

Alkenes: double bonds and addition reactions

Chemistry grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer shows the method first, then the result in bold. Atomic masses used: H 1.0, C 12.0, O 16.0, Cl 35.5, Br 79.9. Check that every equation is balanced and that carbocations are drawn with the charge on the correct carbon.

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Problem 1 Alkene formulae

1. General formula: **C_nH_{2n}** .
2. $n = 5$ gives C_5H_{10} ; $n = 8$ gives **C_5H_{10} and C_8H_{16}** .
3. Four carbons, double bond starting on carbon 2: **but-2-ene**.

Problem 2 Shape of ethene

1. Trigonal planar with three regions of electron density; the angle is about **120°** .
2. Four C-H σ bonds, one C-C σ bond and one π bond: **5 σ bonds and 1 π bond**.
3. The π bond needs the p orbitals on both carbons to be parallel, so rotation would break it. This locks the two CH_2 groups in the same plane.

Problem 3 Spotting unsaturation

1. Add bromine water to each and shake.
2. Hex-1-ene turns it from orange-brown to **colourless**; hexane leaves the orange colour.
3. The product is **1,2-dibromohexane**.

Problem 4 Completing equations

1. $C_3H_6 + H_2 \rightarrow$ **C_3H_8** (propane).
2. $CH_2=CHCH_2CH_3 + Br_2 \rightarrow$ **$CH_2BrCHBrCH_2CH_3$** , written $C_4H_8Br_2$.
3. Propane; 1,2-dibromobutane. Each equation has equal numbers of atoms on both sides, so no coefficients are needed.

Problem 5 Electrophile or nucleophile

1. An electrophile accepts an electron pair.
2. **Electrophiles: H^+ and $Br\delta^+$. Nucleophiles: OH^- and CN^-** (they donate lone pairs).
3. The π bond is a region of high electron density, so it attracts positive species. Negative ions are repelled by it.

Problem 6 Ethene to dibromoethane

1. $\text{C}_2\text{H}_4 + \text{Br}_2 \rightarrow \text{C}_2\text{H}_4\text{Br}_2$.
2. $n = 1.40 / 28.0 = 0.0500 \text{ mol}$.
3. Mole ratio 1 : 1, so $m = 0.0500 \times 187.8 = \mathbf{9.39 \text{ g}}$.

Problem 7 Hydration of ethene

1. $\text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightleftharpoons \text{C}_2\text{H}_5\text{OH}$.
2. $n = 120 / 24.0 = 5.00 \text{ mol}$; $m = 5.00 \times 46.0 = \mathbf{230 \text{ g}}$.
3. Only a small fraction reacts in each pass because the reaction is reversible; recycling raises the overall yield and saves raw material.

Problem 8 Propene and hydrogen bromide

1. Major: **2-bromopropane**; minor: 1-bromopropane.
2. Major route: secondary carbocation $\text{CH}_3\text{CH}^+\text{CH}_3$. Minor route: primary $\text{CH}_3\text{CH}_2\text{CH}_2^+$.
3. Two alkyl groups push electron density towards the secondary carbon, stabilising it more than the primary ion with one alkyl group. The more stable intermediate forms faster.

Problem 9 Symmetrical or not

1. But-2-ene gives **2-bromobutane** only.
2. Pent-1-ene gives **2-bromopentane** as the major product.
3. In but-2-ene both double-bond carbons are equivalent (each has one H and one CH_3), so either carbon gives the same secondary ion.

Problem 10 Tertiary carbocation

1. H adds to the CH carbon: **$(\text{CH}_3)_2\text{C}^+\text{CH}_2\text{CH}_3$** , a tertiary ion.
2. Water attacks, then H^+ is lost: **2-methylbutan-2-ol**.
3. The OH is on a carbon bonded to three other carbons: tertiary.

Problem 11 Percentage yield

1. $n = 8.4 / 42.0 = 0.200 \text{ mol}$.
2. Ratio 1 : 1, so theoretical mass = $0.200 \times 122.9 = 24.6 \text{ g}$.
3. Yield = $18.5 / 24.6 \times 100 = \mathbf{75.3 \%}$ (using 24.58 g).

Problem 12 Polymer repeat units

1. Propene $\text{CH}_2=\text{CHCH}_3$ gives **$-\text{CH}_2-\text{CH}(\text{CH}_3)-$** .
2. **Tetrafluoroethene**, $\text{CF}_2=\text{CF}_2$.
3. Replace the chain bond by a double bond: $\text{CH}_2=\text{CH}(\text{CN})$, **propenenitrile**.

Problem 13 Length of a PVC chain

1. $-\text{CH}_2-\text{CHCl}-$, $\text{C}_2\text{H}_3\text{Cl}$: $24.0 + 3.0 + 35.5 = 62.5 \text{ g/mol}$.
2. $1\,800 \times 62.5 = \mathbf{112\,500 \text{ g/mol}}$ (1.125×10^5).
3. $n = 25\,000 / 62.5 = \mathbf{400 \text{ mol}}$, since the monomer and repeat unit have the same formula.

Problem 14 Why addition occurs

1. The π bond holds a region of high electron density that attracts electrophiles.
2. Ethane has only σ bonds, with no exposed electrons; the C-C and C-H bonds are strong and non-polar.
3. The weaker π bond is replaced by two strong σ bonds, so the process releases energy and **the saturated product is lower in energy**.

Problem 15 Disposal of addition polymers

1. Its chains contain only strong non-polar C-C and C-H bonds, which microbes cannot hydrolyse.
2. Advantage: energy recovered as heat. Drawback: burning PVC releases HCl, which must be removed by scrubbing.
3. Different polymers melt at different temperatures; mixing them gives a poor product, so **sorting keeps the recycled material uniform**.

Problem 16 Relative rates of addition

1. Fastest: 2-methylpropene (800), then propene (25), then ethene (1).
2. Ethene: CH_3CH_2^+ (primary); propene: $\text{CH}_3\text{CH}^+\text{CH}_3$ (secondary); 2-methylpropene: $(\text{CH}_3)_3\text{C}^+$ (tertiary).
3. More alkyl groups stabilise the ion, lowering the activation energy of the slow step.
Tertiary ion gives the fastest reaction.

Problem 17 Finding the errors

1. Error 1: a primary carbocation is shown, but the secondary ion is more stable. Error 2: 1-bromopropane is not the major product.
2. Intermediate $\text{CH}_3\text{CH}^+\text{CH}_3$; major product **2-bromopropane**.
3. The curly arrow must start at the C=C bond and point to the hydrogen, because the π electrons are the nucleophilic site.

Problem 18 Unknown alkene by titration

1. $n(\text{Br}_2) = 8.00 / 159.8 = 0.0501 \text{ mol}$.
2. Alkene : $\text{Br}_2 = 1 : 1$, so $M = 2.10 / 0.0501 = \mathbf{41.9 \text{ g/mol}}$.
3. C_nH_{2n} with $14n = 42$ gives $n = 3$: **C_3H_6 , propene**.

Problem 19 Combustion analysis

1. $n(\text{C}) = 4.40 / 44.0 = 0.100 \text{ mol}$; $n(\text{H}) = 2 \times 1.80 / 18.0 = 0.200 \text{ mol}$. Ratio 1 : 2, empirical formula CH_2 .
2. $56 / 14.0 = 4$, so **C_4H_8** .
3. But-1-ene, Z-but-2-ene, E-but-2-ene and 2-methylpropene. But-2-ene (E or Z) gives only **2-bromobutane**.

Problem 20 Atom economy of ethanol

1. A: $46.0 / (28.0 + 18.0) \times 100 = \mathbf{100 \%}$.
2. B: $46.0 / (108.9 + 40.0) \times 100 = 46.0 / 148.9 = \mathbf{30.9 \%}$.
3. Route A has a far better atom economy and no waste salt; route B needs the halogenoalkane, which itself comes from an alkene, so it adds a step.