

COMPETENCE BASED ORGANIC CHEMISTRY ITEMS

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Scenario 1: Introduction to Organic Chemistry – Unique Properties of Carbon, Isomerism, and Nomenclature

Problem Statement: In a petroleum refinery near the Albertine Graben, quality control chemists analyse hydrocarbon fractions from crude oil containing compounds with molecular formulae C_4H_{10} and C_4H_8 . These exhibit different physical properties and reactivity due to carbon's unique ability to form chains, rings, and multiple bonds. A trainee chemist must prepare a report using molecular models and combustion data to explain these differences to factory workers for safe handling and efficient processing.

Tasks:

- Explain the unique properties of carbon (catenation, tetravalency, ability to form single/double/triple bonds,) that allow formation of diverse organic compounds, homologous series, and isomerism. Link to why organic compounds are so numerous compared to inorganic ones.
- Draw and name (using IUPAC rules) all structural isomers for C_4H_{10} and all structural + geometrical isomers for C_4H_8 . Clearly identify functional groups and types of isomerism. Use molecular models (or describe) to illustrate.
- Predict and explain differences in boiling points, solubility in water, density, and volatility based on intermolecular forces and molecular structure.
- A 2.9 g sample of one isomer undergoes complete combustion analysis giving 82.76% C and 17.24% H by mass. Calculate the empirical formula step-by-step, then determine the molecular formula given $M_r = 58$. Show all working and verify with combustion equation.
- Discuss one major industrial application and one environmental concern.
- In a group project, design a poster or digital presentation comparing the isomers' properties and reactivity; evaluate how functional groups influence chemical behaviour.
- Propose a simple laboratory activity to demonstrate differences in physical properties.

Scenario 2: Alkenes – Electrophilic Addition Mechanisms and Industrial Hydration

Ethene, produced via steam cracking of long-chain alkanes in Uganda's emerging petrochemical sector, is industrially hydrated to ethanol. However, impurities such as hydrogen halides can lead to unwanted side reactions. A chemical engineer must optimise conditions, explain mechanisms, and evaluate sustainability for a production plant report.

Tasks:

- Write the balanced equation for the industrial hydration of ethene to ethanol, stating catalyst and why these conditions are chosen.
- Describe in full detail the electrophilic addition mechanism of ethene with HBr: π -bond attack on electrophile, formation of carbocation intermediate, curly arrows, and stability considerations.
- Apply Markovnikov's rule to predict major and minor products when propene reacts with HBr in the presence/absence of peroxides; explain carbocation stability (primary vs. secondary) with diagrams.
- Describe a chemical test to distinguish ethene from ethane.
- Design a two-step synthetic route from ethene to 1,2-dibromoethane; evaluate reagents/conditions for high yield, minimal by-products, and atom economy.
- Discuss the environmental impact of large-scale alkene use and one sustainable alternative feedstock.
- In groups, analyse a case study on polymer production from alkenes and present on recycling challenges in Uganda.

Scenario 3: Alkyl Halides – Nucleophilic Substitution Mechanisms and Synthetic Routes

A pharmaceutical laboratory in Kampala needs to convert bromoethane into ethylamine for drug synthesis. Elimination side products must be minimised for cost-effectiveness and high atom economy. The team must compare mechanisms and design a safe pathway.

Tasks:

- Classify Bromoethane as primary and explain how the carbon-halogen bond polarity and substrate structure ($1^\circ/2^\circ/3^\circ$) affect reactivity in nucleophilic substitution versus elimination reactions.

- (b) Draw the complete SN2 mechanism for bromoethane reacting with excess ammonia: curly arrows showing nucleophilic attack, transition state, inversion of configuration, and product formation.
- (c) Outline a two-step synthetic route from bromoethane to ethylamine (reagents, conditions); compare with reaction using aqueous NaOH (different product and reason).
- (d) Describe laboratory tests to distinguish the resulting primary amine from the alcohol include observations and equations.
- (e) Calculate the percentage yield if 10.9 g of Bromoethane ($M_r = 109$) produces 4.5 g of ethylamine ($M_r = 45$). Also calculate atom economy for the chosen route and suggest improvements.
- (f) Evaluate factors affecting SN1 vs. SN2 and discuss safety precautions when handling volatile, toxic alkyl halides.
- (g) Propose a small-scale project: perform a test-tube reaction and write a report on observations and mechanism.

Scenario 4: Benzene and Methylbenzene – Electrophilic Substitution and Directing Effects

Benzene obtained from catalytic reforming is nitrated to nitrobenzene, an important intermediate for dyes and explosives. Methylbenzene undergoes substitution faster due to the methyl group. A research chemist must select conditions for selective mono-substitution and design syntheses while considering hazards.

Tasks:

- (a) Explain benzene's unusual stability compared to a hypothetical triene; draw resonance structures and explain why it prefers substitution over addition.
- (b) Describe the detailed mechanism of nitration of benzene: generation of NO_2^+ electrophile using conc. $\text{HNO}_3/\text{H}_2\text{SO}_4$, role of catalyst, curly arrows for attack and regeneration of aromaticity.
- (c) Compare reactivity and orientation (ortho/para vs. meta directing) in electrophilic substitution of benzene versus methylbenzene; explain the activating and directing effect of the $-\text{CH}_3$ group using inductive effects.
- (d) Suggest reagents and controlled conditions for selective monobromination of methylbenzene at the ortho/para positions; predict and name the major products with structures.

- (e) Design a three-step synthesis from benzene to 4-nitromethylbenzene, including reagents, conditions, and yield considerations.
- (f) Evaluate one major industrial application and associated hazards.
- (g) In a group case study, research and present on the safe handling of aromatic compounds in Ugandan industries.

Scenario 5: Alcohols – Oxidation, Dehydration, Distinction Tests, and Applications

Ethanol produced by fermentation of local sugarcane is oxidized in laboratories or industries to ethanal or ethanoic acid. A technician receives a mixture that may contain primary, secondary, and tertiary alcohols and must identify them for further synthetic use or quality control.

Tasks:

- (a) Classify ethanol as a primary alcohol; write oxidation equations to ethanal and ethanoic acid with acidified $K_2Cr_2O_7$, including colour changes and half-equations.
- (b) Describe the elimination (dehydration) mechanism of ethanol to ethene using conc. H_2SO_4 .
- (c) Design a sequence of chemical tests (Lucas reagent for $1^\circ/2^\circ/3^\circ$ distinction, oxidation behaviour with dichromate, or iodoform test) to distinguish primary, secondary, and tertiary alcohols; include expected observations and equations.
- (d) Evaluate real-life applications of ethanol versus health and environmental impacts.
- (e) 0.92 g of an unknown alcohol (containing only C, H, O) produces 1.76 g CO_2 on complete combustion. Calculate the empirical formula step-by-step; suggest possible molecular formulae if Mr is approximately 46 or 60.
- (f) Explain how hydrogen bonding affects boiling points and solubility of alcohols compared to alkanes of similar Mr.
- (g) Propose a project: perform oxidation/distinction experiments in the lab and write a report linking results to industrial applications.

Scenario 6: Phenols – Acidity, Reactivity, and Synthetic Routes

Phenol, traditionally extracted from coal tar, is more acidic and reactive than alcohols and is used in disinfectants and resins (e.g., Bakelite). A laboratory team must compare its behaviour, design a safe synthesis from benzene, and assess real-life risks.

Tasks:

- (a) Explain why phenol is significantly more acidic than ethanol.
- (b) Write equations and observations for: (i) phenol with NaOH , (ii) phenol with Br₂(aq).
- (c) Compare electrophilic substitution reactivity of phenol versus benzene; explain strong activation and ortho/para directing effect of the –OH group.
- (d) Describe specific chemical tests to distinguish phenol from ethanol.
- (e) Outline a multi-step industrial synthetic route from benzene to phenol include reagents and conditions.
- (f) Evaluate one key application and discuss safety/environmental concerns.
- (g) In groups, analyse a case study on phenol use in Uganda and present recommendations for safe handling.

Scenario 7: Carbonyl Compounds – Nucleophilic Addition and Identification

Ethanal (produced by oxidation of ethanol) is used in perfume manufacture, while propanone serves as a common solvent. Both undergo nucleophilic addition. A quality control lab must identify and characterise an unknown carbonyl compound using tests and data.

Tasks:

- (a) Distinguish aldehydes from ketones write equations and describe observations.
- (b) Describe the nucleophilic addition mechanism of ethanal with HCN from dilute KCN and dilute sulphuric acid.
- (c) Predict the product when propanone reacts with 2,4-DNPH.
- (d) A carbonyl compound has Mr = 58 and elemental composition 62.07% C, 10.34% H, 27.59% O. Calculate empirical and molecular formula with full working.
- (e) Propose the reduction of propanone to propan-2-ol.
- (f) Discuss applications in fragrance or polymer synthesis and hazards.
- (g) Design a project: prepare a 2,4-DNPH derivative and determine its melting point for identification.

Scenario 8: Integrated Multi-Step Synthesis – Alkenes to Alcohols to Carbonyls

Propene from cracking processes is converted to propanone (acetone) via hydration followed by oxidation. An engineer must evaluate the entire pathway for yield, selectivity, and green chemistry principles in an industrial context.

Tasks:

- Outline the two-step synthetic route: propene \rightarrow propan-2-ol specify reagents and conditions for each step.
- Describe the electrophilic addition mechanism of propene hydration, applying Markovnikov's rule and explaining carbocation rearrangement possibility.
- Explain chemical tests to distinguish the alcohol intermediate from the final ketone.
- Discuss how Markovnikov addition controls regioselectivity affect overall yield.
- Combustion of 1.2 g of the ketone produces 2.64 g CO₂ and 1.08 g H₂O. Calculate/verify the empirical formula and discuss % yield if theoretical mass is known.
- Evaluate atom economy of the route and suggest green chemistry improvements.
- Prepare a group report comparing this pathway with alternatives from bio-based sources.

Scenario 9: Alkyl Halides – SN1 vs SN2 Mechanisms and Hydrolysis

Tertiary alkyl halides hydrolyze faster than primary ones in aqueous alkali, yielding alcohols that can be further oxidized to carbonyl compounds. A synthesis team must compare mechanisms and design routes while considering stereochemistry.

Tasks:

- Compare SN1 mechanism (using 2-bromo-2-methylpropane) and SN2 (using 1-bromopropane): rate-determining step, carbocation vs. transition state, curly arrows.
- Write the hydrolysis equation for 2-bromopropane to propan-2-ol with aqueous NaOH.
- Design a synthetic route: 1-bromopropane \rightarrow propan-1-ol.
- Explain factors influencing hydrolysis rate.
- Distinguish the resulting primary/secondary/tertiary alcohols using oxidation tests or Lucas reagent.
- Propose a lab project demonstrating rate differences between primary and tertiary halides.

Scenario 10: Benzene Derivatives – Side-Chain Oxidation and Comparison with Phenols

Methylbenzene (toluene) undergoes side-chain oxidation to benzoic acid, while phenol is highly activated for ring substitution and used in resins. Students compare activation effects in a research project.

Tasks:

- Describe the side-chain oxidation of methylbenzene to benzoic (conditions and equation).
- Explain why the –OH group in phenol activates the benzene ring much more strongly than the –CH₃ group in methylbenzene for electrophilic substitution.
- Propose a feasible synthesis from methylbenzene to 4-methylphenol.
- Discuss industrial applications of benzoic acid, phenol and safety concerns.
- Calculate % yield if 10 g benzene is converted to phenol (use stoichiometry to find theoretical yield and compare with 9.2 g actual).
- Evaluate environmental impacts of aromatic compound production and disposal.
- Create a group presentation comparing reactivity of benzene, methylbenzene, and phenol.

Scenario 11: Carbonyl Compounds – Reduction and Multi-Step Routes from Alkenes

A fragrance synthesis requires selective reduction of a carbonyl to an alcohol, starting from an alkene. The team designs a pathway and evaluates efficiency.

Tasks:

- Distinguish an aldehyde from a ketone using selective reduction.
- Write the reduction of butanone to butan-2-ol.
- Design a three-step route from but-1-ene to butanoic acid.
- Compare the nucleophilic addition mechanism (e.g. with HCN) versus reduction mechanisms.
- If 0.5 mol of carbonyl theoretically yields 0.42 mol alcohol, calculate % yield; discuss practical losses.
- Link to applications in perfumes and principles of green synthesis.
- Propose a project to reduce a simple ketone and characterize the product.

Scenario 12: Alkenes and Alkyl Halides – Addition, Elimination, and Polymerization

Chloroethene (vinyl chloride), produced via addition or elimination routes, is polymerized to PVC. A materials chemist evaluates pathways and environmental concerns.

Tasks:

- Describe the free-radical addition of HCl to ethene forming chloroethane.
- Write the E2 dehydrohalogenation mechanism of chloroethane to ethene using alcoholic KOH).
- Outline how Chloroethene undergoes free-radical polymerization to form PVC.
- Distinguish alkenes from alkyl halides using bromine water versus $\text{AgNO}_3(\text{aq})$.
- Propose conditions for high-yield conversions and evaluate the environmental impact of PVC in Uganda).
- Discuss safety in handling halogenated compounds.

Scenario 13: Identification of Unknown Organic Liquids – Alcohols, Phenols, Carbonyls

An unknown liquid from a school or industrial lab shelf could be ethanol, phenol, or ethanal. Quality control requires a systematic test sequence and further conversion to useful products.

Tasks:

- Design a logical sequence of chemical tests to identify the compound (reagents and expected observations for each possibility).
- For the identified alcohol, show stepwise oxidation to carbonyl and then carboxylic acid.
- Compare acidity of phenol versus ethanol with equations and explanations.
- Discuss real-life uses ethanol, phenol and associated hazards.
- Given combustion data: 52.17% C, 13.04% H, 34.78% O, calculate the empirical formula; suggest a possible molecular formula.
- Propose a small project: identify the compound and convert it to one useful derivative.
- Write a lab report linking results to curriculum learning outcomes.

Scenario 14: Benzene and Methylbenzene – Friedel-Crafts Alkylation and Nitration

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Benzene is alkylated to methylbenzene, then nitrated for intermediates in dyes or explosives. Selectivity and safety are critical in industrial scaling.

Tasks:

- (a) Describe the Friedel-Crafts alkylation mechanism for benzene + CH_3Cl with AlCl_3 catalyst.
- (b) Predict and explain the products (ortho/para directing) of nitration of methylbenzene.
- (c) Design a three-step synthesis from benzene to 3-nitrobenzoic acid .
- (d) Compare stability

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