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Education Services

Pre-IB Chemical Research Skills Programme

Chemical Research Skills

A Skills-Building Programme for Independent Chemical Investigation



Module 7

Standardisation and Accurate Titration

Establishing Reliable Solution Concentrations

In this module, you will:

- Understand the purpose of standardisation
- Carry out a titration to determine the concentration of a solution
- Apply stoichiometry and titration calculations
- Evaluate the accuracy, precision and reliability of results
- Recognise sources of error and suggest improvements



$$n = cV$$



Example

$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

(1 : 1)

Sunny Chiam

IB Chemistry Specialist & Examiner-Level Educator
Founder, LearningSparks Education Services
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REFACE

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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Creator of the CHIAM Framework™
Think Chemistry. Think Structurally.

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Module 7 — Standardisation & Primary Standards

How Do We Know the Concentration Is Really Correct?

Learning objectives

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

- distinguish between an intended/calculated concentration and an accurately established concentration
- explain what a standard solution is
- explain why some solutions require standardisation
- define a primary standard
- identify desirable properties of a primary standard
- explain why purity, stability and accurate weighing matter
- distinguish a primary standard from a solution that has been standardised
- explain the purpose of standardisation
- describe how titration can be used for standardisation
- distinguish aliquot, titre and endpoint
- distinguish endpoint from equivalence point
- use titration data to determine an unknown concentration
- select concordant titres appropriately
- recognise why a rough titre is normally not included in the final mean
- identify sources of error in standardisation
- explain why rinsing burettes and pipettes correctly matters
- evaluate whether a standardisation result is trustworthy
- understand that a precise titre does not automatically guarantee an accurate concentration

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1. Return to Module 2

In Module 2, we prepared solutions using:

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

and:

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

Therefore:

$$\boxed{m = CVM}$$

Suppose we want:

$$0.1000 \text{ mol dm}^{-3}$$

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NaOH.

We could calculate the required amount, dissolve it and make the solution up to the calibration mark.

So is the concentration automatically exactly:

$$0.1000\ \text{mol dm}^{-3}?$$

Not necessarily.

This introduces the central distinction:

Calculated concentration ≠ necessarily accurately established concentration

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2. Why might the prepared concentration differ?

Several problems are possible:

- reagent may not be sufficiently pure
- reagent may absorb water from the atmosphere
- reagent may react with gases in air
- solution may change concentration during storage
- weighing may contain systematic or random error
- transfer may be incomplete
- final volume may be inaccurate

Therefore, excellent calculations alone do not guarantee an accurately known concentration.

This repeats a major principle from earlier modules:

Correct calculation ≠ automatically correct experiment

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3. What is a standard solution?

A **standard solution** is a solution whose concentration is accurately known.

Standard solution = solution of accurately known concentration

Standard solutions are essential for:

- titration
- calibration
- quantitative chemical analysis
- determining unknown concentrations

But how do we establish that concentration accurately?

There are two important routes.

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4. Two routes to an accurately known concentration

Route 1 — Direct preparation

Use a highly suitable substance whose amount can be established accurately.

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Primary standard → accurate weighing → known volume → standard solution

Route 2 — Standardisation

Prepare a solution approximately, then determine its actual concentration by reaction with a reliable standard.

Approximate solution → titration against standard → actual concentration

This second process is:

standardisation

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5. What is a primary standard?

A **primary standard** is a substance sufficiently pure, stable and well characterised that a known amount can be obtained accurately by direct weighing and used to establish concentration.

At this level, students can think of it as:

A substance reliable enough to serve as the starting reference for quantitative analysis.

Examples commonly used in appropriate analytical contexts include:

- sodium carbonate, Na_2CO_3
- potassium hydrogen phthalate (KHP)

The exact choice depends on the reaction and required analytical conditions.

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6. What makes a good primary standard?

A good primary standard should ideally have several properties.

1. High purity

If the sample contains impurities:

measured mass ≠ mass of desired substance

This makes the calculated number of moles incorrect.

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2. Stable in air

The substance should not readily:

- decompose
- oxidise
- react with atmospheric gases
- change composition during handling

Otherwise:

mass weighed ⇒/reliable moles

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3. Not significantly hygroscopic

A hygroscopic substance absorbs moisture from the atmosphere.

If a sample absorbs water:

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$$\text{measured mass} = \text{solute mass} + \text{absorbed water}$$

Therefore the calculated moles of the intended compound may be too high.

4. Known composition

The chemical formula and composition must be well defined.

A substance whose composition changes unpredictably is unsuitable as a reference.

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5. Sufficiently large molar mass

A relatively large molar mass can reduce the percentage uncertainty associated with weighing a useful amount.

For example, if the balance uncertainty is fixed, measuring:

$$5.00\ \text{g}$$

generally gives a smaller percentage uncertainty than measuring:

$$0.10\ \text{g}$$

because:

$$\%\ \text{uncertainty} = \frac{\text{absolute uncertainty}}{\text{measured quantity}} \times 100$$

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6. Suitable reaction behaviour

For titrimetric use, the primary standard should react:

- rapidly enough
- predictably
- with known stoichiometry
- sufficiently completely under the chosen conditions

This allows the amount of the other reactant to be calculated reliably.

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7. Why is NaOH commonly standardised?

Sodium hydroxide is a useful example.

Solid NaOH can absorb moisture from the atmosphere.

It can also react with carbon dioxide:

$$\boxed{2\text{NaOH} + \text{CO}_2 \rightarrow \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}}$$

Therefore, simply weighing NaOH pellets and preparing a solution does not necessarily produce a solution whose concentration is known with primary-standard accuracy.

A practical strategy is:

$$\boxed{\text{Prepare NaOH solution} \rightarrow \text{standardise it} \rightarrow \text{determine actual concentration}}$$

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8. What is standardisation?

Standardisation is the experimental determination of the accurate concentration of a solution by reaction with a reliable standard.

For example:

$$\boxed{\text{Primary-standard solution} + \text{NaOH solution} \rightarrow \text{titration}}$$

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From the known amount of primary standard and the measured titre of NaOH:

$$\boxed{\text{actual } c(\text{NaOH})}$$

can be calculated.

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9. Standardisation is not "making the solution standard"

An important distinction:

Standardisation does not magically change the concentration into the desired value.

Suppose the intended NaOH concentration was:

$$0.1000 \text{ mol dm}^{-3}$$

but standardisation gives:

$$0.0976 \text{ mol dm}^{-3}$$

The solution remains:

$$\boxed{0.0976 \text{ mol dm}^{-3}}$$

Standardisation has **determined what the concentration actually is**.

It has not changed it to 0.1000 mol dm^{-3}.

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10. Primary standard vs standardised solution

These ideas should not be confused.

Primary standard

A **substance** suitable for establishing an accurately known amount by direct weighing.

Standard solution

A **solution** whose concentration is accurately known.

Standardised solution

A solution whose concentration has been accurately determined experimentally using a suitable standard.

Therefore:

$$\boxed{\text{Primary standard} \neq \text{standardised solution}}$$

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11. Titration as a quantitative tool

A titration allows us to determine the amount of one substance by reacting it with a known amount or concentration of another.

The logic is:

$$\boxed{\text{Known amount} \rightarrow \text{reaction stoichiometry} \rightarrow \text{unknown amount}}$$

and then:

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

This is why titration is useful for standardisation.

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12. Important titration vocabulary

Aliquot

A precisely measured portion of solution transferred for analysis.

For example:

$$25.00\ \text{cm}^3$$

transferred using a volumetric pipette.

Titrant

The solution delivered from the burette.

Titre

The volume of titrant delivered to reach the endpoint.

$$\boxed{\text{Titre} = \text{final burette reading} - \text{initial burette reading}}$$

Analyte

The substance or solution being determined.

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13. Equivalence point vs endpoint

These terms are related but not identical.

Equivalence point

The theoretical point at which the reactants have reacted in the exact stoichiometric ratio required by the chemical equation.

Endpoint

The experimentally observed point used to indicate that the titration should stop.

For an indicator titration, this may be a persistent colour change.

Ideally:

$$\boxed{\text{Endpoint} \approx \text{equivalence point}}$$

but they are not conceptually identical.

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14. Why does indicator choice matter?

An indicator changes colour over a particular pH range.

A suitable indicator should change colour close to the equivalence region of the titration.

Therefore:

$$\boxed{\text{Indicator choice} \rightarrow \text{endpoint quality} \rightarrow \text{titre quality}}$$

Using an unsuitable indicator can introduce systematic error.

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15. Reading a burette

A burette provides:

- initial reading

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- final reading

Titre:

$$\boxed{V_{\text{titre}} = V_{\text{final}} - V_{\text{initial}}}$$

Example:

Initial:

$$1.35\ \text{cm}^3$$

Final:

$$25.80\ \text{cm}^3$$

Therefore:

$$V_{\text{titre}} = 25.80 - 1.35$$
$$\boxed{24.45\ \text{cm}^3}$$

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16. The burette does not have to start at zero

A common misconception:

"Every titration must start at 0.00 cm³."

No.

What matters is that the initial and final readings are recorded accurately.

For example:

$$2.10 \rightarrow 26.55$$

gives:

$$26.55 - 2.10 = \boxed{24.45\ \text{cm}^3}$$

The titre is still perfectly usable.

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17. Rough titration

The first titration is often used to locate the approximate endpoint.

This is the:

$$\boxed{\text{rough titration}}$$

Its purpose is to determine approximately where the endpoint occurs.

Subsequent titrations can then approach the endpoint more carefully.

The rough titre is normally **not included in the final mean**.

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18. Concordant titres

Repeated titres should show good agreement.

For example:

$$24.40,\ 24.35,\ 24.40\ \text{cm}^3$$

These are closely grouped.

A school laboratory may define concordance using a specified tolerance—for example within:

$$0.10–0.20\ \text{cm}^3$$

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