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 total concentration 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

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

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

We then calculate the total moles of CO_3^{2-} and HCO_3^- needed

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

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

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

Substituting back gives

$$\frac{[\mathrm{CO_3^{2-}}]}{[\mathrm{HCO_3^-}]} = \frac{X}{0.1 - X} = 0.3467$$

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

$$0.100 - X = 0.07426\ \mathrm{mol\ HCO_3^{2-}}$$

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 just the same as the moles of CO_3^{2-} and HCO_3^- calculated above; thus

$$0.02574\ \mathrm{mol\ Na_2CO_3} \times \frac{105.998\ \mathrm{g}}{\mathrm{mol}} = 2.73\ \mathrm{g\ Na_2CO_3}$$

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

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 the HCO_3^- to CO_3^{2-} as shown by the following reaction

$$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$$

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

$$0.100 \text{ mol Na}_2\text{CO}_3 \times \frac{105.998 \text{ g}}{\text{mol}} = 10.60 \text{ g Na}_2\text{CO}_3$$

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

$$CO_3^{2-} + H_3O^+ \rightarrow HCO_3^- + H_2O$$

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 whose pH level matches exactly the desired value. When preparing 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.