Three Ways to Prepare a Buffer

Suppose you are asked to prepare 500 mL of a HCO_3^-/CO_3^{2-} buffer subject to the following conditions: the buffer must have a pH of 9.87 and the combined concentrations of HCO_3^- and CO_3^{2-} must be 0.200 M. How might you prepare this buffer?

We begin by determining the relative amount of weak base (CO_3^{2-}) and weak acid (HCO_3^-) needed to give the desired pH; thus, using the Henderson-Hasselbalch equation we find that

$$\text{pH} = 9.87 = \text{p}K_\text{a} + \log \frac{[CO_3^{2-}]}{[HCO_3^-]} = 10.33 + \log \frac{[CO_3^{2-}]}{[HCO_3^-]}$$

$$\frac{[CO_3^{2-}]}{[HCO_3^-]} = 0.3467$$

We then calculate the total moles of CO_3^{2-} and HCO_3^- that we need to prepare the buffer

$$\text{mol } HCO_3^- + \text{mol } CO_3^{2-} = \frac{0.200 \text{ mol}}{\text{L}} \times 0.500 \text{ L} = 0.100 \text{ mol}$$

Next, we calculate the exact moles of CO_3^{2-} and HCO_3^- needed. Letting X be the moles of CO_3^{2-}, we know that the moles of HCO_3^- are

$$\text{mol } HCO_3^- = 0.100 \text{ mol} - X$$

Substituting back gives

$$\frac{[CO_3^{2-}]}{[HCO_3^-]} = \frac{X}{0.100 - X} = 0.3467$$

$$X = 0.02574 \text{ mol } CO_3^{2-}$$

$$0.100 - X = 0.07426 \text{ mol } HCO_3^-$$

Now that we know how many moles of CO_3^{2-} and HCO_3^- we need, we can determine the amounts of each reagent to use. We have three choices: (i) use solid Na_2CO_3 and solid $NaHCO_3$; (ii) use solid $NaHCO_3$ and convert some of it to CO_3^{2-} by adding a strong base; or (iii) use solid Na_2CO_3 and convert some of it to HCO_3^- by adding a strong acid.

Using Na_2CO_3 and $NaHCO_3$

The moles of Na_2CO_3 and $NaHCO_3$ needed are the moles of CO_3^{2-} and HCO_3^- calculated above; thus

$$0.02574 \text{ mol } Na_2CO_3 \times \frac{105.989 \text{ g}}{\text{mol}} = 2.73 \text{ g } Na_2CO_3$$

$$0.07426 \text{ mol} NaHCO_3 \times \frac{84.0059 \text{ g}}{\text{mol}} = 6.24 \text{ g } NaHCO_3$$

To prepare the buffer, therefore, we add these amounts of the solid reagents to a 500-mL volumetric flask and dilute to volume.

Using $NaHCO_3$ and NaOH

In this approach we begin by weighing out an amount of $NaHCO_3$ equivalent to the total moles of HCO_3^- and CO_3^{2-} needed; thus, we begin with 0.100 moles of $NaHCO_3$, or

$$0.100 \text{ mol } NaHCO_3 \times \frac{84.0059 \text{ g}}{\text{mol}} = 8.40 \text{ g } NaHCO_3$$

Next, we add NaOH, converting 0.02574 moles of HCO_3^- to CO_3^{2-} as shown by the following reaction

$$HCO_3^-(aq) + OH^-(aq) \longrightarrow CO_3^{2-}(aq) + H_2O(l)$$

Thus, we need 0.02574 moles of NaOH, or

$$0.02574 \text{ mol NaOH} \times \frac{1\text{L}}{6 \text{ mol}} \times \frac{1000\text{mL}}{\text{L}} = 4.29 \text{ mL NaOH}$$

To prepare the buffer we add 8.40 g of $NaHCO_3$ to a 500-mL volumetric flask and dissolve it with some water. We then add 4.29 mL of 6 M NaOH and dilute to volume.

Using Na_2CO_3 and HCl

In this approach we begin by weighing out an amount of Na_2CO_3 equivalent to the total moles of HCO_3^- and CO_3^{2-} needed; thus we begin with 0.100 moles of Na_2CO_3, or

$$0.100 \text{ mol } Na_2CO_3 \times \frac{105.998 \text{ g}}{\text{mol}} = 10.60 \text{ g } Na_2CO_3$$

Next, we add HCl, converting 0.07426 moles of CO_3^{2-} to HCO_3^- as shown by the following reaction

$$CO_3^{2-}(aq) + H_3O^+(aq) \longrightarrow HCO_3^-(aq) + H_2O(l)$$

Thus, we need 0.07426 moles of HCl, or

$$0.07426 \text{ mol HCl} \times \frac{1\text{L}}{6 \text{ mol}} \times \frac{1000 \text{ mL}}{\text{L}} = 12.38 \text{ mL HCl}$$

To prepare the buffer we add 10.60 g of Na_2CO_3 to a 500-mL volumetric flask and dissolve it with some water. We then add 12.38 mL of 6 M HCl and dilute to volume.

A Final Comment of Preparing Buffers

For reasons we will discuss later, a buffer prepared following one of these approaches probably will not produce a solution with a pH that matches exactly the desired pH. When we prepare a buffer in the laboratory it often is necessary to adjust the buffer's pH level to the desired value by adding small amounts of either a strong acid or a strong base while monitoring the pH with a pH electrode.