Marks 5

- Buffers made of mixtures of $H_2PO_4^-$ and HPO_4^{2-} are used to control the pH of soft drinks. What is the pH of a 350 mL drink containing 6.0 g of NaH_2PO_4 and 4.0 g of Na_2HPO_4?

  For phosphoric acid, H_3PO_4, pK_{a1} = 2.15, pK_{a2} = 7.20 and pK_{a3} = 12.38.

The formula masses of NaH_2PO_4 and Na_2HPO_4 are:

$M(NaH_2PO_4)$ = (22.99 (Na) + 2×1.008 (H) + 30.97 (P) + 4×16.00 (O)) g mol^{-1}
= 119.976 g mol^{-1}

$M(Na_2HPO_4)$ = (2×22.99 (Na) + 1.008 (H) + 30.97 (P) + 4×16.00 (O)) g mol^{-1}
= 141.958 g mol^{-1}

Hence, the number of moles of each present are:

$n(NaH_2PO_4)$ = mass / formula mass
= 6.0 g / 119.976 g mol^{-1} = 0.050 mol

$n(Na_2HPO_4)$ = 4.0 / 141.958 g mol^{-1} = 0.028 mol

As both are present in the same solution, the ratio of their concentrations is the same as the ratio of these amounts. There is no need to calculate the concentrations, although it does not change the answer.

The relevant equilibrium for this buffer is

$$H_2PO_4^-(aq) \rightleftharpoons HPO_4^{2-}(aq) + H^+(aq)$$

This corresponds to the second ionization of H_3PO_4 so pK_{a2} is used with the base acid being $H_2PO_4^-$ (from NaH_2PO_4) and the base being HPO_4^{2-} (from Na_2HPO_4). The pH can be calculated using the Henderson-Hasselbalch equation:

$$pH = pK_a + \log([base]/[acid])$$
$$= pK_{a2} + \log([HPO_4^{2-}]/[H_2PO_4^-]) = 7.20 + \log(0.028/0.050) = 6.95$$

Briefly describe how this buffer system functions. Use equations where appropriate.

The buffer contains an acid ($H_2PO_4^-$) and its conjugate base (HPO_4^{2-}) and is able to resist changes in pH when H^+ or OH^- is added.

If H^+ is added, the base reacts with it to remove it according to the equilibrium:

$$HPO_4^{2-}(aq) + H^+(aq) \rightleftharpoons H_2PO_4^-(aq)$$

ANSWER CONTINUES ON THE NEXT PAGE

If OH^- is added, the acid reacts with it to remove it according to the equilibrium:

$$H_2PO_4^-(aq) + OH^-(aq) \rightleftharpoons HPO_4^-(aq) + H_2O(l)$$

As long the amounts of the acid and base present are not exceeded, the changes in pH will be small.

Is this buffer better able to resist changes in pH following the addition of acid or of base? Explain your answer.

Maximum buffering occurs when equal amounts of base and acid are present. This buffer has less base than acid present. As a result, it is less able to resist cope with the addition of H^+.

Larger changes in pH result from the addition of acid.