Past-paper walk-through

Solids, Liquids, and Gases ▪ 3.3

eXercise

Questions in this set

- 2025 Q4
- 2025 Q5

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 4

2025 ▪ Q4

A scientist is investigating the properties of a mixture of CH_3OH and H_2CO. The scientist generates the following diagram to represent the mixture.

[Diagram in a large box showing six Lewis-structure molecules scattered at different positions and orientations, representing a mixture of CH_3OH and H_2CO molecules: - Top-left: an H_2CO molecule, $\ddot{O} = C$ with two H atoms attached, two lone pairs on O. - Top-right: an H_2CO molecule (different orientation), H atoms attached to C, C double-bonded to O with two lone pairs. - Middle: a CH_3OH molecule, H—C(—H)(—H)—O(—H) with two lone pairs on O, drawn with C in the center bonded to three H atoms and one O, and the O bonded to one more H. - Middle-left: a CH_3OH molecule (different orientation) with O bonded to C and H, two lone pairs on O, C bonded to three H atoms. - Bottom-middle: an H_2CO molecule, C double-bonded to O (two lone pairs), C bonded to two H atoms below. -

Question 4

Bottom-right: an H_2CO molecule (different orientation), similar structure with O double-bonded to C bonded to two H atoms.]

(a) Identify the hybridization of the valence orbitals of the C atom in the H_2CO molecule.

Question 4

Substance	Melting Point (K)	Boiling Point (K)	Enthalpy of Vaporization (kJ/mol)
CH_3OH	176	338	37.6
H_2CO	181	254	24.2

Question 4

2025 ▪ Q4

A scientist is investigating the properties of a mixture of CH_3OH and H_2CO. The scientist generates the following diagram to represent the mixture.

[Diagram in a large box showing six Lewis-structure molecules scattered at different positions and orientations, representing a mixture of CH_3OH and H_2CO molecules: - Top-left: an H_2CO molecule, $\ddot{O} = C$ with two H atoms attached, two lone pairs on O. - Top-right: an H_2CO molecule (different orientation), H atoms attached to C, C double-bonded to O with two lone pairs. - Middle: a CH_3OH molecule, H—C(—H)(—H)—O(—H) with two lone pairs on O, drawn with C in the center bonded to three H atoms and one O, and the O bonded to one more H. - Middle-left: a CH_3OH molecule (different orientation) with O bonded to C and H, two lone pairs on O, C bonded to three H atoms. - Bottom-middle: an H_2CO molecule, C double-bonded to O (two lone pairs), C bonded to two H atoms below. - Bottom-right: an

Question 4

H_2CO molecule (different orientation), similar structure with O double-bonded to C bonded to two H atoms.]

(b) In the diagram provided, draw a SINGLE dashed line (—-) to represent a strong hydrogen-bonding attraction between one CH_3OH molecule and one H_2CO molecule in the mixture.

Question 4

2025 ▪ Q4

A scientist is investigating the properties of a mixture of CH_3OH and H_2CO. The scientist generates the following diagram to represent the mixture.

[Diagram in a large box showing six Lewis-structure molecules scattered at different positions and orientations, representing a mixture of CH_3OH and H_2CO molecules: - Top-left: an H_2CO molecule, $\ddot{O} = C$ with two H atoms attached, two lone pairs on O. - Top-right: an H_2CO molecule (different orientation), H atoms attached to C, C double-bonded to O with two lone pairs. - Middle: a CH_3OH molecule, H—C(—H)(—H)—O(—H) with two lone pairs on O, drawn with C in the center bonded to three H atoms and one O, and the O bonded to one more H. - Middle-left: a CH_3OH molecule (different orientation) with O bonded to C and H, two lone pairs on O, C bonded to three H atoms. - Bottom-middle: an H_2CO molecule, C double-bonded to O (two lone pairs), C bonded to two H atoms below. - Bottom-right: an

Question 4

H_2CO molecule (different orientation), similar structure with O double-bonded to C bonded to two H atoms.]

(c) The scientist plans to cool a gaseous mixture of CH_3OH and H_2CO to form a liquid mixture and finds data on the two compounds. The data are summarized in the table.

Substance	Melting Point (K)	Boiling Point (K)	Enthalpy of Vaporization (kJ/mol)
CH_3OH	176	338	37.6
H_2CO	181	254	24.2

(c)(i) Propose a temperature to which the mixture should be cooled such that CH_3OH and H_2CO will both be liquids.

(c)(ii) The scientist analyzes the mixture after it is cooled and determines that 8.59 g of $CH_3OH(l)$ is present. Calculate the amount of thermal energy, in kJ, that was removed to condense the 8.59 g of CH_3OH (molar mass 32.04 g/mol) at its boiling point.

Solution 4

(a)

Mark scheme

- sp^2 (the C atom in H_2CO is trigonal planar — one C=O double bond and two C–H single bonds, three electron domains, no lone pairs).

Solution 4

(b)

Mark scheme

- Draw a single dashed line from the H atom of the –OH group on one CH_3OH molecule to the O atom of one H_2CO molecule, representing a hydrogen bond between the H-bond donor (O–H of methanol) and the H-bond acceptor (C=O of formaldehyde).

Solution 4

(c)

Mark scheme

- No separate response required — this is the context/stem giving the melting point, boiling point, and enthalpy of vaporization data table for CH_3OH and H_2CO that parts (i) and (ii) below use.

Solution 4

(c)(i)

Mark scheme

- Propose any temperature in the range 181 K – 254 K, so that both CH_3OH (mp 176 K, bp 338 K) and H_2CO (mp 181 K, bp 254 K) are liquid — i.e., above the higher melting point (181 K, H_2CO) and below the lower boiling point (254 K, H_2CO).

Solution 4

(c)(ii)

Mark scheme

- $8.59\ \text{g CH}_3\text{OH} \times \dfrac{1\ \text{mol CH}_3\text{OH}}{32.04\ \text{g CH}_3\text{OH}} \times \dfrac{-37.6\ \text{kJ}}{1\ \text{mol CH}_3\text{OH}} = -10.1\ \text{kJ}$, so 10.1 kJ of thermal energy are removed (condensing the vapor releases this energy).

Question 5

2025 ▪ Q5

Complete Lewis diagrams and some physical properties for compounds X and Y are given.
| Compound | X | Y | |—|—|—| | Lewis diagram | [Lewis structure of compound X: a central chain of three C atoms; the left C is bonded to three H atoms and to the middle C; the middle C is bonded to an O atom above it (O has two lone pairs, drawn as :O:) and to the right C; the right C is bonded to three H atoms and to the middle C; the middle C is also bonded to a fourth C below it, which is bonded to two H atoms.] | [Lewis structure of compound Y: a central chain analogous to X but with a Si atom in place of the middle C; the left C is bonded to three H atoms and to Si; Si is bonded to an O atom above it (O has two lone pairs, drawn as :O:) and to the right C; the right C is bonded to three H atoms and to Si; Si is also bonded to a C below it,

Question 5

which is bonded to two H atoms.] | | Molar mass | 74.1 g/mol | 90.2 g/mol | | Boiling point | $82°$C | $98°$C |

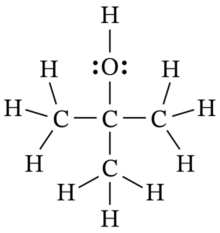
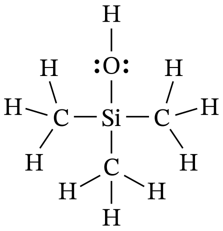
(a) Based on VSEPR theory, predict the geometry around the Si atom in compound Y.

(b) A student claims that compound Y has a higher boiling point than that of compound X because compound Y has stronger London dispersion forces. Do you agree or disagree? Justify your answer.

(c) An equimolar mixture of the two compounds is heated. When the mixture reaches $82°$C, which compound will have the higher vapor pressure? Justify your answer.

(d) The mixture is heated to $198°$C in a sealed, rigid 12.5 L container, at which point both substances are gases and the total pressure in the container is 2.30 atm. Calculate the number of moles of gas particles in the container.

Question 5

Compound	X	Y
Lewis diagram		
Molar mass	74.1 g/mol	90.2 g/mol
Boiling point	82°C	98°C

Solution 5

(a)

Mark scheme

- Tetrahedral (four bonding domains around the Si atom, no lone pairs, per VSEPR theory).

Solution 5

(b)

Mark scheme

- Agree. Compound Y (containing Si) has a larger, more polarizable electron cloud because the Si atom has more occupied electron shells than the C atom in compound X, giving compound Y stronger London dispersion forces and a higher boiling point than compound X.

Solution 5

(c)

Mark scheme

- Compound X will have the higher vapor pressure at $82°C$. Compound X has weaker intermolecular forces than compound Y, so molecules of X are more likely to be in the gas phase at $82°C$. Equivalently: at $82°C$ compound X has reached its boiling point but compound Y has not, so a much greater proportion of X molecules are in the vapor phase, giving X the higher vapor pressure.

Solution 5

(d)

Mark scheme

- Using $PV = nRT$: $n = \dfrac{PV}{RT} = \dfrac{(2.30\ \text{atm})(12.5\ \text{L})}{(0.08206\ \frac{\text{L·atm}}{\text{K·mol}})(471\ \text{K})} = 0.744$ mol.