to the same number of decimal places as the data.

Key words

- **Precise**: results are close together, with little spread about the mean. A smaller uncertainty means more precise results.
- **Accurate**: a result that is close to the true value.



The centre is the true value. Close together = precise; close to the centre = accurate.

- **Repeatable**: the same person, using the same method and equipment, gets similar results.
- **Reproducible**: a different person, or a different method or equipment, gets similar results.
- Another value agrees with your result if it lies inside the range from mean − uncertainty to mean + uncertainty.

How to answer each type of question

Calculate a mean, leaving out an anomaly

2 marks **Grade 4**

1. Spot any result that does not fit the others and leave it out.
2. Add the remaining results and divide by how many there are.
3. Round to the same number of decimal places as the data and give the unit.

Example. A student measured the temperature rise in a reaction four times.

Trial	1	2	3	4
Temperature rise in °C	6.2	6.6	9.1	6.4

Calculate the mean temperature rise. Do not include the anomalous result. [2 marks]

Model answer.

(6.2 + 6.6 + 6.4) ÷ 3 (1)

= 6.4 °C (1)

Calculate the uncertainty of the mean

2 marks **Grade 5**

1. Find the range: highest − lowest.
2. Halve it and write it with ± and the unit.

Example. A student measured the mass of copper oxide made in five repeats.

Repeat	1	2	3	4	5
Mass in g	1.98	2.04	2.01	1.96	2.01

The mean is 2.00 g.
Calculate the uncertainty in the mean. [2 marks]

Model answer.

range = 2.04 − 1.96 = 0.08 g (1)

uncertainty = ± 0.04 g (1)

Suggest how to reduce the uncertainty

1 to 2 marks | Grade 5

1. Name a specific change, such as a balance or measuring cylinder with a higher resolution.
2. Say why it helps: the reading is closer to the true value, or repeat results are closer together.

Example. A student used a balance that reads to the nearest 0.1 g to weigh about 0.5 g of magnesium ribbon.
Suggest how the student could reduce the uncertainty in the mass. Give a reason. [2 marks]

Model answer. Use a balance with a higher resolution, e.g. one that reads to 0.01 g (1). The uncertainty in each reading is then much smaller compared with the mass being measured (1).

Compare results using their uncertainties

2 to 3 marks | Grade 8

1. Compare the sizes of the uncertainties: smaller means more precise.
2. Work out each range (mean − uncertainty to mean + uncertainty).
3. Say whether the expected value lies inside each range, and which mean is closer to it (more accurate).

Example. Two groups measured the volume of hydrogen produced by the same reaction.

Group	Volume of hydrogen in cm^3
A	47.2 ± 0.4
B	48.0 ± 1.5

The expected volume is 48.2 cm^3.
Compare the two groups' results. [3 marks]

Model answer. Group A's results are more precise because their uncertainty is smaller (1). Group B's mean is closer to the expected value, so it is more accurate (1). 48.2 cm^3 lies within Group B's range (46.5 to 49.5 cm^3) but not within Group A's range (46.8 to 47.6 cm^3) (1).

Don’t lose marks

- Including the anomalous result in the mean or the range.
- Giving the whole range as the uncertainty instead of half of it.
- Leaving out the ± sign or the unit.
- Mixing up precise (close together) and accurate (close to the true value).
- Giving the mean to more decimal places than the data, e.g. 36.733 cm^3 from readings to 0.1 cm^3.

More tips

Memory tricks

- Uncertainty is half the spread: find the range, then halve it.
- Sense check: the mean must lie between the lowest and highest values you used.
- Think of darts: a tight group is precise; a group around the bullseye is accurate. You can be precise without being accurate.
- Draw a quick number line from mean − uncertainty to mean + uncertainty to see whether another value falls inside.

Exam technique

- Show the range as its own line of working: it is often worth a mark on its own.
- When comparing results, quote numbers: the ranges, and whether a value lies inside them.
- Use 'precise', 'accurate', 'repeatable' and 'reproducible' with their exact meanings, and avoid vague words such as 'reliable'.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Calculate a mean from repeat readings**
Add up the results, leaving out any anomalous ones, and divide by how many you added.

Grade 4 — **Find the range of a set of results**
Range = highest value − lowest value.

Grade 5 — **Identify an anomalous result**
A result that clearly does not fit the pattern of the others; leave it out of the mean.

Grade 5 — **Calculate the uncertainty from the range**
Uncertainty = ± half the range, e.g. a range of 0.4 g gives ± 0.2 g.

Grade 5 — **Write a mean with its uncertainty**
Give the mean ± uncertainty with a unit, e.g. 24.3 ± 0.2 cm^3.

Grade 8 — **Use uncertainties to compare sets of results**
A smaller uncertainty means more precise results; check whether a value lies within mean ± uncertainty.

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