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Pre-IB Chemical Research Skills Programme

Chemical Research Skills

A Skills-Building Programme for Independent Chemical Investigation



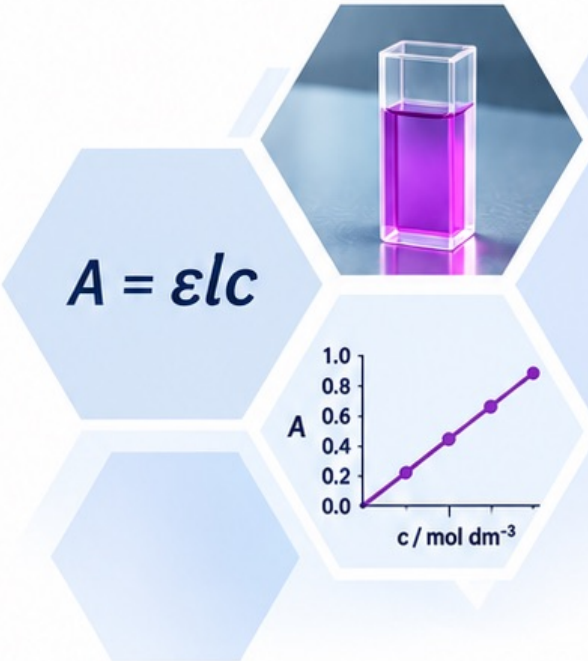
Module 4

Calibration Curves and UV–Vis Spectroscopy

From Measurement to Quantitative Analysis

In this module, you will:

- Understand the principle of UV–Vis spectroscopy
- Apply the Beer–Lambert law ($A = \varepsilon lc$)
- Prepare and measure a series of calibration standards
- Construct and evaluate a calibration curve
- Use the calibration curve to determine an unknown concentration



Sunny Chiam

IB Chemistry Specialist & Examiner-Level Educator
Founder, LearningSparks Education Services
Creator of the CHIAM Framework™

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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Founder, LearningSparks Education Services
Creator of the CHIAM Framework™
Think Chemistry. Think Structurally.

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Module 4 — Calibration Curves & UV–Vis
1-Minute Chemical Research Skills — Pre-IB Chemistry
Learning objectives
By the end of this module, you should be able to:

- explain the purpose of a **calibration curve**
- explain what a UV–Vis spectrophotometer measures
- distinguish between **absorbance** and **transmittance**
- explain why wavelength selection matters
- identify and explain the significance of λ_{max}
- use the Beer–Lambert relationship

$$\boxed{A = \varepsilon l c}$$

- explain why absorbance is proportional to concentration under suitable conditions
- prepare and use a set of calibration standards
- plot absorbance against concentration
- distinguish between data points and a **best-fit line**
- interpret the gradient and intercept of a calibration relationship
- explain the purpose of a **blank**
- identify when a calibration range is unsuitable
- recognise the difference between **interpolation and extrapolation**
- use a calibration equation to determine an unknown concentration
- identify important experimental controls in UV–Vis measurements

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1. Why do we need calibration?
Suppose you have an unknown blue solution.
You place it in a spectrophotometer and obtain:

$$A = 0.46$$

What does 0.46 mean?
By itself, not very much.
The instrument has given us a **measurement**, but we still need to connect that measurement to the chemical quantity we want:

$$\boxed{\text{concentration}}$$

To do that, we first measure solutions whose concentrations are already known.
For example:

Concentration / mol dm^{-3}	**Absorbance**
0.020	0.12
0.040	0.25

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Concentration / mol dm^{-3}	Absorbance
0.060	0.37
0.080	0.49
0.100	0.62

Now we can establish a relationship between:

known concentration → measured absorbance

This is the principle of **calibration**.

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2. What is a calibration curve?

A calibration curve is a graph showing the relationship between an **instrumental response** and known values of the quantity being measured.

In our case:

Concentration → Absorbance

Therefore, we normally plot:

x-axis

Concentration

y-axis

Absorbance

Why?

Because concentration is the known independent quantity used to calibrate the instrumental response.

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3. The logic of calibration

Calibration involves two stages.

Stage 1 — Build the relationship

Known concentrations
↓
Measure absorbance
↓
Plot calibration curve
↓
Determine mathematical relationship

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Stage 2 — Use the relationship

Unknown solution
↓
Measure absorbance
↓
Use calibration relationship
↓
Determine unknown concentration

This is what makes calibration so powerful.

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4. What does UV–Vis mean?

UV–Vis stands for:

Ultraviolet–Visible spectroscopy/spectrophotometry

The approximate wavelength regions are:

$$\text{UV: } 200 - 400 \text{ nm}$$
$$\text{Visible: } 400 - 700 \text{ nm}$$

A UV–Vis spectrophotometer measures how strongly a sample absorbs light at particular wavelengths.

In simplified form:

Light → Sample → Remaining transmitted light

The instrument compares the light entering the sample with the light transmitted through it.

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5. Absorption and transmission

Imagine light of intensity I_0 enters the sample.

After passing through the sample, the transmitted light has intensity I.

Some light has been absorbed.

We define **transmittance**:

$$T = \frac{I}{I_0}$$

Therefore, if most light passes through:

T is high

If much of the light is absorbed:

T is low

Percentage transmittance is:

$$\%T = 100T$$

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6. What is absorbance?

Absorbance describes how strongly the sample attenuates the selected light due to absorption.

It is related logarithmically to transmittance:

$$\boxed{A = -\log_{10} T}$$

or:

$$\boxed{A = \log_{10}\left(\frac{I_0}{I}\right)}$$

Therefore:

High transmittance

$$\Rightarrow \text{low absorbance}$$

Low transmittance

$$\Rightarrow \text{high absorbance}$$

Absorbance is **dimensionless**.

It is commonly reported without a unit.

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7. A quick numerical example

Suppose:

$$T = 0.50$$

Then:

$$A = -\log_{10}(0.50)$$
$$A \approx 0.301$$

If:

$$T = 0.10$$

then:

$$A = -\log_{10}(0.10)$$
$$A = 1.00$$

So a sample transmitting only 10% of the incident light has a higher absorbance than one transmitting 50%.

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8. Why does wavelength matter?

A coloured substance does not absorb all wavelengths equally.

Suppose we scan a solution across different wavelengths.

We might obtain:

Absorbance

that changes with:

λ

The resulting graph is an **absorption spectrum**.

One wavelength may show particularly strong absorption.

This wavelength is called:

$\boxed{\lambda_{\max}}$

pronounced:

lambda max

It is the wavelength of **maximum absorbance** under the stated conditions.

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9. Why measure at $\lambda_{\max}$?

Suppose a concentration change produces only a tiny absorbance change at one wavelength but a much larger absorbance change near $\lambda_{\max}$.

Measurement near $\lambda_{\max}$often gives:

- stronger absorbance
- greater sensitivity to concentration changes
- better ability to distinguish between similar concentrations

Therefore:

For quantitative UV–Vis analysis, measurements are often made at or near $\lambda_{\max}$.

But the wavelength must also be appropriate for the analyte and experimental conditions.

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10. Beer–Lambert law

The central quantitative relationship is:

$\boxed{A = \varepsilon l c}$

where:

Symbol	Meaning	Typical unit
A	Absorbance	no unit
ε	Molar absorption coefficient	$dm^3\ mol^{-1}\ cm^{-1}$
l	Path length	cm
c	Concentration	$mol\ dm^{-3}$

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For a particular species at a fixed wavelength and under fixed conditions:

$$\varepsilon = \text{constant}$$

If the same cuvette is used:

$$l = \text{constant}$$

Therefore:

$$A = \varepsilon l c$$

becomes:

$$\boxed{A \propto c}$$

within the range where Beer–Lambert behaviour is sufficiently linear.
This is the chemical basis of the calibration curve.

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11. What does $A \propto c$ mean?

If all relevant conditions remain constant:
Doubling concentration should approximately double absorbance.
For example:

$$c = 0.020 \; A = 0.12$$

If concentration doubles:

$$c = 0.040$$

we might expect approximately:

$$A \approx 0.24$$

This proportional relationship allows concentration to be determined from absorbance.

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12. Path length matters

Beer–Lambert law also tells us:

$$A \propto l$$

A longer path through the absorbing solution gives the light more opportunity to interact with absorbing species.
Therefore:

$$l \uparrow \Rightarrow A \uparrow$$

This is why the **cuvette path length must be controlled**.
A common cuvette path length is:

$$\boxed{1.00 \text{ cm}}$$

If different path lengths are used without accounting for them, absorbance values cannot be compared directly.

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13. What is a cuvette?

A **cuvette** is a small transparent sample cell placed inside the spectrophotometer.
It holds the solution through which the light passes.
Depending on wavelength range, cuvettes may be made from:

- quartz

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- glass
- suitable plastics

For UV measurements, **quartz is commonly required** because ordinary glass and many plastics absorb significantly in parts of the UV region.
For visible measurements, suitable glass or plastic cuvettes may often be used.
Always check the cuvette's specified wavelength range.

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14. Cuvette handling matters

Even a good calibration can be damaged by poor cuvette technique.
Common problems include:

- fingerprints
- droplets on the outside
- scratches
- bubbles
- inconsistent orientation
- different fill levels where the beam is not fully covered
- contamination from a previous solution

Good practice includes:

- handle cuvettes by the upper or non-optical surfaces
- wipe optical faces with suitable lint-free tissue
- check for bubbles
- use consistent orientation
- ensure sufficient solution covers the light path
- rinse appropriately with the solution to be measured when required

These are not merely “lab manners”.
They affect the measurement.

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15. What is a blank?

Suppose the analyte is dissolved in water and other reagents are also present.
The instrument may detect absorption or optical effects from:

- solvent
- reagents
- cuvette

We want the measurement to represent the analyte response as far as possible.
Therefore, we use a **blank**.
A blank normally contains:
everything in the sample matrix except the analyte being measured, as appropriate to the method.
The instrument is referenced using the blank before measuring samples.
Conceptually:

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