

4.4.1 Acid–base models, pH and Ka

Name: _____ Class: _____ Date: _____ **Total: 26 marks**

KEY WORDS dissociation

Objective

Choose the strong/weak acid or base model and check its assumptions. Questions and marking guidance are original.

1 Key knowledge and worked examples

An acid donates H^+ ; a base accepts H^+ . Conjugate partners differ by one H^+ . Strong/weak concerns dissociation; concentrated/dilute concerns amount per volume.

■ Worked method

For weak HA, $K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$. If water contributes negligibly and dissociation is small, $[\text{H}^+] \approx \sqrt{K_a c}$. At $K_a = 1.80 \times 10^{-5} \text{ mol dm}^{-3}$ and $c = 0.100 \text{ mol dm}^{-3}$:

$$[\text{H}^+] \approx \sqrt{1.80 \times 10^{-5} \times 0.100} = 1.34 \times 10^{-3} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log_{10}(1.34 \times 10^{-3}) = 2.87$$

The fraction dissociated is 1.34%, supporting the approximation. Measured pH gives $x = 10^{-\text{pH}}$ and $K_a = x^2/(c - x)$ if HA is the only significant source of ions. A calibrated pH meter, known concentration and controlled temperature support core practical 11.

2 Practice

2.1 Give the conjugate acid of NH_3 and conjugate base of H_2PO_4^- . [2]

2.2 Calculate pH of $0.0250 \text{ mol dm}^{-3}$ HCl in the ideal dilute strong-acid model. [2]

2.3 At 298 K, $K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$. Calculate pH of $0.00200 \text{ mol dm}^{-3}$ NaOH. [3]

3 Exam-style questions

3.1 A $0.0800 \text{ mol dm}^{-3}$ monoprotic acid has pH 3.00. Calculate K_a without replacing $c - x$ by c , and find percentage dissociation. [4]

3.2 A weak acid obeys the small-dissociation model. Predict the pH change on a tenfold dilution and compare with a monoprotic strong acid in its valid concentration range. Explain one limit. [3]

3.3 0.610 g of a monoprotic acid with molar mass 122 g mol^{-1} is made up to 250.0 cm^3 . Its measured pH is 3.00. Calculate concentration and K_a using $c - x$ for the equilibrium acid concentration. Give two measurement controls. [6]

3.4 At 298 K, equimolar $0.0100 \text{ mol dm}^{-3}$ solutions give these pH values: strong monoprotic acid 2.0; weak monoprotic acid 3.4; strong monobasic alkali 12.0; weak base 10.6; sodium ethanoate 8.4. Explain the acid/base comparisons and the salt result. Predict the pH rise after 100-fold and 1000-fold dilution of the acids, while their simple models remain valid. [6]

Solutions

Original marking guidance: M1 method, A1 accuracy, B1 explanation.

2.1 NH_4^+ ; HPO_4^{2-} .

2.2 $pH = -\log_{10}(0.0250) = 1.60$.

2.3 $[H^+] = K_w/[OH^-] = 5.00 \times 10^{-12} \text{ mol dm}^{-3}$; $pH = 11.30$.

3.1 $x = 10^{-3.00} = 0.00100 \text{ mol dm}^{-3}$. $K_a = x^2/(0.0800 - x) = 1.27 \times 10^{-5} \text{ mol dm}^{-3}$.
Percentage = $100(0.00100/0.0800) = 1.25\%$.

3.2 Weak acid $[H^+]$ falls by $\sqrt{10}$, giving pH increase about 0.5. Strong acid pH increases by 1. At extreme dilution water ionisation is significant, or increased dissociation can invalidate the weak-acid approximation.

3.3 $n = m/M = 0.610/122 = 0.00500 \text{ mol}$; $c = n/V = 0.00500/0.2500 = 0.0200 \text{ mol dm}^{-3}$. $x = 10^{-3.00} = 0.00100 \text{ mol dm}^{-3}$. $K_a = x^2/(c - x) = 10^{-6}/0.0190 = 5.26 \times 10^{-5} \text{ mol dm}^{-3}$. Calibrate the pH meter with suitable buffers and control temperature, or use a volumetric flask accurately/rinse the electrode between samples.

3.4 Partial dissociation gives the weak acid fewer H^+ ions and higher pH than the equimolar strong acid. The weak base gives fewer OH^- ions and lower pH than the strong alkali. Ethanoate accepts H^+ from water, producing OH^- , so its salt is alkaline. Strong-acid pH rises by 2 and 3 respectively. Small-dissociation weak-acid pH rises approximately by 1 and 1.5. These comparisons require the approximations to remain valid; water contribution or increased fractional dissociation can invalidate extrapolation.