International Chemistry Competition

Edition of 2026

Semi-Final Round – Solutions

Problem A: Hand Warmers (4 Points)

On cold winter days, disposable hand warmers are commonly used by hikers, skiers, and athletes to keep their hands warm for several hours. These small packets contain a mixture of iron powder, salt, activated carbon, and other materials. Once the sealed package is opened, oxygen from the air enters the packet and reacts slowly with the iron. Since this oxidation process is exothermic, heat is released continuously over an extended period of time.

A simplified overall reaction for the oxidation of iron is shown below:

$$4\,\mathrm{Fe} + X\,\mathrm{O_2} \rightarrow 2\,\mathrm{Fe_2O_3}$$

For this problem, use the following data: The molar mass of iron is $M(\mathrm{Fe}) = 55.8\,\mathrm{g/mol}$, and the molar mass of oxygen is $M(\mathrm{O_2}) = 32.0\,\mathrm{g/mol}$. Assume oxygen is present in excess.

(a) Complete the reaction equation by determining the missing coefficient X.

(b) One hand warmer contains 8.40 g of iron powder.

Assuming that the iron is completely converted into iron oxide, calculate the following quantities:

- The amount of iron present, in mol.
- The amount of oxygen consumed, in mol.

(c) Using your results from part (b), calculate the mass of iron oxide produced, in g.

Basic Solution

(a) $X = 3$.
(b)

$$n(\mathrm{Fe}) = \frac{8.40\,\mathrm{g}}{55.8\,\mathrm{g/mol}} = 0.151\,\mathrm{mol}$$

From the balanced equation,

$$4\,\mathrm{Fe} : 3\,\mathrm{O_2}$$

so

$$n(\mathrm{O_2}) = 0.151 \times \frac{3}{4} = 0.113\,\mathrm{mol}$$

(c) From the balanced equation,

$$4\,\mathrm{Fe} \rightarrow 2\,\mathrm{Fe_2O_3}$$

thus

$$n(\mathrm{Fe_2O_3}) = 0.151 \times \frac{2}{4} = 0.0755\,\mathrm{mol}$$

The molar mass of $\mathrm{Fe_2O_3}$ is

$$M(\mathrm{Fe_2O_3}) = 2(55.8) + 3(16.0) = 159.6\,\mathrm{g/mol}$$

Therefore,

$$m(\mathrm{Fe_2O_3}) = 0.0755 \times 159.6 = 12.1\,\mathrm{g}$$

Problem B: Banana Aroma (6 Points)

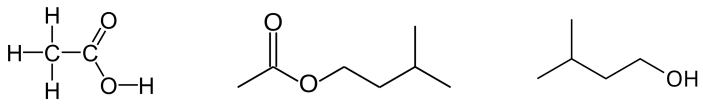
A small food chemistry company is developing artificial flavorings for use in candy, beverages, and baked products. One of their most successful products is an artificial banana aroma, which is widely used because of its characteristic fruity smell. Although natural bananas contain many different volatile compounds, much of the recognizable aroma originates from the ester isoamyl acetate.

To produce this compound on an industrial scale, the chemists react isoamyl alcohol with acetic acid in the presence of concentrated sulfuric acid. The reaction is carried out under reflux in order to heat the reaction mixture without losing volatile substances.

The overall reaction equation is as follows:

$$\text{isoamyl alcohol} + \text{acetic acid} \rightleftharpoons \text{isoamyl acetate} + H_2O$$

The structural formulas of the three organic compounds are shown below:



A B C

(a) Match the molecular structures labeled A, B, and C to the corresponding compounds in the reaction equation above.

(b) For each of the compounds identified in part (a), identify the principal functional group present in the molecule.

(c) During the first experiments, the chemists observe that the reaction proceeds only very slowly in the absence of sulfuric acid.

Explain why sulfuric acid accelerates the esterification reaction.

(d) In order to optimize the industrial process, several modifications of the reaction conditions are discussed. Among the proposed changes are the following:

(a) Continuously removing water from the reaction mixture.

(b) Continuously adding water to the reaction mixture.

(c) Strongly cooling the reaction vessel.

Which of these modifications would increase the ester yield most effectively?

(e) The boiling points of the three compounds involved in the reaction are listed in the table below:

Compound	Boiling point
Isoamyl alcohol	$131\,^{\circ}\mathrm{C}$
Isoamyl acetate	$142\,^{\circ}\mathrm{C}$
Acetic acid	$118\,^{\circ}\mathrm{C}$

Alcohols and, in particular, carboxylic acids often possess unusually high boiling points compared with many organic compounds of similar molar mass. Explain this observation in terms of intermolecular interactions.

Basic Solution

(a) A: isoamyl alcohol. B: acetic acid. C: isoamyl acetate.
(b) Isoamyl alcohol: alcohol (hydroxyl) functional group. Acetic acid: carboxylic acid functional group. Isoamyl acetate: ester functional group.
(c) Sulfuric acid acts as an acid catalyst by protonating the carbonyl oxygen of the carboxylic acid, making the carbonyl carbon more electrophilic and therefore more reactive toward nucleophilic attack by the alcohol.
(d) Continuously removing water from the reaction mixture would increase the ester yield most effectively, because removing a product shifts the equilibrium toward ester formation according to Le Châtelier's principle.
(e) Alcohols and especially carboxylic acids form strong intermolecular hydrogen bonds. These interactions require additional energy to overcome, leading to unusually high boiling points. Carboxylic acids can additionally form hydrogen-bonded dimers, which further increases their boiling points.

Problem C: Nitrogen Chain (8 Points)

Use the content of the article "Crystalline nitrogen chain radical anions.", Lister-Roberts, R., Galano, D., van IJzendoorn, B. et al. Crystalline nitrogen chain radical anions. Nat. Chem. 18, 686–694 (2026), to answer the questions below. Usually, 1-2 sentences are enough to answer each question.

(a) Why are long nitrogen chains generally unstable under ambient conditions?

(b) What was the main chemical species isolated in this paper?

(c) Why does electron delocalization increase the stability of the $\{N_4\}$ radical anion, and which structural feature enables this stabilization?

(d) Which experimental technique confirmed the presence of an unpaired electron in [1]$^{\bullet-}$?

(e) Which common organic molecule was used as an analogy for the π-bonding in the $\{N_4\}$ chain?

(f) Why do intermediate $N{-}N$ bond lengths support delocalized bonding in the $\{N_4\}$ chain?

(g) Why did the authors study several substituted derivatives instead of only one compound?

(h) Why was the reaction with aldehydes important evidence for nitrene formation?

Basic Solution

(a) Because they tend to release very stable N_2 gas.
(b) A metal-free $\{N_4\}$ radical anion.
(c) Delocalization spreads the unpaired electron over many atoms, lowering the molecule's energy; the aromatic rings enable this delocalization.
(d) EPR spectroscopy.
(e) 1,3-butadiene.
(f) Because the bonds are neither purely single nor purely double bonds.
(g) To investigate how substituents affect stability and electronic structure.
(h) Because nitrenes are known to activate aldehyde C–H bonds to form amides.