A buffer solution is a solution that resists a change in pH when a small quantity of acid or base is added.

1. (a) A buffer solution is made by mixing 0.510 mol of methanoic acid with 0.450 mol of sodium methanoate in 500 cm$^3$ of water.

   (i) Write an equation to represent the equilibrium established in the buffer solution.

   $\text{CH}_3COOH + \text{CH}_3COO^- \rightleftharpoons \text{H}_2\text{O} + \text{CH}_3COOH$  (1 mark)

   (ii) Calculate the pH of the buffer solution formed. ($pK_a$ for methanoic acid = 3.75)

   $\text{pH} = \text{p}K_a + \log \frac{\text{[base]}}{\text{[acid]}}$  
   $\text{pH} = 3.75 + \log \frac{\text{0.450 mol}}{\text{0.510 mol}}$  (3 marks)

   (b) Explain how this buffer resists change in pH on:

   (i) addition of a small quantity of acid.

   $\text{H}_2\text{O} + \text{CH}_3COOH \rightarrow \text{CH}_3COO^- + \text{H}_3\text{O}^+$  (1 mark)

   (ii) addition of a small quantity of base.

   $\text{H}_2\text{O} + \text{CH}_3COO^- \rightarrow \text{CH}_3COOH + \text{OH}^-$  (1 mark)

2. Mark and Karen are carrying out a science project on the application of buffer solutions in the human body. They have discovered that a buffer of carbonic acid ($\text{H}_2\text{CO}_3$) and hydrogen carbonate (HCO$_3^-$) is present in blood plasma to maintain a pH of between 7.35 and 7.45.

   (a) They would like to recreate a similar buffer solution in the laboratory. In what proportions should they mix 0.150 mol dm$^{-3}$ solutions of carbonic acid and sodium hydrogen carbonate to give a buffer solution with a pH of 7.40? ($K_a$ for H$_2$CO$_3$ is $4.5 \times 10^{-7}$ mol dm$^{-3}$).

   $\text{mol of carbonate} : \text{mol of bicarbonate} = \text{pH} : \text{p}K_a$  (2 marks)

   (b) Why do you think buffer solutions are needed in the human body?

   $\text{(2 marks)}$
3. Acids and bases answers

3.5. Buffer solutions

1. (a) (i) \( \text{HCOOH(aq)} \rightleftharpoons \text{HCOO}^- (aq) + \text{H}^+ (aq) \)  

(ii) \( pK_a = -\log K_a \Rightarrow K_a = 10^{-3.75} = 1.78 \times 10^{-4} \text{ mol dm}^{-3} \)  
   \[ K_a = \frac{[\text{HCOO}^- (aq)][\text{H}^+ (aq)]}{[\text{HCOOH}(aq)]} \]
   \[ [\text{HCOO}^- (aq)] = 0.450 \text{ mol / 0.5 dm}^3 = 0.90 \text{ mol dm}^{-3} \]
   \[ [\text{HCOOH}(aq)] = 0.510 \text{ mol / 0.5 dm}^3 = 1.02 \text{ mol dm}^{-3} \]
   Substituting these values in we get, \( 1.78 \times 10^{-4} \text{ mol dm}^{-3} = 0.90 \times [\text{H}^+(aq)] / 1.02 \)

   \( \therefore [\text{H}^+(aq)] = 2.02 \times 10^{-4} \text{ mol dm}^{-3} \)  

   \( \therefore \text{pH} = 3.70 \)  

(b) (i) On the addition of \( \text{H}^+ \) ions, according to Le Châtelier’s principle, the equilibrium shifts to the left to remove the extra \( \text{H}^+ \) ions added and maintain the pH approximately constant.  

(ii) On the addition of \( \text{OH}^- \) ions, the \( \text{OH}^- \) ions react with the HCOOH to produce water molecules and more HCOO\(^-\); \( \text{HCOOH} + \text{OH}^- \rightarrow \text{HCOO}^- + \text{H}_2\text{O} \)

   This removes the \( \text{OH}^- \) and so the pH remains approximately constant.  

2. (a) \( \text{H}_2\text{CO}_3(aq) \rightleftharpoons \text{HCO}_3^- (aq) + \text{H}^+ (aq) \)

   pH of desired buffer = 7.40, so \( [\text{H}^+(aq)] = 10^{-7.40} = 3.98 \times 10^{-8} \text{ mol dm}^{-3} \)  
   \[ K_a = \frac{[\text{HCO}_3^-(aq)][\text{H}^+(aq)]}{[\text{H}_2\text{CO}_3(aq)]} \]

   \( \therefore [\text{HCO}_3^-(aq)] = K_a = 4.5 \times 10^{-7} \text{ mol dm}^{-3} = 11.3 \)

   Since both stock solutions are of an equal concentration they should mix the two in a ratio of \( 11.3 : 1 \text{ HCO}_3^- : \text{H}_2\text{CO}_3 \)

(b) Many reactions in the human body rely on enzymes. Enzymes work only under very precise conditions. If the pH moves outside of a narrow range, the enzymes slow or stop working and can be denatured. Hence maintaining a constant pH is essential.  

3.6. More complex buffer calculations

1. \( \text{CH}_3\text{CH}_2\text{COOH} + \text{NaOH} \rightarrow \text{CH}_3\text{CH}_2\text{COO}^-\text{Na}^+ + \text{H}_2\text{O} \)

   Moles of NaOH = 0.015 dm\(^3\) \times 0.100 \text{ mol dm}^{-3} = 1.5 \times 10^{-3} \text{ mol}  

   \( \therefore \) moles of \( \text{CH}_3\text{CH}_2\text{COOH} \) will decrease by \( 1.5 \times 10^{-3} \text{ mol} \) and moles of \( \text{CH}_3\text{CH}_2\text{COO}^-\text{Na}^+ \) will increase by \( 1.5 \times 10^{-3} \text{ mol} \).