A-Level Chemistry

Structure of Benzene

Question Paper

Time available: 68 minutes
Marks available: 66 marks

1. Kekulé suggested this structure for benzene. 

Benzene is now represented by this structure. 

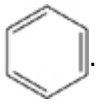
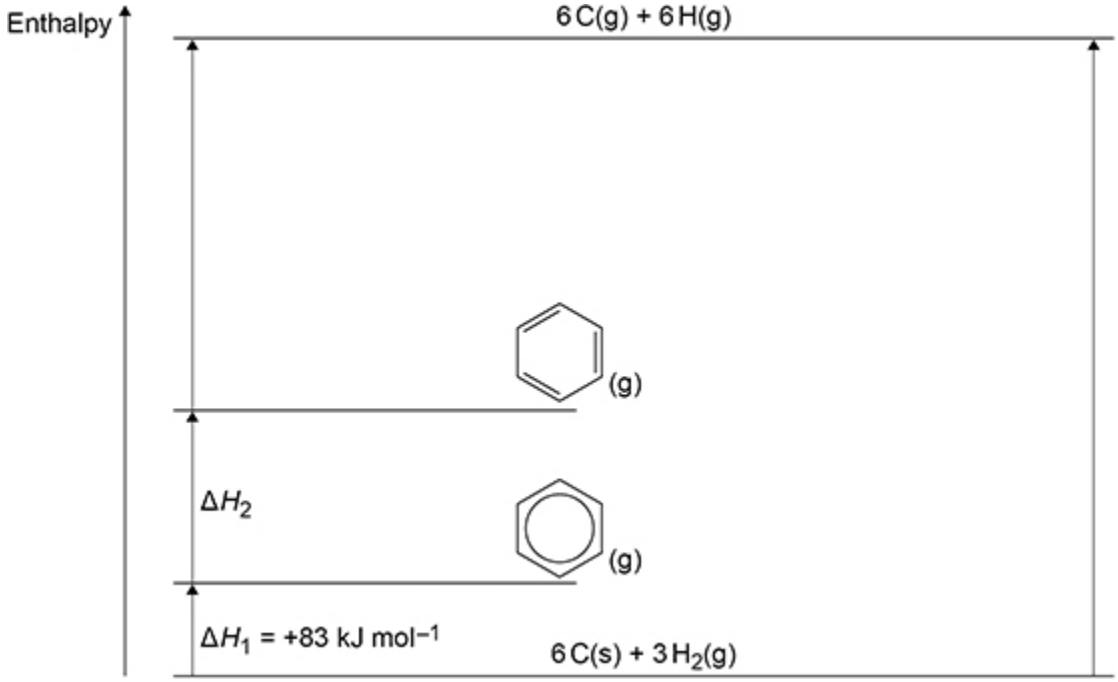
Figure 1 shows the relative stability of  compared to  .

Figure 1



(a) Use **Figure 1** and the data shown in the table below to calculate ΔH_2

	ΔH / kJ mol^{-1}
Enthalpy of atomisation for carbon	+715
Enthalpy of atomisation for hydrogen	+218
Bond enthalpy (C–C)	+348
Bond enthalpy (C=C)	+612
Bond enthalpy (C–H)	+412

ΔH_2 _____ kJ mol^{-1}

(3)

(b) Explain, in terms of structure and bonding, why 

is more thermodynamically stable than 

_____

_____

_____

(1)

(c) A mixture of concentrated nitric acid and concentrated sulfuric acid reacts with benzene.

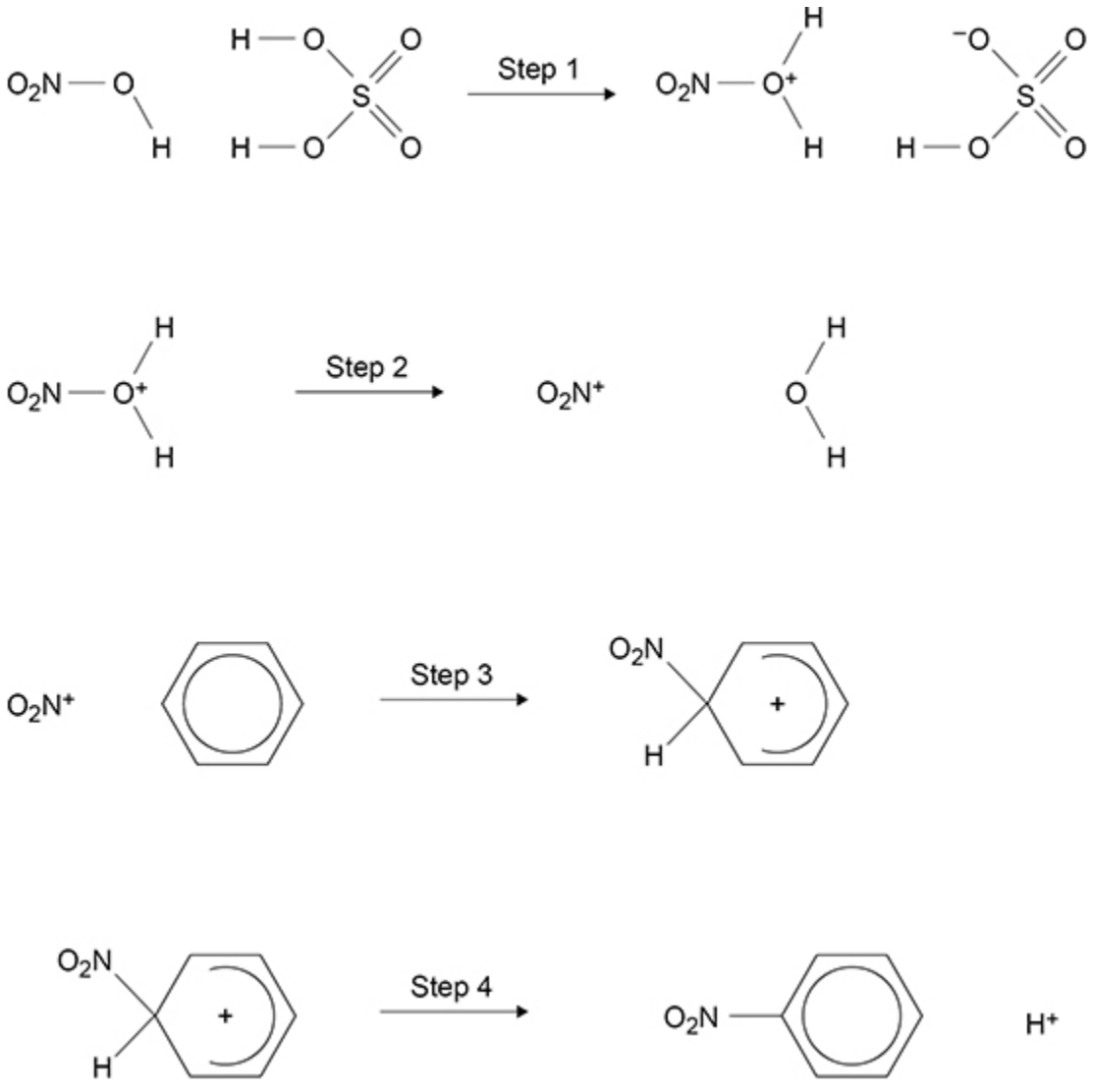
Figure 2 shows the incomplete mechanism for this reaction.

Name the mechanism.

Complete the mechanism in **Figure 2** by adding
- any lone pairs of electrons involved in each step
- **two** curly arrows in step **1**
- a curly arrow in step **2**
- a curly arrow in step **3**
- a curly arrow in step **4**.

Name of mechanism _____

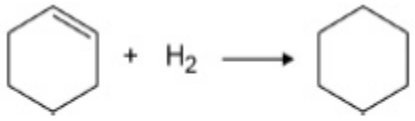
Figure 2



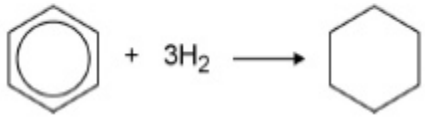
(5)

(Total 9 marks)

2. Data about the hydrogenation of cyclohexene and of benzene are given.



$\Delta H^{\ominus} = -120 \text{ kJ mol}^{-1}$



$\Delta H^{\ominus} = -208 \text{ kJ mol}^{-1}$

(a) Explain the bonding in and the shape of a benzene molecule.
Compare the stability of benzene with that of the hypothetical cyclohexa-1,3,5-triene molecule.
Use the data in your answer.

(6)

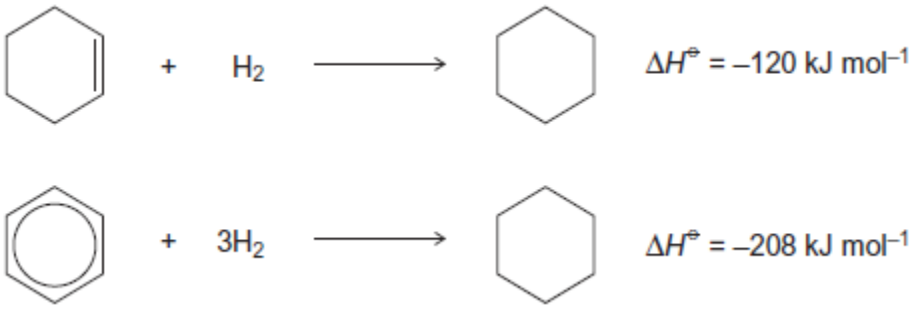
(b) The enthalpy of hydrogenation of cyclohexa-1,3-diene is **not** exactly double that of cyclohexene.

Suggest a value for the enthalpy of hydrogenation of cyclohexa-1,3-diene and justify your value.

(3)

(Total 9 marks)

3. Equations for the hydrogenation of cyclohexene and of benzene, together with the enthalpies of hydrogenation, are shown.



(a) (i) Use these data to show that benzene is 152 kJ mol^{-1} more stable than the hypothetical compound cyclohexa−1,3,5−triene.

(1)

(ii) State, in terms of its bonding, why benzene is more stable than cyclohexa−1,3,5−triene.

_____

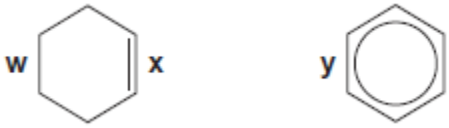
_____

_____

_____

(1)

(b) Three carbon−carbon bonds are labelled on the structures shown.
These bonds are of different lengths.

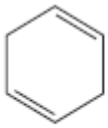


Write the letters **w**, **x** and **y** in order of **increasing** bond length.

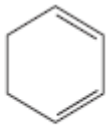
_____

(1)

(c) The structures of two cyclic dienes are shown.



cyclohexa-1,4-diene



cyclohexa-1,3-diene

(i) Use the enthalpy of hydrogenation data given opposite to calculate a value for the enthalpy of hydrogenation of cyclohexa−1,4−diene.

_____

_____

(1)

(ii) Predict a value for the enthalpy of hydrogenation of cyclohexa−1,3−diene.

_____

(1)

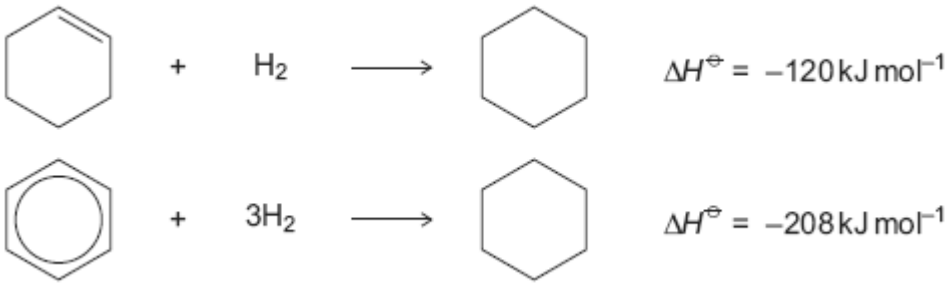
(iii) Explain your answers to part (i) and part (ii) in terms of the bonding in these two dienes.

(3)

(Total 8 marks)

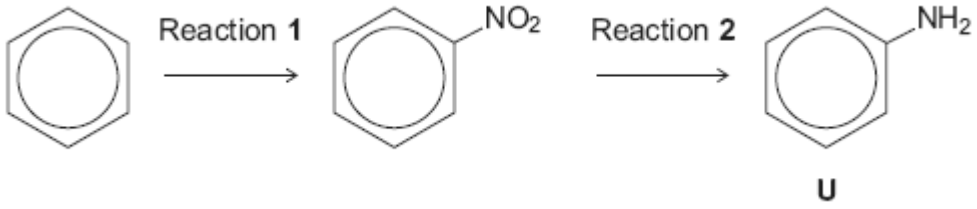
4. The hydrocarbons benzene and cyclohexene are both unsaturated compounds. Benzene normally undergoes substitution reactions, but cyclohexene normally undergoes addition reactions.

(a) The molecule cyclohexatriene does not exist and is described as hypothetical. Use the following data to state and explain the stability of benzene compared with the hypothetical cyclohexatriene.



(4)

(b) Benzene can be converted into amine **U** by the two-step synthesis shown below.



U

The mechanism of Reaction **1** involves attack by an electrophile.

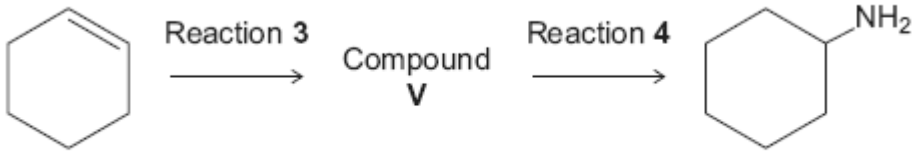
Give the reagents used to produce the electrophile needed in Reaction **1**.

Write an equation showing the formation of this electrophile.

Outline a mechanism for the reaction of this electrophile with benzene.

(6)

(c) Cyclohexene can be converted into amine **W** by the two-step synthesis shown below.



W

Suggest an identity for compound **V**.

For Reaction **3**, give the reagent used and name the mechanism.

For Reaction **4**, give the reagent and condition used and name the mechanism.

Equations and mechanisms with curly arrows are **not** required.

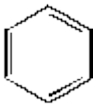
(6)

(d) Explain why amine **U** is a weaker base than amine **W**.

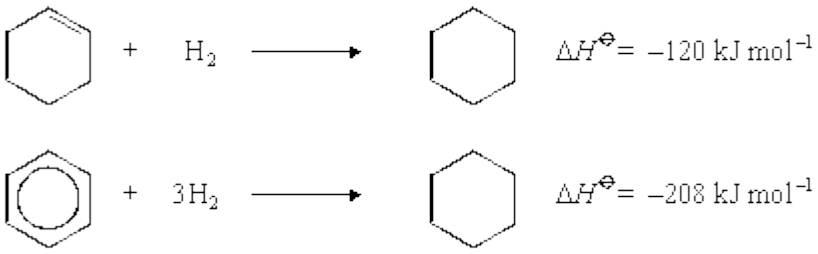
(3)

(Total 19 marks)

5. (a) Use the following data to show the stability of benzene relative to the hypothetical cyclohexa-1,3,5-triene.

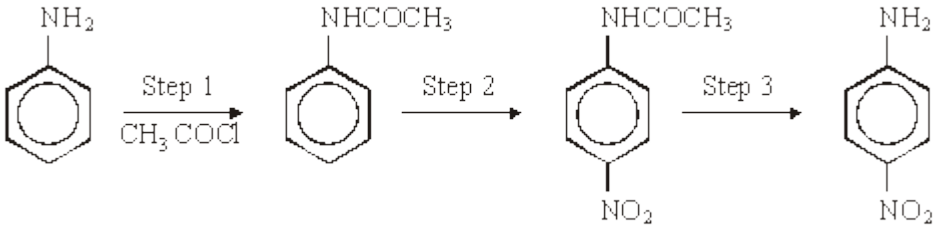


Give a reason for this difference in stability.



(4)

(b) Consider the following reaction sequence which starts from phenylamine.



(i) State and explain the difference in base strength between phenylamine and ammonia.

(3)

(ii) Name and outline a mechanism for the reaction in Step 1 and name the organic product of Step 1.

(6)

(iii) The mechanism of Step 2 involves attack by an electrophile. Give the reagents used in this step and write an equation showing the formation of the electrophile. Outline a mechanism for the reaction of this electrophile with benzene.

(6)

(iv) Name the type of linkage which is broken in Step 3 and suggest a suitable reagent for this reaction.

(2)

(Total 21 marks)