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Education Services

Pre-IB Chemical Research Skills Programme

Chemical Research Skills

A Skills-Building Programme for Independent Chemical Investigation



Module 2

Preparing Standard Solutions

From Calculations to Accurate Preparation

In this module, you will:

- Understand what a standard solution is and why it is used
- Carry out calculations to determine the required quantities
- Prepare standard solutions using volumetric apparatus
- Evaluate the accuracy and reliability of the prepared solutions



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PREFACE

Learning to Think Like a Chemical Researcher

Pre-IB Chemical Research Skills Programme | Modules 1–10

Chemistry is more than the study of substances, reactions, and scientific principles. It is also a discipline built upon observation, questioning, experimentation, measurement, and evidence-based reasoning. For many students, learning chemistry begins with understanding concepts, applying equations, and performing laboratory experiments according to established instructions. These are essential foundations. However, there is an important difference between following an experimental procedure and understanding how to design one.

This distinction becomes particularly significant when students progress into the International Baccalaureate Diploma Programme (IBDP), where independent scientific investigation forms an important part of their learning experience. Students are increasingly expected to formulate meaningful research questions, select appropriate analytical techniques, justify experimental decisions, evaluate the quality of their measurements, and draw conclusions supported by scientific evidence. Yet these research skills do not necessarily develop simply through learning more chemistry content or completing more laboratory experiments. They require deliberate preparation.

The **Pre-IB Chemical Research Skills Programme** was developed to address this need.
Drawing upon my experience as an IB Chemistry educator and examiner, I have observed that students may possess a reasonable understanding of chemical concepts yet encounter considerable difficulty when asked to translate those concepts into an independent investigation.

A student may understand concentration but struggle to prepare a suitable series of standard solutions. Another may know the Beer–Lambert law but remain uncertain about constructing and interpreting a calibration curve. Others may be familiar with experimental procedures yet find it challenging to explain why a particular analytical technique is appropriate, how many measurements are necessary, or whether their results are sufficiently reliable to support a conclusion.

These difficulties are not always the result of insufficient chemical knowledge. Often, they reflect a missing connection between conceptual understanding and experimental research design. This programme seeks to build that connection.

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Organised into ten progressive modules, the programme introduces students to the essential thinking processes and practical skills involved in chemical research. Beginning with the formulation of research questions, students gradually develop their understanding of quantitative solution preparation, dilution, calibration, analytical techniques, standardisation, measurement reliability, and experimental planning.

Each module builds upon the skills established in the preceding modules, encouraging students to recognise that scientific research is not a collection of isolated laboratory techniques. Rather, it is a connected process in which every experimental decision must serve a clear scientific purpose.

Throughout the programme, particular emphasis is placed on a fundamental principle:
A sophisticated-looking experiment is not necessarily a good experiment. A simple experiment that is thoughtfully designed, carefully measured, and critically evaluated can be an excellent scientific investigation.

Students are therefore encouraged not merely to ask *what should I do?* but also *why should I do it this way?*

Why is a volumetric flask preferable to a measuring cylinder when preparing a standard solution? Why might several smaller extractions be more effective than a single extraction? Why is a calibration curve necessary? Why can repeated measurements still produce inaccurate results? How can we determine whether an experimental method is capable of answering a research question?

These questions represent the foundations of scientific reasoning.
Importantly, this programme is not intended to replace the IB Chemistry syllabus, nor is it a shortcut to completing an Internal Assessment (IA) or Extended Essay (EE). Instead, it provides an early introduction to the research skills that students will eventually need when undertaking more demanding independent investigations.

The intention is to help students enter the IB Diploma Programme with greater confidence, stronger experimental awareness, and a more structured approach to scientific problem-solving. By the end of these ten modules, students should begin to appreciate that successful chemical research does not start with selecting an impressive experiment or sophisticated instrument.

It begins with a meaningful question, followed by careful consideration of the evidence required to answer it.

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Ultimately, the purpose of this programme is not simply to teach students how to conduct experiments. It is to develop their ability to think independently, make scientifically justified decisions, and approach chemical investigations with clarity, confidence, and intellectual curiosity.That is where meaningful scientific research begins.

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Think Chemistry. Think Structurally.

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Module 2 — Preparing Standard Solutions
1-Minute Chemical Research Skills — Pre-IB Chemistry
Learning objectives
By the end of this module, you should be able to:

- explain what a **standard solution** is
- calculate the mass of solute required to prepare a solution of known concentration
- distinguish between **concentration, amount and volume**
- prepare a standard solution accurately using a **volumetric flask**
- explain why a measuring cylinder is unsuitable for high-accuracy solution preparation
- perform **quantitative transfer**
- correctly make a solution **up to the calibration mark**
- identify common experimental errors and predict their effects on calculated concentration
- distinguish between **accuracy and precision** in volumetric preparation

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1. What is a standard solution?
A **standard solution** is a solution whose concentration is accurately known.
For example:

$$C(\mathrm{NaCl}) = 0.1000\ \mathrm{mol\ dm^{-3}}$$

This means every $1.000\ \mathrm{dm^3}$ of the solution contains:

$$0.1000\ \mathrm{mol}$$

of NaCl.
Standard solutions are fundamental to quantitative chemistry because they provide a **known reference**.
They are used in:

- titration
- calibration curves
- spectrophotometry
- reaction-rate studies
- quantitative analysis
- preparation of further diluted solutions

If the concentration of your standard is wrong, every result that depends on it may also be wrong.

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2. The concentration relationship

The fundamental equation is:

$$\boxed{C = \frac{n}{V}}$$

where:

- C= concentration / mol dm^{-3}
- n= amount / mol
- V= solution volume / dm^3

Rearranging:

$$\boxed{n = CV}$$

If a solid is used to prepare the solution:

$$\boxed{n = \frac{m}{M}}$$

where:

- m= mass / g
- M= molar mass / g mol^{-1}

Combining the relationships:

$$m = nM$$

and since:

$$n = CV$$

we obtain:

$$\boxed{m = CVM}$$

This is one of the most useful equations when preparing a standard solution from a solid.

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3. Watch the volume units

A very common error is using volume in **cm^3** directly in:

$$C = \frac{n}{V}$$

when concentration is expressed in mol dm^{-3}.

Remember:

$$1\ \text{dm}^3 = 1000\ \text{cm}^3$$

Therefore:

$$250.0\ \text{cm}^3 = 0.2500\ \text{dm}^3$$

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and:

$$100.0\ \text{cm}^3 = 0.1000\ \text{dm}^3$$

Quick conversion

$$\boxed{\text{cm}^3 \div 1000 = \text{dm}^3}$$

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4. Worked example — How much solid is needed?

Suppose we want to prepare:

$$250.0\ \text{cm}^3$$

of:

$$0.1000\ \text{mol dm}^{-3}\ \text{Na}_2\text{CO}_3$$

Given:

$$M_r(\text{Na}_2\text{CO}_3) = 106.0$$

Step 1 — Convert volume

$$250.0\ \text{cm}^3 = 0.2500\ \text{dm}^3$$

Step 2 — Calculate amount

$$n = CV$$
$$n = (0.1000)(0.2500)$$
$$n = 0.02500\ \text{mol}$$

Step 3 — Calculate mass

$$m = nM$$
$$m = (0.02500)(106.0)$$
$$\boxed{m = 2.650\ \text{g}}$$

Therefore, **2.650 g of Na_2CO_3** is required.
But calculating the mass is only half the problem.
We must now turn that mass into **exactly 250.0 cm³ of solution**.

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5. Why not simply add 250 cm³ of water?

This is a crucial distinction.
Suppose the instruction says:
Prepare **250.0 cm³ of solution**.
It does **not** mean:
Add 250.0 cm³ of water to the solute.

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When a substance dissolves, the final volume is not necessarily equal to:

$$V_{\text{water}} + V_{\text{solute}}$$

Instead, we:

1. dissolve the solute in **less than the final volume**
2. transfer it to a volumetric flask
3. add water until the **total solution volume** reaches the calibration mark

Therefore:

The calibration mark represents the final volume of solution, not the volume of solvent added.

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6. Preparing the standard solution

A good general procedure is:

Step 1 — Accurately weigh the solid

Use an appropriate balance.

Record the actual mass used.

For example:

$$m = 2.650\ \text{g}$$

Step 2 — Dissolve the solid

Transfer the solid into a beaker.

Add a relatively small volume of deionised/distilled water.

Stir until the solid has completely dissolved.

Do **not** fill the beaker to 250 cm^3.

Step 3 — Transfer the solution

Pour the solution into the volumetric flask, preferably using a funnel.

But some solution may remain:

- on the beaker walls
- on the stirring rod
- on the funnel

This brings us to an important research skill.

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7. Quantitative transfer

Quantitative transfer means transferring essentially all of the substance from one container to another.

After transferring the solution:

1. rinse the beaker with a small amount of deionised water
2. transfer the rinsing into the volumetric flask
3. rinse the stirring rod if necessary

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4. rinse the funnel into the flask
5. repeat if appropriate

Why?

Because any solute left behind means:

$$n_{\text{actual in flask}} < n_{\text{calculated}}$$

The final solution would therefore have a concentration lower than intended.

The rinsings are part of the sample — not waste.

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8. Make up to the mark

Once the solution has been quantitatively transferred:

Add deionised water until the liquid level approaches the calibration mark.

As you get close to the mark:

Slow down.

Use a dropping pipette if necessary.

The final few drops matter.

The bottom of the meniscus should align with the calibration line for a colourless aqueous solution.

Correct viewing position

Your eye should be:

level with the meniscus

not above it and not below it.

This avoids **parallax error**.

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9. Why is there only one line on a volumetric flask?

A volumetric flask is not designed to measure many different volumes.

It is designed to contain **one specific volume very accurately**.

For example:

$$250.0\ \text{cm}^3$$

The narrow neck allows a very small change in volume to produce a noticeable change in liquid height.

This makes the calibration mark easier to read accurately.

That is why volumetric flasks have their characteristic shape:

large bulb + narrow neck + single calibration line

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10. Volumetric flask vs measuring cylinder

Suppose you need exactly:

$$250.0\ \text{cm}^3$$

of solution.

Which apparatus should you use?

Measuring cylinder

Useful for:

- approximate or moderately accurate volumes
- routine liquid measurement
- situations where very high accuracy is unnecessary

But it contains many graduations and has a relatively wide bore.

Volumetric flask

Designed specifically to contain a fixed volume with higher accuracy.

Therefore:

For preparing a standard solution, use a volumetric flask — not a measuring cylinder.

The important question is not:

"Can this apparatus measure volume?"

It is:

"Is its uncertainty appropriate for the purpose?"

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11. The last drop problem

Imagine the meniscus is just below the line.

You add water too quickly.

Now it is above the calibration mark.

Can you simply remove some solution with a dropper?

Usually, **no**.

Why?

Once the solution has been mixed, removing solution removes:

- solvent **and**
- dissolved solute

in the same proportion.

You cannot restore the original amount of solute simply by removing some solution.

The preparation should generally be repeated if accurate concentration is required.

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12. What happens if too much water is added?

Remember:

$$C = \frac{n}{V}$$

If the amount of solute $n$remains constant but Vbecomes too large:

$$V \uparrow$$

therefore:

$$C \downarrow$$

So:

Overfilling the volumetric flask produces a solution that is too dilute.

Conversely, if the flask is underfilled:

$$V \downarrow$$

therefore:

$$C \uparrow$$

The solution is too concentrated.

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13. Mix thoroughly

After making up to the mark:

1. stopper the flask securely
2. invert the flask several times
3. allow the solution to flow from one end to the other
4. repeat until thoroughly mixed

Why?

Immediately after adding the final water, the concentration may not be uniform throughout the flask.

A standard solution must be **homogeneous** before it is used.

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14. Common errors — and their effects

A researcher should be able not only to identify an error, but also to predict its **directional effect**.

Error 1 — Some solute is left in the beaker

Less solute reaches the flask:

$$n \downarrow$$

Therefore:

$$\boxed{C \downarrow}$$

Actual concentration is **too low**.

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