Chem Factsheet
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Practical Chemistry: Investigative Approaches

Introduction

Chemistry is a practical subject and chemists employ an investigative approach to laboratory work. An investigative approach means identifying and defining a problem, establishing an empirical means for measuring and testing a potential solution, and providing valid supporting evidence. To support the development of required practical skills, the Common Practical Assessment Criteria (CPAC) framework is applied to students completing the Practical Endorsement Qualification. These test the competencies of students against five assessment criteria, see **Table 1**:

Table 1

CPAC 1	Following written instructions correctly requiring little or no interventions.
CPAC 2	Selecting and correctly using appropriate apparatus; identifying and managing variables, completing an appropriate number of measurements within a relevant range.
CPAC 3	Identifying and managing hazardous materials and working safely using a range of apparatus and materials.
CPAC 4	Completing and recording observations with care and precision using appropriate modes of presentation.
CPAC 5	Using appropriate software or tools to process data and carry out research and complete well-organised reports.

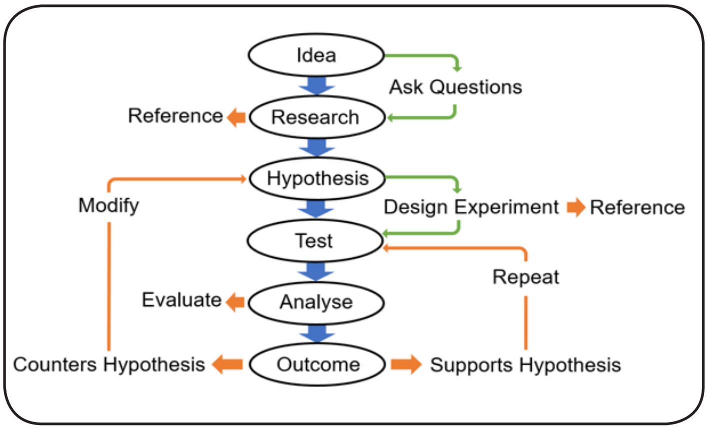
Scientific Method

Scientific method means designing an experimental procedure for testing a hypothesis in a practical context. This may lead to a modification of the original hypothesis.

> ***Key Point:***
> *A hypothesis is a proposed explanation made as a starting point for investigating an observed phenomenon that is tested using the scientific method.*

When a hypothesis continues to be substantiated through testing experimentally, its explanation for the observed phenomenon is called a theory. **Figure 1** shows a schematic describing the basic steps for following the scientific method.

Figure 1



Quantitative vs. Qualitative

Investigative approaches can be divided into quantitative or qualitative tasks. Quantitative investigations depend on correctly identifying and implementing apparatus for measuring quantities. **Table 2** lists frequently used apparatus for completing basic measurements:

Table 2

Quantity	Apparatus	Precision
Mass	top-pan balance	± 0.005 g
	analytical balance	± 0.0005 g
Volume	measuring cylinder	± 0.5 cm^3 (ml)
	burette	± 0.05 cm^3 (ml)
	graduated pipette	± 0.06 cm^3 (ml)
	volumetric flask	± 0.2 cm^3 (ml)
Temperature	thermometer	± 0.5 °C
	digital thermometer	± 0.05 °C
Time	stopwatch	± 0.2 s

> ***Note:*** *The precision using a stopwatch is based on the average reaction time using a manually operated stopwatch, ± 0.2 s, compared with the precision of a typical stopwatch, which is 0.01 s. Using automated sensors allows the full precision of the stopwatch to be achieved.*

Measurement errors are obtained by determining the total measured errors associated with the procedure, i.e. the sum of all measuring errors is calculated. For example, when measuring changes in volume using a burette, two measurements are required; at the start and end of the titration.

$$\text{percentage measuring error} = \frac{\text{apparatus limitation}}{\text{amount measured}} \times 100\%$$

The choice of apparatus used to measure quantities will depend on whether the measured substances are limiting or excess reagents. Greater accuracy and precision is required when measuring limiting reagents.

> ***Key Point:***
> *The limiting reagent is totally consumed in a chemical reaction. This brings the reaction to an end.*

Qualitative investigations require empirical observations to obtain non-numerical data. This typically involves the identification of substances through observing and recording the outcomes of chemical tests, for example; ions in solution, evolved gases, or identifying organic functional groups. It is important to use correct terminology and provide clear and concise data when recording observations. **Table 3** lists commonly used terminology for recording qualitative observations.

Table 3

Appearance	**State**	Solid	precipitate (solid) forms in solution
			(solid) dissolves in solution
		Liquid or solution	miscible – liquids mix to form a homogeneous solution
			immiscible – liquids do not mix and forms layers
			clear (transparent) solution (contains no solid matter)
		Gas	bubbles (fizzes) from solid in solution
			bubbles (effervescences) form in mixed solutions.
	Colour	Solid	e.g. white, blue, green, etc.
		Solution	e.g. colourless, green, red-brown, etc.

Analysis can also involve using instruments, for example; melting-point determination, chromatography and spectroscopy. By applying an investigative approach, scientists obtain appropriate and collaborative evidence to support the outcome of the investigation.

Research

The first step planning a scientific investigation requires researching relevant ideas and theories that have previously been explored, tested and documented. Researching procedural methods helps identify appropriate apparatus and reagents that may support an investigation. It is important to critically review researched content and modify procedures to best meet the resources available. Scientists will test and trial aspects of a procedure to determine if it will provide a valid outcome. This approach will consider:

- What reagents should be used?
- The amounts of each reagent to be used?
- Which variables should be measured and controlled?
- Which apparatus is most appropriate to obtain good, valid measurements?
- Is the procedure safe and appropriate for the aims of the investigation?

The identification and management of variables is a key consideration when completing an investigation:

- The independent variable is managed, i.e. the experimenter will manipulate the independent variable to affect the outcome.
- The dependent variable is affected by changes made on the independent variable. It is the measured outcome.
- Control variables may also affect the outcome and are therefore managed to reduce or eliminate their influence in the investigation.

Potential sources for obtaining information to support a planned investigation include:

- Textbooks
- Course notes and other course materials
- Journals
- Websites
- Media sources

Different source materials should be used to collaborate specific chemical principle with three or more sources confirming the ideas involved. Contradicting content may be used to challenge selected ideas or procedures. This allows for the presentation of a null hypothesis statement that establishes a default position where there is no relationship between two measured phenomena. The rejection of a null hypothesis increases the confidence that the tested hypothesis provides a good explanation of an observed phenomenon.

Referencing

There are several systems for referencing content. It is important that whichever system is chosen that it is used consistently throughout a report. Referencing sources acknowledges the work completed by other people and illustrates the diverse range of materials used. This improves the reliability and credibility of the report presented.

The author-number, or Vancouver System, uses numbers within the text. These numbers refer to numbered entries in the reference list. **Table 4a** provides a summary of the main in-text citations covering the author-number referencing style.

Table 4a

Referencing in Text (author-number style)	
Reference numbers should be cited in the correct numerical sequence.	
Single entry[1]	Apply at the end of the sentence, after the punctuation, or after the relevant word or compound.
Single entry[2] (ref.10) **Single entry[2 10]**	A reference number required when a word or phrase has a superscript number already should be written in brackets, or a space left between the two superscript numbers.
Multiple entries[3,5,12] **Multiple entries[6-9,14]**	Multiple references should include all citations in the text. Commas with no spaces are used. If a sequence of reference numbers is consecutive, use an en-dash.
Surname[13] **Surname et al[13]**	Authors mentioned with their first citation in the text do not require initials. For three of more authors the first name is stated followed by et al, the Latin abbreviation for 'and other persons'.

An alternative referencing style is the author-date, or Harvard system. This uses partial citations enclosed in brackets and embedded in the text. **Table 4b** illustrates examples of using the author-date in-text citation style.

Table 4b

Referencing in Text (author-date style)	
Format styles	Text content (Author, Year) with in-text citation.
	Text content by Author (Year) with in-text citation.
	'Text content with in-text citation' (Author, Year, p. xx).
Quote formats	Author's direct quotes are put 'in quotation marks' with page numbers provided (Year, p. xx).
	Large quotes are presented as a separate paragraph with the named source leading into the paragraph or given after the paragraph.
Online sources	Website citations to give: (Author, Year), or Author (Year). Year refers to date of publication or date of last update.
	Citations to online documents to give: (Author, Year) or Author (Year). Year refers to year of publication.

A bibliography section is completed at the end of a report. The formats applied for the author-number and author-date are similar and require the inclusion of details against each of the sources used:

- If applying the author-number referencing style the references should be listed in numerical order, according to the order of citations in the text.
- If applying the author-date referencing style, the references should be listed in alphabetical order.

Table 4c

Completing the Referencing or Bibliography Section of a Report	
Book/Author(s) Authors to be listed in alphabetical order	A. Name, B. Name and C. Name, Book Title, Publisher, Publisher Location, Year.
Book/Chapter	A. Name, in Book Title, ed. Editor Name(s), Publisher, Publisher Location, Edition, Year, Chapter, Page(s).
Journal	A. Name, B. Name and C. Name, Journal Title, Year, Volume, Page(s).
Online	Name of resource, URL, (accessed date).
Lectures	A. Name, Lecture Title, Place, Month, Year.

Risk Assessments

An investigative approach requires planning and implementing an investigation safely. This means identifying the hazards of all chemical substances handled and determining the safest procedures based on the reagents available.

A competed risk assessment will be made for:

- All reagents to be used and their concentrations.
- All likely products formed in the reaction.
- Any potential intermediates that may be produced in the reaction.

Table 5 provides a summary of the information expected when completing a risk assessment on chemical reagents. The example illustrates how reagent concentration is a factor when determining how hazardous a substance is classed.

Table 5

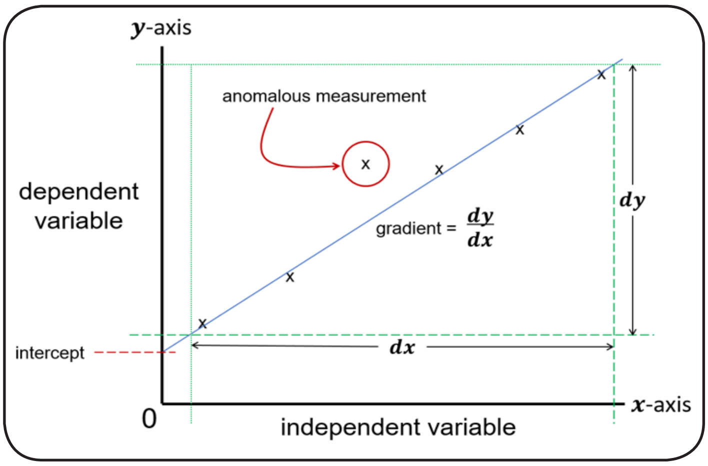
Substance	Hazards	Handling	Disposal	Hazard Notes
HCl(aq) (7.0M)	Corrosive/ Irritant	Wear splash-proof goggles. Avoid inhaling fumes. Use a fume cupboard.	Neutralise small quantities. Pour down a foul-water drain.	Card 47: DANGER skin, eyes, respiratory
HCl(aq) (4.0M)	Irritant	Wear eye protection Avoid skin contact.		Card 47: WARNING skin, eyes, respiratory
HCl(aq) (0.5M)	Not Hazardous	Wear eye protection		Currently not classified as hazardous

The card number provides a direct reference to the CLEAPSS hazard-card. CLEAPSS refers to the Consortium of Local Education Authorities for the Provision of Science Services, an advisory service providing support in science.

Implementation and Analysis

A successful investigative approach applies a diverse range of practical skills and techniques to obtain accurate and valid experimental data. This includes measuring data using appropriate apparatus and recording and presenting the data correctly. Measurements are recorded using simple, well-organised tables with headers, correct units and data recorded to an appropriate number of significant figures. Graphical presentations allow measured data to be extrapolated or manipulated to demonstrate trends. Graphs are completed with a title and with both axes labelled with units of measurement. **Figure 2** describes the standard requirements when completing a graph. Note that anomalous measurements must be plotted on the graph, but they may be labelled and discounted when completing a line or curve of best fit.

Figure 2



Questions

1) Comment and correct observations recorded for the following reactions:
   a) Magnesium ribbon is added to excess dilute hydrochloric acid: *hydrogen gas is liberated, and the magnesium disappears*.
   b) Aqueous hydroxide ions are added to copper(II) sulphate solution: *solution goes cloudy*.
2) Comment on each of the following investigative approaches:
   a) Using purple potassium manganate(VII), a student decides to take readings from the top of the meniscus, when completing measurements using a burette, as these are easier to complete.
   b) Investigating how the concentration of Reagent A affects the rate of a reaction involving Reagent A and Reagent B, a student ensures a large excess of Reagent B is used when completing the experiment.
   c) The reagents for a reaction include solutions of; hydrogen peroxide, potassium iodide, sodium thiosulphate and starch. The risk assessment also includes iodine.
3) Referring to **Table 2**, determine the measuring error associated with the following:
   a) 10.02 g of sodium hydroxide measured using a top-pan balance, is dissolved to make a 250 cm^3 standard solution using a volumetric flask.
   b) Delivering a 20.6 cm^3 titrant using a standard burette.

Answers

1 a) Bubbles of gas are produced and the magnesium dissolves forming a clear, colourless solution.
   b) Blue precipitate forms.

2) a) Error is not increased as the change in volume is measured.
   b) Using large excess ensures the effect on reaction rate due to changes in the concentration of Reagent B is negligible.
   c) Iodine to a product and a risk assessment must be completed.

3) a) 0.2 %
   b) 0.5 %

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