Problem 4. (30 points). In this problem you must show your calculations and explain how you derived the results. Neglect changes in the total volume of your solution when an acid or base is added. Use the back of the page if you need more space.

Cacodylic acid is a weak acid with $K_a = 5.37\ 10^{-7}$ M. You prepared 500 mL of 0.2 M stock solution of this acid.

(a) (15 points) Determine the pH of this solution. Show your assumptions and calculations. If you need more space use the back of this page.

$HA \rightleftharpoons H^+ + A^-$

Initial conditions: $[H^+] = 10^{-7}$ M; $[HA] = 0,2$ M; $[A^-] = 0$

Let x denote the amount (expressed as a molar concentration) of acid that dissociated. Then final molar concentrations are $[A^-] = x$ M; $[HA] = (0,2 - x)$ M; final conc. of H^+ then $= (10^{-7} + x)$ M

$$\Rightarrow K_a = \frac{(10^{-7} + x)\, x}{0,2 - x} \text{ M}.$$

From here we obtain $x^2 + x(10^{-7} + K_a) - 0,2 \cdot K_a = 0$ (all units here are in M). Solving this equation, we get

$x = 1,64 \cdot 10^{-4}$ M; $\Rightarrow [H^+] = (10^{-7} + 1.64 \cdot 10^{-4})$ M $\approx 1.64 \cdot 10^{-4}$ M

pH = 3,79

(b) (5 points) What is the pH range in which cacodylic acid can act as a good buffer?

$pK_a \pm 1 \Rightarrow 5.27$ to 7.27

(c) (5 points) You want to adjust the pH of the stock solution prepared in problem (a) so that it corresponds to the ideal buffering conditions for cacodylic acid. You have at your disposal only two reagents: 1M NaOH and 1M HCl. Which of the two reagents (if any) could serve your purpose? Explain your reasoning.

Ideal buffering conditions are at $pH = pK_a = 6.27$. The pH of our solution is lower (3.79), hence we need to add base (NaOH) to raise the pH. Adding NaOH will neutralize the acid (decrease [HA]) and increase the conc. of the conjugate base ($[A^-]$).

(c) (5 points) After you have decided which reagent to use (see problem (c)), you start adjusting the pH. Calculate the volume of the reagent that you have to add to the stock solution (prepared in (a)) in order to bring its pH to the optimal buffering conditions for cacodylic acid.

At the optimal buffering conditions, $[A^-] = [HA]$. The total initial amount of acid was $0.2\,M \times 0.5\,L = 0.1$ mole. To neutralize 50% of it we have to add 0.05 moles of NaOH, which corresponds to a volume of

$$\frac{0.05\ \text{mole}}{1\ \text{mole/L}} = 0.05\,L = 50\,mL$$