

Benzene structure and electrophilic substitution

Chemistry grades 11-12 (A Level · IB · Class 11-12) · Test answers (mark scheme)

The answers give the expected response and the marks. Alternative correct wording earns the mark, and follow-through applies to calculations.

Level: Chemistry grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.3.10

Question 1 Bond lengths (2 marks)

If the Kekulé structure were correct, benzene would have three short C=C bonds (0.134 nm) alternating with three longer C-C bonds (0.154 nm). The bonds are all equal and intermediate, so the electrons are **delocalised** over the ring.

Marking: 1 for the predicted alternating bonds; 1 for equal intermediate length showing delocalisation.

Question 2 Enthalpy of hydrogenation (3 marks)

- a. $3 \times (-120) = -360 \text{ kJ/mol}$.
- b. $-208 - (-360) = +152 \text{ kJ/mol}$; benzene is 152 kJ/mol more stable than the localised triene because of delocalisation.

Marking: (a) 1; (b) 1 for the value, 1 for the meaning.

Question 3 Nitration of benzene (4 marks)

- a. Concentrated nitric acid and concentrated sulfuric acid at a temperature **below 55 °C**.
- b. $\text{C}_6\text{H}_6 + \text{HNO}_3 \rightarrow \text{C}_6\text{H}_5\text{NO}_2 + \text{H}_2\text{O}$.
- c. Higher temperature gives further substitution (dinitrobenzene).

Marking: (a) 1 for the acids, 1 for the temperature; (b) 1; (c) 1.

Question 4 The intermediate (3 marks)

- a. The positive charge is delocalised over the five carbon atoms, so the ring is no longer fully delocalised.
- b. The C-H bond breaks, H^+ is lost and its electrons restore the delocalised ring.
- c. The halogen carrier (FeBr_3) accepts Br^- from Br_2 to make a stronger electrophile, and it is regenerated.

Marking: 1 mark for each part.

Question 5 Substitution, not addition (2 marks)

Addition would destroy the delocalised ring and lose the stabilisation energy of 152 kJ/mol. Substitution keeps the ring intact, so the aromatic stability is retained in the product.

Marking: 1 for the ring being kept; 1 for the stability argument.

Question 6 Friedel-Crafts alkylation (2 marks)

$\text{C}_6\text{H}_6 + \text{CH}_3\text{Cl} \rightarrow \text{C}_6\text{H}_5\text{CH}_3 + \text{HCl}$, catalysed by anhydrous AlCl_3 .

Marking: 1 for the equation; 1 for the catalyst.

Question 7 Percentage yield (3 marks)

$n(\text{C}_6\text{H}_6) = 3.90 \div 78.0 = 0.0500 \text{ mol}$; theoretical mass = $0.0500 \times 157.0 = 7.85 \text{ g}$;
percentage yield = $5.18 \div 7.85 \times 100 = \mathbf{66.0 \%}$.

Marking: 1 for moles; 1 for theoretical mass; 1 for yield.

Question 8 Using methylbenzene in schools (1 mark)

Benzene is carcinogenic and toxic, while methylbenzene or esters are less hazardous and still show the same type of reaction.

Marking: 1 mark for the toxicity of benzene.