How Buffers Impact the Change of pH

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Academic Honesty Statement

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**Abstract**

The impact of buffers on the change of pH was investigated in this experiment. This is an important topic as buffers are vital to the maintenance of blood pH and natural waterways (Sanders, 2020). The impact of an ammonium buffer solution was tested against a NaCl solution and a DI water solution by adding 1M HCl to one set of the solutions and 1M NaOH to a second set of the solutions and observing the pH change at every step as the strong acid and strong base was added. The results were all fairly similar except for NaOH being added into the buffer after it exceeded its buffer capacity. The results indicate that the use of the Henderson-Hassalbalch equation may not be accurate for the pH of a buffer system past its capacity.

**Introduction**

This report explores the impact of buffers on pH change (Sanders, 2020). Buffers are solutions of weak acid (acids that do not fully ionize in solution) with their weak conjugate base (bases that do not fully ionize in solution) or weak bases and their weak conjugate acid (Sanders, 2020). They resist pH change by reacting with the products from the dissolution of a strong acid or base (acids and bases that fully ionize in solution) (Sanders, 2020). Generic examples of buffer solutions with acid added to it can be seen in reactions (1) and (2) while generic examples of buffer solutions with base added to it can be seen in reactions (3) and (4).

(HA/A-) buffer with acid added

H3O+ (aq) + A- (aq) HA (aq) + H2O (l) (1)

(BH+/B) buffer with acid added

H3O+ (aq) + B (aq) HB+ (aq) + H2O (l) (2)

(HA/A-) buffer with base added

OH- (aq) + HA (aq) A- (aq) + H2O (l) (3)

(BH+/B) buffer with base added

OH- (aq) + BH+ (aq) B (aq) + H2O (l) (4)

Buffers lower the pH change caused by strong acids and bases due to weak acids and bases having a low product formed to remaining reactant ratio (dissociation constant) which causes H3O+ and OH- to be consumed to restore balance (Sanders, 2020). This, however, does not prevent pH change as weak acid is produced which would also lower the pH, but only to a lesser degree (Sanders, 2020). This can be seen in equation (5) and in the negative log of the equation (Henderson-Hassalbalch equation) in equation (6).

(7)

(6)

However, buffers are only effective for a certain amount of acid/base added (buffer capacity) and for ±1 pH of its pKa (buffer range), which is dependent on the concentrations of the weak acid and weak base (Sanders, 2020). This can be seen with a closer examination of equation (6) as the pH would remain similar to pKa as long as the concentrations of the weak acid and base stay similar (Sanders, 2020).

In this experiment, the buffer was made with the weak acid acetic acid (C2H4O2) and its weak conjugate base acetate (C2H3O2) and tested against an NaCl solution and DI water solution (Sanders, 2020). To test how the buffer would impact pH change, two identical copies of each solution was made with one set having 1M HCl added to it dropwise with the pH recorded after each drop and the other set having 1M NaOH added to it dropwise with the pH recorded after each drop (Sanders, 2020). It is hypothesized that in the DI water and NaCl solutions, the pH would change drastically after the first drop of both HCl and NaOH then continue to change, but by a lesser degree; while in the buffer solution, the pH would change slowly as the HCl and NaOH is added, only having a drastic change after reaching the buffer capacity.

**Methods**

50 mL of 0.1M C2H4O2 is added to a beaker using a graduated cylinder and its pH is measured (Sanders, 2020). ≈1 g of sodium acetate along with a stir bar is added to the beaker to make the buffer solution (Sanders, 2020). 50 mL of DI water is added to a separate beaker with a stir bar using a graduated cylinder and has its pH measured to create the DI water solution (Sanders, 2020). 50 mL of 0.1M NaCl is added to separate beaker with a stir bar using a graduated cylinder and has its pH measured to create the NaCl solution (Sanders, 2020). A copy of each solution is made (Sanders, 2020). One copy of each solution is placed on the hot plate for the stir bar to be turned on and mix the solution (Sanders, 2020). 1 drop of 1M HCl is added to the solution and the pH is checked and recorded in the notebook, this is repeated until 10 drops of HCl has been added to the solutions (Sanders, 2020). The remaining copy of each solution replaces their counterparts (Sanders, 2020). 1 drop of 1M NaOH is added to the solution and the pH is checked and recorded in the notebook, this is repeated until 10 drops of NaOH has been added to the solutions (Sanders, 2020).

**Results**

Table 1. Change in pH of the buffer solution after HCl/NaOH has been added

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | measured | calculated | difference in pH |  |
| pH of acetic acid solution (0.1M) | 2.93 | 2.87 | 0.06 |  |
| pH of acetate buffer | 5.58 | 5.26 | 0.32 |  |
|  |  |  |  |  |
| mL HCl added | total mol HCl added | measured pH | calculated pH | difference in pH |
| 1 | 0.0001 | 5.46 | 5.25 | 0.21 |
| 2 | 0.0002 | 5.37 | 5.24 | 0.13 |
| 3 | 0.0003 | 5.29 | 5.23 | 0.06 |
| 4 | 0.0004 | 5.22 | 5.22 | 0 |
| 5 | 0.0005 | 5.15 | 5.21 | 0.06 |
| 6 | 0.0006 | 5.09 | 5.2 | 0.11 |
| 7 | 0.0007 | 5.03 | 5.19 | 0.16 |
| 8 | 0.0008 | 4.97 | 5.18 | 0.21 |
| 9 | 0.0009 | 4.91 | 5.17 | 0.26 |
| 10 | 0.001 | 4.86 | 5.15 | 0.29 |
|  |  |  |  |  |
| mL NaOH added | total mol NaOH added | measured pH | calculated pH | difference in pH |
| 1 | 0.0001 | 5.68 | 5.27 | 0.41 |
| 2 | 0.0002 | 5.81 | 5.28 | 0.53 |
| 3 | 0.0003 | 5.99 | 5.29 | 0.7 |
| 4 | 0.0004 | 6.35 | 5.31 | 1.04 |
| 5 | 0.0005 | 11.14 | 5.32 | 5.82 |
| 6 | 0.0006 | 12.23 | 5.33 | 6.9 |
| 7 | 0.0007 | 23.47 | 5.34 | 18.13 |
| 8 | 0.0008 | 12.61 | 5.35 | 7.26 |
| 9 | 0.0009 | 12.71 | 5.36 | 7.35 |
| 10 | 0.001 | 12.77 | 5.37 | 7.4 |

Table 2. Change in pH of the DI water solution after HCl/NaOH has been added

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | measured | calculated | difference in pH |  |
| pH of DI H2O | 6.72 | 6.98 | 0.26 |  |
|  |  |  |  |  |
| mL HCl added | total mol HCl added | measured pH | calculated pH | difference in pH |
| 1 | 0.0001 | 2.11 | 2.71 | 0.6 |
| 2 | 0.0002 | 1.86 | 2.41 | 0.55 |
| 3 | 0.0003 | 1.74 | 2.25 | 0.51 |
| 4 | 0.0004 | 1.64 | 2.13 | 0.49 |
| 5 | 0.0005 | 1.55 | 2.04 | 0.49 |
| 6 | 0.0006 | 1.51 | 1.97 | 0.46 |
| 7 | 0.0007 | 1.41 | 1.91 | 0.5 |
| 8 | 0.0008 | 1.35 | 1.86 | 0.51 |
| 9 | 0.0009 | 1.31 | 1.82 | 0.51 |
| 10 | 0.001 | 1.28 | 1.78 | 0.5 |
|  |  |  |  |  |
| mL NaOH added | total mol NaOH added | measured pH | calculated pH | difference in pH |
| 1 | 0.0001 | 11.88 | 11.29 | 0.59 |
| 2 | 0.0002 | 12.18 | 11.59 | 0.59 |
| 3 | 0.0003 | 12.34 | 11.75 | 0.59 |
| 4 | 0.0004 | 12.46 | 11.87 | 0.59 |
| 5 | 0.0005 | 12.54 | 11.96 | 0.58 |
| 6 | 0.0006 | 12.61 | 12.03 | 0.58 |
| 7 | 0.0007 | 12.66 | 12.09 | 0.57 |
| 8 | 0.0008 | 12.72 | 12.14 | 0.58 |
| 9 | 0.0009 | 12.76 | 12.18 | 0.58 |
| 10 | 0.001 | 12.81 | 12.22 | 0.59 |

Table 3. Change in pH of the NaCl solution after HCl/NaOH has been added

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | measured | calculated | difference in pH |  |
| pH of .1% NaCl | 6.91 | 6.98 | 0.07 |  |
|  |  |  |  |  |
| mL HCl added | total mol HCl added | measured pH | calculated pH | difference in pH |
| 1 | 0.0001 | 1.91 | 2.71 | 0.8 |
| 2 | 0.0002 | 1.67 | 2.41 | 0.74 |
| 3 | 0.0003 | 1.53 | 2.25 | 0.72 |
| 4 | 0.0004 | 1.42 | 2.13 | 0.71 |
| 5 | 0.0005 | 1.35 | 2.04 | 0.69 |
| 6 | 0.0006 | 1.28 | 1.97 | 0.69 |
| 7 | 0.0007 | 1.23 | 1.91 | 0.68 |
| 8 | 0.0008 | 1.19 | 1.86 | 0.67 |
| 9 | 0.0009 | 1.15 | 1.82 | 0.67 |
| 10 | 0.001 | 1.12 | 1.78 | 0.66 |
|  |  |  |  |  |
| mL NaOH added | total mol NaOH added | measured pH | calculated pH | difference in pH |
| 1 | 0.0001 | 12.11 | 11.29 | 0.82 |
| 2 | 0.0002 | 12.34 | 11.59 | 0.75 |
| 3 | 0.0003 | 12.47 | 11.75 | 0.72 |
| 4 | 0.0004 | 12.56 | 11.87 | 0.69 |
| 5 | 0.0005 | 12.63 | 11.96 | 0.67 |
| 6 | 0.0006 | 12.69 | 12.03 | 0.66 |
| 7 | 0.0007 | 12.74 | 12.09 | 0.65 |
| 8 | 0.0008 | 12.77 | 12.14 | 0.63 |
| 9 | 0.0009 | 12.81 | 12.18 | 0.63 |
| 10 | 0.001 | 12.83 | 12.22 | 0.61 |

**Discussion**

As the hypothesis suggested, in the DI water and NaCl solutions, the pH changed drastically after the first drop of both HCl and NaOH continued to change, but by a lesser degree; while in the buffer solution, the pH changed slowly as the HCl and NaOH is added, only having a drastic change after reaching the buffer capacity. The calculated pH using the Henderson-Hassalbalch equation led to similar values for pH in all cases except after the buffer had reached capacity, meaning this would work well in most cases to calculate pH. The acetic acid buffer, an acidic buffer, did not reach its capacity when HCl was added but reached its capacity when NaOH was added; however, an ammonium buffer, which would likely be basic, would likely not reach capacity from the addition of NaOH but would likely reach capacity from the addition of HCl (Sanders, 2020). The experiment can be improved with the addition of a basic buffer solution in addition to the acidic buffer solution already used to better demonstrate buffer range.

**References**

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**Appendix A: Calculations**

Calculation A.1. pH of acetic acid solution (0.1M)

|  |  |  |  |
| --- | --- | --- | --- |
|  | acetic acid | CH3CO2- | H3O+ |
| i | 0.1 | 0 | 0 |
| c | -x | +x | +x |
| e | 0.1-x | x | x |

[acetic acid] = 0.0987 [CH3CO2-] = 0.0013

4.74+log(0.0013/0.0987) = 2.8705

Calculation A.2. pH of acetate buffer

0.98/59.044/0.05=0.3320 M of CH3COO-

|  |  |  |  |
| --- | --- | --- | --- |
|  | acetic acid | CH3CO2- | H3O+ |
| i | 0.1 | 0.3320 | 0 |
| c | -x | +x | +x |
| e | 0.1-x | 0.3320+x | x |

[acetic acid] = 0.1000 [CH3CO2-] = 0.3320

4.74+log(0.3320/0.1000)=5.2612

Calculation A.3. Example acetic acid buffer + HCl calculation (1 mL HCl)

0.0001/0.051 = 0.0020 M

|  |  |  |  |
| --- | --- | --- | --- |
|  | acetic acid | CH3CO2- | H3O+ |
| i | 0.098039216 | 0.325446892 | 0.001960784 |
| c | -x | +x | +x |
| e | 0.0980392156863-x | 0.325446891717+x | 0.00196078431372+x |

[acetic acid] = 0.1020 [CH3CO2-] = 0.3235

4.74+log(0.3235/0.1020)=5.25

Calculation A.4. Example acetic acid buffer + NaOH calculation (1 mL NaOH)

0.0001/0.051 = 0.0020 M

|  |  |  |  |
| --- | --- | --- | --- |
|  | acetic acid | CH3CO2- | H3O+ |
| i | 0.098039216 | 0.325446892 | -0.001960784 |
| c | -x | +x | +x |
| e | 0.0980392156863-x | 0.325446891717+x | -0.001960784314+x |

[acetic acid] = 0.09613 [CH3CO2-] = 0.3273

Calculation A.5. pH of DI water

|  |  |  |  |
| --- | --- | --- | --- |
|  | H2O | H3O+ | OH- |
| i | 55 | 0 | 0 |
| c | -x | +x | +x |
| e | 55-x | +x | +x |

Calculation A.6. Example DI water + HCl calculation (1 mL HCl)

0.0001/0.051 = 0.0020 M

HCl is a strong acid therefore [HCl] = [H+]

-log(.0020)=2.71

Calculation A.7. Example DI water + NaOH calculation (1 mL NaOH)

0.0001/0.051 = 0.0020 M

NaOH is a strong acid therefore [NaOH] = [OH-]

14-log(.0020)=11.29

Calculation A.8. pH of NaCl solution

there is nothing for the dissolved ions to react with, the generation of minimal HCl and NaOH cancel each other out, calculation is the same as DI water

|  |  |  |  |
| --- | --- | --- | --- |
|  | H2O | H3O+ | OH- |
| i | 55 | 0 | 0 |
| c | -x | +x | +x |
| e | 55-x | +x | +x |

Calculation A.9. Example NaCl + HCl calculation (1 mL HCl)

0.0001/0.051 = 0.0020 M

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | H2O | HCl | H3O+ | Cl- |
| i | 53.9215686 | 0.00196078 | 0 | 0.1 |
| c | -x | -x | +x | +x |
| e | 53.921568627451-x | 0.00196078431372549-x | 0+x | 0.1+x |

= 0.00199

Common ion effect is minimal and can be ignored due to the strength of the acid

Therefore [HCl] approximates [H3O+]

-log(.0020)=2.71

Calculation A.10. Example NaCl + NaOH calculation (1mL NaOH)

Similar to NaCl + HCl

0.0001/0.051 = 0.0020 M

14-log(.0020)=11.29