

## 4.4.1 Acid–base models, pH and $K_a$

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

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

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

The fraction dissociated is 1.34%, supporting the approximation. Measured pH gives  $x = 10^{-pH}$  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]

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**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]

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### 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]

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**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]

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

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**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]

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## Solutions

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

**2.1**  $\text{NH}_4^+$ ;  $\text{HPO}_4^{2-}$ .

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

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

**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  $[\text{H}^+]$  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  $\text{H}^+$  ions and higher pH than the equimolar strong acid. The weak base gives fewer  $\text{OH}^-$  ions and lower pH than the strong alkali. Ethanoate accepts  $\text{H}^+$  from water, producing  $\text{OH}^-$ , 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.