Unit 2 · Ionic Equilibrium

ANSWER KEY · FOR TEACHERS

Full marks 33

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

i. ✓ **True** K · 4

ii. ✗ **False**: The conjugate base of a strong acid is a very weak base: the stronger the acid, the weaker its conjugate base.

iii. ✓ **True**

iv. ✗ **False**: The degree of ionization of a weak acid rises as its solution is diluted (Ostwald's dilution law).

v. ✓ **True**

vi. ✗ **False**: A precipitate forms when the ionic product exceeds the solubility product.

vii. ✓ **True**

viii. ✗ **False**: A solution of sodium acetate is basic: acetate ions, from a weak acid, react with water to give OH^- ions.

Each carries 0.5 mark.

2 Label the diagram

1. add dilute HCl
2. pass H_2S (in dilute HCl)
3. pass H_2S (in NH_4OH)
4. add $(NH_4)_2CO_3$

K · 2

Each carries 0.5 mark.

3 Multiple choice

i. **b.** $H_2PO_4^-$ K · 1

A conjugate acid is the base with one proton more: $HPO_4^{2-} + H^+ = \mathbf{H_2PO_4^-}$. PO_4^{3-} is its conjugate base.

ii. **a.** increases, because the self-ionization of water is endothermic U · 1

Self-ionization is the reverse of neutralization, which gives out heat, so it is endothermic, and by Le Chatelier's principle K_w increases with temperature. The water stays neutral: $[H^+]$ still equals $[OH^-]$.

iii. **c.** 12.0 A · 1

Each $Ba(OH)_2$ gives two OH^-: $[OH^-] = 0.010$ mol/L, pOH = 2.0, so pH = 14.0 − 2.0 = **12.0**. 11.7 forgets the factor of 2.

iv. **d.** NH_4Cl U · 1

NH_4Cl is the salt of a strong acid and a weak base: NH_4^+ reacts with water, $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$, and the solution is acidic. NaCl and KNO_3 are neutral; CH_3COONa is basic.

v. **c.** 5.76 A · 1

$pH = pK_a + \log([salt]/[acid]) = 4.76 + \log 10 = 4.76 + 1 = \mathbf{5.76}$.

4 Short answers

a. MARKING SCHEME U · 2

✓ $\alpha = \sqrt{(K/C)}$: α is inversely proportional to the square root of the concentration of a weak electrolyte.

✓ HCl is completely ionized at every concentration: there is no ionization equilibrium.

b. MARKING SCHEME U · 2

✓ NaCl adds Na^+, the ion common to the soap.

✓ The ionic product of the soap exceeds its solubility product, so it separates.

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c. MARKING SCHEME A · 3

- ✓ BaF_2: $[Ba^{2+}][F^-]^2$, $4s^3$.
- ✓ Ag_3PO_4: $[Ag^+]^3[PO_4{}^{3-}]$, $27s^4$.
- ✓ Bi_2S_3: $[Bi^{3+}]^2[S^{2-}]^3$, $108s^5$.

5 Long answer

ANSWER U · 4

A **buffer solution** resists a change in its pH when a small amount of acid or base is added to it. NH_4Cl is completely ionized, so the buffer holds a large store of $NH_4{}^+$; NH_4OH, a weak base whose ionization is suppressed by the common ion, is mostly present as NH_4OH.
Added acid is neutralized by the weak base, $NH_4OH + H^+ \rightarrow NH_4{}^+ + H_2O$; added base joins ammonium ions to make the weak base, which hardly ionizes, $NH_4{}^+ + OH^- \rightarrow NH_4OH$. Only the ratio of the two partners changes, a little.
$pOH = pK_b + \log([salt]/[base])$, and $pH = 14 - pOH$.

MARKING SCHEME

- ✓ A buffer resists a change of pH when a little acid or base is added.
- ✓ Added H^+ is taken by NH_4OH (equation).
- ✓ Added OH^- is taken by $NH_4{}^+$ (equation).
- ✓ $pOH = pK_b + \log([salt]/[base])$; $pH = 14 - pOH$.

6 Numerical problems

a. ANSWER A · 4

i. $\alpha = \sqrt{K_a/C} = \sqrt{6.3 \times 10^{-5}/0.040} = 0.040$, that is **4.0%**: under 5%, so the shortcut holds.
ii. $[H^+] = C\alpha = \sqrt{K_aC} = \sqrt{2.52 \times 10^{-6}} = \mathbf{1.59 \times 10^{-3}\ mol/L}$.
iii. $pH = -\log(1.59 \times 10^{-3}) = \mathbf{2.80}$.
iv. $[OH^-] = K_w/[H^+] = 1.0 \times 10^{-14} / 1.59 \times 10^{-3} = \mathbf{6.3 \times 10^{-12}\ mol/L}$.

MARKING SCHEME

- ✓ $\alpha = 4.0\%$, under 5%, so the shortcut holds.
- ✓ $[H^+] = 1.59 \times 10^{-3}$ mol/L.
- ✓ pH = 2.80.
- ✓ $[OH^-] = 6.3 \times 10^{-12}$ mol/L.

b. ANSWER A · 4

i. $MgF_2 \rightleftharpoons Mg^{2+} + 2\,F^-$: $K_{sp} = s(2s)^2 = 4s^3 = 4 \times (2.35 \times 10^{-4})^3 = \mathbf{5.19 \times 10^{-11}\ mol^3\ L^{-3}}$.
ii. Molar mass = 24 + 2 × 19 = 62 g/mol; $2.35 \times 10^{-4} \times 62 = \mathbf{0.0146\ g/L}$.
iii. $[F^-] \approx 0.050$ mol/L from NaF, so $K_{sp} = s \times (0.050)^2$: $s = 5.19 \times 10^{-11} / 2.5 \times 10^{-3} = \mathbf{2.1 \times 10^{-8}\ mol/L}$.
iv. $2.35 \times 10^{-4} / 2.1 \times 10^{-8} \approx$ **11,000 times** less soluble: the **common ion effect** (F^-).

MARKING SCHEME

- ✓ $K_{sp} = 4s^3 = 5.19 \times 10^{-11}\ mol^3\ L^{-3}$.
- ✓ 0.0146 g/L.
- ✓ 2.1×10^{-8} mol/L in NaF.
- ✓ About 11,000 times less: the common ion effect.

7 Think

ANSWER HA · 3

At the equivalence point the flask holds sodium acetate, the salt of a weak acid and a strong base, which is basic: pH about 8.7. The steep part of the curve runs from about pH 7 to 10.
Phenolphthalein changes between pH 8.2 and 10, inside the steep part, so its color changes within a drop of the equivalence point. Methyl orange changes between 3.1 and 4.4, in the slowly rising buffer region, so it would change color long before the equivalence point.

MARKING SCHEME

- ✓ The equivalence point is basic (sodium acetate), about pH 8.7; the jump is about pH 7 to 10.
- ✓ Phenolphthalein (8.2–10) changes within the jump.
- ✓ Methyl orange (3.1–4.4) changes early, in the buffer region.

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8 Activity: Acidic, basic or neutral salts?

(not marked)

WHAT STUDENTS SHOULD FIND

NaCl (HCl strong, NaOH strong): neutral, about pH 7. NH_4Cl (HCl strong, NH_4OH weak): acidic, below 7, because NH_4^+ gives H_3O^+ with water. CH_3COONa (acetic acid weak, NaOH strong): basic, above 7, because CH_3COO^- takes H^+ from water and leaves OH^-. Na_2CO_3 (carbonic acid weak, NaOH strong): basic, about pH 11, because CO_3^{2-} takes H^+ from water.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	7	10	13	3	**33**

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