MEGA LECTURE · A LEVEL CHEMISTRY

# Chapter 15: Alkenes

OCR A Level Chemistry A (H432) — Structured Practice Worksheet


| SPECIFICATION | TOTAL MARKS | SUGGESTED TIME |
|---|---|---|
| 3.2.2 Alkenes: bonding, electrophilic addition, addition polymerisation | 86 | 1 hour 43 minutes |

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**Instructions to candidates**

- Answer **all** questions in the spaces provided. Show all working in calculations.
- Marks are shown in brackets [ ] at the end of each part.

## Question 1 — Bonding in alkenes

3.2.2

a. State the general formula of the alkenes. **[1]**

b. State the hybridisation of the two carbon atoms joined by the C=C double bond, and the bond angle around each of these carbons. **[2]**

c. Describe how the sigma (σ) bond between the two double-bond carbon atoms is formed. **[2]**

d. Describe how the pi (π) bond between the two double-bond carbon atoms is formed, including reference to the orbitals involved. **[3]**

e. Explain why the pi bond is weaker than the sigma bond between the same two carbon atoms. **[2]**

**Question 1 total: 10 marks**

## Question 2 — E/Z isomerism in alkenes

3.2.2

a. Explain why there is no free rotation about the carbon–carbon double bond in an alkene. **[2]**

b. State the two structural conditions that must be met for an alkene to exhibit E/Z isomerism. **[2]**

c. Using but-2-ene, $CH_3CH=CHCH_3$, as an example, explain the difference between the E and Z isomers, using CIP priority rules. **[3]**

d. Explain why but-1-ene, $CH_2=CHCH_2CH_3$, does not show E/Z isomerism. **[2]**

**Question 2 total: 9 marks**

## Question 3 — Electrophilic addition with bromine 3.2.2

a. State the type of mechanism by which alkenes react with bromine. **[1]**

b. Explain why the C=C double bond is a region of high electron density that is attractive to electrophiles. **[2]**

c. Explain, in terms of an induced dipole, how a non-polar bromine molecule, $Br_2$, is able to act as an electrophile when it approaches an alkene. **[2]**

d. In the box below, show the mechanism for the reaction between ethene and bromine, using curly arrows, and showing the intermediate ion and the final organic product. **[4]**

*Electrophilic addition mechanism — ethene + $Br_2$*

e. Name the type of intermediate ion formed in this mechanism, and state its charge. **[1]**

f. Describe the observation, and give a conclusion, when bromine water is added to and shaken with (i) an alkene and (ii) an alkane. **[3]**

**Question 3 total: 13 marks**

## Question 4 — Electrophilic addition with hydrogen bromide 3.2.2

Propene reacts with hydrogen bromide, HBr, to form two possible structural isomers of bromopropane.

a. Write an equation showing the structures of both possible organic products of this reaction. **[2]**

b. In the box below, use curly arrows to show the mechanism for the formation of the major product of this reaction. **[4]**

*Electrophilic addition mechanism — propene + HBr (major product)*

c. State Markovnikov's rule. **[2]**

d. Explain, in terms of carbocation stability, why 2-bromopropane (rather than 1-bromopropane) is the major product of this reaction. **[2]**

e. State the order of stability of primary, secondary and tertiary carbocations, and explain this trend briefly. **[2]**

**Question 4 total: 12 marks**

## Question 5 — Hydrogenation and hydration of alkenes 3.2.2

a. Write an equation for the addition of hydrogen to ethene. **[2]**

b. State the conditions (catalyst and approximate temperature) needed for this reaction. **[2]**

c. State one industrial use of the hydrogenation of alkenes. **[2]**

d. Write an equation for the addition of steam to ethene to produce ethanol. **[2]**

e. State the conditions used industrially for this hydration reaction (catalyst, temperature and pressure). **[2]**

**Question 5 total: 10 marks**

## Question 6 — Addition polymerisation 3.2.2

a. Define *addition polymerisation*. **[2]**

b. **[3]**

In the box below, draw the repeat unit of poly(propene), formed from propene monomer, showing the correct continuation bonds.

*Repeat unit of poly(propene)*

c. Chloroethene, $CH_2=CHCl$, is polymerised industrially. Name the polymer formed, and state one use of this polymer. **[2]**

d. Explain why addition polymers such as poly(ethene) are generally chemically unreactive (inert). **[2]**

e. The repeat unit of a certain addition polymer is $-[CH_2-CH(CH_3)]-$. Deduce the structure and name of the alkene monomer used to form this polymer. **[3]**

**Question 6 total: 12 marks**

## Question 7 — Polymer disposal

3.2.2

a. Explain why addition polymers such as poly(ethene) are not readily biodegradable. **[2]**

b. State one environmental problem caused by the disposal of non-biodegradable plastic waste in landfill. **[2]**

c. Describe what happens during *feedstock recycling* of addition polymers. **[2]**

d. **[2]**

State one advantage and one disadvantage of incineration as a method of disposing of waste plastic.

**Question 7 total: 8 marks**

## Question 8 — Reaction pathways of but-1-ene

3.2.2

But-1-ene, $CH_2{=}CHCH_2CH_3$, undergoes three separate reactions: (i) with bromine, $Br_2$; (ii) with hydrogen bromide, HBr; (iii) with hydrogen, $H_2$/Ni catalyst.

a. Give the name of the organic product formed in reaction (i). **[2]**

b. Give the name of the major organic product formed in reaction (ii). **[2]**

c. Give the name of the organic product formed in reaction (iii). **[2]**

**Question 8 total: 6 marks**

## Question 9 — Extended response

Synoptic

**Alkenes are generally far more reactive than alkanes, even though the C=C double bond (612 kJ mol$^{-1}$) is stronger than a C–C single bond (347 kJ mol$^{-1}$). Explain, with reference to bonding and reaction mechanism, why alkenes react so much more readily than alkanes.** **[6]**

*This question is marked using a level of response.*

**Question 9 total: 6 marks**

**PAPER TOTAL: 86 MARKS**

# MARK SCHEME — Chapter 15: Alkenes

*Award marks independently unless stated. ECF applies to calculations.*

**Q1 (a) [1]**

- $C_nH_{2n}$. (1)

**Q1 (b) [2]**

- $sp^2$ hybridised. (1)
- Bond angle of 120°. (1)

**Q1 (c) [2]**

- Formed by the direct/end-on overlap of two $sp^2$ hybrid orbitals (one from each carbon)... (1)
- ...along the axis joining the two nuclei. (1)

**Q1 (d) [3]**

- Each carbon has one remaining unhybridised p-orbital, perpendicular to the plane of the $sp^2$ orbitals. (1)
- These two p-orbitals overlap sideways, above and below the plane of the molecule. (1)
- This forms a pi bond, with electron density concentrated in two lobes above and below the C=C axis. (1)

**Q1 (e) [2]**

- The p-orbitals in a pi bond overlap only sideways rather than directly end-on. (1)
- This gives less effective orbital overlap than in a sigma bond, so the pi bond is weaker (more easily broken). (1)

**Q2 (a) [2]**

- Rotation about the C=C bond would require breaking the pi bond (sideways overlap of p-orbitals). (1)
- This requires a large amount of energy not available under normal conditions, so rotation about the double bond is restricted/prevented. (1)

**Q2 (b) [2]**

- Each carbon of the C=C double bond must be attached to two different groups. (2; 1 mark for each carbon)

**Q2 (c) [3]**

- On each carbon, $CH_3$ has higher CIP priority than H (carbon has a higher atomic number than hydrogen). (1)
- In the Z-isomer, the two higher-priority $CH_3$ groups are on the same side of the double bond. (1)
- In the E-isomer, the two higher-priority $CH_3$ groups are on opposite sides of the double bond. (1)

**Q2 (d) [2]**

- One of the double-bond carbons, $CH_2$=, is attached to two identical hydrogen atoms. (1)
- Since this carbon does not have two different groups attached, the molecule cannot show E/Z isomerism. (1)

**Q3 (a) [1]**

- Electrophilic addition. (1)

**Q3 (b) [2]**

- The pi bond is a region of high electron density above and below the plane of the C=C bond. (1)
- This region of concentrated negative charge attracts electron-deficient species (electrophiles). (1)

**Q3 (c) [2]**

- As the non-polar $Br_2$ molecule approaches the electron-rich C=C pi bond, the high electron density repels/distorts the electrons in the Br–Br bond. (1)
- This induces a temporary/instantaneous dipole in the $Br_2$ molecule ($Br^{\delta+}$–$Br^{\delta-}$), with the δ+ bromine atom attracted to the pi bond, making $Br_2$ behave as an electrophile. (1)

**Q3 (d) [4]**

- Curly arrow from the pi bond to the δ+ bromine atom of $Br_2$. (1)
- Curly arrow from the Br–Br bond to the other bromine atom, forming $Br^-$. (1)
- Cyclic bromonium ion (or carbocation) intermediate shown with a positive charge. (1)
- Curly arrow from a lone pair on $Br^-$ attacking the intermediate to form the final product, 1,2-dibromoethane, $CH_2BrCH_2Br$. (1)

**Q3 (e) [1]**

- A bromonium ion (cyclic), positively charged (accept: carbocation, positively charged). (1)

**Q3 (f) [3]**

- (i) With an alkene, the orange/brown bromine water is decolourised (turns colourless), showing the presence of a C=C double bond (unsaturation). (2)
- (ii) With an alkane, the bromine water remains orange/brown (no reaction), showing the absence of a C=C double bond (saturated). (1)

**Q4 (a) [2]**

- $CH_3CH{=}CH_2$ + HBr → $CH_3CHBrCH_3$ (2-bromopropane) and $CH_3CH_2CH_2Br$ (1-bromopropane) (2; 1 mark for each correct structure/isomer)

**Q4 (b) [4]**

- Curly arrow from the pi bond to the δ+ hydrogen atom of HBr. (1)
- Curly arrow from the H–Br bond to the Br atom, forming $Br^-$. (1)
- Secondary carbocation intermediate shown, with positive charge on the central (secondary) carbon. (1)
- Curly arrow from a lone pair on $Br^-$ to the positive carbon, forming 2-bromopropane. (1)

**Q4 (c) [2]**

- When a hydrogen halide (or other unsymmetrical reagent, HX) adds across the C=C double bond of an unsymmetrical alkene... (1)
- ...the hydrogen atom adds to the carbon that already has the greater number of hydrogen atoms attached (the major product forms via the more stable carbocation intermediate). (1)

**Q4 (d) [2]**

- The intermediate leading to 2-bromopropane is a secondary carbocation, whereas the intermediate leading to 1-bromopropane is a primary carbocation. (1)
- Alkyl groups are electron-donating (positive inductive effect), so the secondary carbocation is more stabilised than the primary carbocation, so it forms preferentially, giving 2-bromopropane as the major product. (1)

**Q4 (e) [2]**

- Stability order: tertiary > secondary > primary. (1)
- Each additional alkyl group attached to the positively charged carbon donates electron density towards it (positive inductive effect), further stabilising the carbocation. (1)

**Q5 (a) [2]**

- $CH_2{=}CH_2(g)$ + $H_2(g)$ → $CH_3CH_3(g)$ (2; 1 for correct product, 1 for balancing/state symbols)

**Q5 (b) [2]**

- Nickel catalyst. (1)
- Temperature of approximately 150 °C. (1)

**Q5 (c) [2]**

- Used to convert unsaturated vegetable oils (containing C=C bonds) into saturated fats, e.g. in the manufacture of margarine. (2)

**Q5 (d) [2]**

- $CH_2{=}CH_2(g)$ + $H_2O(g)$ → $CH_3CH_2OH(g)$ (2; 1 for correct product, 1 for balancing/state symbols)

**Q5 (e) [2]**

- Catalyst: phosphoric acid ($H_3PO_4$, on a solid support). (1)
- Conditions: temperature of approximately 300 °C and pressure of approximately 60–70 atm. (1)

**Q6 (a) [2]**

- A reaction in which many unsaturated monomer molecules (each containing a C=C double bond) join together... (1)
- ...to form a single long-chain saturated polymer molecule, with no other product formed. (1)

**Q6 (b) [3]**

- Repeat unit drawn as $-[CH_2-CH(CH_3)]-$. (1)
- A continuation bond shown at each end of the repeat unit, extending the chain. (1)
- Correct positioning of the $CH_3$ branch and correct bonding shown throughout. (1)

**Q6 (c) [2]**

- Poly(chloroethene) [poly(vinyl chloride)/PVC]. (1)
- Use: e.g. window frames, pipes, insulation for electrical cables, flooring (any one). (1)

**Q6 (d) [2]**

- Addition polymers such as poly(ethene) contain only strong, non-polar C–C and C–H sigma bonds. (1)
- These bonds have high bond enthalpies and are not easily attacked/broken by common reagents (e.g. acids, water, nucleophiles), so the polymer is chemically inert. (1)

**Q6 (e) [3]**

- Monomer: $CH_2=CHCH_3$. (1)
- Name: propene. (1)
- Deduced by reversing the addition polymerisation — splitting the repeat unit into a two-carbon backbone, restoring the C=C double bond and retaining the $CH_3$ branch. (1)

**Q7 (a) [2]**

- Addition polymers consist only of strong, non-polar C–C and C–H bonds, which are not easily broken down/hydrolysed by micro-organisms, enzymes or water. (1)
- Because micro-organisms cannot break these bonds, the polymer persists in the environment for a very long time (not biodegradable). (1)

**Q7 (b) [2]**

- Landfill sites are filling up/running out of space, as plastic does not decompose. (1)
- Buried plastic can leach additives, physically harm wildlife, or persist for a very long time, taking up land that could be used otherwise (any valid environmental issue). (1)

**Q7 (c) [2]**

- Waste polymer is broken down (cracked) by heating, using processes similar to the cracking of crude oil fractions. (1)
- This converts the polymer back into small hydrocarbon molecules (monomers or a mixture of useful chemical feedstocks) that can be used again as a raw material, e.g. to make new polymers or fuels. (1)

**Q7 (d) [2]**

- Advantage: incineration reduces the volume of waste and can generate useful energy/electricity from the heat released. (1)
- Disadvantage: burning plastics can release toxic gases (e.g. HCl from PVC) or, if incomplete, produce CO/soot, and produces $CO_2$ contributing to the greenhouse effect. (1)

**Q8 (a) [2]**

- 1,2-dibromobutane. (2; 1 for correct addition across C1–C2, 1 for correct name)

**Q8 (b) [2]**

- 2-bromobutane (major product, via the more stable secondary carbocation, Markovnikov addition). (2)

**Q8 (c) [2]**

- Butane. (2)

### Q9 [6] — Level of response

- **Level 3 (5–6):** Gives a full and accurate account referencing the accessible, exposed pi-electron density in alkenes that readily attracts electrophiles under mild conditions (electrophilic addition), contrasted with the strong, non-polar, evenly-shared sigma C–H/C–C bonds in alkanes that are unreactive towards ionic reagents and require UV light/radical initiation to react (free-radical substitution); correctly explains that bond strength alone does not determine reactivity.
- **Level 2 (3–4):** Explains one side (why alkenes are reactive, or why alkanes are unreactive) well, with a partial or less complete explanation of the other.
- **Level 1 (1–2):** States that alkenes are more reactive due to the double bond, with limited mechanistic reasoning.

***Indicative content:*** *Although the C=C bond (612 kJ mol$^{-1}$) is stronger overall than a C–C single bond (347 kJ mol$^{-1}$), it consists of a sigma bond plus a weaker pi bond, and it is the pi bond's electrons — concentrated in exposed regions of high electron density above and below the plane of the molecule — that make alkenes reactive: this electron density is readily attacked by electrophiles, even under mild conditions, via electrophilic addition, and the pi bond itself is comparatively weak and broken easily during this process. Alkanes, in contrast, have only strong, non-polar sigma C–H and C–C bonds with their electron density shielded directly between the bonded nuclei; this makes them unattractive to both nucleophiles and electrophiles, so alkanes are generally unreactive except towards free radicals, which require energy (e.g. UV light) to generate by homolytic fission before free-radical substitution can proceed. Reactivity is therefore governed more by the accessibility/polarisability of electron density than by overall bond strength.*

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**END OF MARK SCHEME · 86 marks**