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Education Services

Pre-IB Chemical Research Skills Programme

Chemical Research Skills

A Skills-Building Programme for Independent Chemical Investigation



Module 3

Dilution and Concentration Control

Designing and Preparing a Range of Solutions

In this module, you will:

- Understand the principle of dilution and its applications
- Use the dilution equation ($c_1V_1 = c_2V_2$) to design solution concentrations
- Prepare a range of diluted solutions accurately
- Evaluate the reliability of dilution procedures and solution concentrations



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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 3 — Dilution as a Research Tool

1-Minute Chemical Research Skills — Pre-IB Chemistry

Learning objectives

By the end of this module, you should be able to:

- explain what **dilution** means at the particle and macroscopic levels
- distinguish between a **stock solution** and a **diluted solution**
- use

$$\boxed{C_1V_1 = C_2V_2}$$

correctly

- calculate the volume of stock solution required for a dilution
- describe how to perform a **direct dilution**
- explain what a **serial dilution** is
- calculate concentrations through successive dilution steps
- distinguish between **direct and serial dilution**
- choose an appropriate dilution strategy for an investigation
- recognise how experimental errors can **propagate through a dilution series**
- design a useful concentration range for subsequent quantitative analysis

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1. What is dilution?

Suppose we have:

$$0.500\ \text{mol dm}^{-3}$$

NaCl solution.

We want:

$$0.100\ \text{mol dm}^{-3}$$

NaCl solution.

We could prepare a completely new solution from solid NaCl.

But there is an easier approach:

Take some of the existing solution and add solvent.

This is **dilution**.

Definition

Dilution is the process of decreasing the concentration of a solution by adding solvent.

For aqueous solutions, the solvent is usually deionised or distilled water.

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2. What changes during dilution?

Imagine a sample containing dissolved particles.

Before dilution

Small volume:

● ● ● ● ● ● ● ●

Particles are relatively close together.

After adding water

Larger volume:

● ● ● ● ● ● ● ●

The particles are more spread out.

The **concentration decreases**.

But an important question is:

Did adding water remove any solute?

No.

Therefore, for the portion of stock solution that was transferred:

$$\boxed{n_{\text{before dilution}} = n_{\text{after dilution}}}$$

This is the fundamental principle behind dilution calculations.

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3. Where does $C_1V_1 = C_2V_2$ come from?

We know:

$$n = CV$$

Before dilution:

$$n_1 = C_1V_1$$

After dilution:

$$n_2 = C_2V_2$$

Because dilution does not change the amount of solute in the transferred aliquot:

$$n_1 = n_2$$

Therefore:

$$\boxed{C_1V_1 = C_2V_2}$$

This is not simply a formula to memorise.

It comes from **conservation of the amount of solute during dilution**.

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4. Understanding the symbols

$$C_1V_1 = C_2V_2$$

where:

- C_1= concentration of the **stock/original solution**
- V_1= volume of stock solution transferred
- C_2= concentration of the **diluted solution**
- V_2= **final total volume** of the diluted solution

A very common mistake is misunderstanding V_2.
$V_2$is **not the volume of water added**.
It is the **final volume of solution**.

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5. Stock solution vs diluted solution

A **stock solution** is a relatively concentrated solution of accurately known concentration from which less concentrated solutions can be prepared.
For example:

$$C_{\text{stock}} = 0.5000 \text{ mol dm}^{-3}$$

From this stock we could prepare:

$$0.400,\ 0.300,\ 0.200,\ 0.100 \text{ mol dm}^{-3}$$

solutions.
This is often much more efficient than weighing solid separately for every concentration.

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6. Worked example — Direct dilution

Prepare:

$$100.0 \text{ cm}^3$$

of:

$$0.100 \text{ mol dm}^{-3}$$

solution from a:

$$0.500 \text{ mol dm}^{-3}$$

stock solution.
Use:

$$C_1V_1 = C_2V_2$$

Substitute:

$$(0.500)(V_1) = (0.100)(100.0)$$

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Therefore:

$$V_1 = \frac{(0.100)(100.0)}{0.500}$$

$$\boxed{V_1 = 20.0\ \text{cm}^3}$$

So we need:

20.0 cm³ of stock solution diluted to a final volume of 100.0 cm³.

Notice the wording:

diluted to 100.0 cm³

not:

add 100.0 cm³ of water.

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7. How much water is added?

Students often reason:

$$100.0 - 20.0 = 80.0\ \text{cm}^3$$

and say:

"Add exactly 80.0 cm³ water."

Conceptually this may describe the approximate amount required, but this is **not how an accurate volumetric dilution is normally prepared**.

Instead:

1. transfer the required aliquot of stock solution
2. place it in the volumetric flask
3. add water
4. make the **final solution volume** accurately to the calibration mark

The critical quantity is:

$$\boxed{V_{\text{final}} = 100.0\ \text{cm}^3}$$

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8. How to perform a direct dilution

Suppose we require 100.0 cm³ of 0.100 mol dm⁻³ solution from 0.500 mol dm⁻³ stock.

Step 1 — Calculate V_1

$$V_1 = 20.0\ \text{cm}^3$$

Step 2 — Transfer the stock solution

Accurately transfer the required volume of stock solution into an appropriate volumetric flask.

Depending on the required volume and available apparatus, this might involve:

- volumetric pipette
- graduated pipette
- burette

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The apparatus should have suitable precision for the investigation.

Step 3 — Add solvent

Add deionised water until close to the calibration mark.

Step 4 — Approach the mark carefully

Add the final water dropwise.

For a colourless aqueous solution, align the bottom of the meniscus with the calibration line at eye level.

Step 5 — Mix

Stopper and invert repeatedly.

The diluted solution must be homogeneous before use.

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9. The dilution factor

Another useful concept is the **dilution factor**.

For a dilution:

$$\text{Dilution factor} = \frac{C_1}{C_2}$$

It is also:

$$\text{Dilution factor} = \frac{V_2}{V_1}$$

For example:

$$0.500 \rightarrow 0.100 \text{ mol dm}^{-3}$$

Therefore:

$$\text{Dilution factor} = \frac{0.500}{0.100} = 5$$

This is a **five-fold dilution**.

Also:

$$\frac{100.0}{20.0} = 5$$

The concentration has become one-fifth of the original concentration.

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10. Preparing a concentration series

Suppose our stock solution is:

$$0.500 \text{ mol dm}^{-3}$$

and we want 100.0 cm³ of each solution:

$$0.100,\ 0.200,\ 0.300,\ 0.400 \text{ mol dm}^{-3}$$

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For each:

$$V_1 = \frac{C_2 V_2}{C_1}$$

0.100 mol dm⁻³

$$V_1 = \frac{(0.100)(100.0)}{0.500} = 20.0\ \text{cm}^3$$

0.200 mol dm⁻³

$$V_1 = 40.0\ \text{cm}^3$$

0.300 mol dm⁻³

$$V_1 = 60.0\ \text{cm}^3$$

0.400 mol dm⁻³

$$V_1 = 80.0\ \text{cm}^3$$

Therefore:

Target concentration / mol dm⁻³	Stock volume / cm³	Final volume / cm³
0.100	20.0	100.0
0.200	40.0	100.0
0.300	60.0	100.0
0.400	80.0	100.0
0.500	stock solution	—

Each solution is prepared **independently from the original stock**.
This is an example of **direct dilution**.

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11. What is direct dilution?

In **direct dilution**, every required concentration is prepared directly from the original stock solution.
For example:

$$\boxed{\text{Stock}} \rightarrow 0.100$$
$$\boxed{\text{Stock}} \rightarrow 0.200$$
$$\boxed{\text{Stock}} \rightarrow 0.300$$
$$\boxed{\text{Stock}} \rightarrow 0.400$$

Each preparation is independent.
If one dilution is prepared incorrectly, the others are not automatically affected.
This is an important advantage.

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12. What is serial dilution?

Sometimes we need very low concentrations.

For example:

$$1.00\ \text{mol dm}^{-3}$$

to:

$$0.00100\ \text{mol dm}^{-3}$$

A direct dilution may require transferring an inconveniently small volume.

Instead, we can dilute the solution in **stages**.

This is called **serial dilution**.

Serial dilution is a sequence of successive dilutions in which each diluted solution is used to prepare the next solution.

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13. Example — Ten-fold serial dilution

Start with:

$$1.00\ \text{mol dm}^{-3}$$

Transfer:

$$10.0\ \text{cm}^3$$

and dilute to:

$$100.0\ \text{cm}^3$$

The dilution factor is:

$$\frac{100.0}{10.0} = 10$$

Therefore:

$$1.00 \rightarrow 0.100\ \text{mol dm}^{-3}$$

Now take 10.0 cm³ of the **0.100 mol dm⁻³** solution and dilute again to 100.0 cm³:

$$0.100 \rightarrow 0.0100$$

Repeat:

$$0.0100 \rightarrow 0.00100$$

So:

$$\boxed{1.00 \rightarrow 0.100 \rightarrow 0.0100 \rightarrow 0.00100}$$

Each step is a ten-fold dilution.

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