A-LEVEL CHEMISTRY • EXERCISE SHEET

29.3 Shape and bonding of benzene

Name: _____ Class: _____ Date: _____ **Total: 21 marks**

KEY WORDS delocalised 离域 • benzene 苯 • hybridisation 杂化 • enthalpy change of hydrogenation 氢化焓变

Objective

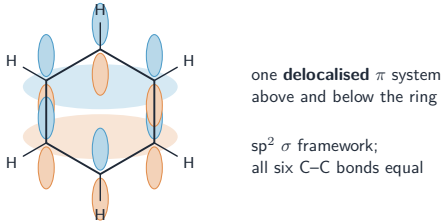
Build the skills to answer exam questions on the **shape and bonding of benzene** 苯的形状与成键 — **sp^2** hybridisation, σ and π bonds, **delocalisation** 离域, and the evidence for it.

You must be able to:

- describe benzene as a planar regular hexagon of sp^2 carbons
- explain the σ framework and the delocalised π system
- use enthalpy of hydrogenation as evidence for delocalisation

1 Worked examples

Bonding and stability



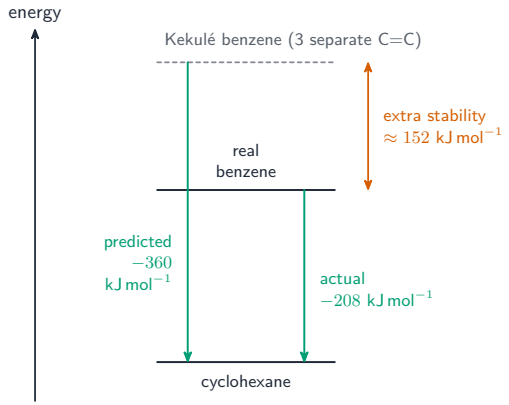
one **delocalised** π system above and below the ring

sp^2 σ framework; all six C–C bonds equal

Each carbon is sp^2: three σ bonds make the flat hexagon; the leftover p orbitals overlap into one delocalised π system

- each C is **sp^2**: three σ bonds (to 2 C + 1 H) in the plane.
- each C keeps one electron in a **p orbital**; these overlap sideways all round → one **delocalised** π ring above and below the plane.
- all six C–C bonds are **equal length** (between single and double); the ring is very stable.

Evidence: enthalpy of hydrogenation



Real benzene releases only 208 $kJ\,mol^{-1}$ vs the Kekulé prediction 360 = 3× cyclohexene → ~152 more stable

The shortfall ($360 - 208 = 152$ kJ mol^{-1}) is the extra stability from delocalisation.

2 Practice

2.1 State the hybridisation of each carbon atom in benzene. [1]

2.2 State what the equal C–C bond lengths in benzene tell you about its bonding. [1]

3 Exam-style questions

3.1 The π system in benzene is formed by the overlap of: [1]

A | B
C | D

A sp^2 hybrid orbitals
B s orbitals
C p orbitals at right angles to the ring
D sp^3 hybrid orbitals

3.2 Hydrogenation of cyclohexene releases 120 kJ mol^{-1}. The Kekulé model of benzene would predict a hydrogenation enthalpy of about: [1]

A B
C D

A -120 kJ mol^{-1}
B -208 kJ mol^{-1}
C -240 kJ mol^{-1}
D -360 kJ mol^{-1}

3.3 Describe the bonding in benzene, referring to sp^2 hybridisation, the σ framework and the delocalised π system. [3]

3.4 The real enthalpy of hydrogenation of benzene is -208 kJ mol^{-1}; the Kekulé prediction is -360 kJ mol^{-1}. State and explain what this difference shows. [2]

3.5 Benzene is a planar molecule with all six C–C bonds of the same length, 0.139 nm. (C–C in ethane is 0.154 nm; C=C in ethene is 0.134 nm.)

(a) Describe the bonding in benzene in terms of sp^2 hybridisation, σ bonds and π bonds. [4]

(b) Explain how the bond-length data support the delocalised model rather than the Kekulé structure. [2]

(c) The enthalpy change of hydrogenation of cyclohexene is -120 kJ mol^{-1}, and of benzene -208 kJ mol^{-1}. Explain what these values show, with a calculation. [3]

(d) Explain why benzene undergoes substitution rather than addition. [3]