



Premium IB tuition — Physics, Chemistry, Maths

IB Chemistry: Uncertainties and Errors

Notes

For both SL and HL students

Contents

1	Core Concepts	2
1.1	What is Uncertainty?	2
1.2	Random vs Systematic Errors	2
1.3	Types of Uncertainty	2
2	Determining Instrument Uncertainties	3
3	Propagating Uncertainties in Calculations	3
3.1	Addition and Subtraction	3
3.2	Multiplication and Division	3
3.3	Exponential Measurements [HL]	4
3.4	Summary Table	4
4	Significant Figures and Rounding	4
5	IA / Lab Report Guidance	4
5.1	Recording Data	4
5.2	Processing Data	5
5.3	Evaluation	5
5.4	Graphs	5
5.5	IA Criteria (Current Syllabus, first assessed 2025)	5
5.6	Common IA Mistakes to Avoid	5

1 Core Concepts

1.1 What is Uncertainty?

Uncertainty is a quantitative indication of the quality of a measurement. It is the range of values around a measurement within which the **true value** is expected to lie.

$$\text{Measurement} = \text{value} \pm \text{uncertainty} \quad \text{e.g. } 25.00 \pm 0.03 \text{ cm}^3$$

Key distinction:

- **Uncertainty** $\neq$ **Error**
- **Uncertainty** describes the unavoidable limitation of measurement (a range)
- **Error** is the difference between a measured value and the true/accepted value

1.2 Random vs Systematic Errors

Type	Definition	Effect	How to Reduce
Random Error	Unpredictable variation above and below a true value	Affects precision	Repeat measurements, calculate mean
Systematic Error	Consistent bias shifting results in one direction	Affects accuracy	Calibrate equipment, improve method

Accuracy = how close a measurement is to the true value

Precision = how close repeated measurements are to each other.

1.3 Types of Uncertainty

Type	Definition	Formula	Example
Absolute	Actual amount by which quantity is uncertain	Given as $\pm$ value	$5.0 \pm 0.1 \text{ cm}$
Fractional	Absolute uncertainty $\div$ measured value	$\Delta x/x$	$0.1/5.0 = 0.02$
Percentage	Fractional $\times 100\%$	$(\Delta x/x) \times 100\%$	$(0.1/5.0) \times 100\% = 2\%$

2 Determining Instrument Uncertainties

Instrument Type	Uncertainty Rule
Analogue scale (ruler, thermometer)	$\pm$ half the smallest scale division
Digital reading (balance, pH meter)	$\pm$ last significant digit
Repeated measurements	$\pm$ half the range $(\max - \min)/2$
Manufacturer's tolerance (volumetric flask, pipette)	Use printed value

Examples:

- Analogue thermometer marked every $1^\circ\text{C} \rightarrow \pm 0.5^\circ\text{C}$ per reading
- Digital balance reading to 0.01 g $\rightarrow \pm 0.01$ g
- Burette (smallest division 0.1 cm^3) $\rightarrow \pm 0.05\text{ cm}^3$ per reading
- Volumetric pipette labelled $25.00 \pm 0.03\text{ cm}^3 \rightarrow \pm 0.03\text{ cm}^3$

3 Propagating Uncertainties in Calculations

3.1 Addition and Subtraction

Rule: Add the **ABSOLUTE** uncertainties

$$\text{If } Z = A + B \text{ or } Z = A - B, \quad \Delta Z = \Delta A + \Delta B$$

Example: Titre = final reading – initial reading.

- Final: $23.60 \pm 0.05\text{ cm}^3$
- Initial: $0.20 \pm 0.05\text{ cm}^3$
- Titre = $23.40 \pm 0.10\text{ cm}^3$

3.2 Multiplication and Division

Rule: Add the **PERCENTAGE** uncertainties

$$\text{If } Z = A \times B \text{ or } Z = A \div B, \quad \% \Delta Z = \% \Delta A + \% \Delta B$$

Example: $n = C \times V$

- $C = 0.100 \pm 0.002 \text{ mol dm}^{-3} \rightarrow \% \Delta C = 2\%$
- $V = 23.40 \pm 0.10 \text{ cm}^3 \rightarrow \% \Delta V = 0.43\%$
- $\% \Delta n = 2\% + 0.43\% = 2.43\%$

3.3 Exponential Measurements [HL]

Rule: Multiply the percentage uncertainty by the power

$$\text{If } Z = A^n, \quad \% \Delta Z = n \times \% \Delta A$$

Example: Volume of sphere $V = \frac{4}{3}\pi r^3$

- $r = 2.50 \pm 0.05 \text{ cm} \rightarrow \% \Delta r = 2\%$
- $\% \Delta V = 3 \times 2\% = 6\%$

3.4 Summary Table

Operation	Rule
Addition / Subtraction	Add absolute uncertainties
Multiplication / Division	Add percentage uncertainties
Power (A^n) [HL]	Multiply $\%$ uncertainty by n

4 Significant Figures and Rounding

- **Uncertainties** should have **ONE** significant figure.
- The measured value should have the same number of **decimal places** as the uncertainty.
- Final calculated answer should have the same number of **significant figures** as the least precise data used.

Example: Calculated value: 12.477395, Uncertainty: $\pm 0.1 \rightarrow$ Final answer: 12.5 ± 0.1 .

5 IA / Lab Report Guidance

5.1 Recording Data

- **Uncertainties are mandatory** in data tables.
- Include uncertainty in column headings: e.g., Mass / g ($\pm 0.01 \text{ g}$).
- All values from the same instrument should have **consistent decimal places**.
- For titrations, **only average concordant results** (within $\pm 0.10 \text{ cm}^3$) are used.

5.2 Processing Data

- Show **one full worked example** of each calculation type.
- **Propagate uncertainties** through all calculations.
- Present processed data in a **new, clearly labelled table**.

5.3 Evaluation

- Compare **percentage error** with **percentage uncertainty**.
- If % error < % uncertainty → result is accurate within experimental uncertainty.
- If % error > % uncertainty → systematic error is likely present.
- Identify **specific sources** of error and suggest **improvements**.

5.4 Graphs

- Include **error bars** if using graphs.
- Use R^2 to evaluate the fit of trend lines.

5.5 IA Criteria (Current Syllabus, first assessed 2025)

Criterion	Marks	Key Requirement
Research Design	6	Methodological decisions explained
Data Analysis	6	Data processed accurately, uncertainties treated appropriately
Conclusion	6	Conclusions connected to evidence
Evaluation	6	Improvements justified by evidence

5.6 Common IA Mistakes to Avoid

1. Not propagating uncertainties through calculations.
2. Confusing random and systematic errors.
3. Not comparing % error to % uncertainty.
4. Using too many significant figures in uncertainties (uncertainties should have **ONE** significant figure).
5. Not showing worked examples of calculations.

This study guide is provided free for IB Chemistry students.

For more resources, visit www.iblaurel.com