Answers to 3.7 Paper 2

Question One

a $K_s = [Ba^{2+}][OH^-]^2$ A

b **i** Solubility products are only constant at a particular temperature (usually 298 K). A

ii Solubility products only apply to sparingly soluble ionic compounds. A

iii Solubility products only apply if the solution is in equilibrium with its solid, in other words, is saturated. A

c $K_s = 4s^3$ (where s is the solubility of the barium hydroxide)

$= 1.32 \times 10^{-2}$

$s = 0.149 \text{ mol L}^{-1}$

$= 25.52 \text{ g L}^{-1}$

$= 6.38$ g per 250 mL

> 5.10 g so not saturated

OR:

$$n(Ba(OH)_2) = \frac{5.10 \text{ g}}{171.3 \text{ g mol}^{-1}} = 0.0298 \text{ mol}$$

$$c(Ba(OH)_2) = \frac{0.0298 \text{ mol}}{0.250 \text{ L}} = 0.119 \text{ mol L}^{-1}$$

$K_s = 4s^3$

$= 1.32 \times 10^{-2}$

$s = 0.149 \text{mol L}^{-1}$

$> 0.119 \text{ mol L}-1$ so not saturated

A = correct method, M = correct calculation with minor error, E = correct calculation and argument

d A saturated solution is one which contains the maximum amount of dissolved solid at a particular temperature – in the presence of undissolved solid.
A = first part or equivalent, M = plus presence of undissolved solid

Question Two

a $pH = -\log_{10}[H_3O^+]$

$[H_3O^+] = 10^{-pH}$

$= 3.16 \times 10^{-4} \text{ mol L}^{-1}$ A

b $K_a = \frac{[H_3O^+][Lac^-]}{[HLac]}$ OR equivalent

$[HLac] = \frac{[H_3O^+]^2}{K_a}$ because $[H_3O^+] = [Lac^-]$

$$= \frac{(3.16 \times 10^{-4})^2}{1.3 \times 10^{-4}}$$

$= 7.68 \times 10^{-4} \text{ mol L}^{-1}$

A = correct method but minor error, M = correct answer

c Adding sodium lactate increases the lactate ion concentration which shifts the equilibrium to the left

$$HLac + H_2O \rightleftharpoons Lac^- + H_3O^+$$

This reduces the hydronium ion, $[H_3O^+]$, concentration, so the pH increases.

OR The lactate ion reacts with water, so the equilibrium

$$Lac^- + H_2O \rightleftharpoons HLac + OH^-$$

moves to the right, so the pH increases.

OR Sodium lactate is the salt of a weak acid so its solution is basic, so the pH increases.

A = correct effect on pH, M = answer backed by correct reasoning

d i Bathing a decaying tooth in a solution containing Ca^{2+} and HPO_4^{2-} ions will reform the enamel of the tooth because this drives both reactions to the left. Increasing $[Ca^{2+}]$ and $[HPO_4^{2-}]$ causes more $Ca_3(PO_4)_2(s)$ to form which in turn causes an increase in $Ca_5(PO_4)_3OH(s)$, the tooth enamel.

$2Ca_5(PO_4)_3OH(s) + 2H_3O^+(aq) \rightleftharpoons 3Ca_3(PO_4)_2(s) + Ca^{2+}(aq) + 4H_2O(l)$ Reaction (1)

$Ca_3(PO_4)_2(s) + 2H_3O^+(aq) \rightleftharpoons 3Ca^{2+}(aq) + 2HPO_4^{2-}(aq) + 2H_2O(l)$ Reaction (2)

A = mentions shift to left, M = correct reasoning

ii Strontium is in the same group as calcium, so Sr^{2+} ions in the solution would also shift both equilibria to the left by removing $HPO_4^{2-}(aq)$ ions by precipitation as $Sr_3(PO_4)_2(s)$

A = mentions same group, M = plus idea of precipitation

e A buffer solution resists changes to pH when small amounts of acid or base are added. HCO_3^- reacts with added acid, while H_2CO_3 reacts with added base.

$$H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+$$

Added acid moves equilibrium to left and added base moves equilibrium to right.

A = mentions how a buffer works, M = explains how *this* buffer works

f $CaF_2(s) \rightleftharpoons Ca^{2+}(aq) + 2F^-(aq)$

$$K_s = [Ca^{2+}][F^-]^2$$

$$3.2 \times 10^{-11} = 1.96 \times 10^{-3}\text{ mol L}^{-1}[F^-]^2$$

$$[F^-] = \sqrt{\frac{3.20 \times 10^{-11}}{1.96 \times 10^{-3}}}$$

$$= 1.28 \times 10^{-4}\text{ mol L}^{-1}$$

A = correctly uses K_s, M = correct calculation with 1 minor error or units not given, E = concentration correct with units

Question Three

a NH_4NO_3 is an ionic salt and completely ionises in water: $NH_4NO_3(s) + \text{water} \rightarrow NH_4^+(aq) + NO_3^-$.
NH_3, however, is a weak base and only partially ionises (dissociates) with water forming fewer ions; it has an equilibrium reaction with water: $NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

The greater the number of charge carriers, the better the conductivity.

A = correctly identifies NH_3 as a weak base or NH_4NO_3 as a soluble salt, M = correctly identifies both compounds, E = plus links answer back to relative numbers of charge carriers

b NH_3 is a weak base: $NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ $[H_3O^+] < 1 \times 10^{-7}$

NH_4NO_3 is the salt of a weak base and will be weakly acidic: $[H_3O^+] > 1 \times 10^{-7}$

$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

HNO_3 is a strong acid: $HNO_3(l) + H_2O(l) \rightarrow H_3O^+(aq) + NO_3^-(aq)$ $[H_3O^+] = 1 \times 10^{-1} \equiv [HNO_3]$

A = identifies the strong acid and weak base, M = correctly identifies all three, but incomplete argument, E = comprehensive answer linked to $[H_3O^+]$

Question Four

a Correct part of curve marked and labelled (outer limits 1–13 mL, inner limits 4–10 mL of HCl added). A

b $pK_a = 9.2$ (± 0.1 mL) [pK_a = pH at half-equivalence point ie. at 7.5 mL] A

c $NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ Excess $OH^-(aq)$, hence basic. A

d

$$V_{tot} = 40 \text{ mL}$$

$$n(H_3O^+)_{unreacted} = 0.100 \text{ mol L}^{-1} \times 10 \times 10^{-3} \text{ L} = 0.00100 \text{ mol}$$

$$c(H_3O^+) = \frac{0.00100 \text{ mol}}{0.040 \text{ L}} = 0.025 \text{ mol L}^{-1}$$

$$\text{pH} = -\log_{10}[H_3O^+] = -\log_{10}(0.025 \text{ mol L}^{-1}) = 1.6$$

M = correct calculations with minor error (V_{tot} ± 40 mL), E = correct calculations

e Curve starts at pH = 13 and it is a flatter curve. The shape does not change after the equivalence point.
A = two parts correct, M = all parts correct

f The indicator changes colour on the vertical portion of the graph; pH close to pK_a, for NaOH.
For NH_3 phenolphthalein changes colour not in the vertical part of the graph, but in the buffer region.
A = one point mentioned, M = both points mentioned

g **i** NH_3 A

ii At pH = 10 only 1.5 mL of HCl so NH_3 predominates
OR pH > pK_a so [base] > [conjugate acid] M

Judgement Statement

Achievement	**11 questions answered correctly.** **A minimum of 11 × A**
Merit	**13 questions answered correctly with 7 at Merit level.** **A minimum of 6 × A + 7 × M**
Excellence	**15 questions answered correctly with 9 at Merit level and 3 at Excellence level.** **A minimum of 3 × A + 9 × M + 3 × E**