Unit 9 · Organic Compounds

ANSWER KEY · FOR TEACHERS

Full marks 51

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. aliphatic
2. alicyclic
3. heterocyclic
4. delocalization
5. isomers
6. addition
7. substitution
8. elimination

K · 4

Each carries 0.5 mark.

2 Multiple choice

i. **c.** 139 pm — K · 1

All six are 139 pm, between a double bond (134 pm) and a single bond (154 pm), because benzene's π electrons are spread evenly round the ring. 120 pm is a triple bond.

ii. **b.** $(4n + 2)$ π electrons — K · 1

A flat, completely conjugated ring is aromatic with $4n + 2$ π electrons ($n = 0, 1, 2\ldots$). A ring with $4n$ π electrons would be antiaromatic.

iii. **b.** position isomers — U · 1

Same formula ($C_4H_{10}O$), same chain, same group (–OH), but the –OH is on carbon 1 in one and carbon 2 in the other: position isomers.

iv. **c.** the cyclopentadienyl anion, $C_5H_5^-$ — U · 1

$C_5H_5^-$ is flat and every ring carbon takes part, with $2 \times 2 + 2 = 6$ π electrons ($n = 1$). Cyclobutadiene has 4 and cyclooctatetraene 8 (and is tub-shaped); cyclohexane has none.

v. **c.** $CH_3CH_2Br + KOH\ (alc) \rightarrow CH_2{=}CH_2 + KBr + H_2O$ — A · 1

HBr is removed from neighboring carbons and a double bond forms: elimination. The first is addition, the second and fourth substitution.

3 Label the diagram

1. Open chain (aliphatic) chains, straight or branched
2. Alicyclic cyclohexane
3. Aromatic benzene
4. Heterocyclic another atom in the ring: pyridine

K · 4

Each carries 1 mark.

4 Very short answers

a. MARKING SCHEME — K · 1

✓ C_nH_{2n}.

b. MARKING SCHEME — K · 1

✓ 180°.

c. MARKING SCHEME — U · 1

✓ One σ and one π.

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d. MARKING SCHEME A · 1

✓ Propanone, CH_3COCH_3.

5 Short answers

a. MARKING SCHEME U · 2

✓ Its delocalized π electrons make the ring unusually stable.

✓ Addition would break up that ring of electrons, so it resists addition (it reacts by substitution).

b. MARKING SCHEME U · 2

✓ Both are C_4H_{10}, but their atoms are joined differently: different compounds.

✓ The branched molecule is more compact, touches its neighbors less, and boils lower.

c. MARKING SCHEME A · 2

✓ The –CHO carbon can only be at the end of a chain: always carbon 1.

✓ A C=O inside the chain would be a ketone, a different group.

d. MARKING SCHEME A · 2

✓ Light splits chlorine molecules into atoms that start the reaction; in the dark there is no reaction.

✓ In bright sunlight it can run out of control, giving carbon and hydrogen chloride.

6 Long answers

a. ANSWER U · 4

Hückel's rule: a cyclic, planar molecule in which every ring atom takes part in a continuous ring of π electrons is aromatic if it contains $(4n + 2)$ π electrons, where $n = 0, 1, 2, 3...$

Benzene, C_6H_6: a flat ring of six carbons, each in a double bond; 3 double bonds give 6 π electrons. $4n + 2 = 6$ gives $n = 1$, a whole number: aromatic.

Naphthalene, $C_{10}H_8$: two flat fused rings, all ten carbons in double bonds; 5 double bonds give 10 π electrons. $4n + 2 = 10$ gives $n = 2$, a whole number: aromatic.

MARKING SCHEME

✓ A cyclic, planar ring with every atom in a continuous ring of π electrons.

✓ It is aromatic if it has $(4n + 2)$ π electrons, $n = 0, 1, 2...$

✓ Benzene: 3 double bonds, 6 π electrons, $n = 1$.

✓ Naphthalene: 5 double bonds, 10 π electrons, $n = 2$.

b. ANSWER U · 4

Isomerism is the existence of two or more compounds with the same molecular formula but different structural formulas, and so different properties; such compounds are isomers.

- **Chain isomerism:** the isomers have different carbon skeletons. Example: butane, $CH_3CH_2CH_2CH_3$, and 2-methylpropane, $CH_3CH(CH_3)CH_3$, both C_4H_{10}.
- **Position isomerism:** the same skeleton and the same functional group (or multiple bond), in different positions. Example: but-1-ene, $CH_2{=}CHCH_2CH_3$, and but-2-ene, $CH_3CH{=}CHCH_3$, both C_4H_8.
- **Functional isomerism:** the same molecular formula but different functional groups. Example: ethanol, CH_3CH_2OH (an alcohol), and methoxymethane, CH_3OCH_3 (an ether), both C_2H_6O.

MARKING SCHEME

✓ Same molecular formula, different structural formulas and properties.

✓ Chain: different skeletons; butane and 2-methylpropane.

✓ Position: the same skeleton and group, in different places; but-1-ene and but-2-ene.

✓ Functional: different functional groups; ethanol and methoxymethane.

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c. ANSWER A · 4

X is **ethene**, $CH_2{=}CH_2$ (it decolorizes bromine water, so it has a double bond).
$CH_2{=}CH_2 + H_2 \rightarrow CH_3CH_3$ (Ni, heat): **addition**; Y is **ethane**.
$CH_3CH_3 + Cl_2 \rightarrow CH_3CH_2Cl + HCl$ (diffused sunlight): **substitution**; Z is **chloroethane**.

MARKING SCHEME

- ✓ X is ethene (it has a double bond).
- ✓ $CH_2{=}CH_2 + H_2 \rightarrow CH_3CH_3$: addition; Y is ethane.
- ✓ $CH_3CH_3 + Cl_2 \rightarrow CH_3CH_2Cl + HCl$: substitution.
- ✓ Z is chloroethane.

7 Numerical problems

a. ANSWER A · 2

$14n = 84$, so $n = 6$: **C_6H_{12}, cyclohexane**. Check: $6 \times 12 + 12 \times 1 = 84$.

MARKING SCHEME

- ✓ $14n = 84$, so $n = 6$.
- ✓ C_6H_{12}, cyclohexane.

b. ANSWER A · 3

π electrons $= 3 \times 2 + 0 =$ **6**. Every ring carbon takes part (the charged carbon's empty orbital completes the ring), the ring is flat, and $4n + 2 = 6$ gives **$n = 1$**: **aromatic**.

MARKING SCHEME

- ✓ $3 \times 2 + 0 = 6$ π electrons.
- ✓ The ring is flat, and every carbon takes part.
- ✓ $4n + 2 = 6$ gives $n = 1$: aromatic.

c. ANSWER A · 3

Molar mass of $CH_4 = 16$ g/mol, so 8 g is 0.5 mol.
$CH_3Cl = 12 + 3 + 35.5 = 50.5$ g/mol: $0.5 \times 50.5 =$ **25.25 g** of chloromethane.
HCl: 0.5 mol, which at STP is $0.5 \times 22.4 =$ **11.2 L**.

MARKING SCHEME

- ✓ 8 g of methane = 0.5 mol.
- ✓ $0.5 \times 50.5 = 25.25$ g of chloromethane.
- ✓ $0.5 \times 22.4 = 11.2$ L of hydrogen chloride.

d. ANSWER HA · 3

$14n - 2 = 40$, so $n = 3$: **C_3H_4, propyne**, $CH{\equiv}C{-}CH_3$.
Bonds: the C≡C is 1 σ + 2 π; the C–C single bond is 1 σ; the four C–H bonds are 4 σ. Total **6 σ and 2 π** bonds.

MARKING SCHEME

- ✓ $14n - 2 = 40$, so $n = 3$.
- ✓ C_3H_4, propyne, $CH{\equiv}C{-}CH_3$.
- ✓ 6 σ and 2 π bonds.

8 Think

ANSWER HA · 3

Shake it with bromine solution: hex-1-ene takes the color away at once, and cyclohexane doesn't. Their molecular masses are the same, since they have the same formula. They are functional isomers: an alkene and a cycloalkane.

MARKING SCHEME

- ✓ Bromine solution: only the alkene takes the color away at once.
- ✓ The same formula gives the same mass.
- ✓ They are functional isomers.

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9 Activity: All the structural isomers of C_5

(not marked)

WHAT STUDENTS SHOULD FIND

Exactly three isomers: pentane (36 °C), 2-methylbutane (28 °C) and 2,2-dimethylpropane (9.5 °C), all chain isomers. A methyl on carbon 3 of a four-carbon chain is 2-methylbutane again, counted from the other end. The more branched, the lower the boiling point.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	12	15	18	6	**51**

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