Buffer solutions

Education in Chemistry
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These questions are based on the information about the lateral flow test, pH balanced shampoo and ocean acidification given on the fact sheet and will allow you to practise the mathematical skills required for calculations involving pH and buffer solutions.

Part 1: pH and pK_a calculations

pH and pK_a are commonly involved in calculations related to buffer solutions. Therefore, it is important to be confident with the use of $\log_{10}$, which is the mathematical system that underpins the concept of pH and pK_a.

[H^+]	**10**	**1**	**0.1**	**0.01**	**0.001**
standard form	1×10^1	1×10^0	1×10^{-1}	1×10^{-2}	1×10^{-3}
$\log_{10}$	1	0	-1	-2	-3
pH	-1	0	1	2	3

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

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

Rearrange to make [H^+] or pH the subject.

The conversion between pK_a and K_a works in a similar way.

Try these questions

1. Calculate the hydrogen ion concentration when the pH is 7.40 as in the lateral flow test solution.

2. The lateral flow test will not work if acidic substances in the sample cause the hydrogen ion concentration to exceed 1.60×10^{-7} mol dm^{-3}. Calculate the pH of this hydrogen ion concentration.

3. Use the pK_a of the hydrogen carbonate ion given on the fact sheet to calculate the K_a for the dissociation of this acid.

4. Some shampoos use a buffer based on 2-hydroxyethanoic acid rather than citric acid to control the pH. 2-Hydroxyethanoic acid has a K_a of 1.48×10^{-4} mol dm^{-3}. Calculate the pK_a of this acid and compare it with the pK_a for the first dissociation of citric acid given on the fact sheet to decide which of the two acids is stronger.

5. The change in ocean pH from 8.2 to 8.1 that has resulted from human activity does not seem like very much. However, the increase in hydrogen ion concentration is more significant. Calculate the hydrogen ion concentration of pH 8.2 and 8.1, and then use this to calculate the percentage increase in hydrogen ion concentration.

Part 2: using the Henderson–Hasselbalch equation

This equation is, in fact, just a different mathematical form of the equilibrium constant equation for the dissociation of a weak acid: $HA(aq) \rightleftharpoons H^+(aq) + A^-(aq)$. Here is how it can be derived.

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

Rearrange to make $[H^+]$ the subject.

$$[H^+] = K_a \times \frac{[HA]}{[A^-]}$$

Take $-\log_{10}$ of both sides.

$$pH = pK_a + \log_{10}\frac{[A^-]}{[HA]}$$

Note that $[A^-]$ and $[HA]$ have inverted. This is because we have changed $-\log_{10}$ to $+\log_{10}$.

Rearrange to make the salt/acid ratio the subject.

$$\frac{[A^-]}{[HA]} = 10^{pH - pKa}$$

Some problems may involve finding the salt/acid ratio needed to buffer at a particular pH. In this case, the Henderson–Hasselbalch equation can be rearranged to make the ratio the subject as shown.

Try these questions

6. Use the pK_a for dihydrogen phosphate given on the fact sheet to calculate the salt/acid concentration ratio required to achieve the required pH for the lateral flow test of 7.40.

7. Calculate the pH of a shampoo which contains 0.0010 mol dm^{-3} citric acid and 0.0090 mol dm^{-3} monosodium citrate ($C_6H_7O_7^-Na^+$). Use the pK_a for first dissociation of citric acid given on the fact sheet.

8. If the hydrogen carbonate ion concentration in the ocean is 0.0018 mol dm^{-3} and has a pH of 8.10, calculate the carbonate ion concentration. Use the pK_a for hydrogen carbonate given on the fact sheet.

Part 3: making buffer solutions by partial neutralisation

Buffer solutions are usually made by partially neutralising the weak acid with a strong base. This converts some of the acid into the salt, while leaving the rest of the acid unchanged. The result is a mixture of the acid and its salt. Some more extended problems may involve using stoichiometry to calculate how much weak acid or strong base you need to achieve a given salt/acid ratio.

Try these questions

9. In the preparation of a shampoo, 100 cm^3 of an aqueous solution containing 0.0100 mol dm^{-3} citric acid was partially neutralised by adding 20 cm^3 of 0.040 mol dm^{-3} aqueous sodium hydroxide.

   a. Use the first dissociation of citric acid to write an equation for the neutralisation of the acid with sodium hydroxide and then calculate the salt/acid ratio in the resulting mixture.

   b. Use your answer in part a. and the pK_a for the first dissociation of citric acid to calculate the pH of the buffer solution in the shampoo.

10. In the phosphate buffer, the salt/acid ratio needed to achieve a required pH of 7.4 is about 1.5.

   a. Write an ionic equation for the reaction of dihydrogen phosphate with sodium hydroxide to form the hydrogen phosphate ion.

   b. A supply of phosphate buffer is made by partially neutralising 500 cm^3 of 0.100 mol dm^{-3} aqueous sodium dihydrogen phosphate with a suitable volume of 0.200 mol dm^{-3} aqueous sodium hydroxide. Calculate the volume of 0.200 mol dm^{-3} aqueous sodium hydroxide required to give a salt/acid ratio of 1.5.