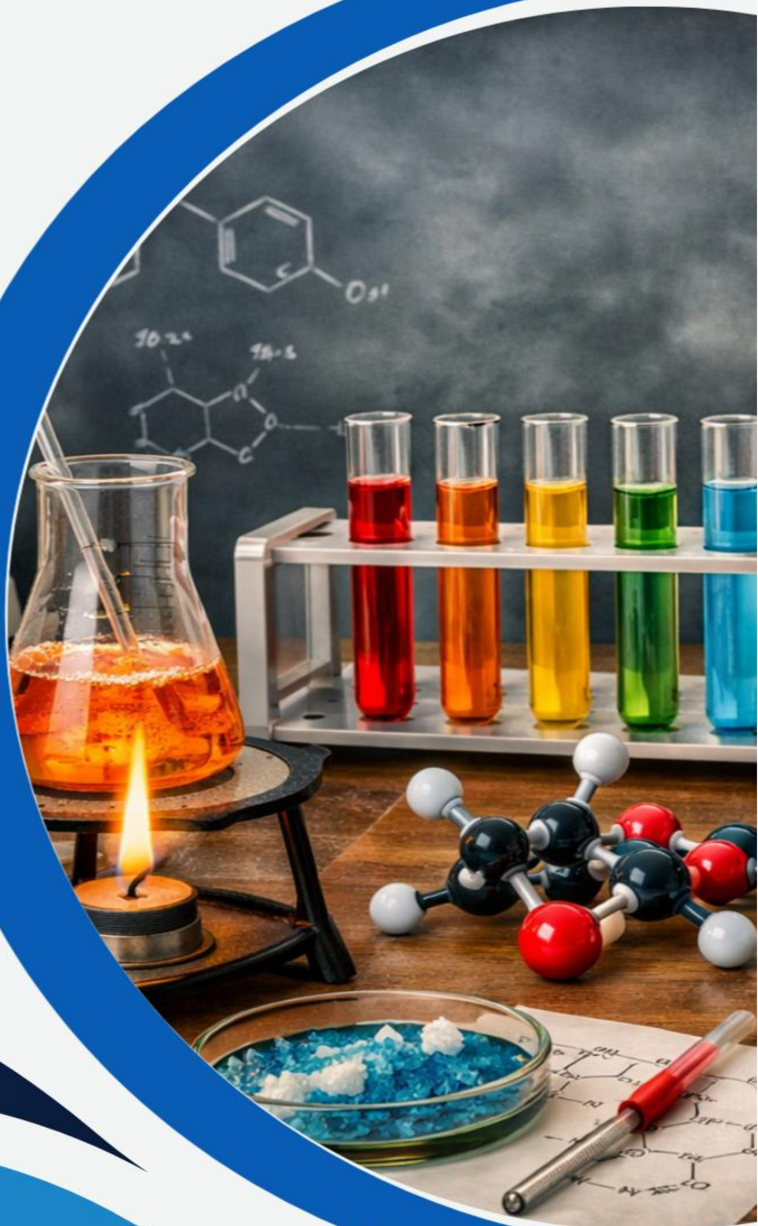
CHM208

GENERAL CHEMISTRY PRACTICAL IV



- **Course code: CHM 208**
- **Course title: CHM 208: General Chemistry Practical IV** (1 Unit C: PH 45)
- **Course credit load:** (1 Unit C: PH 45)
- **List of Series**:

Series 1: **Laboratory Safety and Rules in General Chemistry**

Series 2: **Preparation of Esters, Aldehydes, and Ketones**

Series 3: **Vinegar Analysis and Chromatographic Techniques**

Series 4: **Thin Layer Chromatography Applications**

Series 5: **Alcohol Dehydration and Functional Group Analysis**

Main Parts

Introduction

In every chemistry laboratory, safety is the foundation upon which all practical work is built. Imagine entering a laboratory where chemicals, glassware, and equipment are in constant use: without clear rules and safe practices, accidents can occur easily, leading to harm or disruption of learning. This Series is designed to prepare you for responsible laboratory work by emphasising the importance of safety and the rules that govern laboratory conduct. By mastering these principles, you will not only protect yourself and others but also create an environment where scientific exploration can thrive.

The aim of this Series is to equip you with the knowledge and skills required to practise safe laboratory habits, to follow established rules of conduct, and to apply these principles consistently during chemistry practical sessions.

We shall commence this Series by examining the fundamentals of laboratory safety, including the importance of safety awareness, the role of safety equipment, and the use of personal protective equipment. Next, we will move on to laboratory rules and conduct, focusing on behaviour, safe handling of chemicals and glassware, and proper waste disposal and emergency procedures.

Finally, we will conclude with practical applications of safety rules, where you will explore case studies, demonstrations of safe practices, and the use of safety checklists to reinforce your learning. This sequential approach will ensure that you gain both theoretical understanding and practical readiness for safe laboratory work.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** define the importance of laboratory safety in chemistry practicals,
- **SLO 1.2** explain the functions of general safety equipment and personal protective equipment (PPE),
- **SLO 1.3** describe appropriate laboratory behaviour and rules for handling chemicals and glassware,
- **SLO 1.4** apply correct procedures for waste disposal and emergency response in laboratory settings, and
- **SLO 1.5** evaluate case studies of laboratory incidents to demonstrate safe practices using safety checklists.

1.1 Fundamentals of Laboratory Safety

1.1.1 Importance of safety in chemistry laboratories

Safety in the laboratory is the foundation of effective scientific practice. The **importance of safety** refers to the need to protect yourself, your colleagues, and the environment from harm while conducting experiments. Accidents can occur due to carelessness, lack of preparation, or misunderstanding of procedures. By following safety rules, you minimise risks such as chemical burns, inhalation of toxic fumes, or fire hazards. A safe laboratory environment also ensures that experiments are conducted accurately without contamination or disruption.

Fill in the blank: The set of practices, rules, and precautions designed to prevent accidents and protect individuals in the laboratory is called __________________.

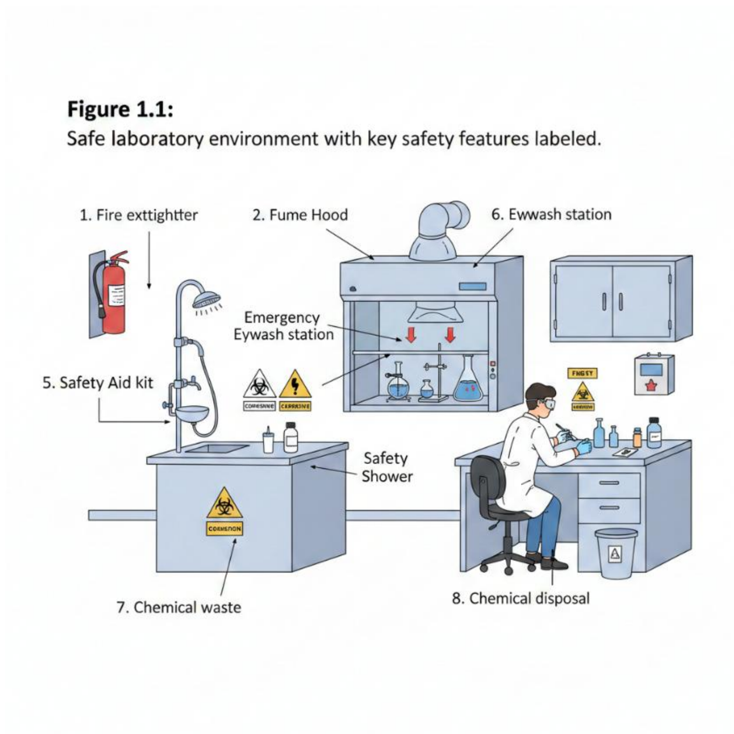


Figure 1.1: Safe laboratory environment with key safety features labelled

AI prompt: “Generate a labelled diagram of a chemistry laboratory highlighting safety features such as fire extinguisher, fume hood, eyewash station, and PPE.”
Search string: “chemistry laboratory safety diagram OER”

1.1.2 General safety equipment and their uses

Safety equipment refers to tools and devices designed to prevent or reduce accidents in the laboratory. Common examples include fire extinguishers, safety showers, eye wash stations, fume hoods, and first aid kits. A **fire extinguisher** is used to put out small fires, while a **safety shower** and **eye wash station** are used to rinse chemicals off the body or eyes. A **fume hood** protects you from inhaling harmful vapours by ventilating them safely. Knowing the location and proper use of this equipment is critical for responding quickly to emergencies.

Fill in the blank: The equipment used to prevent inhalation of harmful vapours in the laboratory is called a ___________________.

Plate 1.1: Common laboratory safety equipment

AI prompt: “Create an image showing fire extinguisher, eyewash station, and fume hood in a chemistry laboratory.”
Search string: “laboratory safety equipment images OER”

1.1.3 Personal protective equipment (PPE)

Personal protective equipment (PPE) refers to clothing and gear worn to protect the body from hazards in the laboratory. Examples include lab coats, safety goggles, gloves, and closed-toe shoes. A **lab coat** protects your skin and clothing from chemical spills, while **safety goggles** shield your eyes from splashes or flying particles. **Gloves** prevent direct contact with harmful substances, and **closed-toe shoes** protect your feet from spills or broken glass. Wearing PPE is not optional; it is a requirement for safe laboratory practice.

Fill in the blank: The protective clothing and accessories worn to reduce exposure to hazards in the laboratory are collectively called __________________.

Personal Protective Equipment (PPE for Chemistry Chemistry Laboratories

Item		Description	Required
Lab Coat	Flame-resistant, knee-length	✓	✓
Safety Goggles	ANSI-rated, splash-proof	✓	✓
Gloves	Chemical-resistant (nitrile/latex)	✓	✓
		✓	✓
Closed-toe Shoes	Sturdy, covering entire foot	✓	✓
Long Pants/Skirts	Ankles covered, no exposed skin	✓	✓

Box 1.1: Checklist for personal protective equipment in chemistry laboratories

Lab coat
Safety goggles
Gloves
Closed-toe shoes

AI prompt: “Generate a checklist table of personal protective equipment required in a chemistry laboratory.”
Search string: “personal protective equipment checklist chemistry OER”

Pilot questions 1.1

The set of practices and precautions designed to prevent accidents in the laboratory is called:
A. Laboratory safety
B. Laboratory conduct
C. Laboratory management
D. Laboratory analysis

The equipment used to prevent inhalation of harmful vapours is the:
A. Eyewash station
B. Fire extinguisher
C. Fume hood
D. Safety shower

Which of the following is not considered personal protective equipment?
A. Safety goggles

B. Gloves
C. Closed-toe shoes
D. Test tube rack

The immediate relief system for chemical splashes in the eyes is the:
A. Safety shower
B. Eyewash station
C. Fume hood
D. Fire extinguisher

Wearing a lab coat in the laboratory primarily protects against:
A. Broken glass
B. Chemical spills
C. Fire hazards
D. Noise

1.2 Laboratory Rules and Conduct

1.2.1 General behaviour in the laboratory

Maintaining proper **laboratory behaviour** means following rules of conduct that ensure safety and efficiency. This includes avoiding horseplay, keeping work areas tidy, and paying attention to instructions. You should never eat, drink, or apply cosmetics in the laboratory, as this can lead to contamination. Respect for colleagues and equipment is also essential, since careless actions can endanger others and damage valuable resources.

Fill in the blank: The expected standards of behaviour that ensure safety, efficiency, and respect for others in the laboratory are called __________________.

Figure 1.2: Responsible behaviour in the laboratory

AI prompt: “Generate a labelled illustration of students working responsibly in a chemistry

laboratory, showing tidy benches and proper conduct."
Search string: "chemistry laboratory student behaviour OER"

1.2.2 Handling chemicals and glassware safely

Chemicals and glassware are central to laboratory work, yet they can be hazardous if mishandled. **Chemical handling** refers to the safe practices of measuring, transferring, and storing chemicals to prevent accidents. Learners should always read labels carefully, use appropriate containers, and avoid direct contact with chemicals. **Glassware safety** involves using beakers, flasks, and test tubes correctly, checking for cracks before use, and handling hot glassware with protective tools.

Fill in the blank: The safe practices of measuring, transferring, and storing substances in the laboratory are collectively referred to as __________________.

Plate 1.2: Safe handling of chemicals and glassware

AI prompt: "Create an image of a student wearing PPE while safely handling chemicals and glassware in a chemistry laboratory."
Search string: "safe handling chemicals glassware OER"

1.2.3 Waste disposal and emergency procedures

Waste disposal in the laboratory involves separating chemical waste, biological waste, and broken glass into designated containers. Never pour chemicals down the sink unless instructed, as this can cause environmental harm. **Emergency procedures** are the steps taken when accidents occur, such as chemical spills, fires, or injuries. These include alerting the instructor, using safety equipment like fire extinguishers or eye wash stations, and evacuating if necessary. Knowing these procedures ensures quick and effective responses to emergencies.

Fill in the blank: The steps taken to respond to accidents such as spills, fires, or injuries in the laboratory are called __________________.

Emergency Procedures for Chemistry Laboratiores

Essential Actions for a Safe Laboratory

Situation	Immediate Action	Additional Steps
Chemical Spill on Skin/ Eyes	Immediately flush affected area with water for 15-20 minutes. medical attention. Notfy supervisor.	Use eywash station/safety shower. Remove contimated clothing. Seetical atention. Await instructions
Fire Alarm	Turn off all burners, water, & electrical devices. Close all containers	Evacuute calmly using designated Assemble a point. Notify supervisor
Minor Fire (Beaker size)	If safe, smother with a watch glass or use fire extirrigher	Alert others. Evacute if fire spreads or cannot t in imedined. Notfy supervisor
Minor Fire (Beaker size)	If safe, smother with a spreads glass or cant inmeduatly contained	Alert others behind you if Dot attempt to fight firet imergency services
Major Fire	Immediurtely pull fire alarm. Evaccute the building	Close doors behind you if safe. Await emergency services
Broken Glassware	Do NOT handle with bare hands. Use brush & dustpan	Dispose of broken glass in designated "Broken Glass" container Notify supervisor of incident

Box 1.2: Key emergency procedures in chemistry laboratories

Report all accidents immediately to the supervisor
Use eyewash stations or safety showers for chemical exposure
Follow evacuation routes during fire alarms
Dispose of broken glass in designated containers

AI prompt: “Generate a checklist table of emergency procedures in a chemistry laboratory.” Search string: “chemistry laboratory emergency procedures OER”

Pilot questions 1.2

The expected standards of behaviour that ensure safety and respect in the laboratory are called:

A. Laboratory conduct
B. Laboratory management
C. Laboratory safety equipment
D. Laboratory analysis

The safe practices of measuring, transferring, and storing substances in the laboratory are referred to as:

A. Waste disposal
B. Chemical handling
C. Glassware safety
D. Emergency procedures

Which of the following is the correct way to dispose of broken glass?

A. In the chemical waste bin
B. In the general rubbish bin
C. In designated glass disposal containers
D. In the sink

The immediate steps taken to respond to accidents such as spills or fires are known as:

A. Laboratory conduct
B. Emergency procedures
C. Waste disposal
D. Chemical handling

Which of the following is not part of safe glassware handling?

A. Checking for cracks before use
B. Using protective tools for hot glassware
C. Leaving broken glass on the bench
D. Handling beakers and flasks carefully

1.3 Practical Application of Safety Rules

1.3.1 Case studies of laboratory incidents

Learning from past mistakes is one of the most effective ways to understand the importance of safety. **Case studies** are detailed accounts of real or simulated laboratory incidents that highlight what went wrong and how it could have been prevented. For example, a spill caused by improper chemical labelling demonstrates the need for clear identification, while an injury from broken glassware shows why inspection before use is essential. By analysing these cases, learners can connect theory with practice and appreciate the consequences of neglecting safety rules.

Fill in the blank: Detailed accounts of real or simulated laboratory incidents that highlight causes and prevention are called __________________.

Laboratory Safety Case Study: Chemical Mismanagement

Feature	Details
Incident	**Chemical spill** occurring when a student unknowingly used a corrosive substance from a mislabeled container.
Primary Cause	**Human error**; specifically, the failure to verify the container's contents against the original label or Safety Data Sheet (SDS) before use.
Consequence	**Minor chemical burns** to the student's hand due to direct skin contact with the improperly identified hazardous material.
Prevention	Implementation of strict **labeling protocols**, mandatory reading of labels before every use, and regular chemical hygiene plan (CHP) audits to ensure all containers are accurately marked.

Box 1.3: Example case study of a laboratory incident

Incident: Chemical spill due to mislabelled container
Cause: Failure to check labels before use
Consequence: Minor burns to student's hand
Prevention: Proper labelling and careful reading of chemical containers

AI prompt: "Generate a case study table showing an example of a laboratory incident, its cause, consequence, and prevention."
Search string: "chemistry laboratory case study safety OER"

1.3.2 Demonstration of safe laboratory practices

A **demonstration** is a guided performance that shows learners how to apply safety rules during practical work. Instructors often demonstrate correct procedures such as measuring chemicals, disposing of waste, or using safety equipment. Observing these demonstrations helps learners internalise safe habits and replicate them during their own experiments. Demonstrations also provide opportunities to ask questions and clarify uncertainties.

Fill in the blank: A guided performance that shows learners how to apply safety rules during practical work is called a __________________.

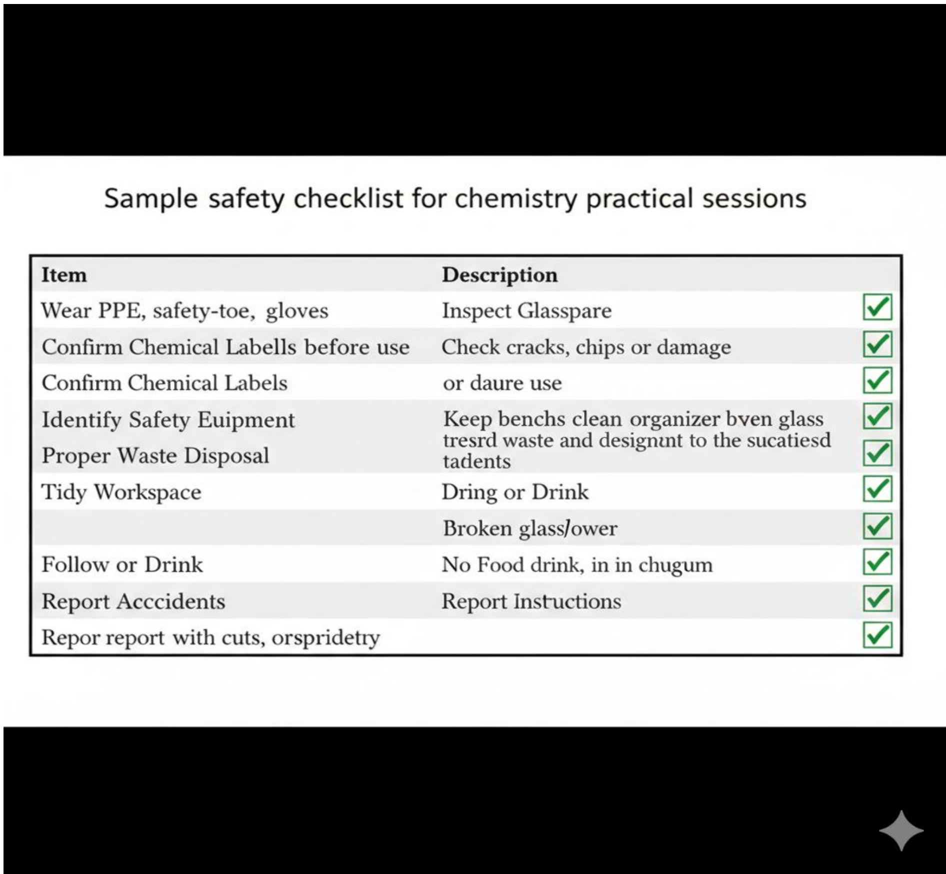
Plate 1.3: Demonstration of safe laboratory practices

AI prompt: “Create an image of a chemistry instructor demonstrating safe chemical handling to students wearing PPE.”
Search string: “chemistry laboratory demonstration safety OER”

1.3.3 Safety checklists for practical sessions

A **safety checklist** is a structured list of rules and reminders used before and during laboratory sessions. It ensures that you do not overlook essential precautions, such as checking equipment, wearing PPE, and knowing emergency exits. Safety checklists are practical tools that help maintain discipline and consistency in applying safety rules. They also serve as a record of compliance, showing that safety measures were followed.

Fill in the blank: A structured list of items or actions that must be completed to ensure safety in the laboratory is called a ___________________.



Sample safety checklist for chemistry practical sessions

Item	Description	
Wear PPE, safety-toe, gloves	Inspect Glasspare	✓
Confirm Chemical Labells before use	Check cracks, chips or damage	✓
Confirm Chemical Labels	or daure use	✓
Identify Safety Euipment	Keep benchs clean organizer bven glass	✓
Proper Waste Disposal	tresrd waste and designunt to the sucatiesd tadents	✓
Tidy Workspace	Dring or Drink	✓
	Broken glass/ower	✓
Follow or Drink	No Food drink, in in chugum	✓
Report Acccidents	Report Instuctions	✓
Repor report with cuts, orspridetry		✓

Table 1.1: Sample safety checklist for chemistry practical sessions

Wear PPE (lab coat, goggles, gloves, closed shoes)
Inspect glassware for cracks
Confirm chemical labels before use
Identify location of safety equipment (eyewash, fire extinguisher)
Dispose of waste in designated containers

AI prompt: “Generate a table showing a sample safety checklist for chemistry practical sessions.”
Search string: “chemistry laboratory safety checklist OER”

Pilot questions 1.3

Detailed accounts of laboratory incidents that highlight causes and prevention are called:
- A. Demonstrations
- B. Case studies
- C. Safety checklists
- D. Laboratory rules

A guided performance that shows learners how to apply safety rules during practical work is called a:
- A. Case study
- B. Demonstration

C. Safety checklist
D. Laboratory conduct

Which of the following is not typically included in a safety checklist?
A. Wearing PPE
B. Inspecting glassware
C. Confirming chemical labels
D. Recording experimental results

The main purpose of a safety checklist is to:
A. Provide theoretical knowledge of safety rules
B. Reduce the likelihood of forgetting important steps
C. Replace demonstrations of safe practices
D. Record case studies of incidents

Analysing a chemical spill caused by mislabelling is an example of:
A. Demonstration
B. Case study
C. Safety checklist
D. Emergency procedure

Series Summary

This Series on **Laboratory Safety and Rules in General Chemistry** was designed to highlight the importance of safe practices in laboratory environments. You began by exploring the fundamentals of laboratory safety, including why safety is essential, the functions of general safety equipment, and the role of personal protective equipment. You then examined laboratory rules and conduct, focusing on appropriate behaviour, safe handling of chemicals and glassware, and correct waste disposal and emergency procedures. Finally, you applied these principles through case studies of laboratory incidents, demonstrations of safe practices, and the use of safety checklists to reinforce discipline and preparedness.

By completing this Series, you should now be able to **define the importance of laboratory safety (SLO 1.1)**, **explain the functions of safety equipment and PPE (SLO 1.2)**, **describe appropriate laboratory behaviour and handling rules (SLO 1.3)**, **apply correct procedures for waste disposal and emergency response (SLO 1.4)**, and **evaluate case studies to demonstrate safe practices using checklists (SLO 1.5)**. These outcomes ensure that you are well-prepared to work responsibly and confidently in chemistry laboratories, safeguarding both yourself and others.

Glossary of Terms

Case study: A real or simulated example of an incident used to analyse causes, consequences, and lessons learned.

Chemical handling: The correct procedures for using, transferring, and storing chemicals safely to prevent accidents or contamination.

Emergency procedures: Steps to follow when accidents occur in the laboratory, such as chemical spills, fires, or injuries, to minimise harm.

Fire extinguisher: A device used to put out small fires in the laboratory.

Fume hood: A ventilated enclosure that protects laboratory workers from inhaling harmful vapours by safely removing them from the workspace.

Glassware safety: Practices for handling laboratory glassware carefully, checking for cracks, and disposing of broken pieces in designated containers.

Laboratory behaviour: The expected conduct in a laboratory, including attentiveness, tidiness, and avoidance of unsafe actions such as eating or horseplay.

Personal protective equipment (PPE): Clothing and gear such as lab coats, safety goggles, gloves, and closed-toe shoes worn to protect the body from laboratory hazards.

Safety checklist: A structured list of rules and reminders used before and during laboratory sessions to ensure all safety measures are followed.

Safety equipment: Tools and devices such as safety showers, eye wash stations, and first aid kits designed to prevent or reduce accidents in the laboratory.

Waste disposal: The correct separation and removal of chemical, biological, and glass waste into designated containers to prevent harm and contamination.

Concept Check Questions [Series 1]

Objective Questions

Laboratory safety is essential because it protects __________________, colleagues, and the environment from harm.
(Linked to SLO 1.1)

Which of the following is considered personal protective equipment (PPE)?
A. Fire extinguisher
B. Safety goggles
C. Fume hood
D. Eye wash station
(Linked to SLO 1.2)

Broken glassware must be disposed of in __________________ containers, not regular bins.
(Linked to SLO 1.3)

Chemical waste should never be poured down the __________________ unless specifically instructed.
(Linked to SLO 1.4)

A safety checklist is a structured list of rules and reminders used before and during __________________ sessions.
(Linked to SLO 1.5)

Short-Answer Questions

Define personal protective equipment (PPE) and give two examples.
(Linked to SLO 1.2)
State one reason why eating or drinking in the laboratory is prohibited.
(Linked to SLO 1.3)
Describe the function of a fume hood in the laboratory.
(Linked to SLO 1.2)
Give one example of an emergency procedure and explain its importance.
(Linked to SLO 1.4)
Explain why safety checklists are important in maintaining discipline during laboratory sessions.
(Linked to SLO 1.5)

Long-Answer Questions

Analyse the importance of laboratory safety equipment and PPE in preventing accidents.
(Linked to SLO 1.2)
Evaluate the role of laboratory rules and conduct in ensuring safe handling of chemicals and glassware.
(Linked to SLO 1.3)
Assess how case studies and demonstrations of safe practices help learners apply safety rules effectively.
(Linked to SLO 1.5)

Answers to Concept Check Questions [Series 1]

Objective Questions

Yourself
B. Safety goggles
Designated glass disposal containers
Sink
Laboratory sessions

Short-Answer Questions

PPE refers to clothing and gear worn to protect the body from hazards. Examples include lab coats and gloves.
Eating or drinking is prohibited because it can lead to contamination or accidental ingestion of harmful substances.
A fume hood ventilates harmful vapours away from the user, preventing inhalation.

Using an eye wash station after a chemical splash is important to prevent permanent eye damage.

Safety checklists ensure that essential precautions are not overlooked, reinforcing consistent safe behaviour.

Long-Answer Questions

Question 1

Basic response: Safety equipment such as fire extinguishers and PPE like goggles protect against accidents by reducing exposure to hazards.

Value-added response: Outstanding learners may extend by discussing how proper training in equipment use enhances confidence and reduces panic during emergencies.

Question 2

Basic response: Laboratory rules such as careful handling of chemicals and proper disposal of glassware prevent accidents and contamination.

Value-added response: Learners may extend by linking these rules to professional standards in industry and research, showing how discipline in the lab translates to workplace safety.

Question 3

Basic response: Case studies highlight real incidents, while demonstrations show correct procedures, helping learners apply safety rules.

Value-added response: Learners may extend by explaining how reflective practice and checklist use build a culture of safety, preparing them for independent laboratory work.

Answers to Pilot Questions [Series 1]

Part 1.1 Fundamentals of Laboratory Safety

Laboratory safety
Fume hood
Personal protective equipment (PPE)

Part 1.2 Laboratory Rules and Conduct

Laboratory conduct
Chemical handling
In designated glass disposal containers
Emergency procedures
Leaving broken glass on the bench

Part 1.3 Practical Application of Safety Rules

Case studies
Demonstration
Recording experimental results
Reduce the likelihood of forgetting important steps
Case study

References and Attributions [Series 1]

Textual Sources

Atkins, P., & Jones, L. (2010). *Chemical Principles: The Quest for Insight* (5th ed.). Oxford University Press.
Housecroft, C. E., & Sharpe, A. G. (2018). *Inorganic Chemistry* (5th ed.). Pearson.
IUPAC. (1997). *Compendium of Chemical Terminology (the "Gold Book")*.

Illustrations (Figures, Plates, Tables, Boxes)

Figure 1.1 Safe laboratory environment with key safety features labelled
AI prompt: "Generate a labelled diagram of a chemistry laboratory highlighting safety features such as fire extinguisher, fume hood, eyewash station, and PPE."
Search string: "chemistry laboratory safety diagram OER"
Plate 1.1 Common laboratory safety equipment
AI prompt: "Create an image showing fire extinguisher, eyewash station, and fume hood in a chemistry laboratory."
Search string: "laboratory safety equipment images OER"
Box 1.1 Checklist for personal protective equipment in chemistry laboratories
AI prompt: "Generate a checklist table of personal protective equipment required in a chemistry laboratory."
Search string: "personal protective equipment checklist chemistry OER"
Figure 1.2 Responsible behaviour in the laboratory
AI prompt: "Generate a labelled illustration of students working responsibly in a chemistry laboratory, showing tidy benches and proper conduct."
Search string: "chemistry laboratory student behaviour OER"
Plate 1.2 Safe handling of chemicals and glassware
AI prompt: "Create an image of a student wearing PPE while safely handling chemicals and glassware in a chemistry laboratory."
Search string: "safe handling chemicals glassware OER"
Box 1.2 Key emergency procedures in chemistry laboratories
AI prompt: "Generate a checklist table of emergency procedures in a chemistry laboratory."
Search string: "chemistry laboratory emergency procedures OER"
Box 1.3 Example case study of a laboratory incident
AI prompt: "Generate a case study table showing an example of a laboratory incident, its cause, consequence, and prevention."
Search string: "chemistry laboratory case study safety OER"

Plate 1.3 Demonstration of safe laboratory practices
AI prompt: "Create an image of a chemistry instructor demonstrating safe chemical handling to students wearing PPE."
Search string: "chemistry laboratory demonstration safety OER"
Table 1.1 Sample safety checklist for chemistry practical sessions
AI prompt: "Generate a table showing a sample safety checklist for chemistry practical sessions."
Search string: "chemistry laboratory safety checklist OER"

Notes on Attribution

AI-generated illustrations are documented with prompts and should be noted with the generation date and platform used.
Where OERs are used, attribution must comply with the licence terms of the source.
References are presented in APA style for consistency.

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- **Course title: CHM 208: General Chemistry Practical IV** (1 Unit C: PH 45)
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- **List of Series**:

Series 1: **Laboratory Safety and Rules in General Chemistry**

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Series 3: **Vinegar Analysis and Chromatographic Techniques**

Series 4: **Thin Layer Chromatography Applications**

Series 5: **Alcohol Dehydration and Functional Group Analysis**

Suggested Outline

Main Parts

2.1 Introduction to Organic Compound Preparation
2.1.1 Overview of esters, aldehydes, and ketones
2.1.2 General laboratory methods for organic synthesis
2.2 Preparation of Esters
2.2.1 Principles of esterification
2.2.2 Laboratory procedure for ester preparation
2.2.3 Applications of esters in everyday life

Introduction

Organic compounds such as esters, aldehydes, and ketones are central to both industrial applications and everyday life. From the pleasant fragrances of esters in perfumes to the role of aldehydes and ketones in food flavouring and pharmaceuticals, these compounds are widely encountered. In the chemistry laboratory, learning how to prepare them provides a practical foundation for understanding organic synthesis and its relevance to real-world contexts. This Series will guide you through the essential methods and considerations involved in their preparation.

The aim of this Series is to equip you with the knowledge and skills required to prepare esters, aldehydes, and ketones in the laboratory, to explain the principles behind their synthesis, and to apply safe and effective practices during organic compound preparation.

We shall commence this Series by introducing the general principles of organic compound preparation, including an overview of esters, aldehydes, and ketones, and the laboratory methods used in synthesis. Next, we will focus on the preparation of esters, examining the principles of esterification, laboratory procedures, and their everyday applications. Following that, we will continue with the preparation of aldehydes and ketones, exploring methods of synthesis and comparing their properties and uses. Finally, we will conclude with practical considerations in organic compound preparation, where we will discuss safety precautions, recording observations, and troubleshooting common errors. This structured approach will ensure that you gain both theoretical understanding and practical competence in preparing these important organic compounds.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 2.1 define the key characteristics of esters, aldehydes, and ketones, and explain general laboratory methods for their preparation,
SLO 2.2 demonstrate the laboratory procedure for preparing esters and explain the principles of esterification,
SLO 2.3 apply methods for synthesising aldehydes and ketones, and describe their comparative properties and uses,
SLO 2.4 evaluate safety precautions, recording practices, and troubleshooting strategies in organic compound preparation.

2.1 Introduction to Organic Compound Preparation

2.1.1 Overview of esters, aldehydes, and ketones

Organic compounds such as **esters**, **aldehydes**, and **ketones** are central to both laboratory synthesis and industrial applications. **Esters** are compounds formed by the reaction between a carboxylic acid and an alcohol, often recognised by their pleasant fruity odours. **Aldehydes** are organic compounds containing a carbonyl group (C=O) bonded to at least one hydrogen atom, while **ketones** contain a carbonyl group bonded to two carbon atoms. These functional groups determine the reactivity and properties of the compounds, making them useful in perfumes, solvents, and pharmaceuticals.

Fill in the blank: A compound formed from the reaction between a carboxylic acid and an alcohol is called an __________________.

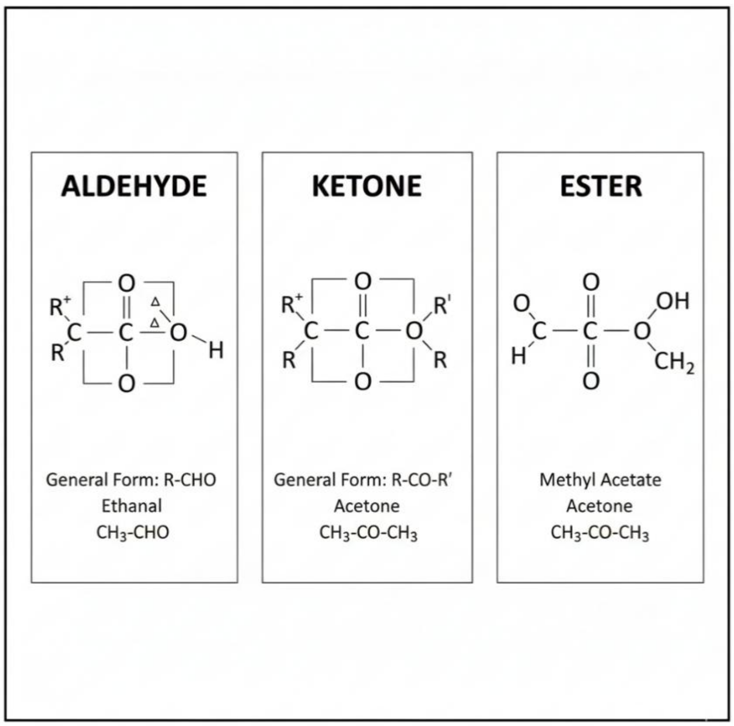


Figure 2.1: Structural comparison of esters, aldehydes, and ketones

AI prompt: "Generate a labelled diagram showing the chemical structures of esters, aldehydes, and ketones side by side."
Search string: "esters aldehydes ketones structural diagram OER"

2.1.2 General laboratory methods for organic synthesis

Organic synthesis refers to the process of constructing organic compounds through controlled chemical reactions. In the laboratory, common methods include **esterification**, where esters are prepared by reacting carboxylic acids with alcohols in the presence of an acid catalyst, and **oxidation reactions**, which can convert primary alcohols into aldehydes and secondary alcohols into ketones. These methods require careful control of conditions such as temperature, catalysts, and reaction time to ensure successful preparation.

Fill in the blank: The process of constructing organic compounds through chemical reactions is called __________________.

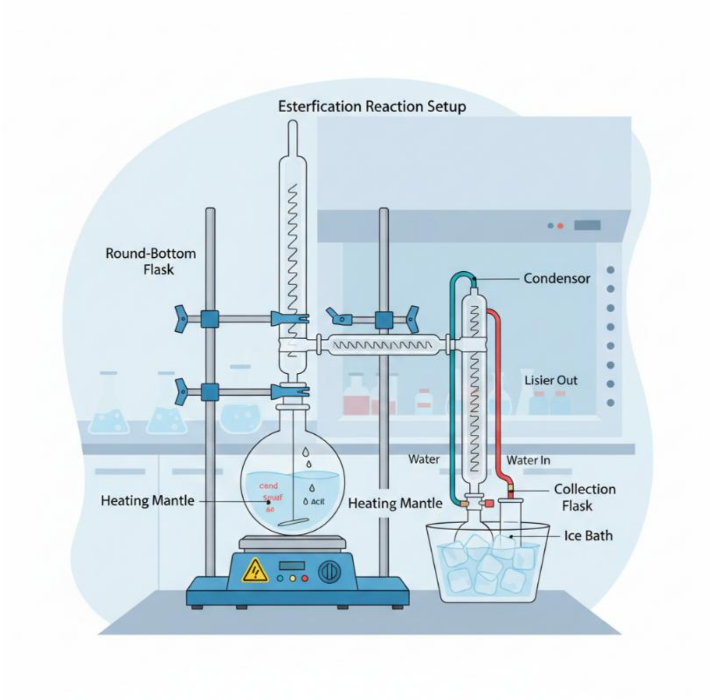


Plate 2.1: Laboratory setup for esterification

AI prompt: “Create an image of a chemistry laboratory setup showing esterification with a round-bottom flask, condenser, and heating mantle.”
Search string: “esterification laboratory setup OER”

Pilot questions 2.1

A compound formed from the reaction between a carboxylic acid and an alcohol is called:
- A. Aldehyde
- B. Ketone
- C. Ester
- D. Hydrocarbon
- (Linked to SLO 2.1)

Which functional group is present in both aldehydes and ketones?
- A. Hydroxyl group
- B. Carbonyl group
- C. Carboxyl group
- D. Amino group
- (Linked to SLO 2.1)

The process of constructing organic compounds through chemical reactions is called:

A. Organic synthesis
B. Organic analysis
C. Organic decomposition
D. Organic extraction
(Linked to SLO 2.1)

Esters are commonly prepared by heating a carboxylic acid with an alcohol in the presence of:

A. A base catalyst
B. An acid catalyst
C. A neutral solvent
D. A reducing agent
(Linked to SLO 2.2)

Oxidation of a secondary alcohol typically produces a:

A. Ketone
B. Aldehyde
C. Ester
D. Carboxylic acid
(Linked to SLO 2.3)

2.2 Preparation of Esters

2.2.1 Principles of esterification

Esterification is the chemical reaction in which a carboxylic acid reacts with an alcohol to form an **ester** and water. This process is usually catalysed by an acid such as concentrated sulphuric acid, which speeds up the reaction and helps remove water to drive the equilibrium towards ester formation. Esters are characterised by their pleasant, often fruity odours, which make them useful in flavourings and perfumes.

Fill in the blank: The reaction between a carboxylic acid and an alcohol in the presence of an acid catalyst produces an __________________.

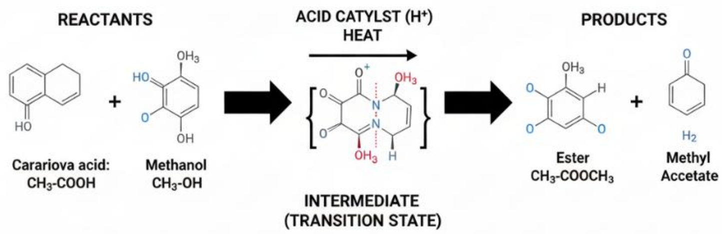


Figure 2.2: General reaction scheme for esterification

AI prompt: “Generate a labelled diagram showing esterification reaction between a carboxylic acid and an alcohol forming an ester and water.”
Search string: “esterification reaction diagram OER”

2.2.2 Laboratory procedure for ester preparation

In the laboratory, esters can be prepared by heating a mixture of a carboxylic acid and an alcohol with a few drops of concentrated sulphuric acid. The reaction is typically carried out in a round-bottom flask fitted with a condenser to prevent loss of volatile substances. After heating, the mixture is poured into water, where the ester separates as a distinct layer due to its immiscibility. The ester can then be purified by washing and drying.

Fill in the blank: In esterification, concentrated __________________ is commonly used as the catalyst.

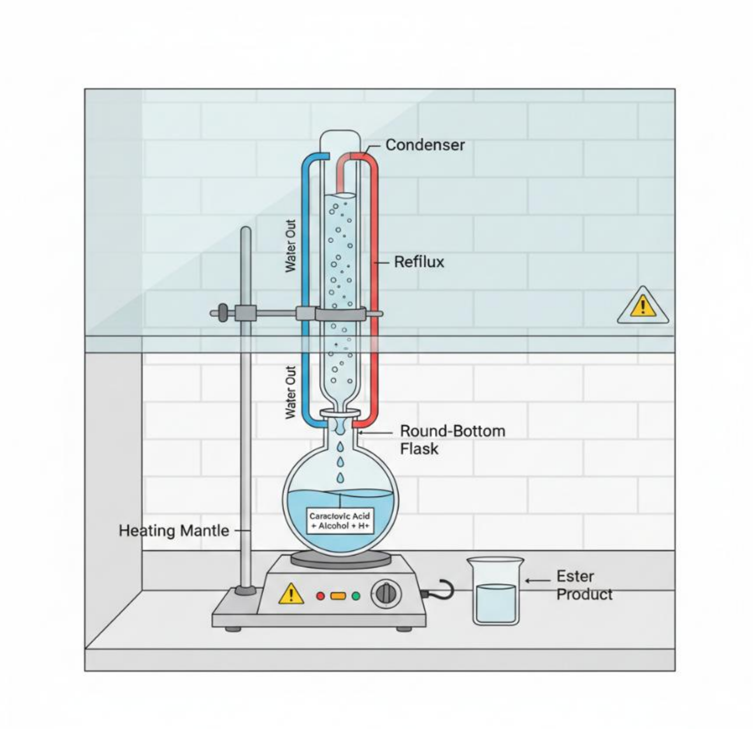


Plate 2.2: Reflux setup for ester preparation

AI prompt: “Create an image of a reflux apparatus used in esterification, showing round-bottom flask, condenser, and heating mantle.”
Search string: “reflux apparatus esterification OER”

2.2.3 Applications of esters in everyday life

Esters are widely used in everyday life due to their distinctive properties. Many esters are responsible for the flavours and fragrances of fruits, making them valuable in the food and perfume industries. They are also used as solvents in paints and varnishes, and as plasticisers to improve the flexibility of plastics. In medicine, esters serve as intermediates in drug synthesis and as components of anaesthetics.

Fill in the blank: The ester responsible for the characteristic smell of bananas is ____________________ acetate.

Category	Typical Application	Common Example(s)	Key Feature
Flavourings	Artificial fruit flavours in sweets, beverages, and baked goods.	Isoamyl acetate (banana), Ethyl butanoate (pineapple), Methyl butanoate (apple).	Mimics natural fruit oils to "trick" the brain into tasting specific fruits.
Fragrances	Perfumes, cosmetics, soaps, and air fresheners.	Benzyl acetate (jasmine), Linalyl acetate (lavender), Octyl acetate (orange).	Small, volatile molecules that evaporate easily to release pleasant scents.
Solvents	Paint thinners, varnishes, lacquers, and adhesives.	Ethyl acetate, Butyl acetate.	Polar solvents that dissolve many organic substances but are relatively non-toxic.
Nail Polish Remover	Solvent used to dissolve nail lacquer/enamel.	Ethyl acetate (often labelled "non-acetone").	Effectively removes stains and fats without the harshness of pure acetone.
Plastics	Flexible PVC, toys, cables, and food packaging.	Phthalate esters (plasticisers).	Added to plastics to increase flexibility, softness, and workability.
Synthetic Fibres	Clothing (Terylene/Dacron), curtains, and car seats.	Polyester (specifically Polyethylene Terephthalate or PET).	Long-chain polymers made of repeating ester units; resistant to shrinking and wrinkling.

Box 2.1: Everyday uses of esters

Flavourings in food and beverages
Fragrances in perfumes and cosmetics
Solvents in paints and nail polish removers
Raw materials in plastics and synthetic fibres

AI prompt: "Generate a table listing everyday uses of esters such as flavourings, fragrances, solvents, and plastics."
Search string: "applications of esters everyday life OER"

Pilot questions 2.2

The reaction between a carboxylic acid and an alcohol in the presence of an acid catalyst produces:
A. Aldehyde
B. Ketone
C. Ester
D. Hydrocarbon
(Linked to SLO 2.2)

In esterification, concentrated __________ is commonly used as the catalyst.
(Linked to SLO 2.2)

Which laboratory technique is used to prevent loss of volatile components during esterification?
A. Filtration
B. Reflux
C. Distillation
D. Extraction
(Linked to SLO 2.2)

The ester responsible for the characteristic smell of bananas is:
A. Ethyl acetate
B. Isoamyl acetate
C. Methyl salicylate
D. Butyl acetate
(Linked to SLO 2.2)

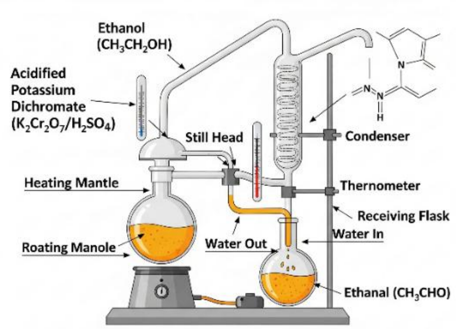
Name one industrial application of esters apart from flavourings and fragrances.
(Linked to SLO 2.2)

2.3 Preparation of Aldehydes and Ketones

2.3.1 Methods of preparing aldehydes

Aldehydes are organic compounds containing a carbonyl group (C=O) bonded to at least one hydrogen atom. They can be prepared in the laboratory through several methods. One common method is the **oxidation of primary alcohols**, where a primary alcohol is gently oxidised to form an aldehyde. For example, ethanol can be oxidised to ethanal using acidified potassium dichromate under controlled conditions. Another method involves **ozonolysis of alkenes**, where alkenes are cleaved by ozone to produce aldehydes.

Fill in the blank: Oxidation of a primary alcohol typically produces an ___________________



$$CH_3CH_2OH + [O] \xrightarrow{[O]} CH_3CHO + H_2O$$

$$Cr_2O72^3 \text{ (orange)} + 14H^+ + 6e^{\ominus} \rightarrow 2Cr^{3+} (gr^{3+} \text{ green}) + 7H_2O$$

Figure 2.3: Oxidation of a primary alcohol to an aldehyde

AI prompt: "Generate a labelled diagram showing oxidation of ethanol to ethanal using an oxidising agent."
Search string: "oxidation of primary alcohol to aldehyde diagram OER"

2.3.2 Methods of preparing ketones

Ketones are organic compounds containing a carbonyl group bonded to two carbon atoms. They are typically prepared by the **oxidation of secondary alcohols**, where the alcohol is oxidised to form a ketone. For example, propan-2-ol can be oxidised to propanone. Another method is **Friedel–Crafts acylation**, in which an aromatic compound reacts with an acyl chloride in the presence of a Lewis acid catalyst to form an aromatic ketone.

Fill in the blank: Oxidation of a secondary alcohol typically produces a __________________.

Plate 2.3: Laboratory setup for ketone preparation

AI prompt: "Create an image of a laboratory setup showing oxidation of a secondary alcohol to a ketone using reflux apparatus."
Search string: "oxidation secondary alcohol to ketone laboratory setup OER"

2.3.3 Comparative properties and uses of aldehydes and ketones

Although aldehydes and ketones both contain the carbonyl group, their properties differ due to structural variations. **Aldehydes** are generally more reactive than ketones because the carbonyl carbon is bonded to a hydrogen atom, making it more susceptible to oxidation. Aldehydes are widely used in the manufacture of perfumes, dyes, and resins. **Ketones**, on the other hand, are stable and commonly used as solvents (e.g., acetone) and in the production of pharmaceuticals.

Fill in the blank: Aldehydes are generally more reactive than ketones because the carbonyl carbon is bonded to a __________________ atom.

Application Category	Aldehydes (R-CHO)	Ketones (R-CO-R')
Flavouring Agents	Cinnamaldehyde (cinnamon), Vanillin (vanilla), and Benzaldehyde (almonds) are primary food additives.	Diacetyl provides artificial butter flavor; Fructose (a keto-sugar) is a natural sweetener.
Fragrances	Used as "top notes" in perfumes (e.g., Chanel No. 5); Citral (lemon) and Lilial (lily) are common floral scents.	Acetophenone provides jasmine and cherry scents; Civetone and Muscone are used for musk-like odors.
Solvents	Less commonly used as pure solvents due to higher reactivity and oxidation.	Acetone is the standard solvent for nail polish remover and paint thinners; Butanone (MEK) is used in glues.
Preservatives	Formaldehyde (as Formalin) is used to preserve biological specimens and in embalming.	Generally not used as primary preservatives.
Disinfectants	Glutaraldehyde is a potent cleaner that kills bacteria and viruses on surgical tools.	Acetone has mild disinfectant properties but is primarily used for cleaning industrial equipment.
Plastics & Polymers	Formaldehyde is critical for making Bakelite (electrical switches) and melamine resins.	Cyclohexanone is a key precursor used to manufacture Nylon-6.
Biology & Medicine	Retinal is essential for the process of vision in the human eye.	Steroid hormones (Testosterone, Progesterone, Cortisone) are naturally occurring ketones.

Box 2.2: Comparative uses of aldehydes and ketones

Aldehydes: flavourings, perfumes, intermediates in synthesis
Ketones: solvents, pharmaceuticals, plastics

AI prompt: "Generate a table comparing uses of aldehydes and ketones in everyday applications."
Search string: "uses of aldehydes and ketones comparison OER"

Pilot questions 2.3

Oxidation of a primary alcohol typically produces:
A. Ketone
B. Aldehyde
C. Ester
D. Carboxylic acid
(Linked to SLO 2.3)

Oxidation of a secondary alcohol typically produces:
A. Aldehyde
B. Ketone
C. Ester
D. Carboxylic acid
(Linked to SLO 2.3)

Which method involves reacting an aromatic compound with an acyl chloride in the presence of a catalyst?
A. Esterification
B. Friedel–Crafts acylation
C. Ozonolysis
D. Reduction
(Linked to SLO 2.3)

Aldehydes are generally more reactive than ketones because the carbonyl carbon is bonded to a:
A. Oxygen atom
B. Hydrogen atom
C. Carbon atom
D. Nitrogen atom
(Linked to SLO 2.3)

Name one industrial application of ketones.
(Linked to SLO 2.3)

2.4 Practical Considerations in Organic Compound Preparation

2.4.1 Safety precautions in organic synthesis

When carrying out **organic synthesis**, it is essential to follow strict **safety precautions** to protect yourself and others. Organic reactions often involve flammable solvents, corrosive acids, or toxic reagents. Always wear personal protective equipment (PPE), including lab coat, gloves, and safety goggles. Work in a fume hood when handling volatile or hazardous chemicals, and ensure that fire extinguishers and first aid kits are accessible. Proper ventilation and careful disposal of waste are also critical to maintaining a safe environment.

Fill in the blank: Wearing goggles, gloves, and a lab coat are examples of __________________.

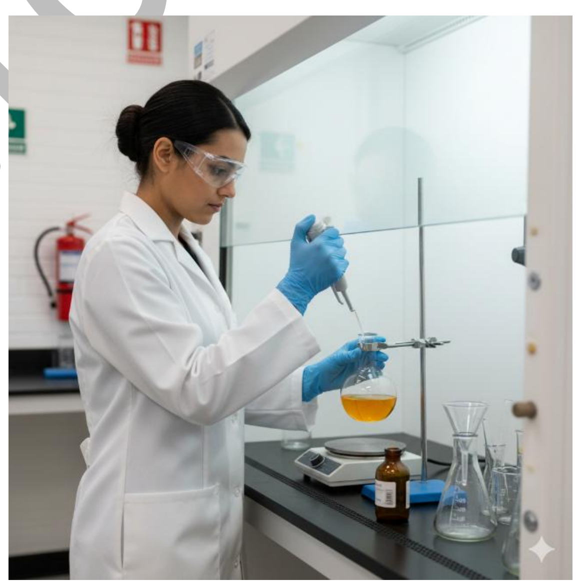


Plate 2.4: Use of PPE during organic synthesis

AI prompt: "Create an image of a student in a chemistry laboratory wearing goggles, gloves, and a lab coat while handling chemicals."
Search string: "chemistry laboratory PPE organic synthesis OER"

2.4.2 Recording observations and results

Accurate **recording of observations** is a vital part of laboratory work. This involves noting physical changes such as colour, odour, or phase separation, as well as quantitative data like temperature, time, and yield. Recording results ensures reproducibility and allows for comparison with theoretical expectations. A well-maintained laboratory notebook serves as both a scientific record and a legal document, supporting accountability and reliability in research.

Fill in the blank: A well-maintained __________________ serves as both a scientific record and a legal document in laboratory practice.

Best Practices for Recording Laboratory Data

Tip	Description	Rationale
Immediate Recording	Document data live as experiments progress; never rely on memory or scrap paper.	Prevents data loss and ensures the chronological order of events.
Standardized Units	Use consistent SI units (e.g., grams, millilitres, Kelvin) throughout the entry.	Avoids calculation errors and ensures results can be easily compared.
Document Anomalies	Explicitly note unexpected changes, spills, or instrument fluctuations.	Provides context for "outlier" data and helps in troubleshooting the experiment.
Authentication	Ensure every entry is dated and signed by the person performing the work.	Establishes a legal and professional record for intellectual property and accountability.
Ink Only	Always write in permanent blue or black ink; never use pencil or erasable pens.	Ensures a permanent, tamper-proof record of original observations.
Correction Protocol	Cross out errors with a single line and initial them; do not use correction fluid.	Maintains transparency and allows the original entry to remain legible.
Visual Evidence	Include sketches, taped-in printouts, or references to digital image files.	Enhances the description of complex setups or physical changes like colour shifts.

Box 2.3: Tips for effective recording of laboratory observations

Record data immediately during experiments.
Use clear and consistent units of measurement.
Note any unexpected changes or anomalies.
Keep entries dated and signed.

AI prompt: “Generate a table listing tips for effective recording of laboratory observations and results.”
Search string: “laboratory notebook recording observations OER”

2.4.3 Common errors and troubleshooting in preparation

Even with careful planning, **common errors** can occur during organic synthesis. These include incomplete reactions due to insufficient heating, contamination from impure reagents, or incorrect measurements of reactants. **Troubleshooting** refers to the process of identifying and correcting these issues. For example, if an ester yield is unexpectedly low, checking the purity of the alcohol and acid or ensuring the reflux time was sufficient may resolve the problem. Developing troubleshooting skills helps learners build confidence and resilience in laboratory practice.

Fill in the blank: Identifying and correcting problems during organic synthesis is known as __________________.

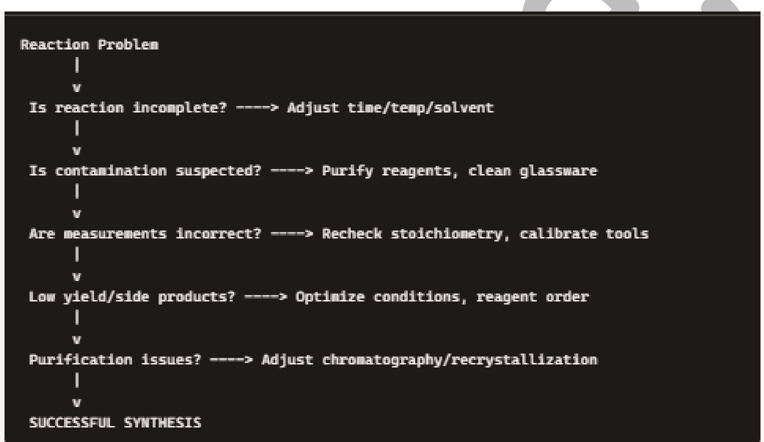


Figure 2.4: Troubleshooting process in organic compound preparation

AI prompt: “Generate a flowchart showing common errors in organic synthesis such as incomplete reaction, contamination, and incorrect measurements, with troubleshooting steps.”
Search string: “organic synthesis troubleshooting flowchart OER”

Pilot questions 2.4

Wearing goggles, gloves, and a lab coat are examples of:
A. Emergency procedures
B. Safety precautions
C. Troubleshooting steps
D. Recording observations
(Linked to SLO 2.4)

A well-maintained ___________ serves as both a scientific record and a legal document in laboratory practice.
(Linked to SLO 2.4)

Which of the following is a common error in organic synthesis?
A. Using pure reagents
B. Incomplete reaction due to insufficient heating
C. Recording observations immediately
D. Wearing PPE
(Linked to SLO 2.4)

Identifying and correcting problems during organic synthesis is known as:
A. Recording
B. Troubleshooting
C. Safety precaution
D. Observation
(Linked to SLO 2.4)

Suggest one way to improve the yield of an ester if the reaction appears incomplete.
(Linked to SLO 2.4)

Series Summary

This Series on **Preparation of Esters, Aldehydes, and Ketones** was designed to introduce you to the principles and practical methods of synthesising key organic compounds. You began with an overview of esters, aldehydes, and ketones, learning their defining characteristics and general laboratory methods of preparation. You then explored esterification in detail, including the laboratory procedure for preparing esters and their wide-ranging applications in everyday life. Building on this, you studied the preparation of aldehydes and ketones, examining methods such as oxidation of alcohols and comparing their properties and uses. Finally, you considered practical aspects of organic synthesis, focusing on safety precautions, accurate recording of observations, and troubleshooting strategies.

By completing this Series, you should now be able to **define the key characteristics of esters, aldehydes, and ketones, and explain general laboratory methods for their preparation (SLO 2.1)**, **demonstrate ester preparation and explain the principles of esterification (SLO 2.2)**, **apply methods for synthesising aldehydes and ketones and describe their comparative properties and uses (SLO 2.3)**, and **evaluate safety precautions, recording practices, and troubleshooting strategies in organic compound preparation (SLO 2.4)**. These outcomes ensure that you are well-prepared to carry out organic synthesis responsibly and effectively, with both theoretical understanding and practical competence.

Glossary of Terms

Aldehyde: An organic compound containing a carbonyl group (C=O) bonded to at least one hydrogen atom, often formed by the oxidation of primary alcohols.

Carbonyl group: A functional group consisting of a carbon atom double-bonded to an oxygen atom, found in aldehydes and ketones.

Ester: An organic compound formed when a carboxylic acid reacts with an alcohol, usually in the presence of an acid catalyst, producing a substance with a fruity odour.

Esterification: The chemical reaction between a carboxylic acid and an alcohol to form an ester and water, typically catalysed by concentrated sulphuric acid.

Ketone: An organic compound containing a carbonyl group bonded to two carbon atoms, often formed by the oxidation of secondary alcohols.

Organic synthesis: The process of constructing organic compounds through controlled chemical reactions, such as esterification or oxidation.

Oxidation: A chemical process in which a substance loses electrons; in organic chemistry, it often refers to the conversion of alcohols into aldehydes or ketones.

Primary alcohol: An alcohol in which the hydroxyl group (–OH) is attached to a carbon atom bonded to only one other carbon atom; can be oxidised to form aldehydes.

Secondary alcohol: An alcohol in which the hydroxyl group (–OH) is attached to a carbon atom bonded to two other carbon atoms; can be oxidised to form ketones.

Troubleshooting: The process of identifying the source of an error in an experiment and applying corrective measures to improve results.

Concept Check Questions [Series 2]

Objective Questions

The functional group common to aldehydes and ketones is the __________________ group.
(Linked to SLO 2.1)

The process of preparing esters by reacting carboxylic acids with alcohols in the presence of an acid catalyst is called __________________.
(Linked to SLO 2.2)

Aldehydes are commonly prepared by the controlled oxidation of __________________ alcohols.
(Linked to SLO 2.3)

Ketones are commonly prepared by the oxidation of __________________ alcohols.
(Linked to SLO 2.3)

Recording observations immediately in a __________________ ensures reproducibility and accuracy in laboratory work.
(Linked to SLO 2.4)

Short-Answer Questions

Define esterification and explain why concentrated sulphuric acid is used in the process.
(Linked to SLO 2.2)

State one everyday application of esters and explain its relevance.
(Linked to SLO 2.2)

Describe one laboratory method for preparing aldehydes.
(Linked to SLO 2.3)

Explain one difference in the reactivity of aldehydes compared to ketones.
(Linked to SLO 2.3)
Identify one common error in organic synthesis and suggest a troubleshooting strategy.
(Linked to SLO 2.4)

Long-Answer Questions

Analyse the importance of esterification in both laboratory practice and industry.
(Linked to SLO 2.2)
Evaluate the comparative properties and uses of aldehydes and ketones, highlighting their significance in everyday life.
(Linked to SLO 2.3)
Assess the role of safety precautions, recording practices, and troubleshooting strategies in ensuring successful organic compound preparation.
(Linked to SLO 2.4)

Answers to Concept Check Questions [Series 2]

Objective Questions

Carbonyl
Esterification
Primary
Secondary
Laboratory notebook

Short-Answer Questions

Esterification is the reaction between a carboxylic acid and an alcohol to form an ester and water. Concentrated sulphuric acid is used as a catalyst and to remove water, driving the reaction forward.
Esters are used in perfumes because of their pleasant fruity odours, making them valuable in fragrance production.
Aldehydes can be prepared by oxidising primary alcohols, such as converting ethanol to ethanal using acidified potassium dichromate.
Aldehydes are more reactive than ketones because the carbonyl carbon is bonded to a hydrogen atom, making it more susceptible to oxidation.
Incorrect measurement of reagents is a common error. Troubleshooting involves rechecking reagent quantities and repeating the experiment with corrected measurements.

Long-Answer Questions

Question 1

Basic response: Esterification is important because it allows the preparation of esters, which are widely used in flavourings, perfumes, and solvents.
Value-added response: Outstanding learners may extend by discussing industrial applications such as the production of biodiesel and the role of esterification in pharmaceutical synthesis.

Question 2

Basic response: Aldehydes are reactive and used in perfumes and resins, while ketones are stable and used as solvents and in pharmaceuticals.
Value-added response: Learners may extend by comparing their oxidation behaviour, noting that aldehydes can be easily oxidised to acids, whereas ketones resist oxidation, making them useful in stable formulations.

Question 3

Basic response: Safety precautions, accurate recording, and troubleshooting ensure that experiments are conducted responsibly and results are reliable.
Value-added response: Learners may extend by linking these practices to professional laboratory standards, emphasising how they build a culture of safety and reproducibility in research and industry.

Answers to Pilot Questions [Series 2]

Part 2.1 Introduction to Organic Compound Preparation

Ester
Carbonyl group
Organic synthesis
An acid catalyst
Ketone

Part 2.2 Preparation of Esters

Ester
Sulphuric acid
Reflux
Isoamyl acetate
Plastics (or synthetic fibres, pharmaceuticals, solvents)

Part 2.3 Preparation of Aldehydes and Ketones

Aldehyde
Ketone
Friedel–Crafts acylation
Hydrogen atom
Solvents (or pharmaceuticals, plastics)

Part 2.4 Practical Considerations in Organic Compound Preparation

Safety precautions
Laboratory notebook
Incomplete reaction due to insufficient heating
Troubleshooting
Extend reflux time (or check purity of reagents)

References and Attributions [Series 2]

Textual Sources

Atkins, P., & Jones, L. (2010). *Chemical Principles: The Quest for Insight* (5th ed.). Oxford University Press.
Housecroft, C. E., & Sharpe, A. G. (2018). *Inorganic Chemistry* (5th ed.). Pearson.
IUPAC. (1997). *Compendium of Chemical Terminology (the "Gold Book")*.

Illustrations (Figures, Plates, Tables, Boxes)

Figure 2.1 Structural comparison of esters, aldehydes, and ketones
AI prompt: "Generate a labelled diagram showing the chemical structures of esters, aldehydes, and ketones side by side."
Search string: "esters aldehydes ketones structural diagram OER"
Plate 2.1 Laboratory setup for esterification
AI prompt: "Create an image of a chemistry laboratory setup showing esterification with a round-bottom flask, condenser, and heating mantle."
Search string: "esterification laboratory setup OER"
Figure 2.2 General reaction scheme for esterification
AI prompt: "Generate a labelled diagram showing esterification reaction between a carboxylic acid and an alcohol forming an ester and water."
Search string: "esterification reaction diagram OER"
Plate 2.2 Reflux setup for ester preparation
AI prompt: "Create an image of a reflux apparatus used in esterification, showing round-bottom flask, condenser, and heating mantle."
Search string: "reflux apparatus esterification OER"
Box 2.1 Everyday uses of esters
AI prompt: "Generate a table listing everyday uses of esters such as flavourings,

fragrances, solvents, and plastics."
Search string: "applications of esters everyday life OER"

Figure 2.3 Oxidation of a primary alcohol to an aldehyde
AI prompt: "Generate a labelled diagram showing oxidation of ethanol to ethanal using an oxidising agent."
Search string: "oxidation of primary alcohol to aldehyde diagram OER"

Plate 2.3 Laboratory setup for ketone preparation
AI prompt: "Create an image of a laboratory setup showing oxidation of a secondary alcohol to a ketone using reflux apparatus."
Search string: "oxidation secondary alcohol to ketone laboratory setup OER"

Box 2.2 Comparative uses of aldehydes and ketones
AI prompt: "Generate a table comparing uses of aldehydes and ketones in everyday applications."
Search string: "uses of aldehydes and ketones comparison OER"

Plate 2.4 Use of PPE during organic synthesis
AI prompt: "Create an image of a student in a chemistry laboratory wearing goggles, gloves, and a lab coat while handling chemicals."
Search string: "chemistry laboratory PPE organic synthesis OER"

Box 2.3 Tips for effective recording of laboratory observations
AI prompt: "Generate a table listing tips for effective recording of laboratory observations and results."
Search string: "laboratory notebook recording observations OER"

Figure 2.4 Troubleshooting process in organic compound preparation
AI prompt: "Generate a flowchart showing common errors in organic synthesis such as incomplete reaction, contamination, and incorrect measurements, with troubleshooting steps."
Search string: "organic synthesis troubleshooting flowchart OER"

Notes on Attribution

AI-generated illustrations are documented with prompts and should be noted with the generation date and platform used.

Where OERs are used, attribution must comply with the licence terms of the source.

References are presented in APA style for consistency.

- **Course code: CHM 208**
- **Course title: CHM 208: General Chemistry Practical IV** (1 Unit C: PH 45)
- **Course credit load:** (1 Unit C: PH 45)
- **List of Series**:

Series 1: **Laboratory Safety and Rules in General Chemistry**

Series 2: **Preparation of Esters, Aldehydes, and Ketones**

Series 3: **Vinegar Analysis and Chromatographic Techniques**

Series 4: **Thin Layer Chromatography Applications**

Series 5: **Alcohol Dehydration and Functional Group Analysis**

Proposed Outline

3.1 Introduction to Vinegar Analysis

Definition and composition of vinegar
Importance of vinegar analysis in food chemistry
Overview of analytical methods

3.2 Acid–Base Titration of Vinegar

Principle of titration
Laboratory procedure for vinegar titration
Calculations of acetic acid concentration
Sources of error and accuracy considerations

3.3 Chromatographic Techniques in Organic Analysis

Definition of **chromatography** (separation based on differential movement through a medium)
Types of chromatography (paper, thin-layer, column, gas chromatography)
Applications in organic compound identification

3.4 Practical Applications and Safety Considerations

Case studies: vinegar quality control and food industry standards
Safety precautions in titration and chromatography experiments
Recording and interpreting results effectively

Introduction

In the last Series, we explored the preparation of esters, aldehydes, and ketones, focusing on their synthesis, properties, and practical considerations in the laboratory. Building on that foundation, this Series shifts attention to analytical techniques, specifically vinegar analysis and chromatography, which are essential tools for determining composition and purity in everyday substances and organic compounds. These methods are widely used in food chemistry, pharmaceuticals, and research, making them highly relevant to your study of applied organic chemistry.

The aim of this Series is to equip you with the knowledge and skills needed to analyse vinegar using acid–base titration and to apply chromatographic techniques for separating and identifying organic compounds.

We shall commence this Series by introducing vinegar analysis, considering its composition and significance in food chemistry. Next, we will study acid–base titration of vinegar, focusing on the principles, procedures, and calculations involved. Following that, we will move on to chromatographic techniques, examining different types and their applications in organic analysis. Finally, we will conclude with practical applications and safety considerations, ensuring you are prepared to carry out these experiments effectively and responsibly.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 3.1 define vinegar and explain its composition and relevance in food chemistry,
SLO 3.2 demonstrate how to carry out acid–base titration of vinegar to determine acetic acid concentration,
SLO 3.3 calculate the concentration of acetic acid in vinegar samples using titration data,
SLO 3.4 describe the principles of chromatographic techniques used in organic analysis,
SLO 3.5 apply paper or thin-layer chromatography to separate and identify organic compounds, and
SLO 3.6 evaluate safety precautions and recording practices required for titration and chromatography experiments.

3.1 Introduction to Vinegar Analysis

3.1.1 Definition and composition of vinegar

Vinegar is a dilute solution of acetic acid (CH_3COOH) in water, usually containing about 4–8% acetic acid by volume. It is produced through the fermentation of ethanol by acetic acid bacteria. In addition to acetic acid, vinegar may contain small amounts of other organic acids, flavour compounds, and minerals depending on its source, such as apple cider vinegar or wine vinegar. These components contribute to its taste, aroma, and nutritional value.

Fill in the blank: Vinegar is a dilute solution of __________________ in water.

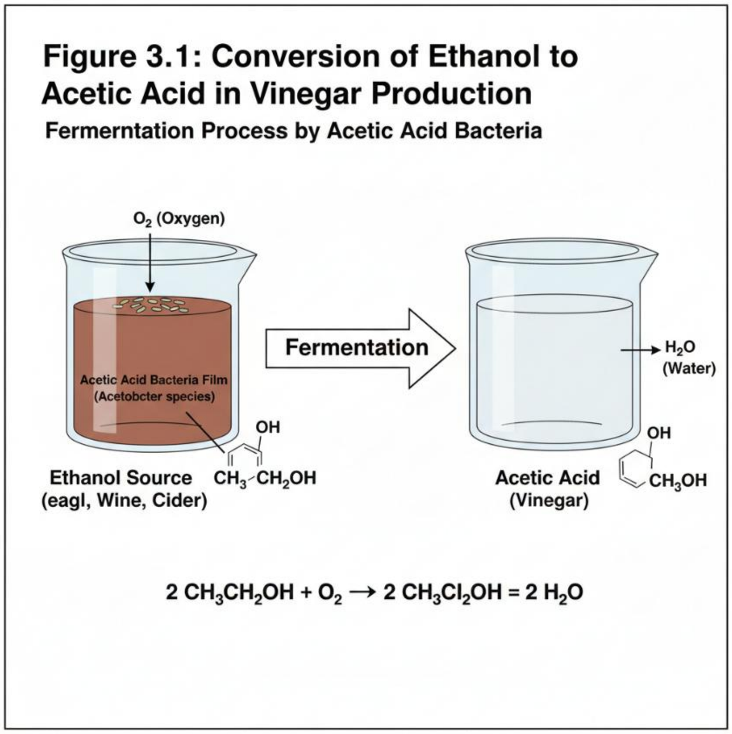


Figure 3.1: Conversion of ethanol to acetic acid in vinegar production

AI prompt: "Generate a labelled diagram showing fermentation of ethanol to acetic acid by bacteria."
Search string: "vinegar fermentation ethanol to acetic acid diagram OER"

3.1.2 Importance of vinegar analysis in food chemistry

Analysing vinegar is important in **food chemistry** because its acetic acid concentration determines flavour, preservation ability, and compliance with food industry standards. Accurate analysis ensures that vinegar meets regulatory requirements and provides consistent quality for consumers. In addition, vinegar analysis helps detect adulteration or dilution, which can affect both safety and market value.

Fill in the blank: The concentration of __________________ in vinegar determines its strength and effectiveness in preservation.

Category	Specific Use	Scientific/Practical Function
Food Preservation	**Pickling** vegetables (cucumbers, onions, etc.).	The low pH (high acidity) inhibits the growth of **spoilage-causing bacteria**, extending shelf life.
Flavouring	Salad dressings, marinades, and sauces.	Adds a "bright" acidic note that balances fats and enhances the flavour profile of dishes.
Household Cleaning	Removing **limescale** and glass streaks.	Acetic acid reacts with alkaline deposits (like calcium carbonate) to dissolve mineral buildup and cut through grease.
Medicinal	Management of minor skin irritations or blood sugar control.	Historically used as a mild antiseptic; modern studies suggest it may improve insulin sensitivity during high-carb meals.
Cosmetic	**Hair rinses** and skin toners.	Helps restore the natural acidic pH of the skin and scalp, smoothing the hair cuticle for extra shine.
Weed Control	Natural herbicide for garden paths.	High concentrations of vinegar dehydrate plant tissues, acting as a non-toxic alternative to synthetic weed killers.

Box 3.1: Everyday uses of vinegar

Food preservation (pickling)
Flavouring in cooking
Household cleaning agent
Medicinal and cosmetic applications

AI prompt: "Generate a table listing everyday uses of vinegar such as food preservation, flavouring, cleaning, and medicinal applications."
Search string: "everyday uses of vinegar OER"

3.1.3 Overview of analytical methods

Several **analytical methods** are used to determine the composition and quality of vinegar. The most common is **acid–base titration**, which measures the concentration of acetic acid by neutralising it with a standard base such as sodium hydroxide. Chromatographic techniques, including paper and thin-layer chromatography, can also be applied to separate and identify organic compounds present in vinegar. These methods provide both quantitative and qualitative information, ensuring a comprehensive analysis.

Fill in the blank: The most common method for analysing vinegar is __________________ titration.

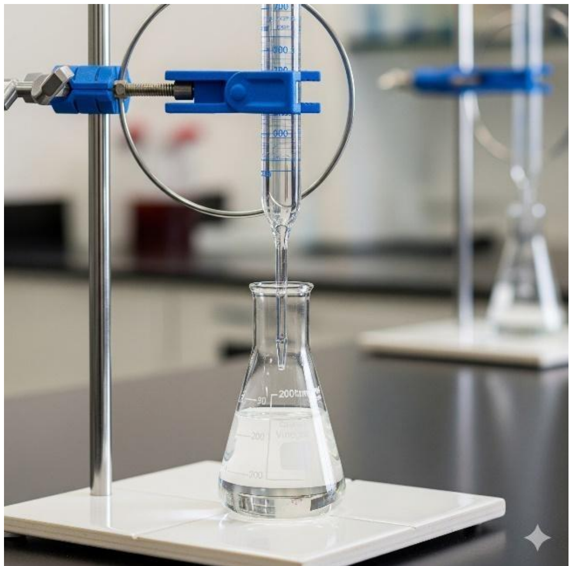


Plate 3.1: Laboratory titration setup for vinegar analysis

AI prompt: “Create an image of a laboratory titration setup with burette, flask, and sodium hydroxide solution used for vinegar analysis.”
Search string: “vinegar titration laboratory setup OER”

Pilot questions 3.1

Vinegar is a dilute solution of:
- A. Ethanol
- B. Acetic acid
- C. Hydrochloric acid
- D. Citric acid

(Linked to SLO 3.1)

The concentration of ___________ in vinegar determines its strength and effectiveness in preservation.

(Linked to SLO 3.1)

Which method is most commonly used to analyse vinegar in food chemistry?
- A. Chromatography
- B. Distillation
- C. Acid–base titration
- D. Filtration

(Linked to SLO 3.2)

Name one everyday use of vinegar apart from cooking.

(Linked to SLO 3.1)

3.2 Acid–Base Titration of Vinegar

3.2.1 Principle of titration

Titration is an analytical technique used to determine the concentration of a solution by reacting it with another solution of known concentration. In the case of vinegar, the acetic acid present is titrated against a standard base, usually sodium hydroxide (NaOH). An **indicator** such as phenolphthalein is added to signal the endpoint, which occurs when the acid has been completely neutralised by the base. This colour change marks the point at which calculations can be made to determine the concentration of acetic acid in the vinegar sample.

Fill in the blank: In vinegar titration, acetic acid is neutralised by a standard solution of __________________.

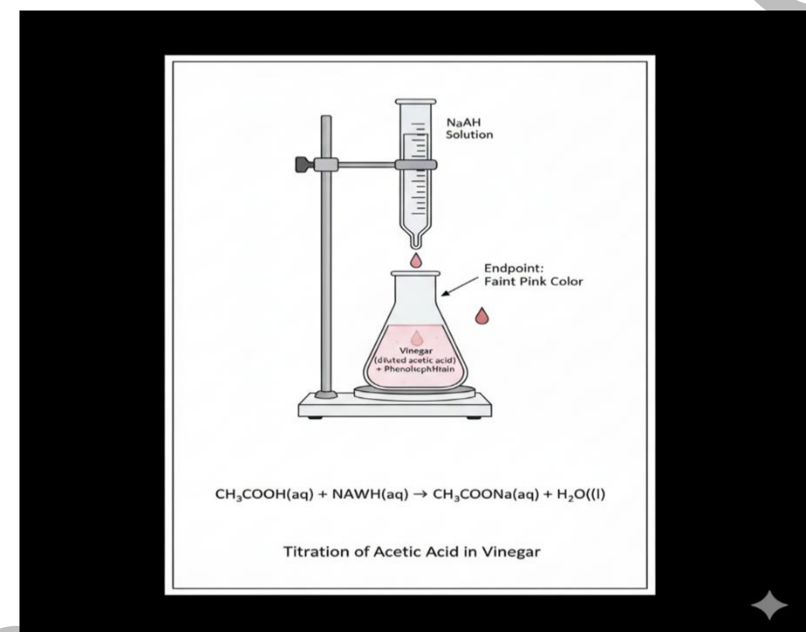


Figure 3.2: Neutralisation of acetic acid in vinegar by sodium hydroxide

AI prompt: “Generate a labelled diagram showing acid–base titration of vinegar with sodium hydroxide and phenolphthalein indicator.”
Search string: “vinegar titration neutralisation diagram OER”

3.2.2 Laboratory procedure for vinegar titration

The laboratory procedure for vinegar titration involves several steps. First, a measured volume of vinegar is placed in a conical flask, and a few drops of phenolphthalein indicator are added. A burette is filled with standard sodium hydroxide solution, which is then added drop by drop to the vinegar while swirling the flask. As the titration progresses, the solution changes colour, and the endpoint is reached when a faint pink colour persists. The volume of sodium hydroxide used is recorded, and the experiment is repeated to obtain consistent results.

Fill in the blank: The indicator commonly used in vinegar titration is __________________.

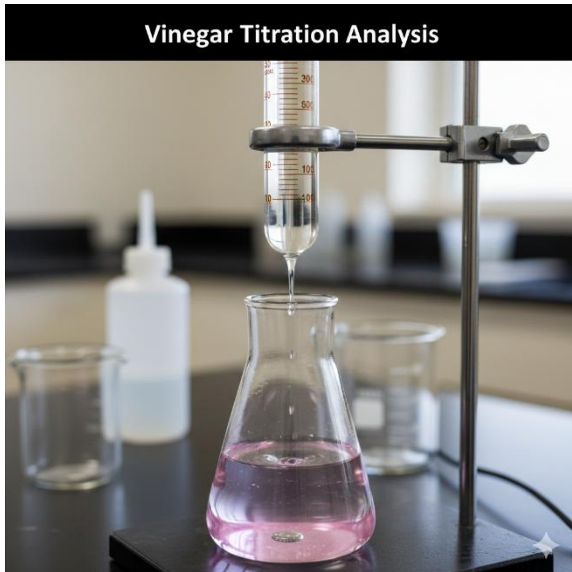


Plate 3.2: Laboratory setup for vinegar titration

AI prompt: “Create an image of a laboratory titration setup showing burette, conical flask with vinegar, and phenolphthalein indicator.”
Search string: “vinegar titration laboratory setup OER”

3.2.3 Calculations of acetic acid concentration

Once the titration is complete, the concentration of acetic acid in vinegar can be calculated using the titration formula:

M1V1=M2V2

Here, M1 and V1 represent the molarity and volume of the acetic acid solution, while M2 and V2 represent the molarity and volume of the sodium hydroxide solution. By rearranging the equation, the molarity of acetic acid can be determined. This value can then be converted into grams per litre or percentage concentration, depending on the requirement.

Fill in the blank: In vinegar titration, acetic acid reacts with sodium hydroxide in a __________ ratio.

$$CH_3COOH_{(aq)} + NaOH_{(aq)} \rightarrow CH_3COONa_{(aq)} + H_2O_{(l)}$$

Steps for Calculating Acetic Acid Concentration

Step	Action	Mathematical Formula / Note
1. Record Titrant Volume	Note the exact volume of **NaOH** added to reach the endpoint.	$V_{NaOH} = \text{Final Reading} - \text{Initial Reading}$
2. Calculate Moles of Base	Convert volume to liters and multiply by the known concentration.	$n_{NaOH} = C_{NaOH} \times V_{NaOH}$
3. Apply Mole Ratio	Use the balanced equation to find the moles of acid.	$n_{CH_3COOH} = n_{NaOH}$ (since ratio is $1:1$)
4. Calculate Acid Concentration	Divide the moles of acid by the initial volume of the vinegar sample.	$C_{CH_3COOH} = \frac{n_{CH_3COOH}}{V_{vinegar}}$
5. Optional: Convert to %	Multiply the molarity by the molar mass (60.05 g/mol) to find mass/volume percent.	$\%(w/v) = \frac{\text{Molarity} \times 60.05}{10}$

Box 3.2: Steps for calculating acetic acid concentration

Record the volume of sodium hydroxide used.
Calculate moles of sodium hydroxide using concentration and volume.
Apply the 1:1 mole ratio to find moles of acetic acid.
Divide by the volume of vinegar to obtain concentration.

AI prompt: “Generate a table outlining steps for calculating acetic acid concentration in vinegar titration.”
Search string: “vinegar titration calculation steps OER”

3.2.4 Sources of error and accuracy considerations

Like all experiments, titration is subject to **sources of error**. Common errors include misreading the burette, adding sodium hydroxide too quickly, or failing to detect the exact endpoint. Accuracy can be improved by repeating the titration several times and taking an average of consistent readings. Using clean equipment, precise measurements, and careful observation also help minimise errors.

Fill in the blank: Repeating titrations until concordant results are obtained improves __________________.

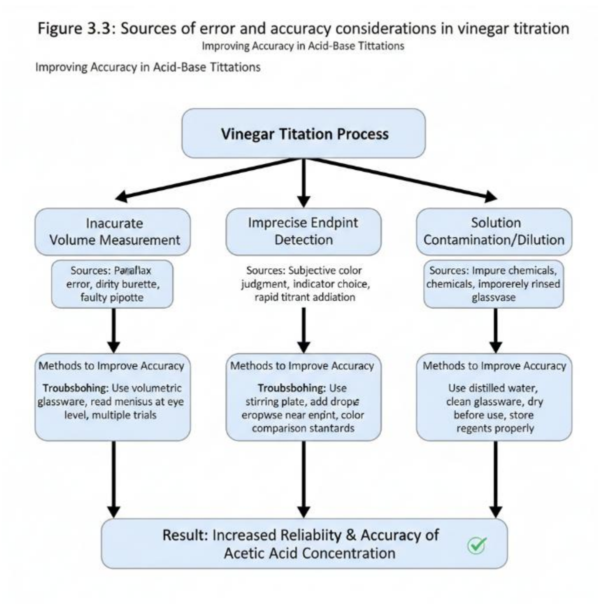


Figure 3.3: Sources of error and accuracy considerations in vinegar titration

AI prompt: “Generate a flowchart showing common errors in vinegar titration such as inaccurate measurement and endpoint detection, with methods to improve accuracy.”
Search string: “vinegar titration errors and accuracy OER”

Pilot questions 3.2

In vinegar titration, acetic acid is neutralised by:
A. Hydrochloric acid
B. Sodium hydroxide
C. Sulphuric acid
D. Potassium nitrate
(Linked to SLO 3.2)

The indicator commonly used in vinegar titration is:
A. Methyl orange
B. Phenolphthalein
C. Litmus
D. Bromothymol blue
(Linked to SLO 3.2)

In vinegar titration, acetic acid reacts with sodium hydroxide in a __________ ratio.
(Linked to SLO 3.3)

Which of the following is a common source of error in titration?
A. Using freshly prepared solutions
B. Inaccurate measurement of volumes
C. Repeating titrations until concordant results are obtained

D. Using clean equipment
(Linked to SLO 3.3)

Suggest one way to improve the accuracy of vinegar titration results.
(Linked to SLO 3.3)

3.3 Chromatographic Techniques in Organic Analysis

3.3.1 Definition of chromatography

Chromatography is a separation technique used to identify and analyse components of a mixture by allowing them to move at different rates through a medium. The principle is based on differences in solubility and interaction between the mobile phase (the solvent) and the stationary phase (the medium). This makes chromatography a powerful tool in organic analysis, as it can separate compounds that are otherwise difficult to distinguish.

Fill in the blank: Chromatography separates components of a mixture based on differences in __________________ between phases.

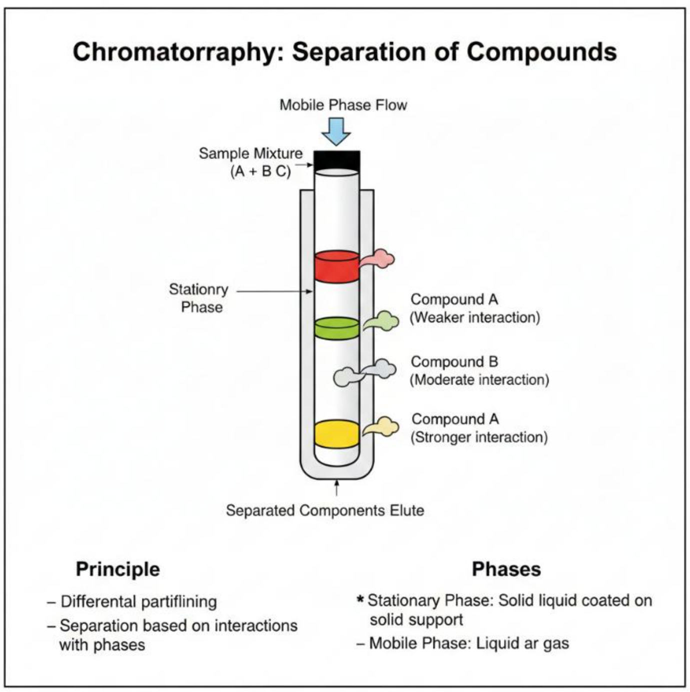


Figure 3.4: Principle of chromatography

AI prompt: "Generate a labelled diagram showing chromatography with stationary phase and mobile phase separating different compounds."
Search string: "chromatography principle stationary mobile phase diagram OER"

3.3.2 Types of chromatography

There are several types of chromatography, each suited to different applications:

Paper chromatography: Uses absorbent paper as the stationary phase. It is simple and often used in teaching laboratories to separate coloured compounds such as inks or plant pigments.

Thin-layer chromatography (TLC): Uses a thin layer of silica gel or alumina coated on a plate as the stationary phase. It is more versatile than paper chromatography and widely used in organic chemistry for monitoring reactions.

Column chromatography: Involves packing a column with silica or alumina and passing a solvent through it. It is useful for separating larger quantities of compounds.

Gas chromatography (GC): Uses a gaseous mobile phase and is highly effective for volatile compounds. It is often used in forensic science and environmental analysis.

Fill in the blank: Thin-layer chromatography uses a thin layer of ________________ or alumina as the stationary phase.

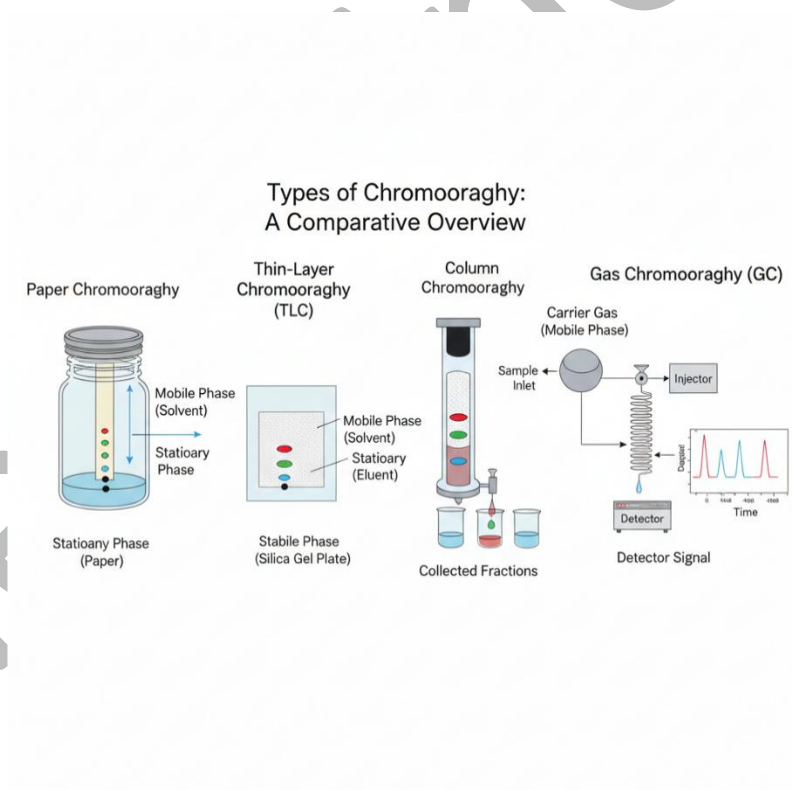


Plate 3.3: Types of chromatography techniques

AI prompt: "Create an image showing paper chromatography, thin-layer chromatography,

column chromatography, and gas chromatography setups side by side."
Search string: "types of chromatography paper TLC column GC OER"

3.3.3 Applications in organic compound identification

Chromatography is widely applied in **organic compound identification**. For example, TLC can be used to monitor the progress of a chemical reaction by showing whether starting materials have been converted into products. Paper chromatography can separate pigments in plant extracts, while gas chromatography can identify volatile compounds in perfumes or food flavourings. These applications make chromatography an essential tool in both research and industry.

Fill in the blank: Thin-layer chromatography can be used to monitor the __________________ of a reaction.

Applications of Chromogoaghy

Versatile Analytical & Preparative Techniques

Application Category	Specific Use Case	Technique Examples	Key Benefits/Source
Monitoring Reaction Progress	Track conversion of reactants, formation of products, and internediates over time.	TLC, GC, HPLC	Real-time feedback, optimization of yield. [1]
Identifing Unknown Compounds	Qualitive analysis of complex mixtures.	GC-MS, LC-MS, TLC	High sensitivity, accurate identiflation via spectral spectral libraries. [2]
Puriffing compounds for isolation & collection	Separate compounds for isolation	Column Chromocoragy, Preparative HPLC, Flash Chramooragha	Quality control, detect contaniants, pharmactulales.
Analying Food & Phamacutical Products	GC, HPLE, HPTLC	High purity isolation for research, pharmacuales.	Safety, quality assurance, regulatory compliance. [1, 6]

1. researchgate.net - Applications of Chromooraghy: Principle, Types, Uses, Diagram

Sources
2. microbenotes.com - Chromooraghy: Principle, Types, in Food Analysis...
3. mdpfi.com – Application of Chromooraghy in Applications of Gas Chromocoraghy

Box 3.3: Applications of chromatography in organic analysis

Monitoring reaction progress
Identifying unknown compounds
Purifying mixtures
Analysing food and pharmaceutical products

AI prompt: “Generate a table listing applications of chromatography such as monitoring reactions, identifying compounds, purifying mixtures, and analysing food products.”
Search string: “applications of chromatography organic analysis OER”

Pilot questions 3.3

Chromatography separates components of a mixture based on differences in:
- A. Colour
- B. Solubility and interaction
- C. Temperature
- D. Pressure

(Linked to SLO 3.4)

Thin-layer chromatography uses a thin layer of __________ or alumina as the stationary phase.
(Linked to SLO 3.5)

Which type of chromatography is most suitable for separating volatile compounds?
- A. Paper chromatography
- B. Thin-layer chromatography
- C. Column chromatography
- D. Gas chromatography

(Linked to SLO 3.5)

Thin-layer chromatography can be used to monitor the __________ of a reaction.
(Linked to SLO 3.5)

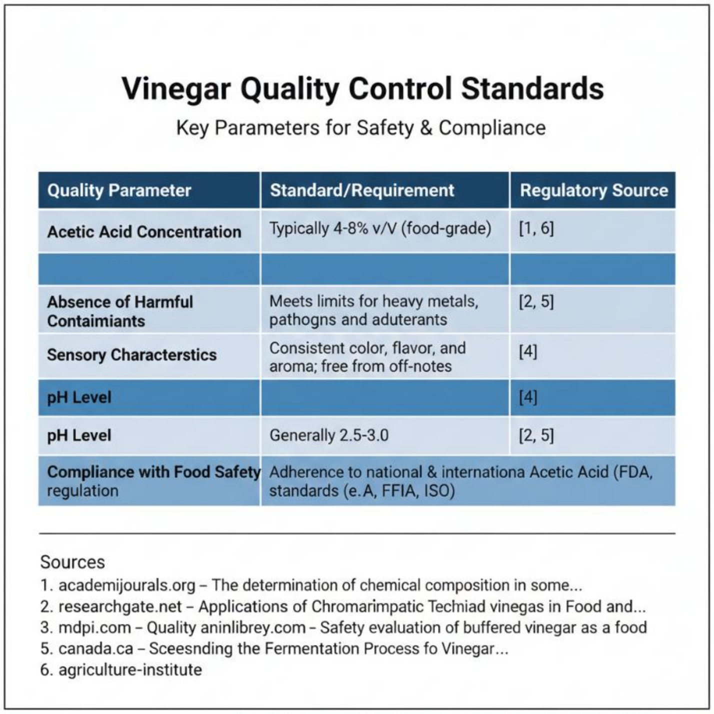
Name one industrial application of chromatography.
(Linked to SLO 3.5)

3.4 Practical Applications and Safety Considerations

3.4.1 Case studies: vinegar quality control and food industry standards

In the food industry, **quality control** refers to the systematic processes used to ensure that products meet safety and regulatory standards. Vinegar analysis is a practical example of this, as the concentration of acetic acid must fall within specified ranges of 4–8% to guarantee both flavour and preservation effectiveness. Food laboratories routinely test vinegar samples to confirm compliance with national and international standards. This demonstrates how laboratory techniques such as titration and chromatography are directly applied in real-world contexts.

Fill in the blank: In the food industry, vinegar analysis is used to confirm compliance with __________________ standards.



Vinegar Quality Control Standards

Key Parameters for Safety & Compliance

Quality Parameter	Standard/Requirement	Regulatory Source
Acetic Acid Concentration	Typically 4-8% v/V (food-grade)	[1, 6]
Absence of Harmful Contaimiants	Meets limits for heavy metals, pathogns and aduterants	[2, 5]
Sensory Characterstics	Consistent color, flavor, and aroma; free from off-notes	[4]
pH Level		[4]
pH Level	Generally 2.5-3.0	[2, 5]
Compliance with Food Safety regulation	Adherence to national & internationa Acetic Acid (FDA, standards (e.A, FFIA, ISO)	

Sources
1. academijourals.org – The determination of chemical composition in some...
2. researchgate.net – Applications of Chromarimpatic Techiad vinegas in Food and...
3. mdpi.com – Quality aninlibrey.com – Safety evaluation of buffered vinegar as a food
5. canada.ca – Sceesnding the Fermentation Process fo Vinegar...
6. agriculture-institute

Box 3.4: Examples of vinegar quality control standards

Acetic acid concentration between 4–8 percent
Absence of harmful contaminants
Consistency in flavour and aroma
Compliance with national food safety regulations

AI prompt: “Generate a table listing vinegar quality control standards such as acetic acid concentration, absence of contaminants, and compliance with food safety regulations.”
Search string: “vinegar quality control standards OER”

3.4.2 Safety precautions in titration and chromatography experiments

Both titration and chromatography require strict **safety precautions**. In titration, sodium hydroxide is corrosive, so gloves and goggles must be worn. Care should be taken when handling glassware to avoid breakage. In chromatography, solvents such as ethanol or acetone may be flammable, so experiments should be conducted in a well-ventilated area or under a fume hood. Following these precautions ensures that experiments are carried out safely and responsibly.

Fill in the blank: Experiments involving flammable or toxic solvents should be conducted in a ___________________.

Plate 3.4: Safe practice in chromatography experiments

AI prompt: “Create an image of a student conducting chromatography in a fume hood while wearing goggles, gloves, and a lab coat.”
Search string: “chromatography laboratory safety PPE OER”

3.4.3 Recording and interpreting results effectively

Accurate **recording of results** is vital for reproducibility and reliability. In titration, burette readings should be noted carefully, and averages taken from consistent trials. In chromatography, the distance travelled by each compound (Rf value) should be measured and recorded. Interpreting these results allows you to compare experimental data with theoretical expectations and draw meaningful conclusions. A well-maintained laboratory notebook serves as both a scientific record and a legal document.

Fill in the blank: In chromatography, the ratio used to identify compounds based on their movement relative to the solvent front is called the __________________ value.

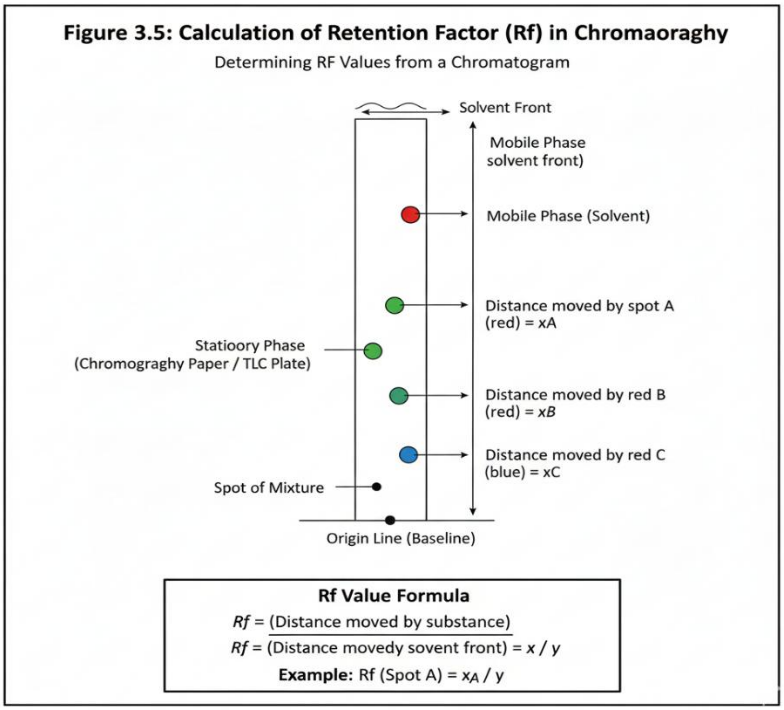


Figure 3.5: Calculation of retention factor (Rf) in chromatography

AI prompt: “Generate a labelled diagram showing calculation of Rf value in chromatography with solvent front and compound spots.”
Search string: “chromatography Rf value calculation diagram OER”

Pilot questions 3.4

In the food industry, vinegar analysis is used to confirm compliance with:
A. Environmental standards
B. Food safety standards
C. Engineering standards
D. Energy efficiency standards
(Linked to SLO 3.6)

Experiments involving flammable or toxic solvents should be conducted in a:
A. Classroom
B. Fume hood
C. Open bench
D. Storage room
(Linked to SLO 3.6)

The ratio used to identify compounds in chromatography based on their movement relative to the solvent front is called the:
A. Endpoint value

B. Retention factor (Rf)
C. Neutralisation constant
D. Concentration ratio
(Linked to SLO 3.6)

Name one safety precaution that must be observed during titration experiments.
(Linked to SLO 3.6)

Suggest one way to ensure accuracy when recording titration results.
(Linked to SLO 3.6)

Series Summary

This Series on **Vinegar Analysis and Chromatographic Techniques** was designed to help you understand how vinegar is studied in food chemistry and how chromatographic methods are applied in organic analysis. You began by exploring the definition and composition of vinegar, its importance in food chemistry, and the analytical methods used to assess its quality. You then learned how to carry out acid–base titration of vinegar, including the principle of titration, the laboratory procedure, calculations of acetic acid concentration, and ways to minimise errors. Building on this, you studied chromatographic techniques, examining their definition, types such as paper and thin-layer chromatography, and their applications in identifying organic compounds. Finally, you considered practical applications and safety considerations, including case studies in vinegar quality control, essential safety precautions, and effective recording and interpretation of results.

By completing this Series, you should now be able to **define vinegar and explain its composition and relevance in food chemistry (SLO 3.1)**, **demonstrate acid–base titration of vinegar and calculate acetic acid concentration (SLO 3.2, SLO 3.3)**, **describe the principles of chromatographic techniques and apply them to separate and identify organic compounds (SLO 3.4, SLO 3.5)**, and **evaluate safety precautions and recording practices in titration and chromatography experiments (SLO 3.6)**. These outcomes ensure that you are well-prepared to apply analytical techniques responsibly and effectively in both academic and industrial contexts.

Glossary of Terms

Acetic acid: The main acid present in vinegar, responsible for its sour taste and preservative qualities.

Chromatography: A separation technique used to isolate and identify components of a mixture based on their movement through a stationary phase and a mobile phase.

Column chromatography: A type of chromatography where a column is packed with a stationary phase such as silica or alumina, and a solvent is passed through to separate compounds.

Gas chromatography (GC): A chromatography technique that uses a gaseous mobile phase to separate volatile compounds, often applied in forensic and environmental analysis.

Indicator: A chemical substance added during titration that changes colour at the endpoint, signalling that neutralisation has occurred.

Paper chromatography: A simple form of chromatography that uses absorbent paper as the stationary phase, often applied to separate coloured compounds such as inks or pigments.

Phenolphthalein: A common acid–base indicator used in titration, which changes from colourless in acidic solutions to pink in basic solutions.

Rf value: In chromatography, the ratio of the distance travelled by a compound to the distance travelled by the solvent front, used to identify compounds.

Stationary phase: The medium in chromatography that does not move, such as paper, silica gel, or alumina, which interacts with compounds to slow their movement.

Thin-layer chromatography (TLC): A chromatography technique that uses a thin layer of silica gel or alumina coated on a plate as the stationary phase, widely used in organic chemistry to monitor reactions.

Titration: An analytical technique used to determine the concentration of a solution by reacting it with another solution of known concentration until the endpoint is reached.

Concept Check Questions [Series 3]

Objective Questions

The main acid present in vinegar is __________________.
(Linked to SLO 3.1)

The indicator commonly used in vinegar titration to signal the endpoint is __________________.
(Linked to SLO 3.2)

The equation used to calculate concentrations in titration is __________________.
(Linked to SLO 3.3)

The type of chromatography that uses silica gel coated on a plate as the stationary phase is __________________ chromatography.
(Linked to SLO 3.5)

In chromatography, the ratio of the distance travelled by a compound to the distance travelled by the solvent front is called the __________________ value.
(Linked to SLO 3.5)

Short-Answer Questions

Define vinegar and explain its relevance in food chemistry.
(Linked to SLO 3.1)

Describe the laboratory procedure for titrating vinegar with sodium hydroxide.
(Linked to SLO 3.2)

State one source of error in vinegar titration and explain how it can be minimised.
(Linked to SLO 3.3)

Identify one application of thin-layer chromatography in organic analysis.
(Linked to SLO 3.5)

Explain why accurate recording of results is important in titration and chromatography experiments.
(Linked to SLO 3.6)

Long-Answer Questions

Analyse the importance of vinegar analysis in food chemistry and industry standards.
(Linked to SLO 3.1)

Evaluate the role of acid–base titration in determining acetic acid concentration, including its strengths and limitations.
(Linked to SLO 3.2, SLO 3.3)

Compare paper chromatography and thin-layer chromatography, highlighting their principles, applications, and limitations.
(Linked to SLO 3.4, SLO 3.5)

Assess the role of safety precautions and recording practices in ensuring reliable titration and chromatography experiments.
(Linked to SLO 3.6)

Answers to Concept Check Questions [Series 3]

Objective Questions

Acetic acid
Phenolphthalein
($M_1V_1 = M_2V_2$)
Thin-layer chromatography
Rf value

Short-Answer Questions

Vinegar is a dilute solution of acetic acid in water, usually 4–8%, and is important in food chemistry for flavour, preservation, and compliance with standards.
Measure vinegar into a conical flask, add phenolphthalein, titrate with sodium hydroxide from a burette until a faint pink colour persists, and record the volume used.
Overshooting the endpoint is a common error; it can be minimised by adding sodium hydroxide slowly near the endpoint and repeating trials for consistency.
Thin-layer chromatography is used to monitor the progress of chemical reactions by showing whether starting materials have been converted into products.
Accurate recording ensures reproducibility, allows comparison with theoretical values, and provides a reliable scientific record.

Long-Answer Questions

Question 1

Basic response: Vinegar analysis ensures that acetic acid concentration meets food industry standards and provides consistent quality for consumers.

Value-added response: Outstanding learners may extend by discussing how vinegar analysis prevents adulteration, supports regulatory compliance, and maintains consumer trust in global markets.

Question 2

Basic response: Acid–base titration is a reliable method for determining acetic acid concentration in vinegar, using neutralisation and indicators.

Value-added response: Learners may extend by noting limitations such as human error in endpoint detection and suggesting alternatives like instrumental analysis for greater precision.

Question 3

Basic response: Paper chromatography separates coloured compounds using absorbent paper, while thin-layer chromatography uses silica gel for more versatile applications.

Value-added response: Learners may extend by comparing resolution, reproducibility, and industrial relevance, noting that TLC is more widely used in organic chemistry research.

Question 4

Basic response: Safety precautions and recording practices protect learners and ensure reliable results in titration and chromatography.

Value-added response: Learners may extend by linking these practices to professional laboratory standards, emphasising their role in building a culture of safety, accountability, and reproducibility in industry and research.

Answers to Pilot Questions [Series 3]

Part 3.1 Introduction to Vinegar Analysis

Acetic acid
Acetic acid
Acid–base titration
Household cleaning (or food preservation, medicinal use)

Part 3.2 Acid–Base Titration of Vinegar

Sodium hydroxide
Phenolphthalein
1:1
Inaccurate measurement of volumes
Repeat titrations until concordant results are obtained

Part 3.3 Chromatographic Techniques in Organic Analysis

Solubility and interaction
Silica gel
Gas chromatography
Progress
Food industry analysis (or pharmaceuticals, reaction monitoring)

Part 3.4 Practical Applications and Safety Considerations

Food safety standards
Fume hood
Retention factor (Rf)
Wearing PPE (e.g., goggles, gloves, lab coat)
Record volumes carefully and repeat titrations for concordant results

References and Attributions [Series 3]

Textual Sources

Atkins, P., & Jones, L. (2010). *Chemical Principles: The Quest for Insight* (5th ed.). Oxford University Press.
Housecroft, C. E., & Sharpe, A. G. (2018). *Inorganic Chemistry* (5th ed.). Pearson.
IUPAC. (1997). *Compendium of Chemical Terminology (the "Gold Book")*.

Illustrations (Figures, Plates, Tables, Boxes)

Figure 3.1 Conversion of ethanol to acetic acid in vinegar production
AI prompt: "Generate a labelled diagram showing fermentation of ethanol to acetic acid by bacteria."
Search string: "vinegar fermentation ethanol to acetic acid diagram OER"

Box 3.1 Everyday uses of vinegar
AI prompt: "Generate a table listing everyday uses of vinegar such as food preservation, flavouring, cleaning, and medicinal applications."
Search string: "everyday uses of vinegar OER"

Plate 3.1 Laboratory titration setup for vinegar analysis
AI prompt: "Create an image of a laboratory titration setup with burette, flask, and sodium hydroxide solution used for vinegar analysis."
Search string: "vinegar titration laboratory setup OER"

Figure 3.2 Neutralisation of acetic acid in vinegar by sodium hydroxide
AI prompt: "Generate a labelled diagram showing acid–base titration of vinegar with sodium hydroxide and phenolphthalein indicator."
Search string: "vinegar titration neutralisation diagram OER"

Plate 3.2 Laboratory setup for vinegar titration
AI prompt: "Create an image of a laboratory titration setup showing burette, conical flask

with vinegar, and phenolphthalein indicator."
Search string: "vinegar titration laboratory setup OER"

Box 3.2 Steps for calculating acetic acid concentration
AI prompt: "Generate a table outlining steps for calculating acetic acid concentration in vinegar titration."
Search string: "vinegar titration calculation steps OER"

Figure 3.3 Sources of error and accuracy considerations in vinegar titration
AI prompt: "Generate a flowchart showing common errors in vinegar titration such as inaccurate measurement and endpoint detection, with methods to improve accuracy."
Search string: "vinegar titration errors and accuracy OER"

Figure 3.4 Principle of chromatography
AI prompt: "Generate a labelled diagram showing chromatography with stationary phase and mobile phase separating different compounds."
Search string: "chromatography principle stationary mobile phase diagram OER"

Plate 3.3 Types of chromatography techniques
AI prompt: "Create an image showing paper chromatography, thin-layer chromatography, column chromatography, and gas chromatography setups side by side."
Search string: "types of chromatography paper TLC column GC OER"

Box 3.3 Applications of chromatography in organic analysis
AI prompt: "Generate a table listing applications of chromatography such as monitoring reactions, identifying compounds, purifying mixtures, and analysing food products."
Search string: "applications of chromatography organic analysis OER"

Box 3.4 Examples of vinegar quality control standards
AI prompt: "Generate a table listing vinegar quality control standards such as acetic acid concentration, absence of contaminants, and compliance with food safety regulations."
Search string: "vinegar quality control standards OER"

Plate 3.4 Safe practice in chromatography experiments
AI prompt: "Create an image of a student conducting chromatography in a fume hood while wearing goggles, gloves, and a lab coat."
Search string: "chromatography laboratory safety PPE OER"

Figure 3.5 Calculation of retention factor (Rf) in chromatography
AI prompt: "Generate a labelled diagram showing calculation of Rf value in chromatography with solvent front and compound spots."
Search string: "chromatography Rf value calculation diagram OER"

Notes on Attribution

AI-generated illustrations are documented with prompts and should be noted with the generation date and platform used.
Where OERs are used, attribution must comply with the licence terms of the source.
References are presented in APA style for consistency.

- **Course code: CHM 208**
- **Course title: CHM 208: General Chemistry Practical IV** (1 Unit C: PH 45)
- **Course credit load:** (1 Unit C: PH 45)
- **List of Series**:

Series 1: **Laboratory Safety and Rules in General Chemistry**

Series 2: **Preparation of Esters, Aldehydes, and Ketones**

Series 3: **Vinegar Analysis and Chromatographic Techniques**

Series 4: **Thin Layer Chromatography Applications**

Series 5: **Alcohol Dehydration and Functional Group Analysis**

Proposed Outline

4.1 Introduction to Thin Layer Chromatography (TLC)

Definition and principle of TLC
Components of a TLC system (stationary phase, mobile phase, sample application)
Advantages of TLC compared to other chromatographic methods

4.2 Laboratory Procedure for TLC

Preparing the TLC plate
Applying samples and developing the chromatogram
Visualising spots using UV light or chemical stains

4.3 Applications of TLC in Organic Chemistry

Monitoring reaction progress
Identifying unknown compounds
Assessing purity of samples
Comparing TLC with other chromatographic techniques

4.4 Practical Considerations and Safety in TLC Experiments

Handling solvents and reagents safely
Recording and interpreting Rf values accurately

Introduction

In the last Series, we explored vinegar analysis and chromatographic techniques, focusing on how titration and chromatography can be applied to determine composition and purity in everyday substances. Building on that foundation, this Series turns specifically to thin layer chromatography (TLC), a versatile and widely used method in organic chemistry. TLC is valued for its simplicity, speed, and effectiveness in separating and identifying compounds, making it a vital tool for both laboratory practice and industrial applications.

The aim of this Series is to introduce you to the principles, procedures, and applications of thin layer chromatography, and to equip you with the skills needed to carry out TLC experiments safely and interpret results accurately.

We shall commence this Series by examining the basic principles of TLC, including its components and advantages. Next, we will move on to the laboratory procedure, where you will learn how to prepare plates, apply samples, and develop chromatograms. Following that, we will explore the applications of TLC in organic chemistry, such as monitoring reactions, identifying compounds, and assessing purity. Finally, we will conclude with practical considerations and safety measures, ensuring you are confident in applying TLC both in academic and professional contexts.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 4.1 define thin layer chromatography (TLC) and explain its principle,
SLO 4.2 describe the components of a TLC system including stationary phase, mobile phase, and sample application,
SLO 4.3 demonstrate how to prepare a TLC plate and develop a chromatogram in the laboratory,
SLO 4.4 apply visualisation techniques such as UV light or chemical stains to identify separated compounds on a TLC plate,
SLO 4.5 analyse applications of TLC in organic chemistry including monitoring reactions, identifying compounds, and assessing purity, and
SLO 4.6 evaluate safety precautions, recording practices, and troubleshooting methods in TLC experiments.

4.1 Introduction to Thin Layer Chromatography (TLC)

4.1.1 Definition and principle of TLC

Thin layer chromatography (TLC) is a technique used to separate and identify compounds in a mixture. It works on the principle that different substances move at different rates when carried by a mobile phase (solvent) across a stationary phase (a thin layer of silica gel or alumina coated on a plate). The separation occurs because compounds interact differently with the stationary phase, depending on their polarity and solubility.

Fill in the blank: In TLC, the plate coated with silica gel or alumina acts as the __________________ phase.

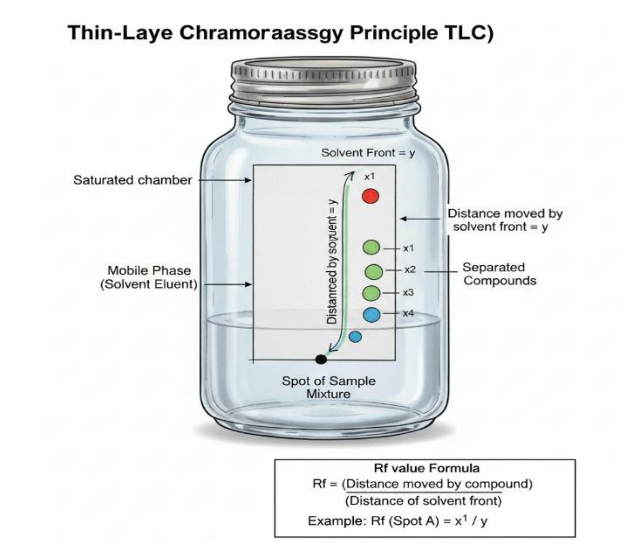


Figure 4.1: Principle of thin layer chromatography

AI prompt: "Generate a labelled diagram showing TLC plate with stationary phase and solvent front as mobile phase."
Search string: "thin layer chromatography principle diagram OER"

4.1.2 Components of a TLC system

A TLC system consists of three main components. The **stationary phase** is the thin layer of silica gel or alumina spread on a plate. The **mobile phase** is the solvent or mixture of solvents that moves up the plate. The **sample application** involves spotting small amounts of the mixture onto the baseline of the plate. Together, these components allow compounds to separate based on their relative affinities for the stationary and mobile phases.

Fill in the blank: The solvent that moves up the TLC plate by capillary action is called the __________________ phase.

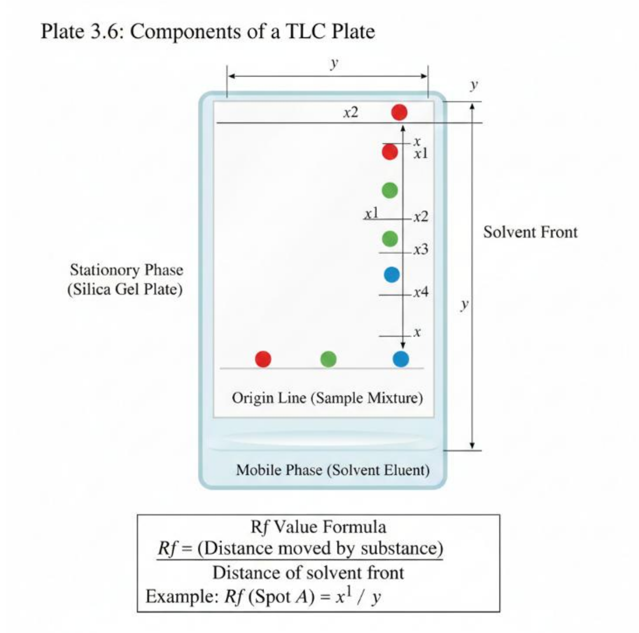


Plate 4.1: Components of a TLC system

AI prompt: "Create an image of a TLC plate showing baseline, sample spots, stationary phase, and solvent front."
Search string: "TLC plate components baseline solvent front OER"

4.1.3 Advantages of TLC compared to other chromatographic methods

TLC offers several advantages over other chromatographic techniques:

It is simple and inexpensive, requiring minimal equipment.

It provides rapid results, often within minutes.

It allows multiple samples to be analysed simultaneously on the same plate.

It is versatile, suitable for a wide range of organic compounds.

Although TLC is less precise than advanced methods like gas chromatography, it remains a valuable tool for quick and effective analysis in teaching laboratories and research.

Fill in the blank: One major advantage of TLC is that it allows __________________ samples to be analysed at the same time.

Advantages of Thin Layer Chromatography (TLC)

Advantage	Description	Source(s)
Simplicity	Requires minimal, inexpensive equipment (chamber, plate, solvent) and a straightforward procedure suitable for routine lab work and teaching.	Chemistry LibreTexts, Microbe Notes
Rapid Results	Separations typically occur within minutes (often under 30 minutes), significantly faster than paper chromatography.	ScienceDirect, Lab-Training
Clearer Separations	Use of rigid supports (glass/plastic) and uniform adsorbent layers reduces diffusion, resulting in well-defined, compact spots and better resolution.	Lab-Training, ResearchGate
High Versatility	Applicable to a wide variety of organic and inorganic compounds; mobile and stationary phases can be easily modified to optimize specific separations.	BYJU'S, ScienceDirect
Cost-Effectiveness	Low operational costs due to minimal solvent usage and inexpensive disposable plates compared to HPLC or GC.	MDPI, Microbe Notes
Parallel Processing	Multiple samples and standards can be run simultaneously on a single plate under identical conditions for direct comparison.	ScienceDirect, EVS Institute
Ease of Visualization	Separated components can be easily visualized using UV light or a vast array of selective chemical spray reagents.	Wikipedia, Khan Academy
Minimal Pre-treatment	Samples often require little to no cleanup before analysis, and even corrosive reagents can be used on the inert plates.	ScienceDirect, Lab-Training

Box 4.1: Advantages of thin layer chromatography

Simple and inexpensive
Rapid results
Clearer separations than paper chromatography
Suitable for a wide range of compounds
Multiple samples can be analysed simultaneously

AI prompt: "Generate a table listing advantages of thin layer chromatography such as simplicity, rapid results, and clearer separations."
Search string: "advantages of thin layer chromatography OER"

Pilot questions 4.1

In TLC, the plate coated with silica gel or alumina acts as the:
A. Mobile phase
B. Stationary phase
C. Solvent front
D. Sample application
(Linked to SLO 4.1)

The solvent that moves up the TLC plate by capillary action is called the:
A. Stationary phase
B. Mobile phase
C. Baseline
D. Retention factor
(Linked to SLO 4.2)

One major advantage of TLC is that it allows __________ samples to be analysed at the same time.
(Linked to SLO 4.1)
Name the three main components of a TLC system.
(Linked to SLO 4.2)
State one advantage of TLC compared to paper chromatography.
(Linked to SLO 4.1)

4.2 Laboratory Procedure for TLC

4.2.1 Preparing the TLC plate

To begin a **TLC experiment**, you must first prepare the plate. A TLC plate is usually made of glass, plastic, or aluminium coated with a thin layer of silica gel or alumina, which acts as the **stationary phase**. Using a pencil, lightly draw a baseline about 1–2 cm from the bottom of the plate. This baseline marks where the samples will be applied. It is important to use a pencil rather than a pen, as ink may interfere with the separation process.

Fill in the blank: The thin layer of silica gel or alumina on a TLC plate acts as the __________________ phase.

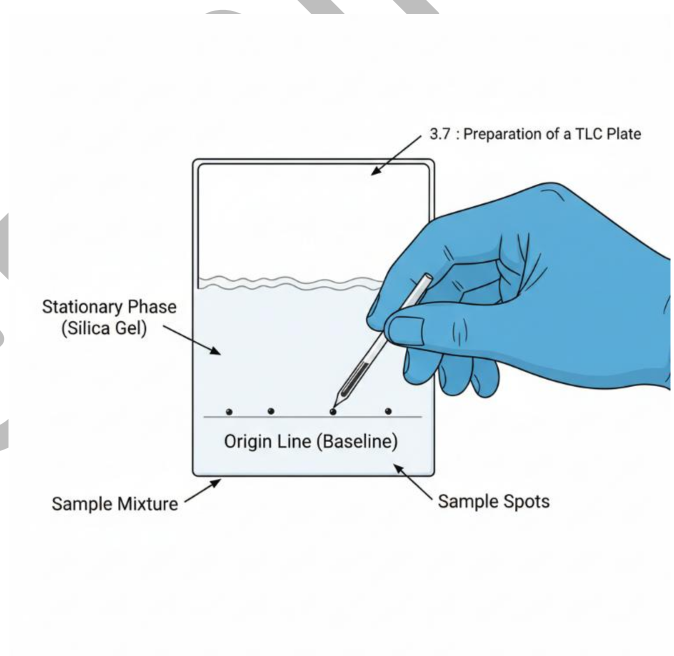


Plate 4.2: Preparing a TLC plate with sample spots

AI prompt: "Create an image of a TLC plate showing baseline, sample spots applied with

capillary tube, and stationary phase labelled."
Search string: "TLC plate preparation baseline sample spots OER"

4.2.2 Applying samples and developing the chromatogram

Once the plate is prepared, small amounts of the sample mixture are applied as tiny spots on the baseline using a capillary tube or micropipette. The plate is then placed upright in a developing chamber containing a shallow layer of solvent, known as the **mobile phase**. As the solvent rises by capillary action, it carries the compounds with it. Different compounds travel at different speeds depending on their interaction with the stationary phase, resulting in separation.

Fill in the blank: The solvent that rises up the TLC plate by capillary action is called the __________________ phase.

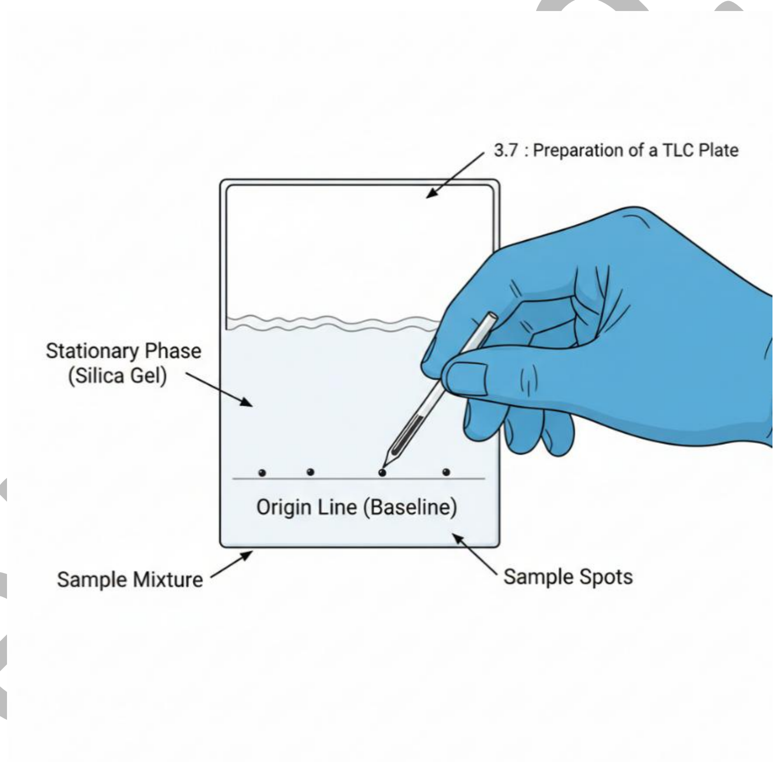


Figure 4.2: Developing a TLC chromatogram

AI prompt: "Generate a labelled diagram showing a TLC plate in a developing chamber with solvent front rising by capillary action."
Search string: "TLC developing chamber solvent front diagram OER"

4.2.3 Visualising spots using UV light or chemical stains

After development, the separated compounds appear as spots on the TLC plate. Some compounds are naturally visible, but many require **visualisation techniques**. Ultraviolet (UV) light can be used to detect compounds that fluoresce or absorb UV radiation. Alternatively, chemical stains such as iodine vapour or ninhydrin can be applied to reveal otherwise invisible spots. These methods make it possible to record and analyse the separation effectively.

Fill in the blank: Compounds that are not visible on a TLC plate can be detected using ___________________ techniques such as UV light or chemical stains.

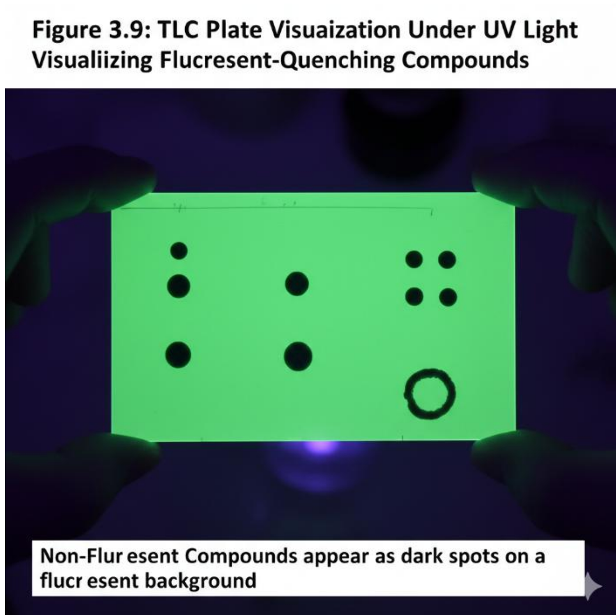


Plate 4.3: Visualising TLC spots using UV light

AI prompt: “Create an image of a TLC plate under UV light showing fluorescent spots after development.”
Search string: “TLC plate UV light visualisation OER”

Pilot questions 4.2

The thin layer of silica gel or alumina on a TLC plate acts as the:
A. Mobile phase
B. Stationary phase
C. Solvent front
D. Sample application
(Linked to SLO 4.3)

The solvent that rises up the TLC plate by capillary action is called the:

A. Stationary phase
B. Mobile phase
C. Baseline
D. Retention factor
(Linked to SLO 4.3)

Compounds that are not visible on a TLC plate can be detected using __________ techniques such as UV light or chemical stains.
(Linked to SLO 4.4)

Name one chemical stain that can be used to visualise spots on a TLC plate.
(Linked to SLO 4.4)

Why is it important to keep sample spots small and well-spaced when preparing a TLC plate?
(Linked to SLO 4.3)

4.3 Applications of TLC in Organic Chemistry

4.3.1 Monitoring reaction progress

One of the most common uses of **thin layer chromatography (TLC)** is to monitor the progress of a chemical reaction. By spotting samples taken at different times onto a TLC plate and developing them, you can compare the appearance or disappearance of spots. This shows whether reactants are being consumed and products are being formed. TLC therefore provides a quick and reliable way to check if a reaction has reached completion.

Fill in the blank: TLC can be used to monitor the __________________ of a chemical reaction by comparing spots of reactants and products.

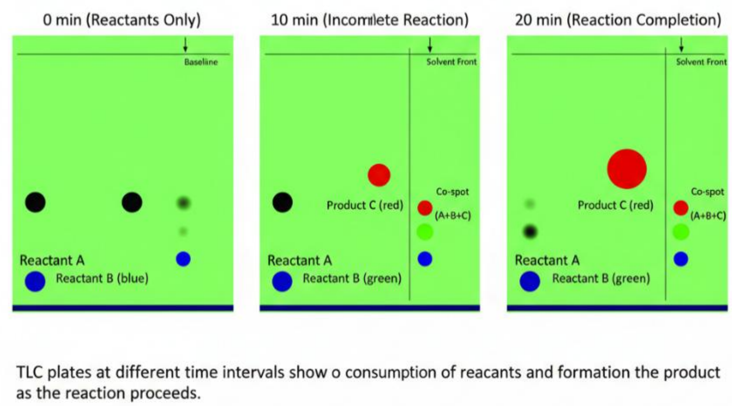


Figure 4.3: Monitoring reaction progress using TLC

AI prompt: “Generate a labelled diagram showing TLC plates at different reaction times with reactant and product spots.”
Search string: “TLC monitoring reaction progress diagram OER”

4.3.2 Identifying unknown compounds

TLC can also be used to identify **unknown compounds** by comparing their movement on the plate with known reference samples. The distance travelled by a compound relative to the solvent front is expressed as the **Rf value**. By comparing Rf values of unknowns with those of known standards, you can make informed conclusions about the identity of the compounds.

Fill in the blank: The ratio used to identify compounds in TLC is called the __________________ value.

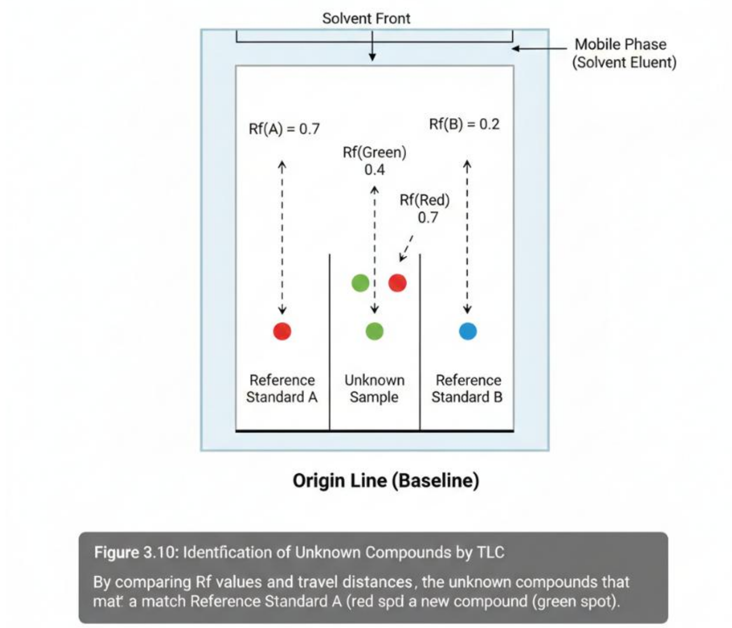


Plate 4.4: Identifying unknown compounds using TLC

AI prompt: “Create an image of a TLC plate showing unknown sample spots compared with known standards, with Rf values labelled.”
Search string: “TLC identifying unknown compounds Rf value OER”

4.3.3 Assessing purity of samples

TLC is widely used to assess the **purity of samples**. A pure compound will usually produce a single spot on the TLC plate, while an impure sample may show multiple spots, indicating the presence of contaminants. This makes TLC a valuable tool for checking the quality of synthesised compounds before further use.

Fill in the blank: A pure compound should produce __________________ spot(s) on a TLC plate.

Uses of TLC in Assessing Purity

Use Case	Description	Significance for Purity
Detecting Impurities	A pure sample typically shows a single spot on a developed TLC plate. Multiple spots indicate the presence of contaminants, side products, or degradation.	Provides immediate visual evidence of whether a substance is a single compound or a mixture.
Confirming Purification Success	TLC is used to analyze fractions from column chromatography. It identifies which fractions contain only the pure target compound and which contain overlapping impurities.	Ensures only high-purity fractions are combined for the final product recovery.
Monitoring Reaction Progress	By comparing the reaction mixture to the starting material (often using a co-spot), researchers can see if the starting material has completely disappeared.	Prevents the isolation of a product that is still contaminated with unreacted starting materials.
Assessing Chemical Stability	Two-dimensional TLC (rotating the plate 90° and re-running it) can determine if a compound is stable on the stationary phase.	Identifies if a compound is pure or if it is decomposing during the analytical process itself.
Identifying Degradation	TLC can quantify the extent of degradation, such as the air oxidation of aldehydes into carboxylic acids, by showing the appearance of new, distinct spots.	Useful for checking the quality of reagents stored in a laboratory over time.
Preliminary Screening	Used as a rapid, low-cost screening tool before more sensitive but expensive techniques like HPLC are employed.	Prevents damage to sensitive instruments (like HPLC columns) by ensuring samples are sufficiently pre-purified.

Box 4.2: Uses of TLC in assessing purity

Detecting impurities in samples
Confirming success of purification methods
Ensuring quality in laboratory and industrial processes

AI prompt: "Generate a table listing uses of TLC in assessing purity such as detecting impurities and confirming purification success."
Search string: "TLC assessing purity organic chemistry OER"

4.3.4 Comparing TLC with other chromatographic techniques

Although TLC is simple and effective, it is less precise than advanced methods such as **gas chromatography (GC)** or **high-performance liquid chromatography (HPLC)**. TLC is best suited for quick checks, teaching laboratories, and preliminary analysis, while GC and HPLC provide more accurate quantitative data. Understanding these differences helps you choose the right technique for your analytical needs.

Fill in the blank: Compared to GC or HPLC, TLC is less ___________________ but more rapid and inexpensive.

Detailed Comparison Table

Feature	Thin Layer Chromatography (TLC)	Gas Chromatography (GC)	High-Performance Liquid Chromatography (HPLC)
Cost	Very Low: Minimal equipment; inexpensive plates and solvents.	Moderate: Lower operational costs than HPLC; uses inexpensive gases like Nitrogen.	High: Expensive high-pressure pumps, specialized columns, and high-purity solvents.
Speed	Fast (Qualitative): Results in <30 mins; can run multiple samples at once.	Very Fast: Analysis of volatile compounds can take seconds to minutes.	Moderate: Runs typically take 10–60 minutes per sample.
Precision	Low: Primarily qualitative/semi-quantitative; limited by visual detection.	High: Highly precise for volatile mixtures; capable of separating hundreds of components.	Very High: The "gold standard" for quantitative analysis and impurity profiling.
Best Use	Quick screening and reaction monitoring.	Volatile and thermally stable compounds.	Non-volatile, polar, and thermally unstable compounds.

Figure 4.4: Comparison of TLC with other chromatographic techniques

AI prompt: “Generate a comparative diagram showing TLC, GC, and HPLC in terms of cost, speed, and precision.”
Search string: “comparison TLC GC HPLC diagram OER”

Pilot questions 4.3

TLC can be used to monitor the __________ of a chemical reaction by comparing spots of reactants and products.
(Linked to SLO 4.5)
The ratio used to identify compounds in TLC is called the __________ value.
(Linked to SLO 4.5)
A pure compound should produce __________ spot(s) on a TLC plate.
(Linked to SLO 4.5)
Name one way TLC can be used to assess the purity of a compound.
(Linked to SLO 4.5)
Compared to GC or HPLC, TLC is less __________ but more rapid and inexpensive.
(Linked to SLO 4.5)

4.4 Practical Considerations and Safety in TLC Experiments

4.4.1 Handling solvents and reagents safely

In **TLC experiments**, solvents such as hexane, ethyl acetate, or acetone are commonly used as the **mobile phase**. These solvents can be flammable or harmful if inhaled, so it is important to work in a well-ventilated area or under a fume hood. Always wear appropriate **personal protective equipment (PPE)**, including gloves, goggles, and a lab coat, to minimise exposure.

Care should also be taken when handling chemical stains such as iodine vapour or ninhydrin, as they can be irritating to the skin and eyes.

Fill in the blank: Experiments involving volatile solvents should be conducted in a __________________.

Plate 3.9: Handling Solvents in a Fume Hood

Safe practice during TLC experiments, highlaliging the use PPE and and proper fume hood technique to prevent inhalalon of hazardous vapors.

Plate 4.5: Safe handling of solvents in TLC experiments

AI prompt: “Create an image of a student handling TLC solvents in a fume hood while wearing goggles, gloves, and a lab coat.”
Search string: “TLC laboratory safety solvents PPE OER”

4.4.2 Recording and interpreting Rf values accurately

The **retention factor (Rf)** is a key measurement in TLC. It is calculated by dividing the distance travelled by the compound by the distance travelled by the solvent front. Accurate measurement requires marking the baseline and solvent front immediately after development. Recording Rf values carefully ensures reproducibility and allows comparison with known standards.

Fill in the blank: The ratio used to identify compounds in TLC is called the __________________ value.

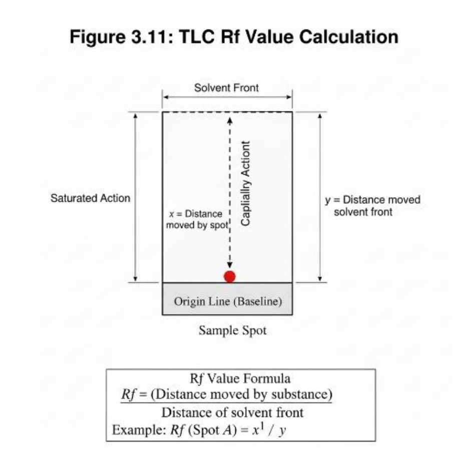


Figure 4.5: Calculation of Rf value in TLC

AI prompt: "Generate a labelled diagram showing calculation of Rf value in TLC with baseline, compound spot, and solvent front."
Search string: "TLC Rf value calculation diagram OER"

4.4.3 Common errors and troubleshooting in TLC experiments

Even with careful preparation, TLC experiments may encounter problems. Common issues include streaking of spots due to applying too much sample, poor separation caused by an unsuitable solvent system, or faint spots that are difficult to visualise. Troubleshooting involves identifying the cause and applying corrective measures, such as adjusting solvent composition, applying smaller sample volumes, or using a different visualisation technique. Developing these skills helps you achieve reliable and reproducible results.

Fill in the blank: Applying large or overlapping sample spots on a TLC plate can lead to __________________ separation.

TLC Troubleshooting Guide

Common Error	Possible Cause	Troubleshooting Method
Large or Overlapping Spots	Sample too concentrated or applied too heavily.	Use fine capillary tubes for application; dilute the sample with more solvent; ensure spot diameter is 2 mm.
Uneven Solvent Front	Chamber not saturated; plate touching chamber walls; uneven slurry thickness.	Ensure the chamber is properly sealed; use filter paper to "wick" and saturate the atmosphere; don't let the plate touch the sides.
Poor Separation	Solvent system polarity is incorrect for the analyte.	Adjust solvent polarity: increase polar solvent (e.g., Ethyl Acetate) to raise or increase non-polar solvent (e.g., Hexane) to lower .
Faint or Missing Spots	Sample too dilute or compound is not UV-active.	Concentrate the sample; spot multiple times in the same location; use UV light or chemical stains (e.g., Iodine) for visualization.
Streaking/Tailing	Sample is overloaded or contains acidic/basic groups that bind to silica.	Dilute the sample; add a few drops of Acetic Acid (for acids) or Triethylamine/Ammonia (for bases) to the mobile phase.
Spots on the Baseline	Solvent level is higher than the spotting line, washing away the sample.	Ensure the solvent level is below the spotting line (approx. 0.5–1 cm from the bottom).
Curved or "Smiley" Front	Plate edges are chipped or the plate was placed at an angle.	Use a ruler to cut plates evenly; snip the bottom corners of the plate; ensure the plate sits flat against the bottom of the jar.

Box 4.3: Common errors and troubleshooting in TLC

Large or overlapping sample spots → use fine capillary tubes
Uneven solvent front → ensure chamber is sealed properly
Poor separation → adjust solvent polarity
Faint spots → use UV light or chemical stains for visualisation

AI prompt: “Generate a table listing common errors in TLC experiments and troubleshooting methods such as adjusting solvent polarity or using fine capillary tubes.”
Search string: “TLC common errors troubleshooting OER”

Pilot questions 4.4

Experiments involving volatile solvents should be conducted in a:
A. Classroom
B. Fume hood
C. Open bench
D. Storage room
(Linked to SLO 4.6)

The ratio used to identify compounds in TLC is called the __________ value.
(Linked to SLO 4.6)

Applying large or overlapping sample spots on a TLC plate can lead to __________ separation.
(Linked to SLO 4.6)

Name one piece of PPE that must be worn during TLC experiments.
(Linked to SLO 4.6)

Suggest one way to troubleshoot poor separation in TLC experiments.
(Linked to SLO 4.6)

Series Summary

This Series on **Thin Layer Chromatography (TLC) Applications** was designed to introduce you to the principles, procedures, and practical uses of TLC in organic chemistry. You began by learning the definition and principle of TLC, exploring its components such as the stationary phase, mobile phase, and sample application, and considering its advantages compared to other chromatographic methods. You then studied the laboratory procedure, including how to prepare a TLC plate, apply samples, develop a chromatogram, and use visualisation techniques such as UV light or chemical stains. Building on this, you examined the applications of TLC, learning how it can be used to monitor reaction progress, identify unknown compounds, assess purity, and compare with other chromatographic techniques. Finally, you considered practical aspects of TLC experiments, focusing on safe handling of solvents, accurate recording of Rf values, and troubleshooting common issues.

By completing this Series, you should now be able to **define TLC and explain its principle (SLO 4.1)**, **describe the components of a TLC system (SLO 4.2)**, **demonstrate how to prepare a TLC plate and develop a chromatogram (SLO 4.3)**, **apply visualisation techniques to identify separated compounds (SLO 4.4)**, **analyse applications of TLC in organic chemistry (SLO 4.5)**, and **evaluate safety precautions, recording practices, and troubleshooting methods in TLC experiments (SLO 4.6)**. These outcomes ensure that you are well-prepared to apply TLC confidently and responsibly in both academic and professional laboratory settings.

Glossary of Terms

Baseline: A pencil line drawn near the bottom of a TLC plate where samples are applied before development.

Capillary action: The process by which the mobile phase solvent rises up the TLC plate, carrying compounds along with it.

Chemical stain: A reagent such as iodine vapour or ninhydrin used to make separated compounds visible on a TLC plate.

Mobile phase: The solvent or mixture of solvents that moves up the TLC plate, transporting compounds during separation.

Personal protective equipment (PPE): Safety gear such as gloves, goggles, and lab coats worn to protect against chemical hazards.

Rf value: The ratio of the distance travelled by a compound to the distance travelled by the solvent front, used to identify compounds in TLC.

Solvent front: The furthest point reached by the mobile phase on the TLC plate during development.

Stationary phase: The thin layer of silica gel or alumina coated on a TLC plate that interacts with compounds to slow their movement.

Thin layer chromatography (TLC): A technique used to separate and identify compounds in a mixture based on their movement through a stationary phase under the influence of a mobile phase.

Visualisation technique: A method such as UV light or chemical staining used to reveal separated compounds on a TLC plate.

Concept Check Questions [Series 4]

Objective Questions

In TLC, the stationary phase is usually a thin layer of ________________ coated on a plate.
(Linked to SLO 4.1)

The solvent that moves up the TLC plate by capillary action is called the ________________ phase.
(Linked to SLO 4.2)

A common visualisation technique for TLC involves placing the plate under ________________ light.
(Linked to SLO 4.4)

The ratio of the distance travelled by a compound to the distance travelled by the solvent front is called the ________________ value.
(Linked to SLO 4.6)

TLC is less precise than advanced methods such as ________________ chromatography.
(Linked to SLO 4.5)

Short-Answer Questions

Define thin layer chromatography (TLC) and explain its principle.
(Linked to SLO 4.1)

Describe the components of a TLC system.
(Linked to SLO 4.2)

Outline the laboratory procedure for preparing a TLC plate and developing a chromatogram.
(Linked to SLO 4.3)

State one application of TLC in organic chemistry.
(Linked to SLO 4.5)

Explain why accurate recording of Rf values is important in TLC experiments.
(Linked to SLO 4.6)

Long-Answer Questions

Analyse the importance of TLC in monitoring reaction progress and assessing purity of samples.
(Linked to SLO 4.5)

Evaluate the role of visualisation techniques in TLC, including their strengths and limitations.
(Linked to SLO 4.4)

Compare TLC with other chromatographic techniques such as GC and HPLC, highlighting their differences in cost, precision, and applications.
(Linked to SLO 4.5)

Assess the role of safety precautions and troubleshooting strategies in ensuring reliable TLC experiments.
(Linked to SLO 4.6)

Answers to Concept Check Questions [Series 4]

Objective Questions

Silica gel or alumina
Mobile phase
UV light
Rf value
High-performance liquid chromatography (HPLC) or gas chromatography (GC)

Short-Answer Questions

TLC is a technique used to separate and identify compounds in a mixture. It works on the principle that compounds move at different rates depending on their interaction with the stationary phase and mobile phase.
A TLC system consists of a stationary phase (silica gel or alumina), a mobile phase (solvent), and sample application (spots placed on the baseline).
Draw a baseline with a pencil, apply sample spots, place the plate in a developing chamber with solvent, allow the solvent to rise by capillary action, and then visualise the separated spots.
TLC can be used to monitor reaction progress, identify unknown compounds, or assess purity.
Accurate recording of Rf values ensures reproducibility, allows comparison with standards, and supports reliable identification of compounds.

Long-Answer Questions

Question 1

Basic response: TLC is important for monitoring reaction progress by showing the disappearance of reactants and appearance of products, and for assessing purity by indicating whether a sample contains contaminants.
Value-added response: Outstanding learners may extend by discussing how TLC provides quick feedback in synthetic chemistry, saving time and resources, and how it complements more advanced techniques for detailed analysis.

Question 2

Basic response: Visualisation techniques such as UV light and chemical stains make separated compounds visible, allowing identification and comparison.

Value-added response: Learners may extend by evaluating limitations, such as the inability of some stains to detect all compounds, and suggesting alternative methods like fluorescence quenching or advanced detectors.

Question 3

Basic response: TLC is inexpensive and quick but less precise than GC or HPLC, which provide quantitative data.

Value-added response: Learners may extend by comparing industrial applications, noting that TLC is used for preliminary checks, while GC and HPLC are essential for pharmaceutical quality control and environmental monitoring.

Question 4

Basic response: Safety precautions such as using PPE and working under a fume hood protect learners, while troubleshooting strategies improve reliability.

Value-added response: Learners may extend by linking these practices to professional laboratory standards, emphasising their role in building a culture of safety, accountability, and reproducibility in industry and research.

Answers to Pilot Questions [Series 4]

Part 4.1 Introduction to Thin Layer Chromatography (TLC)

Stationary phase
Mobile phase
Multiple
Stationary phase, mobile phase, sample application
Clearer separations

Part 4.2 Laboratory Procedure for TLC

Stationary phase
Mobile phase
Visualisation
Iodine vapour (or ninhydrin, UV light)
To ensure clear separation of compounds

Part 4.3 Applications of TLC in Organic Chemistry

Progress
Retention factor (Rf)
One
Detecting impurities in samples
Precise

Part 4.4 Practical Considerations and Safety in TLC Experiments

Fume hood
Retention factor (Rf)
Poor
Goggles (or gloves, lab coat)
Adjust solvent polarity

References and Attributions [Series 4]

Textual Sources

Atkins, P., & Jones, L. (2010). *Chemical Principles: The Quest for Insight* (5th ed.). Oxford University Press.

Housecroft, C. E., & Sharpe, A. G. (2018). *Inorganic Chemistry* (5th ed.). Pearson.

IUPAC. (1997). *Compendium of Chemical Terminology (the "Gold Book")*.

Illustrations (Figures, Plates, Tables, Boxes)

Figure 4.1 Principle of thin layer chromatography
AI prompt: "Generate a labelled diagram showing TLC plate with stationary phase and solvent front as mobile phase."
Search string: "thin layer chromatography principle diagram OER"

Plate 4.1 Components of a TLC system
AI prompt: "Create an image of a TLC plate showing baseline, sample spots, stationary phase, and solvent front."
Search string: "TLC plate components baseline solvent front OER"

Box 4.1 Advantages of thin layer chromatography
AI prompt: "Generate a table listing advantages of thin layer chromatography such as simplicity, rapid results, and clearer separations."
Search string: "advantages of thin layer chromatography OER"

Plate 4.2 Preparing a TLC plate with sample spots
AI prompt: "Create an image of a TLC plate showing baseline, sample spots applied with capillary tube, and stationary phase labelled."
Search string: "TLC plate preparation baseline sample spots OER"

Figure 4.2 Developing a TLC chromatogram
AI prompt: "Generate a labelled diagram showing a TLC plate in a developing chamber

with solvent front rising by capillary action."
Search string: "TLC developing chamber solvent front diagram OER"

Plate 4.3 Visualising TLC spots using UV light
AI prompt: "Create an image of a TLC plate under UV light showing fluorescent spots after development."
Search string: "TLC plate UV light visualisation OER"

Figure 4.3 Monitoring reaction progress using TLC
AI prompt: "Generate a labelled diagram showing TLC plates at different reaction times with reactant and product spots."
Search string: "TLC monitoring reaction progress diagram OER"

Plate 4.4 Identifying unknown compounds using TLC
AI prompt: "Create an image of a TLC plate showing unknown sample spots compared with known standards, with Rf values labelled."
Search string: "TLC identifying unknown compounds Rf value OER"

Box 4.2 Uses of TLC in assessing purity
AI prompt: "Generate a table listing uses of TLC in assessing purity such as detecting impurities and confirming purification success."
Search string: "TLC assessing purity organic chemistry OER"

Figure 4.4 Comparison of TLC with other chromatographic techniques
AI prompt: "Generate a comparative diagram showing TLC, GC, and HPLC in terms of cost, speed, and precision."
Search string: "comparison TLC GC HPLC diagram OER"

Plate 4.5 Safe handling of solvents in TLC experiments
AI prompt: "Create an image of a student handling TLC solvents in a fume hood while wearing goggles, gloves, and a lab coat."
Search string: "TLC laboratory safety solvents PPE OER"

Figure 4.5 Calculation of Rf value in TLC
AI prompt: "Generate a labelled diagram showing calculation of Rf value in TLC with baseline, compound spot, and solvent front."
Search string: "TLC Rf value calculation diagram OER"

Box 4.3 Common errors and troubleshooting in TLC
AI prompt: "Generate a table listing common errors in TLC experiments and troubleshooting methods such as adjusting solvent polarity or using fine capillary tubes."
Search string: "TLC common errors troubleshooting OER"

Notes on Attribution

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References are presented in APA style for consistency.

- **Course code: CHM 208**
- **Course title: CHM 208: General Chemistry Practical IV** (1 Unit C: PH 45)
- **Course credit load:** (1 Unit C: PH 45)
- **List of Series**:

Series 1: **Laboratory Safety and Rules in General Chemistry**

Series 2: **Preparation of Esters, Aldehydes, and Ketones**

Series 3: **Vinegar Analysis and Chromatographic Techniques**

Series 4: **Thin Layer Chromatography Applications**

Series 5: **Alcohol Dehydration and Functional Group Analysis**

Proposed Outline

5.1 Introduction to Alcohols and Dehydration

Definition and classification of alcohols
Concept of dehydration reactions
Importance of dehydration in organic synthesis

5.2 Mechanism of Alcohol Dehydration

Acid-catalysed dehydration process
Formation of carbocations
Zaitsev's rule and product distribution

5.3 Laboratory Procedure for Alcohol Dehydration

Experimental setup and reagents
Observation of products (alkenes)
Safety precautions in handling acids and alcohols

5.4 Functional Group Analysis in Organic Chemistry

Definition of functional groups
Common functional groups and their identification tests
Role of functional group analysis in organic synthesis and quality control

5.5 Practical Considerations and Applications

Troubleshooting issues in dehydration experiments
Applications of dehydration and functional group analysis in industry
Safety and sustainability in organic laboratory practice

Introduction

In the last Series, we examined thin layer chromatography and its applications in organic chemistry, focusing on how compounds can be separated, identified, and analysed. Building on that knowledge, this Series turns to alcohol dehydration and functional group analysis, two essential topics in organic chemistry. Dehydration reactions are important because they transform alcohols into alkenes, while functional group analysis provides a systematic way to identify and classify organic compounds. Together, these concepts form the foundation for understanding chemical reactivity and synthesis.

The aim of this Series is to equip you with the knowledge and skills to explain the principles of alcohol dehydration, carry out laboratory procedures safely, and apply functional group analysis to identify and evaluate organic compounds.

We shall commence this Series by introducing alcohols and the concept of dehydration. Next, we will explore the mechanism of alcohol dehydration, including carbocation formation and Zaitsev's rule. Following that, we will examine the laboratory procedure for alcohol dehydration, focusing on experimental setup, product observation, and safety precautions. Afterwards, we will move on to functional group analysis, where you will learn about common functional groups and their identification tests. Finally, we will conclude with practical considerations and applications, highlighting troubleshooting, industrial uses, and sustainable laboratory practice.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 5.1 define alcohols and explain the concept of dehydration reactions,
SLO 5.2 describe the acid-catalysed mechanism of alcohol dehydration including carbocation formation,
SLO 5.3 analyse product distribution in alcohol dehydration using Zaitsev's rule,
SLO 5.4 demonstrate the laboratory procedure for alcohol dehydration including setup, reagents, and product observation,
SLO 5.5 apply functional group analysis to identify common functional groups using appropriate tests, and
SLO 5.6 evaluate practical considerations, troubleshooting methods, and safety measures in alcohol dehydration and functional group analysis experiments.

5.1 Introduction to Alcohols and Dehydration

5.1.1 Definition and classification of alcohols

Alcohols are organic compounds that contain one or more hydroxyl groups (–OH) attached to a carbon atom. They are classified based on the number of carbon atoms bonded to the carbon bearing the hydroxyl group:

- **Primary alcohols**: The –OH group is attached to a carbon bonded to only one other carbon atom.
- **Secondary alcohols**: The –OH group is attached to a carbon bonded to two other carbon atoms.
- **Tertiary alcohols**: The –OH group is attached to a carbon bonded to three other carbon atoms.

This classification is important because it influences the reactivity of alcohols in chemical reactions.

Fill in the blank: An alcohol with the –OH group attached to a carbon bonded to three other carbons is called a __________________ alcohol.

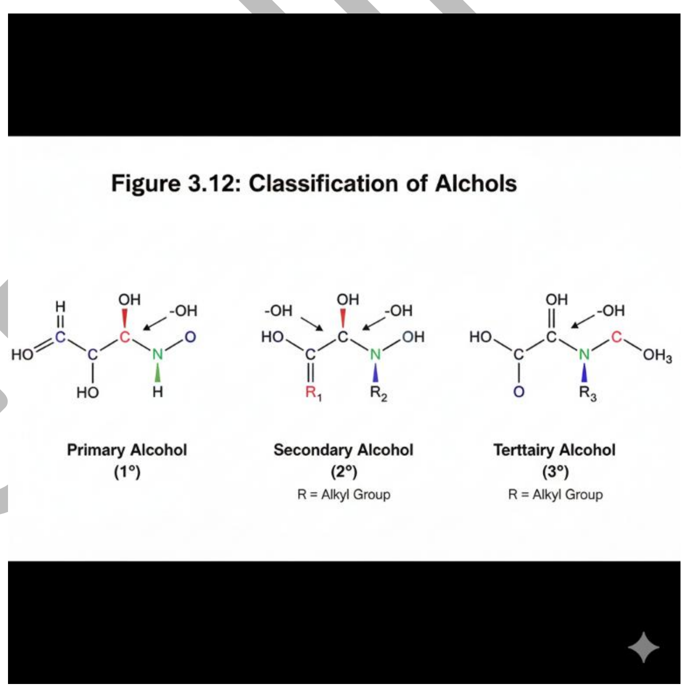

Figure 5.1: Classification of alcohols

AI prompt: “Generate a labelled diagram showing primary, secondary, and tertiary alcohol structures with hydroxyl groups.”
Search string: “classification of alcohols primary secondary tertiary diagram OER”

5.1.2 Concept of dehydration reactions

Dehydration is a chemical reaction in which a molecule of water is removed from a compound. In the case of alcohols, dehydration typically occurs under acidic conditions, producing an alkene as the product. This reaction is significant because it transforms relatively stable alcohols into more reactive alkenes, which serve as building blocks in organic synthesis.

Fill in the blank: The product formed when alcohols undergo dehydration is an __________________.

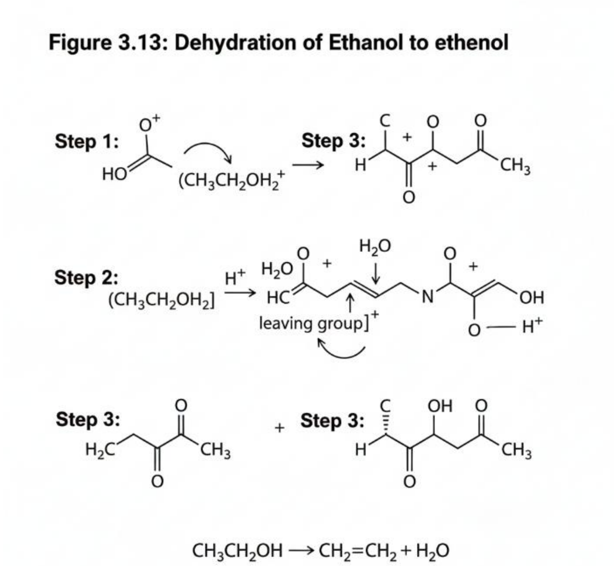

Figure 5.2: Dehydration of ethanol to ethene

AI prompt: "Generate a labelled diagram showing dehydration of ethanol to ethene with water molecule removed."
Search string: "dehydration of ethanol to ethene diagram OER"

5.1.3 Importance of dehydration in organic synthesis

Dehydration reactions are important in **organic synthesis**, as they provide a straightforward method for producing alkenes from alcohols. Alkenes are versatile intermediates that can be used in polymerisation, addition reactions, and industrial processes. For example, ethene produced from ethanol dehydration is a key raw material in the manufacture of plastics such as polyethylene.

Fill in the blank: Dehydration of alcohols is important in industry because it produces __________________, which are versatile intermediates in organic synthesis.

Applications of Alcohol Dehydration

Application Area	Primary Use / Function	Key Chemical Products
Polymerization	Production of monomers from renewable or fossil-based alcohols to create plastics and synthetic rubbers.	Ethylene (for Polyethylene), Propylene (for Polypropylene), Butadiene.
Fuel Production	Manufacture of high-octane fuels and oxygenated fuel additives to improve combustion efficiency.	Bio-olefins, Diethyl ether (DEE) (ignition improver), Aviation fuels.
Pharmaceuticals	Synthesis of complex intermediates used as building blocks for active pharmaceutical ingredients (APIs).	Cyclic ethers, Styrene, and various specialized alkene intermediates.
Solvents	Preparation of industrial-grade solvents through intermolecular dehydration (at lower temperatures).	Diethyl ether, Dibutyl ether, and other symmetrical/cyclic ethers.
Organic Synthesis	Laboratory-scale preparation of reactive compounds for further functional group transformations.	Alkyl halides, Epoxides (from diols), and Alpha-olefins.

Box 5.1: Applications of alcohol dehydration

Production of alkenes for polymerisation
Manufacture of fuels and solvents
Preparation of intermediates in pharmaceuticals
Laboratory synthesis of reactive organic compounds

AI prompt: "Generate a table listing applications of alcohol dehydration such as polymerisation, fuel production, and pharmaceuticals."
Search string: "applications of alcohol dehydration organic synthesis OER"

Pilot questions 5.1

An alcohol with the –OH group attached to a carbon bonded to three other carbons is called a:
A. Primary alcohol
B. Secondary alcohol
C. Tertiary alcohol
D. Quaternary alcohol
(Linked to SLO 5.1)

The product formed when alcohols undergo dehydration is an __________.
(Linked to SLO 5.1)

Dehydration of ethanol produces __________ and water.
(Linked to SLO 5.1)

State one industrial application of alcohol dehydration.
(Linked to SLO 5.1)

Why does the classification of alcohols matter in dehydration reactions?
(Linked to SLO 5.1)

5.2 Mechanism of Alcohol Dehydration

5.2.1 Acid-catalysed dehydration process

Acid-catalysed dehydration is the most common method for converting alcohols into alkenes. In this process, a strong acid such as concentrated sulphuric acid or phosphoric acid acts as a catalyst. The acid protonates the hydroxyl group of the alcohol, making it a better leaving group. Water is then eliminated, and an alkene is formed. This reaction typically requires heating to proceed efficiently.

Fill in the blank: The acid used to protonate the hydroxyl group in alcohol dehydration is typically __________________ acid.

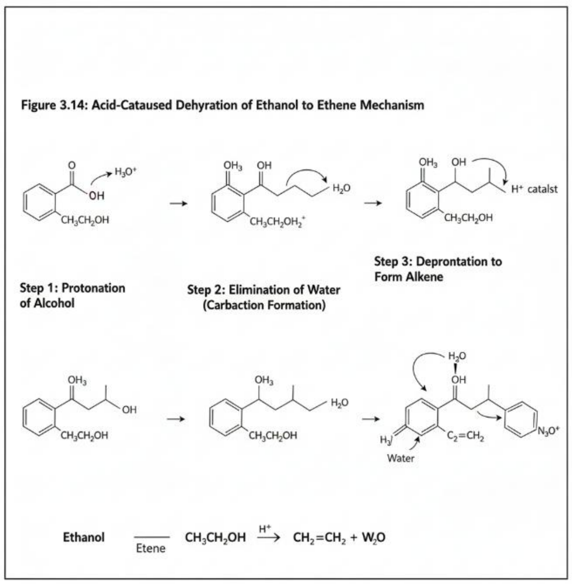

Figure 5.3: Acid-catalysed dehydration of ethanol

AI prompt: "Generate a labelled diagram showing acid-catalysed dehydration of ethanol to ethene with water eliminated."
Search string: "acid catalysed dehydration of ethanol diagram OER"

5.2.2 Formation of carbocations

During dehydration, the departure of the water molecule leaves behind a positively charged intermediate called a **carbocation**. The stability of this carbocation determines the ease of the reaction and the type of product formed. Tertiary carbocations are more stable than secondary, which are more stable than primary. This explains why tertiary alcohols dehydrate more readily than secondary or primary alcohols.

Fill in the blank: The positively charged intermediate formed during alcohol dehydration is called a __________________.

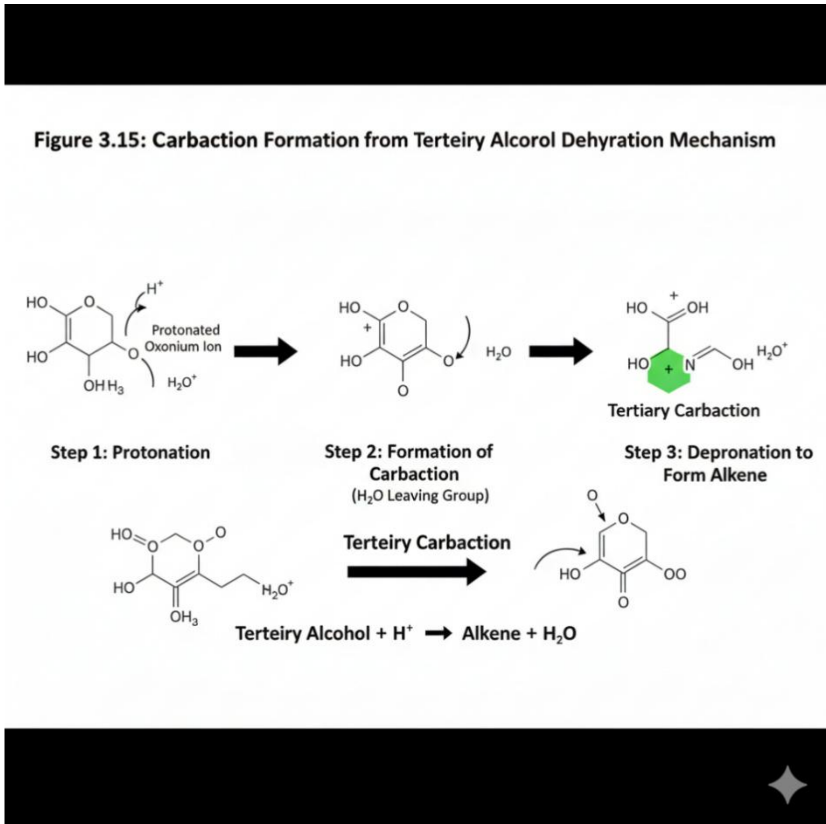

Figure 5.4: Formation of a carbocation during dehydration

AI prompt: “Generate a labelled diagram showing carbocation formation from a tertiary alcohol during dehydration.”
Search string: “carbocation formation alcohol dehydration diagram OER”

5.2.3 Zaitsev’s rule and product distribution

Zaitsev’s rule states that in an elimination reaction, the more substituted alkene (the one with more alkyl groups attached to the double bond) is usually the major product. This occurs because more substituted alkenes are more stable due to hyperconjugation and inductive effects. In alcohol dehydration, this rule helps predict which alkene will dominate when multiple products are possible.

Fill in the blank: According to Zaitsev's rule, the __________________ substituted alkene is usually the major product in dehydration reactions.

Summary of Zaitsev's Rule

Feature	Description	Key Rationale
The Rule	The major product is the alkene formed by removing a hydrogen from the -carbon with the fewest hydrogens.	Minimises energy by forming the most substituted double bond.
Substitution	Favors the more highly substituted alkene (e.g., trisubstituted > disubstituted).	Higher substitution correlates directly with increased product stability.
Stability	More substituted alkenes are more thermodynamically stable.	Stabilized by hyperconjugation and the inductive effect of alkyl groups.
Regioselectivity	The reaction selectively produces one regioisomer (the Zaitsev product) over the Hofmann product.	The transition state leading to the more stable alkene is lower in energy.
Stereochemistry	If the major product can exist as isomers, the trans-alkene is typically favored over the cis-alkene.	Trans-isomers have less steric strain between large alkyl groups.

Box 5.2: Key points about Zaitsev's rule

Major product is the more substituted alkene
Stability arises from hyperconjugation and inductive effects
Predicts product distribution in elimination reactions

AI prompt: "Generate a table summarising Zaitsev's rule with points on product stability and substitution."
Search string: "Zaitsev's rule alcohol dehydration OER"

Pilot questions 5.2

The acid used to protonate the hydroxyl group in alcohol dehydration is typically __________ acid.
(Linked to SLO 5.2)
The positively charged intermediate formed during alcohol dehydration is called a __________.
(Linked to SLO 5.2)
According to Zaitsev's rule, the __________ substituted alkene is usually the major product.
(Linked to SLO 5.3)
Why do tertiary alcohols dehydrate more readily than primary alcohols?
(Linked to SLO 5.2)
State one reason why more substituted alkenes are more stable than less substituted alkenes.
(Linked to SLO 5.3)

5.3 Laboratory Procedure for Alcohol Dehydration

5.3.1 Experimental setup and reagents

To carry out **alcohol dehydration**, you need a suitable laboratory setup. The experiment typically involves heating the alcohol with a strong acid catalyst such as concentrated sulphuric acid or phosphoric acid. The apparatus includes a round-bottom flask fitted with a condenser to collect the gaseous products, which are then passed into a receiver. The acid provides the protons necessary to initiate the reaction, while heat ensures that the elimination of water proceeds efficiently.

Fill in the blank: The acid most commonly used as a catalyst in alcohol dehydration is concentrated __________________ acid.

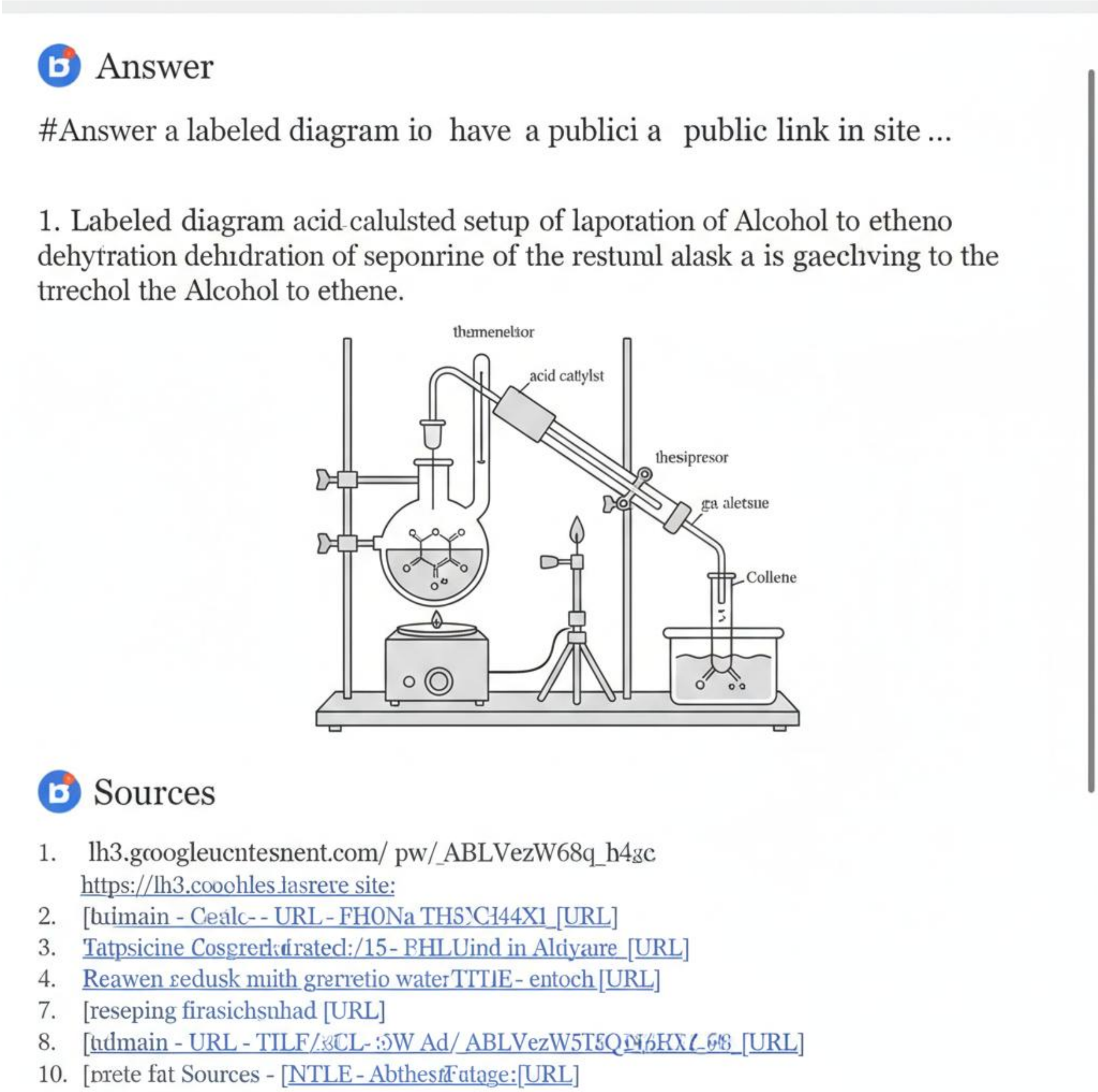

Figure 5.5: Laboratory setup for alcohol dehydration

AI prompt: “Generate a labelled diagram of a laboratory setup for alcohol dehydration showing alcohol in flask, acid catalyst, condenser, and heating source.”
Search string: “alcohol dehydration laboratory setup diagram OER”

5.3.2 Observation of products (alkenes)

The main product of alcohol dehydration is an **alkene**, which can be identified by its physical properties and chemical tests. Alkenes are generally more volatile than alcohols and can be detected by their characteristic reactions, such as decolourising bromine water or reacting with potassium permanganate. These tests confirm the presence of the double bond formed during dehydration.

Fill in the blank: A simple test for alkenes is their ability to decolourise ________________ water.

Plate 5.1: Bromine water test for alkenes

AI prompt: "Create an image showing bromine water test for alkenes, with colour change from orange to colourless."
Search string: "bromine water test for alkenes OER"

5.3.3 Safety precautions in handling acids and alcohols

Strong acids used in dehydration reactions are corrosive, and alcohols can be flammable. It is therefore essential to follow strict safety measures. Always wear **personal protective equipment (PPE)** such as goggles, gloves, and a lab coat. Conduct experiments in a fume hood to avoid inhaling vapours, and ensure that heating is controlled to prevent accidents. Proper disposal of waste chemicals is also necessary to maintain a safe laboratory environment.

Fill in the blank: Experiments involving volatile alcohols and strong acids should always be conducted in a __________________.

Safety Precautions for Alcohol Dehydration

Category	Precautionary Measure	Purpose
Personal Protective Equipment (PPE)	Wear indirectly vented chemical-splash goggles, a buttoned lab coat, and chemical-resistant gloves (nitrile or neoprene).	Protects eyes and skin from corrosive acid splashes and prevents clothing from absorbing hazardous chemicals.
Fume Hood Usage	Conduct the entire experiment inside a certified fume hood with the sash at the lowest functional height.	Exhausts irritating or toxic vapors (e.g., sulfur oxides) and provides a physical shield against potential glass failure or eruptions.
Controlled Heating	Use a heating mantle or sand bath; never use open flames.	Prevents the ignition of flammable alcohol reactants or alkene products.
Chemical Handling	Always add acid to the alcohol/water mixture slowly with constant swirling.	Mitigates highly exothermic reactions that can cause violent splashing or "bumping".
Distillation Safety	Add boiling stones (anti-bumping granules) and never distill the reaction mixture to dryness.	Ensures smooth boiling and prevents the concentration of explosive peroxides or overheating of residue.
Waste Disposal	Collect acidic residue and organic distillates in designated hazardous waste containers.	Prevents environmental contamination and dangerous reactions in laboratory plumbing.

Box 5.3: Safety precautions in alcohol dehydration experiments

Wear goggles, gloves, and a lab coat
Use a fume hood to avoid inhaling vapours
Control heating carefully to prevent accidents
Store and dispose of acids and alcohols properly

AI prompt: "Generate a table listing safety precautions in alcohol dehydration experiments such as PPE, fume hood use, and controlled heating."
Search string: "alcohol dehydration laboratory safety precautions OER"

Pilot questions 5.3

The acid most commonly used as a catalyst in alcohol dehydration is concentrated __________ acid.
(Linked to SLO 5.4)
A simple test for alkenes is their ability to decolourise __________ water.
(Linked to SLO 5.4)
Experiments involving volatile alcohols and strong acids should always be conducted in a __________.
(Linked to SLO 5.6)
State one reason why a condenser is used in the laboratory setup for alcohol dehydration.
(Linked to SLO 5.4)

Name one piece of PPE that must be worn during alcohol dehydration experiments. (Linked to SLO 5.6)

5.4 Functional Group Analysis in Organic Chemistry

5.4.1 Definition of functional groups

A **functional group** is a specific group of atoms within a molecule that determines its characteristic chemical reactions. Examples include hydroxyl (–OH), carbonyl (C=O), carboxyl (–COOH), and amino (–NH_2) groups. Recognising functional groups is essential because they provide a systematic way to classify organic compounds and predict their behaviour in chemical reactions.

Fill in the blank: The group of atoms within a molecule that determines its characteristic chemical reactions is called a __________________ group.

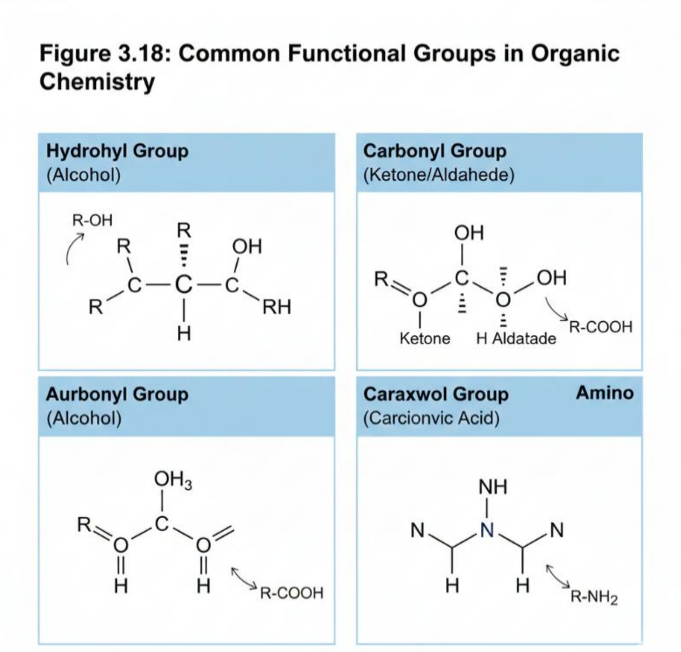

Figure 5.6: Common functional groups in organic chemistry

AI prompt: "Generate a labelled diagram showing hydroxyl, carbonyl, carboxyl, and amino functional groups."
Search string: "functional groups organic chemistry diagram OER"

5.4.2 Common functional groups and their identification tests

Each functional group can be identified using specific **chemical tests**. For example:

Alcohols: Identified by reaction with sodium metal, producing hydrogen gas.

Aldehydes: Identified by the Tollens' test, which produces a silver mirror.

Ketones: Distinguished from aldehydes because they do not give a positive Tollens' test.

Carboxylic acids: Identified by their reaction with sodium carbonate, producing carbon dioxide gas.

These tests are simple yet powerful tools for distinguishing between different classes of organic compounds.

Fill in the blank: The reagent used to detect carbonyl compounds by forming a yellow or orange precipitate is __________________.

Plate 5.2: DNPH test for carbonyl compounds

AI prompt: "Create an image showing DNPH test for carbonyl compounds with formation of orange precipitate."
Search string: "DNPH test carbonyl compounds OER"

5.4.3 Role of functional group analysis in organic synthesis and quality control

Functional group analysis plays a vital role in **organic synthesis** and **quality control**. In synthesis, identifying functional groups helps chemists design reaction pathways and predict product behaviour. In industry, functional group analysis ensures that products meet required standards, such as confirming the purity of pharmaceuticals or verifying the composition of food additives. This makes functional group analysis an essential skill for both academic and professional chemists.

Fill in the blank: Functional group analysis is important in industry because it ensures __________________ of compounds, especially in pharmaceuticals.

Applications of Functional Group Analysis

Application	Description	Impact/Significance
Confirming Product Identity	Verification that a synthetic reaction yielded the intended molecule by identifying its unique functional groups (e.g., detecting a stretch in a ketone synthesis).	Essential for validating laboratory results and developing new medicines.
Ensuring Purity	Qualitative tests (like the test for unsaturation) detect trace functional groups that should not be present in a pure sample.	Crucial for quality control in food additives, cosmetics, and pharmaceuticals.
Detecting Adulteration	Identifying foreign chemical signatures in consumer products, such as detecting non-honey sugars or synthetic fillers in natural extracts.	Used in food safety to identify intentional or accidental contamination and fraud.
Environmental Monitoring	Screening soil and water for specific contaminants like phenolic waste or halogenated hydrocarbons.	Protects public health by monitoring pollution levels in ecosystems.
Forensic Investigations	Identifying unknown residues (drugs, explosives, or bodily fluids) found at crime scenes based on their chemical reactivity.	Provides vital evidence to link suspects to crimes or reconstruct events.
Biological Fingerprinting	Mapping the functional groups in plant extracts or proteins to determine bioactive potential or disease states.	Aids in natural product research and automated medical diagnostics.

Box 5.4: Applications of functional group analysis

Confirming product identity in synthesis
Ensuring purity and quality in pharmaceuticals
Detecting adulteration in food chemistry
Predicting reactivity for designing synthetic pathways

AI prompt: "Generate a table listing applications of functional group analysis such as confirming product identity, ensuring purity, and detecting adulteration."
Search string: "applications of functional group analysis organic chemistry OER"

Pilot questions 5.4

The group of atoms within a molecule that determines its characteristic chemical reactions is called a __________ group.
(Linked to SLO 5.5)

The reagent used to detect carbonyl compounds by forming a yellow or orange precipitate is __________.
(Linked to SLO 5.5)

Functional group analysis is important in industry because it ensures __________ of compounds, especially in pharmaceuticals.
(Linked to SLO 5.5)

State one test that can be used to identify alcohols.
(Linked to SLO 5.5)
Explain why functional group analysis is useful in organic synthesis.
(Linked to SLO 5.5)

5.5 Practical Considerations and Applications

5.5.1 Troubleshooting issues in dehydration experiments

In **alcohol dehydration** experiments, several issues may arise that affect the quality of results. For example, incomplete dehydration can occur if the temperature is too low or if the acid catalyst is insufficient. Overheating may lead to side reactions, producing unwanted by-products such as ethers. To troubleshoot, ensure that the reaction conditions are carefully controlled, and repeat the experiment with adjusted parameters if necessary.

Fill in the blank: Overheating during alcohol dehydration may lead to the formation of unwanted by-products such as ___________________.

Alcohol Dehydration: Common Issues & Troubleshooting

Common Issue	Possible Cause	Troubleshooting & Solutions
Incomplete Dehydration	Reaction temperature is too low for the alcohol's substitution level	Increase temperature to the appropriate range (e.g., for primary alcohols) or increase catalyst strength (use conc. instead of).
Overheating & Side Reactions	Excessively high temperatures lead to ether formation or charring.	Maintain lower temperatures to avoid side reactions like SN2 ether formation. Lower the heating mantle if "white fumes" appear.
Poor Product Yield	Reversible reaction reached equilibrium; starting material was impure.	Remove product via distillation as it forms to shift equilibrium (Le Chatelier's principle). Check purity of starting alcohol to ensure no contaminants are inhibiting the acid catalyst.
Contamination	Residual water or dirty glassware.	Ensure clean, dry apparatus. Add drying agents (e.g., anhydrous to the final distillate to remove trace water.
Bumping or Violent Boiling	Lack of nucleation sites for bubbles.	Add boiling stones or anti-bumping granules to the reaction flask before heating to ensure smooth distillation.
Charring/Black Residue	Sulfuric acid is too concentrated or temperature is too high, leading to oxidation.	Switch to phosphoric acid (which is a non-oxidizing acid catalyst that produces cleaner results.

Box 5.5: Troubleshooting alcohol dehydration experiments

Incomplete dehydration → increase temperature or catalyst strength
Overheating → avoid side reactions such as ether formation
Poor product yield → check purity of starting alcohol
Contamination → ensure clean apparatus and proper handling

AI prompt: “Generate a table listing common issues in alcohol dehydration experiments and troubleshooting methods such as adjusting temperature or catalyst strength.”
Search string: “alcohol dehydration troubleshooting organic chemistry OER”

5.5.2 Applications in industry and research

Both **dehydration reactions** and **functional group analysis** have wide applications in industry. Dehydration is used to produce alkenes, which serve as raw materials for plastics, synthetic fibres, and fuels. Functional group analysis ensures product quality in pharmaceuticals, food chemistry, and petrochemicals by confirming the presence or absence of specific groups. Together, these techniques support innovation and quality control in industrial chemistry.

Fill in the blank: Dehydration of alcohols is widely used in industry to produce __________________, which are essential for polymer and fuel production.

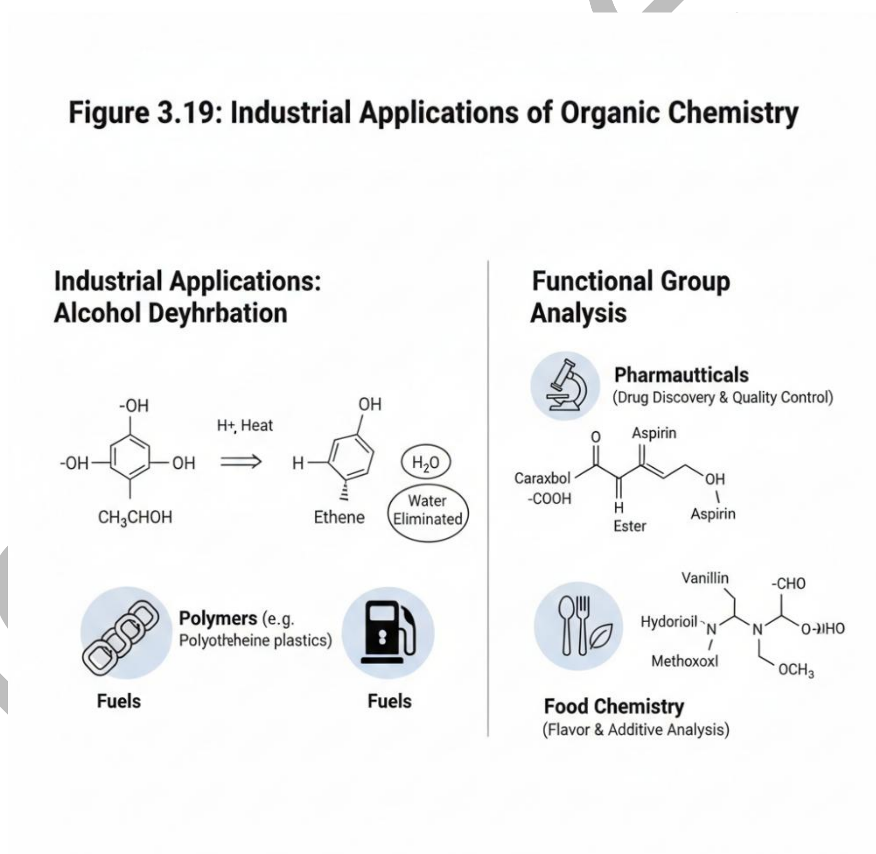

Figure 5.7: Applications of alcohol dehydration and functional group analysis

AI prompt: “Generate a labelled diagram showing industrial applications of alcohol dehydration (alkenes for polymers and fuels) and functional group analysis (pharmaceuticals and food

chemistry).”
Search string: “applications of alcohol dehydration and functional group analysis OER”

5.5.3 Safety and sustainability in organic laboratory practice

Safety and sustainability are essential in modern organic chemistry. Handling concentrated acids and flammable alcohols requires strict adherence to laboratory safety protocols, including the use of **personal protective equipment (PPE)** and fume hoods. Sustainability involves minimising waste, recycling solvents where possible, and adopting greener alternatives to hazardous reagents. By combining safety with sustainability, chemists ensure responsible laboratory practice that protects both people and the environment.

Fill in the blank: One way to make alcohol dehydration more sustainable is to ___________________ solvents where possible.

Plate 5.3: Sustainable practices in organic chemistry laboratories

AI prompt: “Create an image showing sustainable laboratory practices such as solvent recycling, safe disposal of acids, and use of PPE.”
Search string: “sustainable laboratory practices organic chemistry OER”

Pilot questions 5.5

Overheating during alcohol dehydration may lead to the formation of unwanted by-products such as __________.
(Linked to SLO 5.6)
Dehydration of alcohols is widely used in industry to produce __________, which are essential for polymer and fuel production.
(Linked to SLO 5.6)
One way to make alcohol dehydration more sustainable is to __________ solvents where possible.
(Linked to SLO 5.6)
State one industrial application of functional group analysis.
(Linked to SLO 5.5)
Explain why sustainability is important in organic laboratory practice.
(Linked to SLO 5.6)

Series Summary

This Series on **Alcohol Dehydration and Functional Group Analysis** was designed to help you understand how alcohols can be transformed into alkenes and how functional groups are identified and applied in organic chemistry. You began by exploring the definition and classification of alcohols, the concept of dehydration reactions, and their importance in synthesis. You then examined the mechanism of alcohol dehydration, including acid-catalysed processes, carbocation formation, and the application of Zaitsev's rule to predict product distribution. Building on this, you studied the laboratory procedure for alcohol dehydration, learning about the experimental setup, observation of products, and essential safety precautions. The Series also introduced functional group analysis, covering definitions, identification tests, and its role in synthesis and quality control. Finally, you considered practical aspects such as troubleshooting dehydration experiments, industrial applications, and the importance of safety and sustainability in laboratory practice.

By completing this Series, you should now be able to **define alcohols and explain dehydration reactions (SLO 5.1)**, **describe the acid-catalysed mechanism including carbocations (SLO 5.2)**, **analyse product distribution using Zaitsev's rule (SLO 5.3)**, **demonstrate the laboratory procedure for alcohol dehydration (SLO 5.4)**, **apply functional group analysis to identify common groups (SLO 5.5)**, and **evaluate practical considerations, troubleshooting methods, and safety measures in these experiments (SLO 5.6)**. These outcomes ensure you are well-equipped to apply both dehydration and functional group analysis confidently in academic studies and industrial practice.

Glossary of Terms

Acid catalyst: A substance such as concentrated sulphuric acid or phosphoric acid that speeds up the dehydration of alcohols by donating protons.

Alcohols: Organic compounds containing one or more hydroxyl groups (–OH) attached to a carbon atom.

Alkenes: Hydrocarbons with at least one carbon–carbon double bond, often produced by dehydration of alcohols.

Carbocation: A positively charged carbon species formed as an intermediate during alcohol dehydration.

Dehydration reaction: A chemical process in which a molecule of water is removed from a compound, often converting alcohols into alkenes.

Functional group: A specific group of atoms within a molecule that determines its characteristic chemical reactions.

Functional group analysis: The process of identifying functional groups in organic compounds using chemical tests.

Personal protective equipment (PPE): Safety gear such as gloves, goggles, and lab coats used to protect against chemical hazards.

Primary alcohol: An alcohol in which the hydroxyl group is attached to a carbon bonded to only one other carbon atom.

Secondary alcohol: An alcohol in which the hydroxyl group is attached to a carbon bonded to two other carbon atoms.

Tertiary alcohol: An alcohol in which the hydroxyl group is attached to a carbon bonded to three other carbon atoms.

Zaitsev's rule: A principle stating that in elimination reactions, the more substituted alkene is usually the major product.

Concept Check Questions [Series 5]

Objective Questions

Alcohols contain one or more __________________ groups attached to a carbon atom.
(Linked to SLO 5.1)

The acid most commonly used as a catalyst in alcohol dehydration experiments is concentrated __________________ acid.
(Linked to SLO 5.4)

The positively charged intermediate formed during alcohol dehydration is called a __________________.
(Linked to SLO 5.2)

According to Zaitsev's rule, the __________________ substituted alkene is usually the major product.
(Linked to SLO 5.3)

Aldehydes can be identified by the __________________ test, which produces a silver mirror.
(Linked to SLO 5.5)

Short-Answer Questions

Define alcohols and explain how they are classified.
(Linked to SLO 5.1)

Describe the acid-catalysed mechanism of alcohol dehydration.
(Linked to SLO 5.2)

Outline the laboratory procedure for alcohol dehydration, including setup and observation of products.
(Linked to SLO 5.4)

State one industrial application of dehydration reactions.
(Linked to SLO 5.6)

Explain why functional group analysis is important in quality control.
(Linked to SLO 5.5)

Long-Answer Questions

Analyse the importance of carbocation stability in alcohol dehydration reactions.
(Linked to SLO 5.2)

Evaluate the role of Zaitsev's rule in predicting product distribution during alcohol dehydration.
(Linked to SLO 5.3)

Compare functional group analysis with instrumental methods such as spectroscopy in identifying organic compounds.
(Linked to SLO 5.5)

Assess the importance of safety and sustainability in alcohol dehydration experiments.
(Linked to SLO 5.6)

Answers to Concept Check Questions [Series 5]

Objective Questions

Hydroxyl
Sulphuric
Carbocation
More
Tollens'

Short-Answer Questions

Alcohols are organic compounds with hydroxyl groups attached to carbon atoms. They are classified as primary, secondary, or tertiary depending on the number of carbons bonded to the hydroxyl-bearing carbon.

The acid protonates the hydroxyl group, water leaves, and a carbocation forms, which then rearranges or eliminates to produce an alkene.
Heat the alcohol with concentrated acid in a round-bottom flask fitted with a condenser, collect the product, and test for alkenes using bromine water.
Dehydration reactions are used to produce alkenes for plastics and fuels.
Functional group analysis ensures products meet standards, for example confirming the purity of pharmaceuticals.

Long-Answer Questions

Question 1

Basic response: Carbocation stability determines whether primary, secondary, or tertiary carbocations form, influencing the reaction pathway and product yield.
Value-added response: Learners may extend by discussing rearrangements that occur to form more stable carbocations, and how this affects regioselectivity in product formation.

Question 2

Basic response: Zaitsev's rule predicts that the more substituted alkene will be the major product, due to its greater stability.
Value-added response: Learners may extend by considering exceptions, such as steric hindrance or the use of bulky bases, which can lead to Hofmann products instead.

Question 3

Basic response: Functional group analysis uses simple chemical tests to identify groups, while spectroscopy provides more detailed structural information.
Value-added response: Learners may extend by comparing the speed, cost, and accuracy of both methods, noting that functional group tests are useful for quick checks, while spectroscopy is essential for precise analysis.

Question 4

Basic response: Safety ensures protection from corrosive acids and flammable alcohols, while sustainability reduces waste and promotes responsible practice.
Value-added response: Learners may extend by linking sustainability to green chemistry principles, such as solvent recycling and the use of safer catalysts, which benefit both industry and the environment.

This set of concept check questions ensures coverage of all **Series 5 Learning Outcomes**, encouraging learners to recall, explain, analyse, and evaluate alcohol dehydration and functional group analysis.

Answers to Pilot Questions [Series 5]

Part 5.1 Introduction to Alcohols and Dehydration

Tertiary alcohol
Alkene
Ethene
Production of fuels (or polymers, pharmaceuticals)
Because the classification affects reactivity and ease of dehydration

Part 5.2 Mechanism of Alcohol Dehydration

Sulphuric (or phosphoric) acid
Carbocation
More
Because tertiary carbocations are more stable than primary carbocations
Due to hyperconjugation and inductive effects

Part 5.3 Laboratory Procedure for Alcohol Dehydration

Sulphuric acid
Bromine water
Fume hood
To prevent loss of volatile products
Goggles (or gloves, lab coat)

Part 5.4 Functional Group Analysis in Organic Chemistry

Functional group
2,4-dinitrophenylhydrazine (DNPH)
Purity
Iodoform test (or other valid alcohol test)
It helps confirm product identity and predict reactivity

Part 5.5 Practical Considerations and Applications

Ethers
Alkenes
Recycle
Pharmaceutical quality control (or food chemistry)
To protect health, reduce waste, and ensure responsible laboratory practice

References and Attributions [Series 5]

Textual Sources

Clayden, J., Greeves, N., Warren, S., & Wothers, P. (2012). *Organic Chemistry* (2nd ed.). Oxford University Press.
McMurry, J. (2016). *Organic Chemistry* (9th ed.). Cengage Learning.
IUPAC. (1997). *Compendium of Chemical Terminology (the "Gold Book")*.

Illustrations (Figures, Plates, Tables, Boxes)

Figure 5.1 Classification of alcohols
AI prompt: "Generate a labelled diagram showing primary, secondary, and tertiary alcohol structures with hydroxyl groups."
Search string: "classification of alcohols primary secondary tertiary diagram OER"

Figure 5.2 Dehydration of ethanol to ethene
AI prompt: "Generate a labelled diagram showing dehydration of ethanol to ethene with water molecule removed."
Search string: "dehydration of ethanol to ethene diagram OER"

Box 5.1 Applications of alcohol dehydration
AI prompt: "Generate a table listing applications of alcohol dehydration such as polymerisation, fuel production, and pharmaceuticals."
Search string: "applications of alcohol dehydration organic synthesis OER"

Figure 5.3 Acid-catalysed dehydration of ethanol
AI prompt: "Generate a labelled diagram showing acid-catalysed dehydration of ethanol to ethene with water eliminated."
Search string: "acid catalysed dehydration of ethanol diagram OER"

Figure 5.4 Formation of a carbocation during dehydration
AI prompt: "Generate a labelled diagram showing carbocation formation from a tertiary alcohol during dehydration."
Search string: "carbocation formation alcohol dehydration diagram OER"

Box 5.2 Key points about Zaitsev's rule
AI prompt: "Generate a table summarising Zaitsev's rule with points on product stability and substitution."
Search string: "Zaitsev's rule alcohol dehydration OER"

Figure 5.5 Laboratory setup for alcohol dehydration
AI prompt: "Generate a labelled diagram of a laboratory setup for alcohol dehydration showing alcohol in flask, acid catalyst, condenser, and heating source."
Search string: "alcohol dehydration laboratory setup diagram OER"

Plate 5.1 Bromine water test for alkenes
AI prompt: "Create an image showing bromine water test for alkenes, with colour change from orange to colourless."
Search string: "bromine water test for alkenes OER"

Box 5.3 Safety precautions in alcohol dehydration experiments
AI prompt: "Generate a table listing safety precautions in alcohol dehydration experiments such as PPE, fume hood use, and controlled heating."
Search string: "alcohol dehydration laboratory safety precautions OER"

Figure 5.6 Common functional groups in organic chemistry
AI prompt: "Generate a labelled diagram showing hydroxyl, carbonyl, carboxyl, and amino functional groups."
Search string: "functional groups organic chemistry diagram OER"

Plate 5.2 DNPH test for carbonyl compounds

AI prompt: "Create an image showing DNPH test for carbonyl compounds with formation of orange precipitate."
Search string: "DNPH test carbonyl compounds OER"

Box 5.4 Applications of functional group analysis

AI prompt: "Generate a table listing applications of functional group analysis such as confirming product identity, ensuring purity, and detecting adulteration."
Search string: "applications of functional group analysis organic chemistry OER"

Box 5.5 Troubleshooting alcohol dehydration experiments

AI prompt: "Generate a table listing common issues in alcohol dehydration experiments and troubleshooting methods such as adjusting temperature or catalyst strength."
Search string: "alcohol dehydration troubleshooting organic chemistry OER"

Figure 5.7 Applications of alcohol dehydration and functional group analysis

AI prompt: "Generate a labelled diagram showing industrial applications of alcohol dehydration (alkenes for polymers and fuels) and functional group analysis (pharmaceuticals and food chemistry)."
Search string: "applications of alcohol dehydration and functional group analysis OER"

Plate 5.3 Sustainable practices in organic chemistry laboratories

AI prompt: "Create an image showing sustainable laboratory practices such as solvent recycling, safe disposal of acids, and use of PPE."
Search string: "sustainable laboratory practices organic chemistry OER"

Notes on Attribution

AI-generated illustrations are documented with prompts and should be noted with the generation date and platform used.
Where OERs are used, attribution must comply with the licence terms of the source.
References are presented in APA style for consistency.