

Making and reacting esters and acyl chlorides

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

Each answer shows the method and then the final result in bold. Atomic masses used: H 1.0, C 12.0, N 14.0, O 16.0, Na 23.0, Cl 35.5. Always check that equations balance and that equilibria are written with the reversible arrow.

Level: Chemistry grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.3.9

Problem 1 Names of acids and esters

1. **Propanoic acid.**
2. The alkyl group on the oxygen is CH₃ (methyl) and the acid stem is propan: **methyl propanoate.**
3. Ethyl group on oxygen, one carbon in the acid: **ethyl methanoate.**

Problem 2 Acid reactions

1. $2\text{CH}_3\text{COOH} + \text{Mg} \rightarrow (\text{CH}_3\text{COO})_2\text{Mg} + \text{H}_2$
2. $2\text{CH}_3\text{COOH} + \text{Na}_2\text{CO}_3 \rightarrow 2\text{CH}_3\text{COONa} + \text{H}_2\text{O} + \text{CO}_2$
3. $\text{CH}_3\text{COOH} + \text{NaOH} \rightarrow \text{CH}_3\text{COONa} + \text{H}_2\text{O}$

Names of the salts: magnesium ethanoate and sodium ethanoate.

Problem 3 Making methyl propanoate

1. $\text{CH}_3\text{CH}_2\text{COOH} + \text{CH}_3\text{OH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COOCH}_3 + \text{H}_2\text{O}.$
2. Concentrated sulfuric acid; heat under reflux.
3. **C₄H₈O₂** (4 C, 8 H, 2 O).

Problem 4 Hydrolysis products

1. Methanoic acid and ethanol.
2. Sodium methanoate and ethanol.
3. **The alkaline hydrolysis.**

Problem 5 Making an acyl chloride

1. $\text{CH}_3\text{CH}_2\text{COOH} + \text{SOCl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{COCl} + \text{SO}_2 + \text{HCl}.$
2. **Propanoyl chloride.**
3. Both by-products are gases, so they leave the mixture.

Problem 6 Reading an esterification scheme

1. The -COO- group between the C=O carbon and the propyl group.
2. "Propyl" comes from propan-1-ol.
3. $\text{C}_6\text{H}_{12}\text{O}_2$ (3 + 3 carbons, 12 hydrogens, 2 oxygens).

Problem 7 Carbon dioxide from vinegar

1. $\text{CH}_3\text{COOH} + \text{NaHCO}_3 \rightarrow \text{CH}_3\text{COONa} + \text{H}_2\text{O} + \text{CO}_2$.
2. $n = 6.0 / 60.0 = 0.100 \text{ mol}$.
3. $V = 0.100 \times 24.0 = \mathbf{2.40 \text{ dm}^3}$.

Problem 8 Calculating Kc

1. Acid = $0.500 - 0.333 = 0.167 \text{ mol}$ (alcohol also 0.167 mol); water = 0.333 mol .
2. $K_c = / ()$.
3. $K_c = (0.333)^2 / (0.167)^2 = \mathbf{4.0}$ (volume cancels).

Problem 9 Raising the yield

1. Use an excess of one reactant, and remove water or the ester as it forms.
2. A catalyst only increases the rate, so equilibrium is reached sooner but the yield is the same.
3. **Kc is unchanged**, because it depends only on temperature.

Problem 10 Making soap

1. $n = 8.90 / 890 = 0.0100 \text{ mol}$.
2. $n(\text{NaOH}) = 0.0300 \text{ mol}$; mass = $0.0300 \times 40.0 = \mathbf{1.20 \text{ g}}$.
3. Mass of soap = $0.0300 \times 306 = \mathbf{9.18 \text{ g}}$.

Problem 11 Banana flavour

1. $\text{CH}_3\text{COOH} + \text{C}_5\text{H}_{11}\text{OH} \rightleftharpoons \text{CH}_3\text{COOC}_5\text{H}_{11} + \text{H}_2\text{O}$.
2. $n(\text{acid}) = 6.0 / 60.0 = 0.100 \text{ mol}$; theoretical mass = $0.100 \times 130 = 13.0 \text{ g}$.
3. Actual = $0.70 \times 13.0 = \mathbf{9.1 \text{ g}}$.

Problem 12 Why alkaline hydrolysis finishes

1. The acid-catalysed hydrolysis.
2. In alkali, the acid is converted to its carboxylate ion, which is negatively charged and cannot be attacked by the alcohol, so the reverse reaction cannot happen.
3. **Sodium ethanoate**.

Problem 13 Acylation equations

- $\text{CH}_3\text{COCl} + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{COOH} + \text{HCl}$.
- $\text{CH}_3\text{COCl} + \text{C}_2\text{H}_5\text{OH} \rightarrow \text{CH}_3\text{COOC}_2\text{H}_5 + \text{HCl}$.
- $\text{CH}_3\text{COCl} + 2\text{NH}_3 \rightarrow \text{CH}_3\text{CONH}_2 + \text{NH}_4\text{Cl}$** ; the second ammonia molecule absorbs the HCl.

Problem 14 Why acyl chlorides are reactive

- It is bonded to two electronegative atoms, O and Cl, which both pull electron density away.
- Cl^- is a stable ion that departs easily.
- They are corrosive, react violently with water and give off HCl fumes, so **they must be handled in a fume cupboard**.

Problem 15 Atom economy of the acyl chloride route

- $\text{CH}_3\text{CH}_2\text{COOH} + \text{SOCl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{COCl} + \text{SO}_2 + \text{HCl}$.
- $92.5 / (74.0 + 119.0) \times 100 = 92.5 / 193.0 = \mathbf{47.9\%}$.
- Sulfur dioxide and hydrogen chloride.

Problem 16 Rise to equilibrium

- About **0.67 mol/dm^3** (plateau).
- Acid = alcohol = 0.33 mol/dm^3 ; $K_c = 0.67^2 / 0.33^2 = \mathbf{4.0}$ (4.1 with rounded values).
- Rate = $0.20 / 20 = \mathbf{0.010 \text{ mol dm}^{-3} \text{ min}^{-1}}$.

Problem 17 Excess alcohol

- $K_c = x^2 / [(1.00 - x)(3.00 - x)] = 4.0$.
- $3x^2 - 16x + 12 = 0$; $x = (16 - \sqrt{112}) / 6 = \mathbf{0.903 \text{ mol}}$ (the other root is above 1.00).
- Conversion = $0.903 / 1.00 \times 100 = \mathbf{90.3\%}$.

Problem 18 Find the errors

- Chloride leaves first, forming an acylium ion; in reality the nucleophile adds first.
- The ethanol oxygen lone pair attacks the δ^+ carbon, the C=O π electrons move onto O, giving a tetrahedral intermediate.
- The intermediate loses Cl^- and an H^+ from the oxygen, and **these combine to make HCl**.

Problem 19 Back titration of an ester

- $n = 0.400 \times 0.0500 = 0.0200 \text{ mol}$.
- Excess = $0.500 \times 0.0200 = 0.0100 \text{ mol}$, so reacted = $0.0200 - 0.0100 = 0.0100 \text{ mol}$.
- $M = 0.880 / 0.0100 = \mathbf{88.0 \text{ g/mol}}$, formula **$\text{C}_4\text{H}_8\text{O}_2$** ($4(12) + 8 + 32 = 88$).

Problem 20 Making aspirin

1. C: $7 + 4 = 11 = 9 + 2$; H: $6 + 6 = 12 = 8 + 4$; O: $3 + 3 = 6 = 4 + 2$. Balanced.
2. $n = 2.76 / 138.0 = 0.0200$ mol; mass = $0.0200 \times 180.0 = \mathbf{3.60\text{ g}}$.
3. Yield = $2.52 / 3.60 = \mathbf{70.0\%}$; atom economy = $180.0 / (138.0 + 102.0) = \mathbf{75.0\%}$.