Past-paper walk-through

Representations of Equilibrium ▪ 7.8

eXercise

Questions in this set

- 2024 Q5
- 2023 Q2
- 2023 Q7

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 5

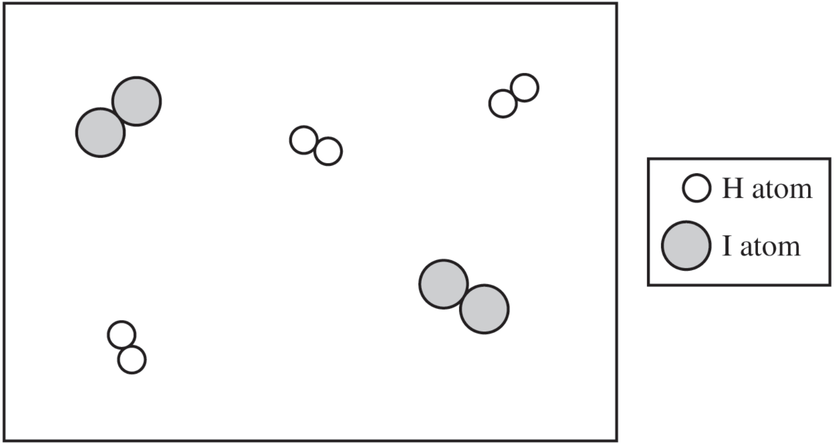
2024 ▪ Q5

$$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g) \qquad \Delta H_{rxn} = -12.19 \text{ kJ/mol}_{rxn}$$

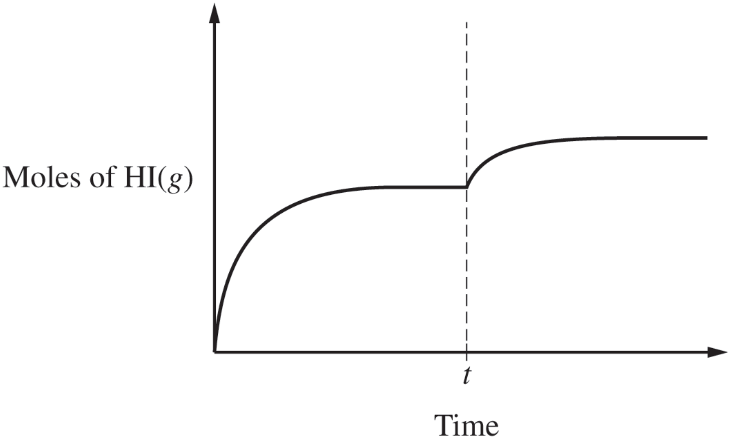
5. Hydrogen gas and iodine gas react to form hydrogen iodide at an elevated temperature, as represented by the following equation.

(a) Write the expression for the equilibrium constant, K_c, for this reaction.

Question 5



Question 5



Question 5

2024 ▪ Q5

$$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g) \qquad \Delta H_{rxn} = -12.19\ \text{kJ/mol}_{rxn}$$

5. Hydrogen gas and iodine gas react to form hydrogen iodide at an elevated temperature, as represented by the following equation.

(b)(i) $H_2(g)$ and $I_2(g)$ are added to a previously evacuated container and allowed to react.

At a certain time, the value of the reaction quotient, Q, is 0.67. The following particle diagram is an incomplete representation of the system at this time. The diagram shows the relative number of $H_2(g)$ and $I_2(g)$ molecules, but the $HI(g)$ molecules are not included. Draw the number of $HI(g)$ molecules needed to complete the diagram so that it accurately represents the system.

Question 5

[Rectangular particle-diagram box containing: 2 pairs of bonded circles representing I_2 molecules — one pair (2 gray/shaded circles bonded together) upper-left, one pair (2 white/open circles bonded together) upper-right; 2 pairs of bonded circles representing H_2 molecules — one pair (2 small white circles bonded) center, one pair (2 gray circles bonded) lower-middle-right, one more pair (2 small white circles bonded) lower-left. A legend to the right of the box: open/white circle = H atom, gray/shaded circle = I atom. Molecule counts shown: 2 I_2 molecules (one gray-gray pair, one white-white pair — actually representing I_2 and possibly another diatomic), plus H2-type pairs — the diagram shows a total of 3 diatomic pairs that are H-containing and 2 that are I-containing among the 5 total pairs drawn, matching an H_2: I_2 ratio consistent with $Q = 0.67$. Student must add the correct number of HI molecules (single white-gray bonded pairs) to complete the diagram.]

Question 5

(b)(ii) A student monitors the number of moles of HI(g) over time. Hypothesize an experimental change that could have been applied to the system in the rigid container at time t to result in the change in the number of moles of HI(g) shown in the graph. Assume that the student did not add more HI(g) to the system.
[Graph: y-axis "Moles of HI(g)" (unlabeled scale), x-axis "Time"; curve rises steeply from the origin, levels off into a plateau, then at a dashed vertical line marked t the curve jumps up abruptly to a new, higher level and levels off again into a second plateau.]
(b)(iii) After equilibrium is established, the mixture is transferred to a larger container at constant temperature. As a result, would the number of moles of HI(g) increase, decrease, or remain the same? Justify your answer.

Solution 5

(a)

Mark scheme

- $K_c = \dfrac{[\mathsf{HI}]^2}{[\mathsf{H}_2][\mathsf{I}_2]}$.

Solution 5

(b)(i)

Mark scheme

- Complete the particle diagram (consistent with part (a)) by drawing enough HI molecules (one H atom + one I atom joined) so that the diagram is consistent with $Q = 0.67 = \dfrac{[\mathrm{HI}]^2}{[\mathrm{H_2}][\mathrm{I_2}]}$, given the numbers of H_2 and I_2 molecules already shown in the box.

Solution 5

(b)(ii)

Mark scheme

- Accept either: decreased the temperature; OR added more $H_2(g)$ and/or $I_2(g)$ to the reaction vessel — either change would shift the equilibrium to produce more $HI(g)$ over time, consistent with the graph's rise in moles of HI after time t.

Solution 5

(b)(iii)

Mark scheme

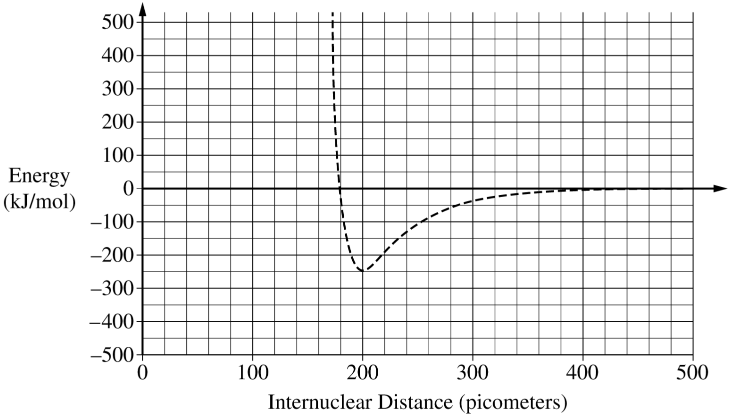
- Remain unchanged. Accept either justification: (1) The moles of gaseous reactants and products in the balanced equation are equal, so transferring to a larger container does not shift the equilibrium (Q remains equal to K), so moles of HI stay the same. (2) Increasing the volume decreases the concentrations of reactants and products by an equal proportion; since there are equal moles of gaseous reactants and products, there is no shift in equilibrium position, so the moles of HI remain the same.

Question 2

2023 ▪ Q2

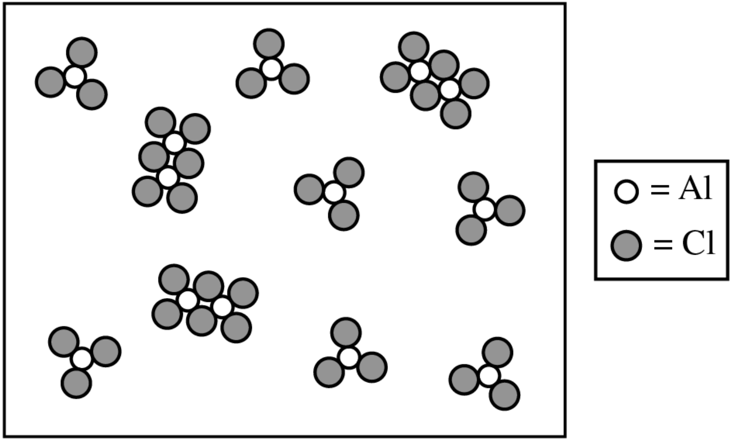
In the gas phase, $AlCl_3$ is a molecular substance. A reaction of gaseous $AlCl_3$ at high temperature is represented by the following balanced equation.
Reaction 1: $AlCl_3(g) \rightarrow Al(g) + 3\,Cl(g) \qquad \Delta H_1^\circ = ?$
(a) How many grams of $Cl(g)$ can be formed from 1.25 mol of $AlCl_3(g)$?

Question 2



ɔn the graph, what is the bond length, in picometers, for Cl_2 ? __________

Question 2



Question 2

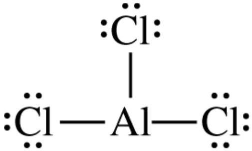


Diagram 1

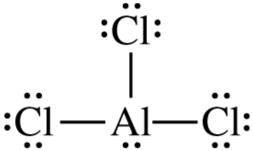


Diagram 2

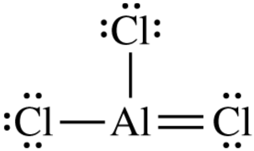


Diagram 3

Question 2

2023 ▪ Q2

In the gas phase, $AlCl_3$ is a molecular substance. A reaction of gaseous $AlCl_3$ at high temperature is represented by the following balanced equation.

Reaction 1: $AlCl_3(g) \rightarrow Al(g) + 3\,Cl(g) \qquad \Delta H_1^\circ = ?$

(b) Additional reactions that involve Al or Cl are shown in the following table.

Reaction Number	Equation	ΔH°_{rxn} (kJ/mol$_{rxn}$)
2	$Al(s) + \frac{3}{2}Cl_2(g) \rightarrow AlCl_3(g)$	-583
3	$Al(s) \rightarrow Al(g)$	$+326$
4	$Cl_2(g) \rightarrow 2\,Cl(g)$	$+243$

Calculate the value of ΔH_1°, in kJ/mol$_{rxn}$, for reaction 1 above using reactions 2, 3, and 4.

Question 2

2023 ▪ Q2

In the gas phase, $AlCl_3$ is a molecular substance. A reaction of gaseous $AlCl_3$ at high temperature is represented by the following balanced equation.

Reaction 1: $AlCl_3(g) \rightarrow Al(g) + 3\,Cl(g) \qquad \Delta H_1^\circ = ?$

(c)(i) A potential energy diagram for Cl_2 is shown in the following graph.
[Graph: potential energy (kJ/mol) vs. internuclear distance (picometers) for Cl_2; y-axis from -500 to 500 kJ/mol in steps of 100; x-axis from 0 to 500 picometers in steps of 100; dashed curve starts high near $x = 0$, plunges to a minimum of about -250 kJ/mol near $x \approx 200$ pm, then rises and levels off near 0 kJ/mol as x increases toward 500 pm.]
Based on the graph, what is the bond length, in picometers, for Cl_2?

Question 2

(c)(ii) A student finds that the average Al – Cl bond length is 220 picometers and the average bond energy is 425 kJ/mol. Draw the potential energy curve for the average Al – Cl bond on the preceding graph.

Question 2

2023 ▪ Q2

In the gas phase, $AlCl_3$ is a molecular substance. A reaction of gaseous $AlCl_3$ at high temperature is represented by the following balanced equation.

Reaction 1: $AlCl_3(g) \rightarrow Al(g) + 3\,Cl(g) \qquad \Delta H_1^\circ = ?$

(d)(i) Three proposed Lewis diagrams for the $AlCl_3(g)$ molecule are shown.
[Diagram 1: Cl bonded to Al with a single bond above (Cl with 3 lone pairs) and two Cl atoms bonded to Al with single bonds on either side (each Cl with 3 lone pairs) — trigonal arrangement, all single Al–Cl bonds, Al with no lone pair shown.] [Diagram 2: same trigonal arrangement of three Cl atoms singly bonded to Al, each Cl shown with 3 lone pairs — visually similar layout to Diagram 1.] [Diagram 3: two Cl atoms singly bonded to Al (each with 3 lone pairs) and one Cl atom double-bonded to Al (shown with 2 lone pairs) — Cl=Al on the right side.]
Diagram 1, Diagram 2, Diagram 3 (labeled beneath each structure).

Question 2

The $AlCl_3(g)$ molecule has a trigonal planar geometry. Which diagram (1, 2, or 3) can be eliminated based on geometry? Justify your choice based on VSEPR theory.
(d)(ii) Which of the three diagrams is the best representation for the bonding in $AlCl_3$? Justify your choice based on formal charges.

Question 2

2023 ▪ Q2

In the gas phase, $AlCl_3$ is a molecular substance. A reaction of gaseous $AlCl_3$ at high temperature is represented by the following balanced equation.

Reaction 1: $AlCl_3(g) \rightarrow Al(g) + 3\,Cl(g) \qquad \Delta H_1^\circ = ?$

(e) $AlCl_3$ is known to dimerize reversibly in the gas phase. The dimerization equilibrium is represented by the following equation.

$$2\,AlCl_3(g) \rightleftharpoons Al_2Cl_6(g)$$

Write the expression for the equilibrium constant, K_p, for this reaction.

Question 2

2023 ▪ Q2

In the gas phase, $AlCl_3$ is a molecular substance. A reaction of gaseous $AlCl_3$ at high temperature is represented by the following balanced equation.

Reaction 1: $AlCl_3(g) \rightarrow Al(g) + 3\,Cl(g) \qquad \Delta H_1^\circ = ?$

(f) A particle-level diagram of an equilibrium mixture of $AlCl_3(g)$ and $Al_2Cl_6(g)$ at $400°$C in a 25 L closed container is shown.

[Particle diagram inside a rectangular box: several clusters of gray/white circles representing $AlCl_3$ monomers (isolated groupings of 1 white Al + 3 gray Cl) and Al_2Cl_6 dimers (larger fused clusters of 2 white Al + 6 gray Cl), scattered throughout the container. Legend: white circle = Al, gray circle = Cl.]

Using the particle-level diagram, calculate the value of K_p for the reaction if the total pressure in the container is 22.1 atm.

Solution 2

(a)

Mark scheme

- $1.25 \text{ mol AlCl}_3 \times \dfrac{3 \text{ mol Cl}}{1 \text{ mol AlCl}_3} \times \dfrac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = 133 \text{ g Cl}$ (3 sig figs).

Solution 2

(b) Mark scheme

- Apply Hess's law using reactions 2, 3, and 4: reverse reaction 2 ($AlCl_3(g) \rightarrow Al(s) + \frac{3}{2}Cl_2(g)$, $\Delta H = -(-583) = +583$ kJ/mol$_{rxn}$) and multiply reaction 4 by $\frac{3}{2}$ ($\frac{3}{2}Cl_2(g) \rightarrow 3\,Cl(g)$, $\Delta H = 1.5(+243) = +365$ kJ/mol$_{rxn}$), then add reaction 3 unchanged: $\Delta H_1^\circ = -\Delta H_2^\circ + \Delta H_3^\circ + 1.5(\Delta H_4^\circ) = -(-583) + 326 + 1.5(243) = 1274$ kJ/mol$_{rxn}$.

Solution 2

(c)(i)

Mark scheme

- Bond length $\approx$ 200 picometers ($\pm$10 pm), read from the internuclear distance at the minimum (lowest potential energy point) of the Cl_2 curve shown.

Solution 2

(c)(ii)

Mark scheme

- Draw a new potential-energy curve for the Al–Cl bond with its minimum at an internuclear distance of 220 ± 10 pm — longer than Cl_2's 200 pm bond length (1 point) — and a minimum energy value of -425 ± 20 kJ/mol that approaches zero as the internuclear distance approaches 500 pm — a shallower well than Cl_2's since the Al–Cl bond energy (425 kJ/mol) is less than the Cl–Cl bond energy shown on the original curve (1 point).

Solution 2

(d)(i)

Mark scheme

- Diagram 2 is not a valid representation. In Diagram 2, Al has four electron domains (three single Al–Cl bonds plus one lone pair on Al), which would give a trigonal pyramidal (not trigonal planar) molecular geometry — inconsistent with the known trigonal planar geometry of $AlCl_3(g)$.

Solution 2

(d)(ii)

Mark scheme

- Diagram 1 is the best representation. All atoms in Diagram 1 have a formal charge of zero, whereas atoms in Diagrams 2 and 3 have nonzero formal charges — the Lewis structure that minimizes (here, eliminates) formal charges is preferred.

Solution 2

(e)

Mark scheme

- $K_p = \dfrac{P_{\mathrm{Al_2Cl_6}}}{(P_{\mathrm{AlCl_3}})^2}$.

Solution 2

(f) Mark scheme

- Using mole fractions read from the particle diagram ($\chi_{\mathsf{AlCl_3}} = \frac{7}{10}$, $\chi_{\mathsf{Al_2Cl_6}} = \frac{3}{10}$) and total pressure 22.1 atm: $K_p = \dfrac{\chi_{\mathsf{Al_2Cl_6}}(P_{total})}{(\chi_{\mathsf{AlCl_3}}(P_{total}))^2} = \dfrac{\frac{3}{10}(22.1)}{(\frac{7}{10}(22.1))^2} = 0.0277.$

Question 7

2023 ▪ Q7

Strontium hydroxide dissolves in water according to the following equation. The K_{sp} expression for strontium hydroxide is provided.

$$Sr(OH)_2(s) \rightleftharpoons Sr^{2+}(aq) + 2\,OH^-(aq) \qquad K_{sp} = [Sr^{2+}][OH^-]^2$$

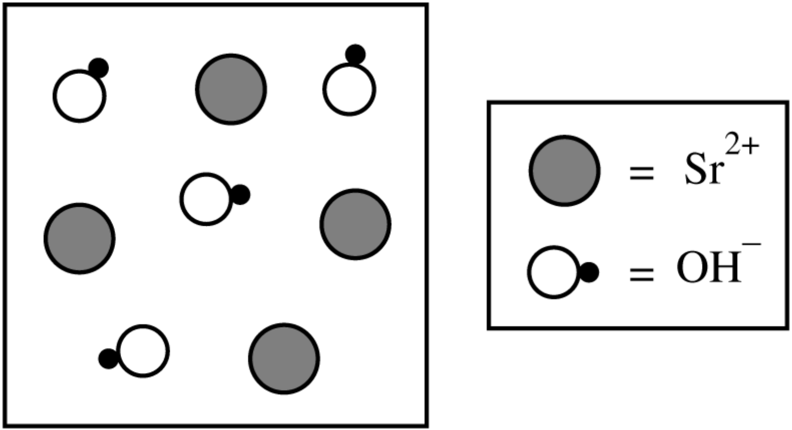
[Particle diagram inside a square box: two "Sr^{2+}" gray circles and several "OH^-" circles (open circle with a small black dot) scattered inside — roughly 3 gray Sr^{2+} circles and 4 OH^- circles shown. Legend beside the box: gray circle = Sr^{2+}; open circle with dot = OH^-.]

(a) A student draws the particulate diagram shown to represent the ions present in an aqueous solution of $Sr(OH)_2$. (Water molecules are intentionally omitted.) Identify the error in the student's drawing.

Question 7

(b)(i) The student prepares a saturated solution by adding excess $Sr(OH)_2(s)$ to distilled water and stirring until no more solid dissolves. The student then determines that $[Sr^{2+}] = 0.043$ *M* in the solution.
Calculate the value of $[OH^-]$ in the solution.
(b)(ii) Calculate the value of K_{sp} for $Sr(OH)_2$.
(c) The student prepares a second saturated solution of $Sr(OH)_2$ in aqueous 0.10 *M* $Sr(NO_3)_2$ instead of water. Will the value of $[OH^-]$ in the second solution be greater than, less than, or equal to the value in the first solution? Justify your answer. (Assume constant temperature.)

Question 7



Solution 7

(a)

Mark scheme

- Accept either: the student's drawing shows an incorrect ratio of Sr^{2+} to OH^- ions (should be 1:2, since $Sr(OH)_2$ dissociates into one Sr^{2+} and two OH^-); or, equivalently, the drawing is not charge-balanced (the total positive and negative charge shown does not sum to zero).

Solution 7

(b)(i)

Mark scheme

- From the dissociation stoichiometry,
$$[\mathsf{OH^-}] = 2[\mathsf{Sr^{2+}}] = \frac{0.043 \text{ mol } \mathsf{Sr^{2+}}}{1 \text{ L}} \times \frac{2 \text{ mol } \mathsf{OH^-}}{1 \text{ mol } \mathsf{Sr^{2+}}} = 0.086 \; M \; \mathsf{OH^-}.$$

(b)(ii)

Mark scheme

- $K_{sp} = [\mathsf{Sr^{2+}}][\mathsf{OH^-}]^2 = (0.043)(0.086)^2 = 3.2 \times 10^{-4}$.

Solution 7

(c)

Mark scheme

- Less than. Because the 0.10 M $Sr(NO_3)_2(aq)$ solution already contains a common ion, $Sr^{2+}(aq)$, the solubility of $Sr(OH)_2$ will be decreased (common-ion effect), resulting in a lower value of $[OH^-]$ than in the first (pure water) solution.