Organic Chemistry - Q&A Study Guide

Unit 8: Basic Principles and Techniques

General Introduction & History

Q1: Who disproved the vital force theory and how? A: F. Wöhler in 1828 synthesized urea (an organic compound) from ammonium cyanate (an inorganic compound), proving that organic compounds could be made in the laboratory without a "vital force."

Q2: What were the key historical milestones in early organic chemistry? A:

- 1780s: Distinction between organic and inorganic compounds
- 1828: Wöhler synthesized urea
- 1845: Kolbe synthesized acetic acid
- 1856: Berthelot synthesized methane

Q3: Why are organic compounds vital for life? A: They form essential biological molecules like DNA (genetic information), proteins (blood, muscles, skin), and are used in materials like clothing, fuels, polymers, dyes, and medicines.

Carbon Hybridization & Shapes

Q4: What are the three hybridization states of carbon and their characteristics? A:

- **sp^3**: Tetrahedral, 109.5°, found in alkanes (CH_4)
- **sp^2**: Trigonal planar, 120°, found in alkenes (C_2H_4)
- **sp**: Linear, 180°, found in alkynes (C_2H_2)

Q5: How does hybridization affect bond properties? A:

- **Bond strength order**: sp > sp^2 > sp^3
- **Bond length order**: sp < sp^2 < sp^3
- **Electronegativity order**: sp > sp^2 > sp^3
- More s-character = shorter, stronger bonds, higher electronegativity

Q6: What are the key characteristics of π bonds? A:

- Formed by lateral overlap of parallel p orbitals
- Restrict rotation around C=C bonds
- Electrons are easily available to attacking reagents
- Most reactive centers in molecules with multiple bonds

Q7: How many σ and π bonds are in $HC{\equiv}C\text{-}CH{=}CH\text{-}CH_3$? A: σ bonds: C-C (4) + C-H (6) = 10 total; π bonds: C≡C (2) + C=C (1) = 3 total

---

Structural Representations

Q8: What are the different types of structural formulas? A:

- **Complete**: Shows all atoms and bonds
- **Condensed**: Omits some bonds, uses subscripts (CH_3CH_3)
- **Bond-line**: Only shows skeletal structure, C and H implied

Q9: How do you represent 3D structures on paper? A:

- **Solid wedge (▲)**: Bond coming toward you
- **Dashed wedge (△)**: Bond going away from you

- **Normal line (—)**: Bond in the plane of paper

Q10: What are the three types of molecular models? A:

- **Framework**: Shows only bonds, emphasizes bonding pattern
- **Ball-and-stick**: Shows atoms as balls, bonds as sticks
- **Space-filling**: Shows relative atomic sizes based on van der Waals radii

---

Classification of Organic Compounds

Q11: How are organic compounds classified structurally? A:

- **Acyclic (Aliphatic)**: Open chain compounds (straight or branched)
- **Cyclic**: Ring compounds
  - **Alicyclic**: Saturated rings (cyclohexane)
  - **Aromatic**: Special ring compounds (benzene)

Q12: What is a functional group? A: An atom or group of atoms that determines the characteristic chemical properties of organic compounds. Examples: -OH, -CHO, -COOH.

Q13: What is a homologous series? A: A group of organic compounds with the same functional group where successive members differ by a $-CH_2$ unit. Examples: alkanes, alcohols, aldehydes.

IUPAC Nomenclature

Q14: What are the rules for naming branched alkanes? A:

1. Find the longest carbon chain (parent)
2. Number to give substituents lowest numbers

3. Name and locate substituents with numbers
4. List substituents alphabetically
5. Use di-, tri-, tetra- for identical groups

Q15: What is the priority order of functional groups for nomenclature? A: -COOH > -SO_3H > -COOR > -COCl > -$CONH_2$ > -CN > -CHO > >C=O > -OH > -NH_2 > >C=C< > -C≡C-

Q16: How do you name substituted benzene compounds? A:

- **Monosubstituted**: substituent + benzene
- **Disubstituted**: Use numbers or ortho (1,2), meta (1,3), para (1,4)
- **Phenyl**: C_6H_5- when benzene is a substituent

Q17: What is the IUPAC name of CH_3-$CH(CH_3)$-CH_2-$CH(Cl)$-CH_3? A: 2-Chloro-4-methylpentane

---

Isomerism

Q18: What are the types of structural isomerism? A:

- **Chain isomerism**: Different carbon skeletons
- **Position isomerism**: Different positions of functional groups
- **Functional group isomerism**: Different functional groups
- **Metamerism**: Different alkyl groups around functional group

Q19: Give examples of functional group isomers with formula C_3H_6O. A: CH_3-CO-CH_3 (propanone, ketone) and CH_3-CH_2-CHO (propanal, aldehyde)

Q20: What is stereoisomerism? A: Compounds with same molecular formula and connectivity but different spatial arrangements. Types: geometrical and optical isomerism.

Reaction Mechanisms

Q21: What is the difference between heterolytic and homolytic bond cleavage? A:

- **Heterolytic**: Unequal breaking, electron pair goes to one fragment, forms ions (carbocation + anion)
- **Homolytic**: Equal breaking, one electron to each fragment, forms free radicals

Q22: What is the stability order of carbocations? A: Tertiary (3°) > Secondary (2°) > Primary (1°) > Methyl (CH_3^+) *Reason*: Greater alkyl substitution provides more hyperconjugation stability.

Q23: What are nucleophiles and electrophiles? A:

- **Nucleophiles**: Electron donors, nucleus-seeking (HO^-, CN^-, NH_3)
- **Electrophiles**: Electron acceptors, electron-seeking (H^+, carbocations, BF_3)

Q24: How do you show electron movement in reactions? A:

- **Curved arrows**: Show electron pair movement
- **Half-headed arrows**: Show single electron movement
- Arrow starts from electron source, points to destination

Electronic Effects

Q25: What is the inductive effect? A: Polarization of σ-bonds due to electronegativity differences, transmitted through the chain but decreases with distance.

Q26: Which groups show +I and -I effects? A:

- **+I (electron donating)**: Alkyl groups (-CH_3, -C_2H_5)
- **-I (electron withdrawing)**: Halogens, -NO_2, -CN, -COOH

Q27: What is resonance and what are the rules for resonance structures? A: Electron delocalization in conjugated systems. Rules:

- Same nuclear positions
- Same number of unpaired electrons
- More covalent bonds = more stable
- Complete octets = more stable
- Less charge separation = more stable

Q28: What is the difference between +R and -R effects? A:

- **+R**: Electron donation into conjugated system (-OH, -OR, -NH_2, halogens)
- **-R**: Electron withdrawal from conjugated system (-COOH, -CHO, -CN, -NO_2)

Q29: What is hyperconjugation? A: Delocalization of σ-electrons (especially C-H bonds) into adjacent p-orbitals or π-systems. Stabilizes carbocations and free radicals.

Q30: Why is $(CH_3)_3C^+$ more stable than $CH_3CH_2^+$? A: $(CH_3)_3C^+$ has nine C-H bonds available for hyperconjugation, while $CH_3CH_2^+$ has fewer, providing less stabilization.

Purification Methods

Q31: When would you use each purification method? A:

- **Sublimation**: Separate sublimable from non-sublimable compounds
- **Simple distillation**: Large b.p. differences (>25°C) or volatile from non-volatile
- **Fractional distillation**: Small b.p. differences (<25°C)
- **Steam distillation**: Steam-volatile, water-immiscible compounds
- **Crystallization**: Different solubilities in same solvent

Q32: What is the principle of steam distillation? A: The mixture boils when sum of vapor pressures ($p_1 + p_2$) equals atmospheric pressure, allowing compounds to distill below their normal boiling points.

Q33: What is Rf value in TLC? A: Rf = Distance moved by substance / Distance moved by solvent front Used to identify compounds in thin layer chromatography.

Q34: What are the two main types of chromatography? A:

- **Adsorption**: Based on differential adsorption (TLC, column)
- **Partition**: Based on differential partitioning between phases (paper chromatography)

Qualitative Analysis

Q35: How do you test for carbon and hydrogen in organic compounds? A:

- Heat compound with CuO
- **Carbon**: Forms CO_2 (test with lime water → turbidity)
- **Hydrogen**: Forms H_2O (test with anhydrous $CuSO_4$ → turns blue)

Q36: What is Lassaigne's test and why is it used? A: Fusion with metallic sodium converts covalent N, S, halogens to ionic forms (NaCN, Na_2S, NaX) which can be detected by specific tests.

Q37: How do you test for nitrogen using Lassaigne's extract? A: Boil extract with $FeSO_4$, then acidify with H_2SO_4. Prussian blue color indicates nitrogen ($Fe_4[Fe(CN)_6]_3$ formation).

Q38: How do you distinguish between Cl^-, Br^-, and I^-? A: Add $AgNO_3$ after acidifying with HNO_3:

- **Cl^-**: White AgCl (soluble in NH_4OH)
- **Br^-**: Pale yellow AgBr (sparingly soluble in NH_4OH)

- **I^-**: Yellow AgI (insoluble in NH_4OH)

Q39: What interferes with halogen tests and how is it removed? A: CN^- and S^{2-} interfere. Remove by boiling extract with concentrated HNO_3 before adding $AgNO_3$.

Quantitative Analysis

Q40: How do you calculate percentage of carbon from CO_2 produced? A: % Carbon = (12/44) × (mass of CO_2/mass of compound) × 100

Q41: How do you calculate percentage of hydrogen from H_2O produced? A: % Hydrogen = (2/18) × (mass of H_2O/mass of compound) × 100

Q42: What is the difference between Dumas and Kjeldahl methods? A:

- **Dumas**: Heat with CuO, collect N_2 gas, measure volume
- **Kjeldahl**: Convert to NH_3, absorb in acid, back-titrate
- **Kjeldahl limitation**: Doesn't work for nitro, azo, or ring nitrogen

Q43: Calculate % nitrogen if 0.3g compound gives 50mL N_2 at 300K and 715mm pressure. A:

- Correct pressure = 715 - 15 = 700mm (subtract aqueous tension)
- Volume at STP = (273 × 700 × 50)/(300 × 760) = 41.9 mL
- % N = (28 × 41.9 × 100)/(22400 × 0.3) = 17.46%

Q44: In Carius method, how do you calculate percentage of halogen? A: % Halogen = (Atomic mass of X/Molecular mass of AgX) × (mass of AgX/mass of compound) × 100

Q45: Why is oxygen usually determined by difference? A: Direct oxygen determination is complex, so it's calculated as: % O = 100 - (% of all other elements)

Q46: What is the molecular mass of $BaSO_4$ and how is it used? A: $BaSO_4$ = 233 g/mol. For sulfur estimation: % S = (32/233) × (mass of $BaSO_4$/mass of compound) × 100

Problem-Solving Questions

Q47: 0.246g of compound gives 0.198g CO_2 and 0.1014g H_2O. Find % C and H. A:

- % C = (12 × 0.198 × 100)/(44 × 0.246) = 21.95%
- % H = (2 × 0.1014 × 100)/(18 × 0.246) = 4.58%

Q48: In Kjeldahl method, 0.5g compound neutralizes 10mL of 1M H_2SO_4. Find % N. A:

- 10mL 1M H_2SO_4 = 20mL 1M NH_3
- 1000mL 1M NH_3 contains 14g N
- 20mL contains (14 × 20)/1000 = 0.28g N
- % N = (0.28 × 100)/0.5 = 56%

Q49: 0.15g compound gives 0.12g AgBr in Carius method. Find % Br. A:

- AgBr = 188 g/mol, Br = 80 g/mol
- % Br = (80 × 0.12 × 100)/(188 × 0.15) = 34.04%

Q50: Draw resonance structures for CH_3COO^-. A:

$CH_3\text{-}C(=O)\text{-}O^- \leftrightarrow CH_3\text{-}C(^-)\text{-}O=O$

The actual structure is a hybrid with partial double bond character in both C-O bonds.

Key Constants & Formulas

Q51: What are the important molar volumes and masses to remember? A:

- 1 mole gas at STP = 22,400 mL
- N_2 = 28 g/mol, CO_2 = 44 g/mol, H_2O = 18 g/mol
- AgCl = 143.5, AgBr = 188, AgI = 235 g/mol
- $BaSO_4$ = 233 g/mol

Q52: What is the general formula for nitrogen percentage in Dumas method? A: % N = (28 × Volume at STP × 100)/(22400 × mass of compound)

Q53: What is the bond length order for carbon bonds? A: C≡C (120 pm) < C=C (134 pm) < C-C (154 pm) Benzene C-C = 139 pm (intermediate between single and double)

Application & Analysis

Q54: Why does benzene have equal C-C bond lengths? A: Due to resonance between two Kekulé structures, all C-C bonds have partial double bond character (139 pm), intermediate between single (154 pm) and double (134 pm) bonds.

Q55: Which is more stable: $O_2NCH_2CH_2O^-$ or $CH_3CH_2O^-$? A: $O_2NCH_2CH_2O^-$ is more stable because the nitro group (-NO_2) withdraws electron density through the inductive effect, stabilizing the negative charge.

Q56: Why are π bonds more reactive than σ bonds? A: π electrons are farther from the nucleus, less tightly held, and more available to attacking reagents compared to σ electrons.

Q57: How does hyperconjugation explain alkyl groups as electron donors? A: C-H σ bonds of alkyl groups can overlap with adjacent p orbitals or π systems, donating electron density and stabilizing positive charges or electron-deficient systems.

Q58: Why is steam distillation useful for essential oils? A: Essential oils are often heat-sensitive and have high boiling points. Steam distillation allows them to vaporize at temperatures below 100°C, preventing decomposition.

Q59: Why can't Kjeldahl method be used for all nitrogen compounds? A: It cannot convert nitrogen in nitro groups (-NO_2), azo groups (-N=N-), or heterocyclic rings (like pyridine) to ammonium sulfate under the reaction conditions.

Q60: What makes tertiary carbocations more stable than primary ones? A: Tertiary carbocations have three alkyl groups providing hyperconjugation stabilization through C-H σ bonds, while primary carbocations have only one alkyl group for stabilization.