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Answers

Practice exam questions

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Check your answers to the questions in this issue.

Carbon capture from wastewater (pp. 8–11)

1 Solution equilibria are heterogeneous, meaning that they contain materials in a mixture of different states. Concentration terms for solids are left out of these equations, as the concentration of a solid is presumed to be constant.

2 **i** **a** $BaSO_4(s) \rightleftharpoons Ba^{2+}(aq) + SO_4^{2-}(aq)$

b $K_{sp} = [Ba^{2+}] [SO_4^{2-}]$

Units = mol dm^{-3} × mol dm^{-3}

Units = mol^2 dm^{-6}

ii **a** $PbCl_2(s) \rightleftharpoons Pb^{2+}(aq) + 2Cl^-(aq)$

b $K_{sp} = [Pb^{2+}] [Cl^-]^2$

Units = mol dm^{-3} × (mol dm^{-3})^2

Units = mol dm^{-3} × mol dm^{-3} × mol dm^{-3}

Units = mol^3 dm^{-9}

iii **a** $Ca_3(PO_4)_2(s) \rightleftharpoons 3Ca^{2+}(aq) + 2PO_4^{3-}(aq)$

b $K_{sp} = [Ca^{2+}]^3 [PO_4^{3-}]^2$

Units = (mol dm^{-3})^3 × (mol dm^{-3})^2

Units = mol dm^{-3} × mol dm^{-3} × mol dm^{-3} × mol dm^{-3} × mol dm^{-3}

Units = mol^5 dm^{-15}

3 **a** $K_{sp} = 1.10 \times 10^{-10}$ mol^2 dm^{-6} = $[Ba^{2+}] [SO_4^{2-}]$

$[Ba^{2+}] = [SO_4^{2-}] = s$

$K_{sp} = 1.10 \times 10^{-10} = s^2$

$\sqrt{1.10 \times 10^{-10}} = s = 1.05 \times 10^{-5}$ mol dm^{-3}

$[Ba^{2+}] = [SO_4^{2-}] = s = 1.05 \times 10^{-5}$ mol dm^{-3}

b $K_{sp} = 1.59 \times 10^{-5}\ mol^3\ dm^{-9} = [Pb^{2+}][Cl^-]^2$

$[Pb^{2+}] = s$ and $[Cl^-] = 2s$

$K_{sp} = 1.59 \times 10^{-5} = s \times (2s)^2 = 4s^3$

$\frac{1.59 \times 10^{-5}}{4} = 3.98 \times 10^{-6} = s^3$

$\sqrt[3]{3.98 \times 10^{-6}} = s = 1.58 \times 10^{-2}\ mol\ dm^{-3}$

$[Pb^{2+}] = s = 1.58 \times 10^{-2}\ mol\ dm^{-3}$ and $[Cl^-] = 2s = 3.16 \times 10^{-2}\ mol\ dm^{-3}$

c $K_{sp} = 2.07 \times 10^{-33}\ mol^5\ dm^{-15} = [Ca^{2+}]^3 [PO_4^{3-}]^2$

$[Ca^{2+}] = 3s$ and $[PO_4^{3-}] = 2s$

$K_{sp} = 2.07 \times 10^{-33} = (3s)^3 \times (2s)^2 = 27s^3 \times 4s^2 = 108s^5$

$\frac{2.07 \times 10^{-33}}{108} = 1.92 \times 10^{-35} = s^5$

$\sqrt[5]{1.92 \times 10^{-35}} = s = 1.14 \times 10^{-7}\ mol\ dm^{-3}$

$[Ca^{2+}] = 3s = 3.42 \times 10^{-7}\ mol\ dm^{-3}$ and $[PO_4^{3-}] = 2s = 2.28 \times 10^{-7}\ mol\ dm^{-3}$

4 **a** $0.100\ mol\ dm^{-3}\ NH_4Cl$

$[NH_4^+] = 0.100\ mol\ dm^{-3}$

$[Mg^{2+}] = [PO_4^{3-}] = s$

$K_{sp} = [Mg^{2+}][NH_4^+][PO_4^{3-}]$

$K_{sp} = 4.37 \times 10^{-14} = s \times 0.1 \times s = 0.1s^2$

$\frac{4.37 \times 10^{-14}}{0.1} = 4.37 \times 10^{-13} = s^2$

$\sqrt{4.37 \times 10^{-13}} = s = 6.61 \times 10^{-7}\ mol\ dm^{-3}$

The concentration of the Mg^{2+} and PO_4^{3-} ions after $0.100\ mol\ dm^{-3}\ NH_4Cl$ is added is the same as the concentration of NH_4^+ and PO_4^{3-} ions after the $Mg(OH)_2$ was added, because for every one mole of NH_4Cl or $Mg(OH)_2$ added, one mole of common ion is added.

b 0.100 mol dm^{-3} $Ca_3(PO_4)_2$

$Ca_3(PO_4)_2(s) \rightleftharpoons 3Ca^{2+}(aq) + 2PO_4^{3-}(aq)$

For every one mole of $Ca_3(PO_4)_2$, we have two moles of PO_4^{3-}.

$[Ca_3(PO_4)_2]$ = 0.100 mol dm^{-3} but $[PO_4^{3-}]$ = 0.200 mol dm^{-3}

$[Mg^{2+}] = [NH_4^+] = s$

$K_{sp} = [Mg^{2+}]\,[NH_4^+]\,[PO_4^{3-}]$

$K_{sp} = 4.37 \times 10^{-14} = s \times s \times 0.2 = 0.2s^2$

$\frac{4.37 \times 10^{-14}}{0.2} = 2.19 \times 10^{-13} = s^2$

$\sqrt{2.19 \times 10^{-13}} = s = 4.68 \times 10^{-7}$ mol dm^{-3}

The concentration of Mg^{2+} and NH_4^+ ions is different from the other calculations, because for every one mole of $Ca_3(PO_4)_2$ added, two moles of common ion are added.

Striking a balance: making the most of dynamic equilibria (pp. 2–6)

1 a Assume that the initial amount of hydroxyethanoic acid is 1 mole. Using the stoichiometry of the equation we can see that for every mole of acid that reacts, half a mole of cyclic ester is produced. We need to calculate the total number of moles present at equilibrium. From this we can work out the mole fractions, which we multiply by the total pressure to find the partial pressures. These partial pressures are used to calculate the equilibrium constant.

	$2HOCH_2COOH$	$C_4H_4O_4$	$2H_2O$
Initial moles	1	0	0
Change	– 0.46	+ ½ × 0.46	+ 0.46
Moles at equilibrium	1 – 0.46 = 0.54	0.23	0.46
Mole fraction	$\frac{0.54}{1.23} = 0.439$	$\frac{0.23}{1.23} = 0.187$	$\frac{0.46}{1.23} = 0.374$
Partial pressure / kPa	0.439 × 25 = 10.98	0.187 × 25 = 4.68	0.374 × 25 = 9.35

Total moles at equilibrium = 0.54 + 0.23 + 0.46 = 1.23

$$K_p = \frac{p(C_4H_4O_4) \times p(H_2O)^2}{p(HOCH_2COOH)^2} = \frac{4.68 \times (9.35)^2}{(10.98)^2} = 3.39 \text{ kPa}$$

b i An increase in temperature causes the rates of both the forward and reverse reactions to increase, so equilibrium is achieved more quickly. As this reaction is endothermic (which we can see from the positive ΔH value), an increase in temperature causes the value of K_p to rise. Hence, the equilibrium position shifts to the right. Increasing the temperature shifts the equilibrium in the direction of the products of the endothermic reaction.

ii An increase in pressure has no effect on the value of K_p. However, because there are 3 moles of gas on the right-hand side of the equation and only 2 moles of gas on the left, the increase in pressure causes the equilibrium position to shift to the left (towards the side with fewer gas molecules).

2 a i The number of moles of NO_2 at equilibrium = $\frac{5.20 \text{ g}}{46 \text{ g mol}^{-1}}$ = 0.113 mol

ii The number of moles of N_2O_4 that reacted = $\frac{0.113 \text{ mol}}{2}$ = 0.0565 mol

iii The original moles of N_2O_4 = $\frac{10.4 \text{ g}}{92 \text{ g mol}^{-1}}$ = 0.113 mol

iv The number of moles of N_2O_4 at equilibrium = 0.113 – 0.0565 = 0.0565 mol

b $K_c = \frac{[NO_2]^2}{[N_2O_4]}$

$K_c = \frac{(0.113\ \text{mol}/4.5\ \text{dm}^3)^2}{0.0565\ \text{mol}/4.5\ \text{dm}^3} = 0.0502\ \text{mol dm}^{-3}$

A common mistake with this type of calculation is to omit the volume of the reaction vessel (in this case 4.5 dm^3).

c $K_p = \frac{p(NO_2)^2}{p(N_2O_4)}$

d **i** The total number of moles at equilibrium = 0.113 + 0.0565 = 0.1695

ii The mole fraction of $NO_2 = \frac{0.113}{0.1695} = 0.6667 = 0.67$

iii The mole fraction of $N_2O_4 = \frac{0.0565}{0.1695} = 0.3333 = 0.33$

iv Partial pressure of NO_2 = 0.6667 × 100 kPa = 66.67 = 67 kPa

v Partial pressure of N_2O_4 = 0.3333 × 100 kPa = 33.33 = 33 kPa

e $K_p = \frac{(66.67\ \text{kPa})^2}{33.33\ \text{kPa}} = 133.4\ \text{kPa}$

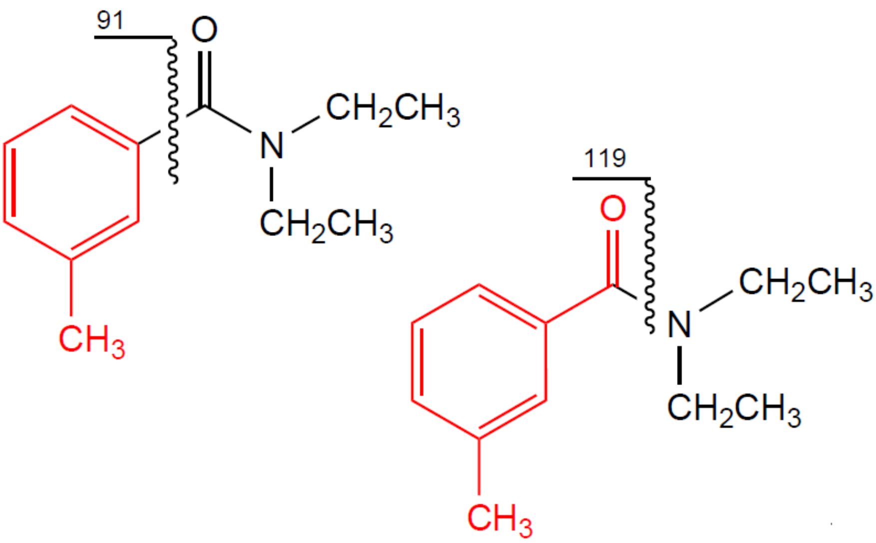
Natural and synthetic insect repellents (pp. 12–15)

1 **a** $C_{12}H_{17}NO$

b **i** 91 $C_7H_7^+$

119 $C_8H_7O^+$

ii



2 **a** **i** $C_8H_{16}O$

ii $C_8H_{14}O$

b **i** PCl_5

fumes of HCl with oct-1-en-3-ol, but not with sulcatone

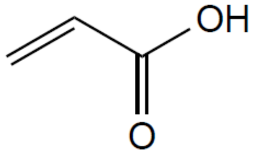
or CH_3COOH (H_2SO_4 catalyst), sweet smelling ester with oct-1-en-3-ol, but not with sulcatone.

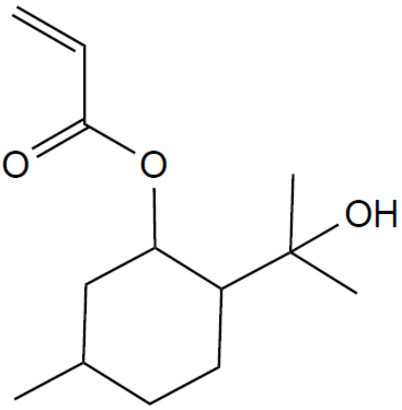
ii 2,4-dinitrophenylhydrazine; orange/yellow precipitate with sulcatone, not with oct-1-en-3-ol.

c **i** In the O–H stretching region, around 3500 cm^{-1}. Oct-1-en-3-ol has an –OH group, sulcatone does not.

ii In the C=O stretching region, around 1700 cm^{-1}. Sulcatone has a C=O group, oct-1-en-3-ol does not.

3





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