

- Buffers made of mixtures of  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$  are used to control the pH of soft drinks. What is the pH of a 350 mL drink containing 6.0 g of  $\text{NaH}_2\text{PO}_4$  and 4.0 g of  $\text{Na}_2\text{HPO}_4$ ?

For phosphoric acid,  $\text{H}_3\text{PO}_4$ ,  $\text{p}K_{\text{a}1} = 2.15$ ,  $\text{p}K_{\text{a}2} = 7.20$  and  $\text{p}K_{\text{a}3} = 12.38$ .

The formula masses of  $\text{NaH}_2\text{PO}_4$  and  $\text{Na}_2\text{HPO}_4$  are:

$$M(\text{NaH}_2\text{PO}_4) = (22.99 (\text{Na}) + 2 \times 1.008 (\text{H}) + 30.97 (\text{P}) + 4 \times 16.00 (\text{O})) \text{ g mol}^{-1} \\ = 119.976 \text{ g mol}^{-1}$$

$$M(\text{Na}_2\text{HPO}_4) = (2 \times 22.99 (\text{Na}) + 1.008 (\text{H}) + 30.97 (\text{P}) + 4 \times 16.00 (\text{O})) \text{ g mol}^{-1} \\ = 141.958 \text{ g mol}^{-1}$$

Hence, the number of moles of each present are:

$$n(\text{NaH}_2\text{PO}_4) = \text{mass} / \text{formula mass} \\ = 6.0 \text{ g} / 119.976 \text{ g mol}^{-1} = 0.050 \text{ mol}$$

$$n(\text{Na}_2\text{HPO}_4) = 4.0 / 141.958 \text{ g mol}^{-1} = 0.028 \text{ mol}$$

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



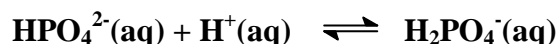
This corresponds to the second ionization of  $\text{H}_3\text{PO}_4$  so  $\text{p}K_{\text{a}2}$  is used with the base acid being  $\text{H}_2\text{PO}_4^-$  (from  $\text{NaH}_2\text{PO}_4$ ) and the base being  $\text{HPO}_4^{2-}$  (from  $\text{Na}_2\text{HPO}_4$ ). The pH can be calculated using the Henderson-Hasselbalch equation:

$$\text{pH} = \text{p}K_{\text{a}} + \log([\text{base}]/[\text{acid}]) \\ = \text{p}K_{\text{a}2} + \log([\text{HPO}_4^{2-}]/[\text{H}_2\text{PO}_4^-]) = 7.20 + \log(0.028/0.050) = 6.95$$

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

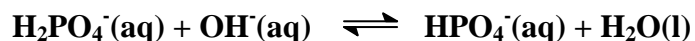
The buffer contains an acid ( $\text{H}_2\text{PO}_4^-$ ) and its conjugate base ( $\text{HPO}_4^{2-}$ ) and is able to resist changes in pH when  $\text{H}^+$  or  $\text{OH}^-$  is added.

If  $\text{H}^+$  is added, the base reacts with it to remove it according to the equilibrium:



ANSWER CONTINUES ON THE NEXT PAGE

**If OH<sup>-</sup> is added, the acid reacts with it to remove it according to the equilibrium:**



**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<sup>+</sup>.**

**Larger changes in pH result from the addition of acid.**