pH, water and weak acids

AQA 7405 · Full A-level

Show your working where needed. Check the worked answers when you finish.

Name _____ Date _____

1. Nitric acid at 298 K

Calculate the pH of 0.0145 mol dm^{-3} HNO_3 at 298 K. Give your answer to two decimal places.

2. Track a proton in both directions

$HCOOH + H_2O \rightleftharpoons HCOO^- + H_3O^+$. Identify the proton donor and proton acceptor in each direction.

3. Barium hydroxide solution

A barium hydroxide solution contains 0.00500 mol dm^{-3} $Ba(OH)_2$. Assume complete dissociation. At this temperature Kw = 1.00×10^{-14} mol^2 dm^{-6}.

Find $[OH^-]$ and the pH.

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4. Pure water at a higher temperature

At a temperature above 298 K, Kw = 5.80 × 10^{-14} mol^2 dm^{-6}. Calculate the pH of pure water at this temperature. Use your result and the ion concentrations to decide whether the water is acidic, alkaline or neutral.

5. Ethanoic acid in water

Ethanoic acid has Ka = 1.80 × 10^{-5} mol dm^{-3}. Write the Ka expression and calculate the pH of a 0.120 mol dm^{-3} solution. State any assumptions.

6. Determine Ka from a pH reading

A 0.0800 mol dm^{-3} solution of a weak monobasic acid has pH 2.92. Calculate Ka using the weak-acid approximation, then calculate pKa.

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7. Evaluate a pH estimate

A student uses [HA] ≈ 0.00500 mol dm^{-3} for a monobasic acid with Ka = 1.00 × 10^{-3} mol dm^{-3} and starting concentration 0.00500 mol dm^{-3}. Their estimate is $[H^+]$ = 0.00224 mol dm^{-3}.

Assess the approximation using the data. Neglect water's ionisation and write the equilibrium concentration of HA in terms of x = $[H^+]$.

8. Hydrochloric acid and sodium hydroxide

Mix 25.0 cm^3 of 0.144 mol dm^{-3} HCl with 20.0 cm^3 of 0.150 mol dm^{-3} NaOH. Assume the volumes are additive.

Calculate the pH after mixing and identify the reagent in excess.

9. Extra challenge · Compare two diluted acids

Separate 10.0 cm^3 samples of 0.120 mol dm^{-3} HCl and of 0.120 mol dm^{-3} HA are each diluted to 100.0 cm^3. Ka for HA is 1.60 × 10^{-5} mol dm^{-3} at this temperature.

Calculate the pH of each diluted acid using the weak-acid approximation for HA. Use your result to check the percentage ionisation of HA.

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Worked answers

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1. Nitric acid at 298 K

Nitric acid dissociates essentially completely, releasing one H^+ per acid molecule. Thus $[H^+] = 0.0145$ mol dm^{-3}.

$pH = -\log_{10}(0.0145) = 1.84$.

2. Track a proton in both directions

Methanoic acid donates H^+ and water accepts H^+.

In the reverse direction H_3O^+ donates H^+ and methanoate ($HCOO^-$) accepts it.

3. Barium hydroxide solution

Each $Ba(OH)_2$ gives two OH^-, so $[OH^-] = 0.0100$ mol dm^{-3}. $[H^+] = Kw/[OH^-] = 1.00 \times 10^{-12}$ mol dm^{-3}.

pH = 12.00.

4. Pure water at a higher temperature

$[H^+] = [OH^-]$ in pure water, so $[H^+] = \sqrt{Kw} = 2.41 \times 10^{-7}$ mol dm^{-3} and pH = 6.62.

The concentrations are equal, so the water is neutral. Its neutral pH at this temperature is 6.62.

5. Ethanoic acid in water

$K_a = [H^+][CH_3COO^-]/[CH_3COOH]$. Assume $[CH_3COO^-] \approx [H^+]$ and $[CH_3COOH] \approx 0.120$ mol dm^{-3}.

$[H^+] \approx \sqrt{(1.80 \times 10^{-5} \times 0.120)} = 1.47 \times 10^{-3}$ mol dm^{-3}. pH ≈ 2.83.

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Worked answers

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6. Determine Ka from a pH reading

$[H^+]$ is 10 to the power −2.92, giving 1.202… × 10^{-3} mol dm^{-3}.

Ka ≈ $[H^+]^2/0.0800$ = 1.81 × 10^{-5} mol dm^{-3}, and pKa ≈ 4.74.

7. Evaluate a pH estimate

The estimate would require about 0.00224 ÷ 0.00500 × 100 = 45% dissociation. At that level the remaining acid concentration differs substantially from the starting value.

If $[H^+]$ is x mol dm^{-3}, x mol dm^{-3} of HA has dissociated, so [HA] = (0.00500 − x) mol dm^{-3}.

8. Hydrochloric acid and sodium hydroxide

$n(H^+)$ = 0.0250 × 0.144 = 0.00360 mol. $n(OH^-)$ = 0.0200 × 0.150 = 0.00300 mol. The acid is in excess because the ions react in a 1:1 ratio.

Excess H^+ = 0.000600 mol in 0.0450 dm^3. $[H^+]$ = 0.0133… mol dm^{-3}, so pH = 1.88.

9. Extra challenge · Compare two diluted acids

Each analytical concentration is 0.120 × 10.0/100.0 = 0.0120 mol dm^{-3}. For HCl, $[H^+]$ = 0.0120 mol dm^{-3}, so the pH is 1.92.

For HA, $[H^+] \approx \sqrt{(1.60 \times 10^{-5} \times 0.0120)} = 4.38 \times 10^{-4}$ mol dm^{-3}, so the pH is approximately 3.36.

The percentage ionisation is $(4.38 \times 10^{-4}/0.0120) \times 100$ = 3.65%. This small fraction supports treating the acid concentration at equilibrium as close to the initial concentration.

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