Introduction: The buffering ability and properties under dilution of acetic acid - sodium acetate buffers was determined. A pH 5 or pH 9 buffer was be prepared using solid sodium acetate or ammonium chloride.

Theory: The pH of a buffer solution, neglecting dissociation, is determined by rearranging the $K_a$ equilibrium expression and using nominal concentrations for the acid and its conjugate base:

$$[H^+] = K_a \frac{[HA]}{[A^-]} \equiv K_a \frac{c_A}{c_B} \quad (1)$$

or equivalently

$$\text{pH} = pK_a + \log \frac{c_B}{c_A} \quad (2)$$

Procedure: The buffering range was determined using buffer ratios 10:1 and 1:10. The pH response was determined after dilution or stresses from added strong acid or strong base. A buffer was constructed at pH choose one: 5 or 9 using solid choose one: sodium acetate trihydrate or ammonium chloride by the addition of 0.1 M choose one: HCl or NaOH.

Results: (Provide the results in the following tables.) The results of the experiments are summarized in Tables 1-5.

Table 1: Buffering Range of 0.5 M Acetic Acid- 0.5 M Acetate Buffers (Part 2A).

<table>
<thead>
<tr>
<th>Ratio Acetic Acid-Acetate</th>
<th>10:1</th>
<th>1:1</th>
<th>1:10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured pH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical pH</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Dilution of Acetic Acid – Acetate Buffer, Acetic Acid, and Sodium Acetate (Part 2B).

<table>
<thead>
<tr>
<th>Solution</th>
<th>Measured pH before</th>
<th>Measured pH after</th>
<th>Theoretical pH before</th>
<th>Theoretical pH after</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1 Buffer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50 M Acetic Acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50 M Acetate</td>
<td></td>
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</tr>
</tbody>
</table>

Table 3: Effect of Addition of Strong Acid or Strong Base (Part 2C).

<table>
<thead>
<tr>
<th>Solution</th>
<th>Measured pH before</th>
<th>Measured pH after</th>
<th>Theoretical pH before</th>
<th>Theoretical pH after</th>
</tr>
</thead>
<tbody>
<tr>
<td>To 0.001 M NaCl add HCl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>add NaOH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To 1:1 Buffer add HCl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>add NaOH</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

(- Theoretical values for 0.001 M NaCl depend on the extent of CO₂ absorption from the atmosphere)
Table 4: Preparation of pH 5 or 9 Buffer from Sodium Acetate or Ammonium Chloride and 0.1 M NaOH or HCl (Part 3). (Choose appropriate substances for your experiment)

<table>
<thead>
<tr>
<th>Mass sodium acetate or ammonium chloride (s)</th>
<th>Concentration of NaOH or HCl (M)</th>
<th>Volume of NaOH or HCl (mL)</th>
<th>Starting pH of completed buffer</th>
<th>pH after acid addition</th>
<th>pH after base addition</th>
</tr>
</thead>
</table>

Discussion:
The action of buffers was characterized. The reaction that determines the pH of the acetic acid-acetate buffers is (Part 2A, 2B, and 2C):

Write the acetic acid-acetate reaction that you are studying as equation 3.

(a). Part 2A: State the buffer range. Explicitly reference the corresponding table, Table 1. In a sentence or two, at most, explain why the range is determined by the 10:1 and 1:10 buffer ratios. How well do the measured values agree with the theoretical values? Explicitly reference Eq. 1 or Eq. 2 in discussing your theoretical predictions.

(b). Part 2B: In a sentence or two, explain the different results for the 1:1 buffer as opposed to pure acetic acid or pure sodium acetate. Explicitly reference the corresponding table, Table 2. How well do the measured values agree with the theoretical values?

(c). Part 2C: In a sentence or two, explain how the 1:1 buffer responds to the addition of strong acid or strong base as opposed to a dilute NaCl solution. Give the chemical reactions that result from the addition of strong acid and from the addition of strong base to the buffered solution. Explicitly reference the corresponding table, Table 3. How well do the measured values agree with the theoretical values?

(d). Part 3: List the components that you used to prepare the buffer in Part 3. If you made a buffer using ammonium chloride, give the chemical reaction that determines the pH. Give the measured pH of your buffer and the theoretical pH of your buffer*. Did your buffer solution act as a buffer? Explicitly reference the corresponding table, Table 4. How well does the measured pH agree with the theoretical value for the buffer, before addition of strong acid or strong base?

(e). Consider the effect of random errors. Use the number of significant figures in the concentrations and the literature pKₐ values to predict the expected number of significant figures in the buffer pH results. Remember the approximate rule that the number of significant figures in the concentration gives the number of significant figures after the decimal point in the pH. For example [H⁺] = 2.31x10⁻⁴ M gives pH = 3.636, but [H⁺] = 2.3x10⁻⁴ M gives pH = 3.64. Compare this expected number of significant figures to the observed differences between the measured pH and theoretical predictions. There are two possibilities for this comparison. Include the appropriate statement in your lab report chosen from the two possibilities:

(1). The expected number of significant figures, as predicted from the uncertainty in the concentrations and the literature pKₐ, is consistent with the observed differences between theory and experiment. As a result the predominant source of random error is __choose from a device measurement__.

(2). The expected number of significant figures, as predicted from the uncertainty in the concentrations and the literature pKₐ, is not consistent with the observed differences
between theory and experiment. A possible additional source of random error is _choose from a device measurement_ that is beyond the expected measurement uncertainty.

(g). To summarize the experiment answer the following questions in a smoothly reading paragraph:

(i). In a buffer, what are the predominant species in solution?
(ii). In forming a buffer, why must the acid-conjugate base pair be weak?
(iii). What is the position of equilibrium that gives the best ability to resist changes in pH from additions of both strong acid and strong base? What is the position of equilibrium for a 1:1 buffer?
(iv). When choosing appropriate buffer components, what is the importance of the $pK_a$ of the acid, compared to the target pH of the buffer?

Literature Cited:

Checklist:
Use complete sentences and provide the proper number of significant figures and units.
All Figures and Tables must have captions.
Refer by number to each figure and table in the body of the text or your report.
Acknowledge any data that were not taken by you or your partner.
Captions start with Figure # or Table # and then a concise description of the contents.
You can write the captions by hand in black pen on attached sheets.
Answer all the questions in the Discussion section of the write-up.
Remove all the italicized prompts in your final report. The report should then read smoothly.

*Note for discussion part d:*
If you did not record the volume of strong acid or strong base that you added to form your pH 5 or pH 9 buffer, then calculate the volume that you should have added, based on the amount of sodium acetate-trihydrate or ammonium chloride that you started with. In your report, state that you calculated the theoretical amount required. (Hint: you don’t need to know the total volume of buffer that you created.)