Designing a Buffer

Challenge

Prepare a buffer that has the following properties.

- a pH of 9.87
- a total concentration of weak acid and conjugate weak base of 0.200 M
- a volume of 500.0 mL

Reagents Available

- 6.0 M HCl
- 6.0 M H_3PO_4
- 6.0 M CH_3COOH
- 6.0 M NaOH
- $NaHCO_3(s)$
- $Na_3PO_4 \cdot 12\,H_2O(s)$
- $NaH_2PO_4(s)$
- $Na_2CO_3(s)$
- $Na_2HPO_4(s)$
- $CH_3COONa \cdot 3\,H_2O(s)$

Tasks to Complete

- identify a conjugate weak acid/weak base pair that you can use to create a buffer with the desired pH and identify the specific reagents you will use; note: there may be more than one possible combination of reagents, but you need just need to identify one combination

  Of the various acids and bases available to us, we can set aside the strong acid (HCl) and the strong base (NaOH). For the remaining species, we want to find a weak acid whose pK_a is within ± 1 pH unit of our desired pH of 9.87. The only weak acid that will work is HCO_3^-, which has a pK_a of 10.33.

- determine the ratio of weak base-to-weak acid that will give you the desired pH

  To find the ratio of the weak base to the weak acid, we use the Henderson-Hasselbach equation

$$9.87 = 10.33 + \log \frac{\text{mol } CO_3^{2-}}{\text{mol } HCO_3^-}$$

  Solving gives the ratio as

$$\frac{\text{mol } CO_3^{2-}}{\text{mol } HCO_3^-} = 0.3467$$

- determine the total moles of weak acid and of weak base you need to prepare the buffer and then determine the exact moles of each

  The combined amount of HCO_3^- and CO_3^{2-} that we need is 0.100 moles (0.500 L of a solution where their combined concentration is 0.200 M). We can express this as an equation

$$\text{mol } HCO_3^- + \text{mol } CO_3^{2-} = 0.100$$

This gives us a pair of simultaneous equations that we can solve to give the moles of each reagent; these are 002574 moles of CO_3^{2-} and 0.07426 moles of HCO_3^-.

- determine the mass (for a solid reagent) or the volume (for a solution reagent) that you need to prepare the buffer

  With the moles in hand, we calculate the grams of Na_2CO_3 and the grams of $NaHCO_3$ by multiplying their respective moles by their molar masses. This gives the final result of 2.73 g of Na_2CO_3 and 6.24 g of $NaHCO_3$.