Chem 237L Lab 2: Buffers and Buffering Properties

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Monday February 1st 2021

Results

Table 1: Experimental Result of Phosphoric acid "A" ID#7 titration using an NaOH titrant at 500mM

pH	Burette Reading (mL)
1.47	0.00
1.47	0.13
1.48	0.25
1.49	0.50
1.51	0.75
1.52	1.00
1.54	1.25
1.61	2.50
1.76	5.00
1.9	7.50
2.05	10.00
2.2	12.50
2.37	15.00
2.55	17.50
2.78	20.00
3.12	22.50
3.45	23.75
3.68	24.25
4.16	24.75
4.48	25.00
5.21	25.63
5.52	26.25
5.85	27.50
6.2	30.00
6.43	32.50
6.62	35.00
6.8	37.50
6.98	40.00
7.17	42.50
7.4	45.00
7.75	47.50
8.08	48.75
8.39	49.38
9.59	50.00
10.02	50.13
10.33	50.25
10.63	50.50
10.81	50.75

10.94	51.00
11.03	51.25
11.36	52.50
11.7	55.00
11.91	57.50
12.08	60.00
12.22	62.50
12.35	65.00
12.46	67.50
12.57	70.00
12.67	72.50
12.76	75.00

Table 2: Experimental Result of Phosphoric acid "B" ID#20 titration using an NaOH titrant at 2000mM

NaOH (mL)	**pH**
0.00	1.47
0.06	1.47
0.12	1.48
0.23	1.49
0.35	1.51
0.46	1.52
0.58	1.54
1.15	1.61
2.30	1.76
3.45	1.90
4.60	2.05
5.75	2.20
6.90	2.37
8.05	2.55
9.20	2.78
10.35	3.12
10.93	3.45
11.16	3.68
11.39	4.16
11.50	4.48
11.79	5.21
12.08	5.52
12.65	5.85
13.80	6.20
14.95	6.43

16.10	6.62
17.25	6.80
18.40	6.98
19.55	7.17
20.70	7.40
21.85	7.75
22.43	8.08
22.71	8.39
23.00	9.59
23.06	10.02
23.12	10.33
23.23	10.63
23.35	10.81
23.46	10.94
23.58	11.03
24.15	11.36
25.30	11.70
26.45	11.91
27.60	12.08
28.75	12.22
29.90	12.35
31.05	12.46
32.20	12.57
33.35	12.67
34.50	12.76

Data Analysis

Table 1: Processed data table for titration of unknown phosphoric acid "A" ID#7 using NaOH as a titrant at 500 mM concentration. Sample calculation where necessary included in appendix.

pH	Burette Reading (mL)	Volume Added (mL)	mmol OH- added	ΔpH	Δmmol OH added	ΔpH/Δ(mmol OH- added)
1.47	0.00					
1.47	0.13	0.13	0.065	0.00	0.065	0
1.48	0.25	0.25	0.125	0.01	0.06	0.166667
1.49	0.50	0.50	0.250	0.01	0.125	0.08
1.51	0.75	0.75	0.375	0.02	0.125	0.16
1.52	1.00	1.00	0.500	0.01	0.125	0.08
1.54	1.25	1.25	0.625	0.02	0.125	0.16
1.61	2.50	2.50	1.250	0.07	0.625	0.112

1.76	5.00	5.00	2.500	0.15	1.25	0.12
1.9	7.50	7.50	3.750	0.14	1.25	0.112
2.05	10.00	10.00	5.000	0.15	1.25	0.12
2.2	12.50	12.50	6.250	0.15	1.25	0.12
2.37	15.00	15.00	7.500	0.17	1.25	0.136
2.55	17.50	17.50	8.750	0.18	1.25	0.144
2.78	20.00	20.00	10.000	0.23	1.25	0.184
3.12	22.50	22.50	11.250	0.34	1.25	0.272
3.45	23.75	23.75	11.875	0.33	0.625	0.528
3.68	24.25	24.25	12.125	0.23	0.25	0.92
4.16	24.75	24.75	12.375	0.48	0.25	1.92
4.48	25.00	25.00	12.500	0.32	0.125	2.56
5.21	25.63	25.63	12.815	0.73	0.315	2.32
5.52	26.25	26.25	13.125	0.31	0.31	1
5.85	27.50	27.50	13.750	0.33	0.625	0.528
6.2	30.00	30.00	15.000	0.35	1.25	0.28
6.43	32.50	32.50	16.250	0.23	1.25	0.184
6.62	35.00	35.00	17.500	0.19	1.25	0.152
6.8	37.50	37.50	18.750	0.18	1.25	0.144
6.98	40.00	40.00	20.000	0.18	1.25	0.144
7.17	42.50	42.50	21.250	0.19	1.25	0.152
7.4	45.00	45.00	22.500	0.23	1.25	0.184
7.75	47.50	47.50	23.750	0.35	1.25	0.28
8.08	48.75	48.75	24.375	0.33	0.625	0.528
8.39	49.38	49.38	24.690	0.31	0.315	0.98
9.59	50.00	50.00	25.000	1.20	0.31	3.87
10.02	50.13	50.13	25.065	0.43	0.065	6.62
10.33	50.25	50.25	25.125	0.31	0.06	5.17
10.63	50.50	50.50	25.250	0.30	0.125	2.4
10.81	50.75	50.75	25.375	0.18	0.125	1.44
10.94	51.00	51.00	25.500	0.13	0.125	1.04
11.03	51.25	51.25	25.625	0.09	0.125	0.72
11.36	52.50	52.50	26.250	0.33	0.625	0.528
11.7	55.00	55.00	27.500	0.34	1.25	0.272
11.91	57.50	57.50	28.750	0.21	1.25	0.168
12.08	60.00	60.00	30.000	0.17	1.25	0.136
12.22	62.50	62.50	31.250	0.14	1.25	0.112
12.35	65.00	65.00	32.500	0.13	1.25	0.104
12.46	67.50	67.50	33.750	0.11	1.25	0.088
12.57	70.00	70.00	35.000	0.11	1.25	0.088
12.67	72.50	72.50	36.250	0.10	1.25	0.08
12.76	75.00	75.00	37.500	0.09	1.25	0.072

Table 2: Processed data table for titration of unknown phosphoric acid "B" ID#20 using NaOH as a titrant at 2000 mM concentration. Sample calculation where necessary included in appendix.

pH	Burette Reading (mL)	Volume Added (mL)	mmol OH- added	ΔpH	Δmmol OH added	ΔpH/Δ(mmol OH- added)
1.47	0.00					
1.47	0.06	0.06	0.120	0.00	0.12	0.000
1.48	0.12	0.12	0.240	0.01	0.12	0.083
1.49	0.23	0.23	0.460	0.01	0.22	0.045
1.51	0.35	0.35	0.700	0.02	0.24	0.083
1.52	0.46	0.46	0.920	0.01	0.22	0.045
1.54	0.58	0.58	1.160	0.02	0.24	0.083
1.61	1.15	1.15	2.300	0.07	1.14	0.061
1.76	2.30	2.30	4.600	0.15	2.3	0.065
1.9	3.45	3.45	6.900	0.14	2.3	0.061
2.05	4.60	4.60	9.200	0.15	2.3	0.065
2.2	5.75	5.75	11.500	0.15	2.3	0.065
2.37	6.90	6.90	13.800	0.17	2.3	0.074
2.55	8.05	8.05	16.100	0.18	2.3	0.078
2.78	9.20	9.20	18.400	0.23	2.3	0.100
3.12	10.35	10.35	20.700	0.34	2.3	0.148
3.45	10.93	10.93	21.860	0.33	1.16	0.284
3.68	11.16	11.16	22.320	0.23	0.46	0.500
4.16	11.39	11.39	22.780	0.48	0.46	1.043
4.48	11.50	11.50	23.000	0.32	0.22	1.455
5.21	11.79	11.79	23.580	0.73	0.58	1.259
5.52	12.08	12.08	24.160	0.31	0.58	0.534
5.85	12.65	12.65	25.300	0.33	1.14	0.289
6.2	13.80	13.80	27.600	0.35	2.3	0.152
6.43	14.95	14.95	29.900	0.23	2.3	0.100
6.62	16.10	16.10	32.200	0.19	2.3	0.083
6.8	17.25	17.25	34.500	0.18	2.3	0.078
6.98	18.40	18.40	36.800	0.18	2.3	0.078
7.17	19.55	19.55	39.100	0.19	2.3	0.083
7.4	20.70	20.70	41.400	0.23	2.3	0.100
7.75	21.85	21.85	43.700	0.35	2.3	0.152
8.08	22.43	22.43	44.860	0.33	1.16	0.284
8.39	22.71	22.71	45.420	0.31	0.56	0.554
9.59	23.00	23.00	46.000	1.20	0.58	2.069
10.02	23.06	23.06	46.120	0.43	0.12	3.583
10.33	23.12	23.12	46.240	0.31	0.12	2.583
10.63	23.23	23.23	46.460	0.30	0.22	1.364
10.81	23.35	23.35	46.700	0.18	0.24	0.750
10.94	23.46	23.46	46.920	0.13	0.22	0.591

11.03	23.58	23.58	47.160	0.09	0.24	0.375
11.36	24.15	24.15	48.300	0.33	1.14	0.289
11.7	25.30	25.30	50.600	0.34	2.3	0.148
11.91	26.45	26.45	52.900	0.21	2.3	0.091
12.08	27.60	27.60	55.200	0.17	2.3	0.074
12.22	28.75	28.75	57.500	0.14	2.3	0.061
12.35	29.90	29.90	59.800	0.13	2.3	0.057
12.46	31.05	31.05	62.100	0.11	2.3	0.048
12.57	32.20	32.20	64.400	0.11	2.3	0.048
12.67	33.35	33.35	66.700	0.10	2.3	0.043
12.76	34.50	34.50	69.000	0.09	2.3	0.039

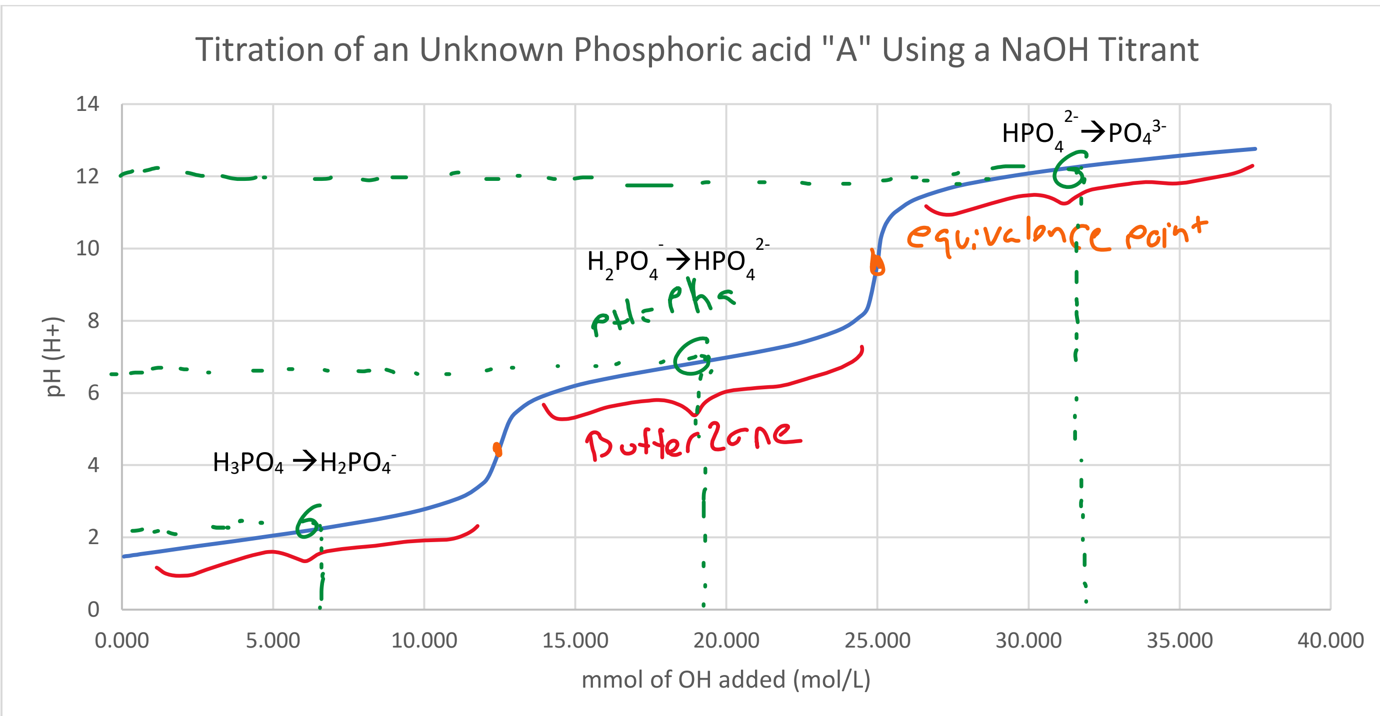


Figure 1: Unknown Phosphoric acid "A" ID#7 titration using a 500 mM NaOH titrant with indicated regions of interest.

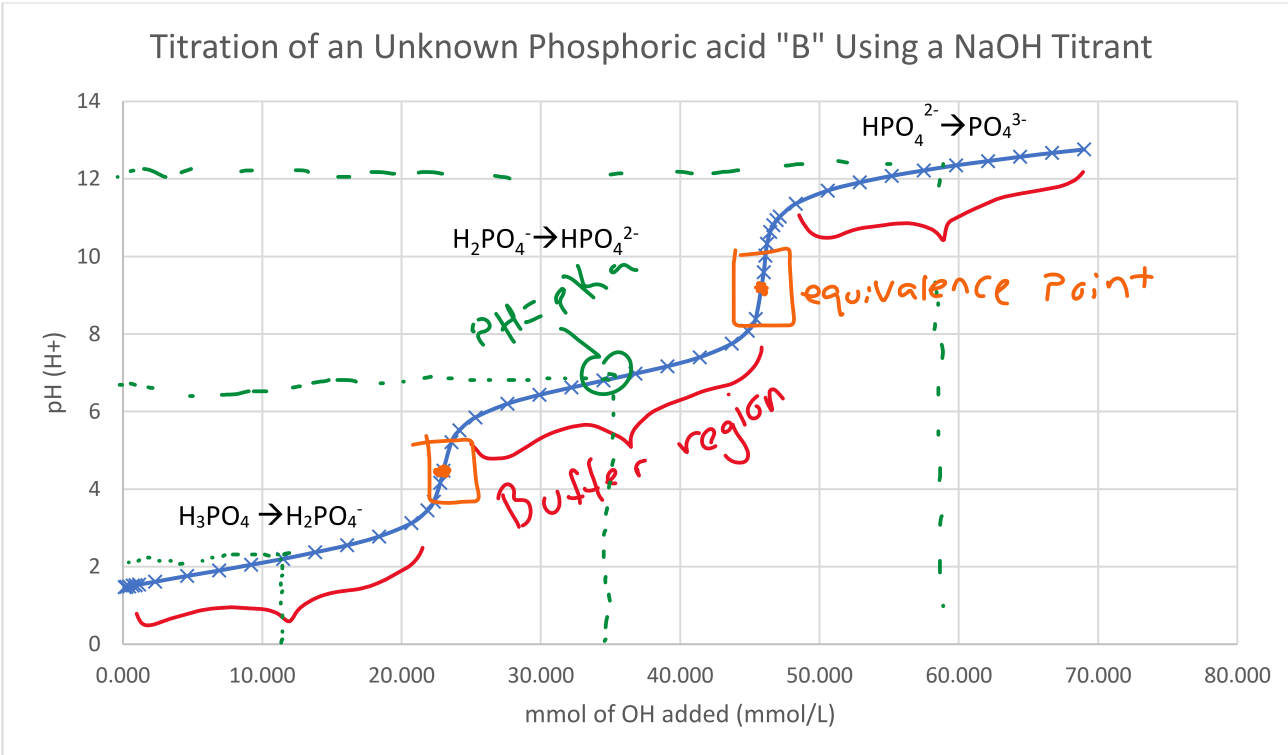


Figure 2: **Unknown Phosphoric acid "A" ID#7 titration using a 500 mM NaOH titrant**

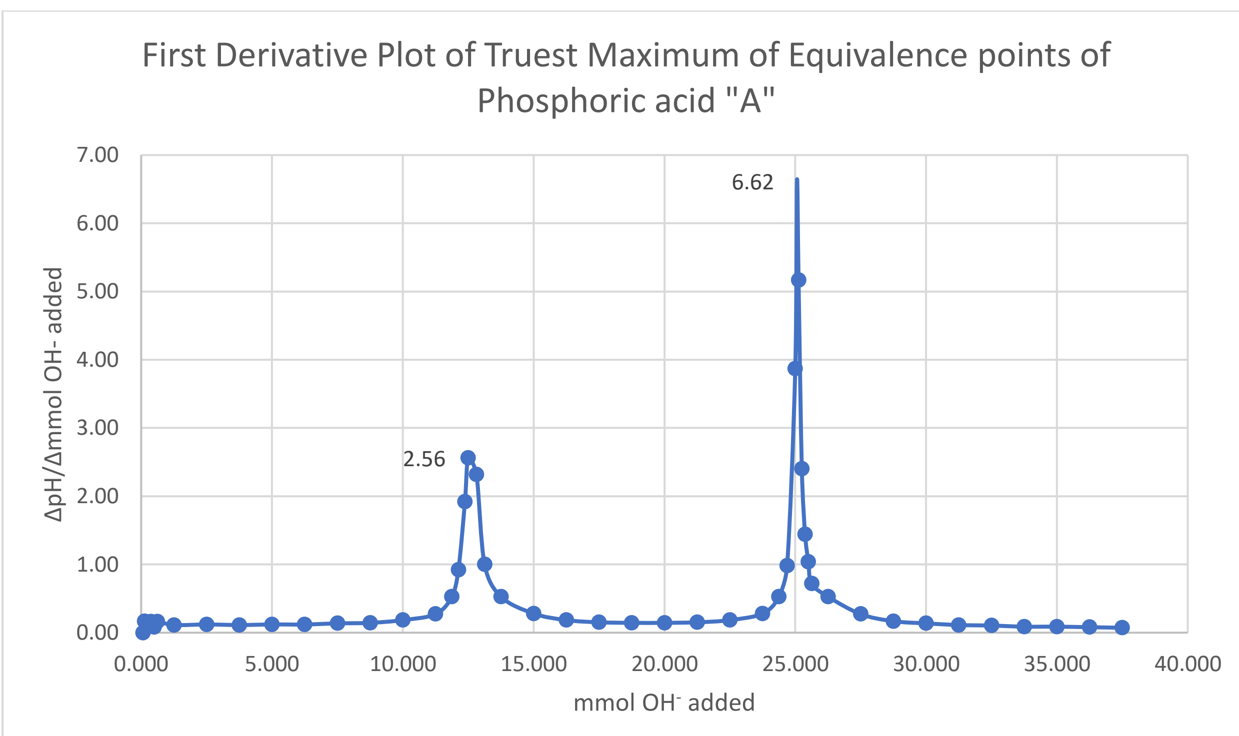


Figure 3: First Derivative plot of truest maxima at the equivalence points for the Titration of Phosphoric acid “A” ID#7 with a 500mM titrant of NaOH

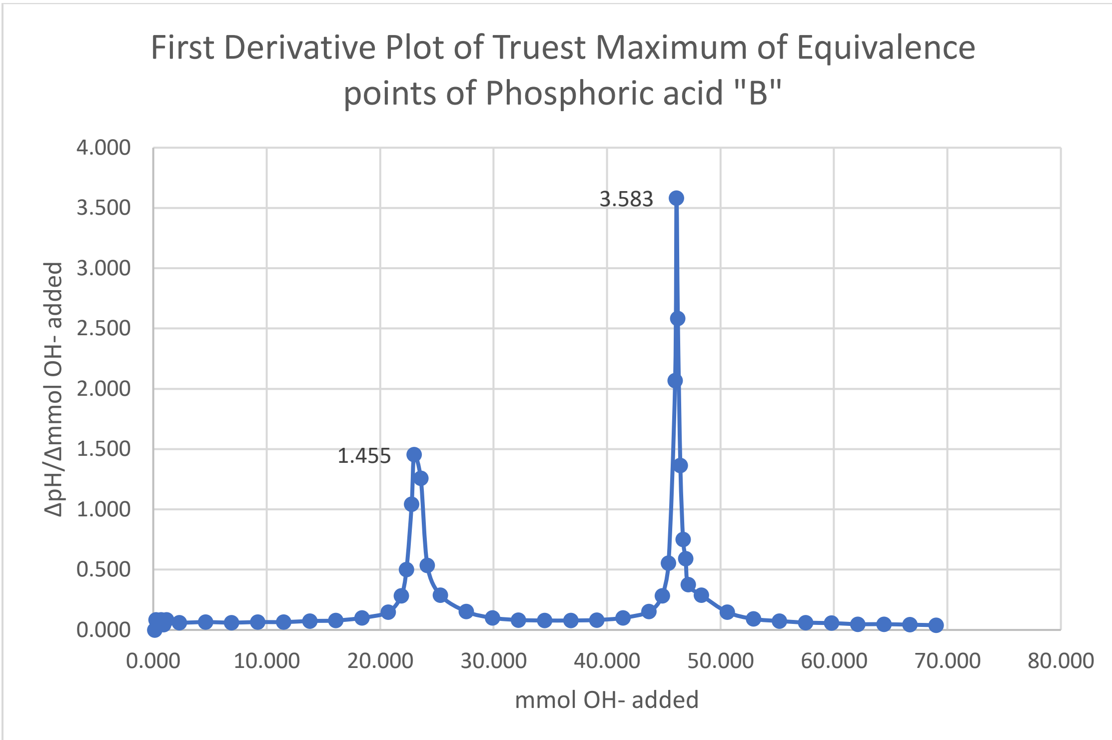


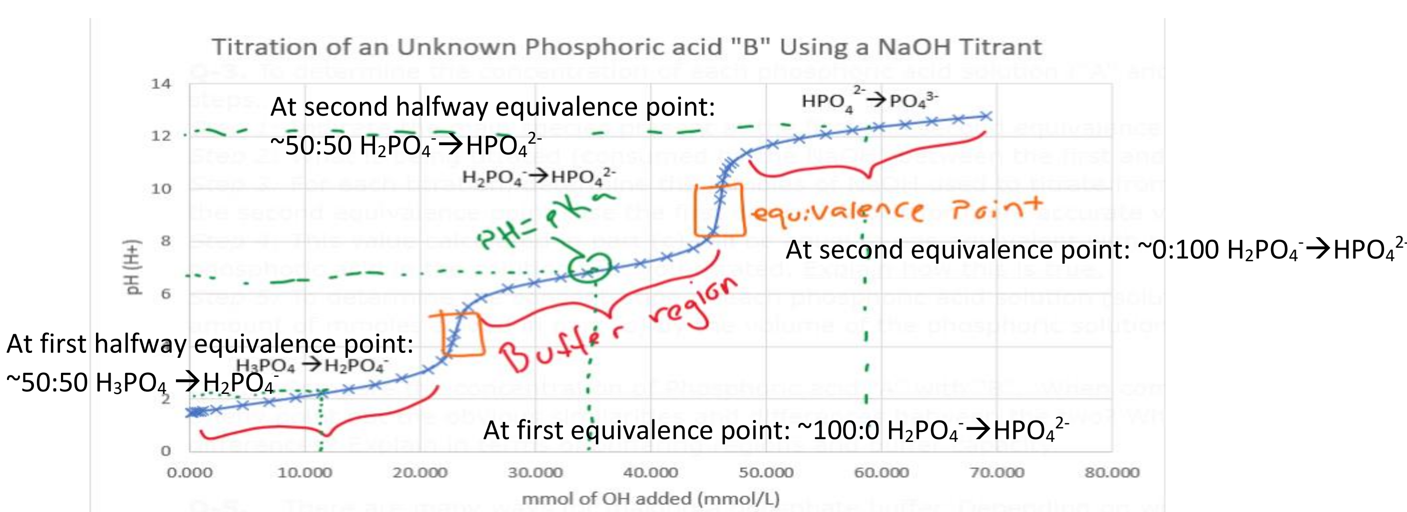
Figure 4: First Derivative plot of truest maxima at the equivalence points for the Titration of Phosphoric acid “B” ID#20 with a 2000mM titrant of NaOH

Report Questions

Q-1. Directly on at least one of your titration curves label the location/s of the following: (a) buffer regions, (b) where pH = pKa values, (c) equivalence point/s (when there is only one species present).

- Please refer to Figure 1 or Figure 2 for identified regions.

Q-2. At locations (b) and (c) above, indicate -directly on the titration curve- the distinct main species present in the solution and their relative amounts. (use the chemical formula of the buffer system you are using - do not use the general terms, HA and A-).



Q-3. To determine the concentration of each phosphoric acid solution (“A” and “B”) complete the following steps…
***Step 1:* Indicate the main species present at the first and second equivalence point**
***Step 2:* What is being titrated (consumed by the NaOH) between the first and second equivalence point?**
***Step 3:* For each titration, determine the mmoles of NaOH used to titrate from the first equivalence point to the second equivalence point (use the first derivative plot for more accurate values).**

- Phosphoric acid “A”: 6.62mmol – 2.56mmol = 4.06mmol
- Phosphoric acid “B”: 3.58mmol – 1.50mmol = 2.08mmol

***Step 4:* This value calculated in part (c) will be equal to one equivalent with respect to the mmoles of phosphoric acid in the solution that you titrated. <u>Explain how this is true.</u>**

- An equivalence point in a titration is when the amount of the titrant added, which in this case is NaOH, that will neutralize the solution. Because phosphoric acid is polyprotic meaning it has multiple ionizable groups, there are multiple equivalence points with their own respective pKa values (Waterloo, 2021). So at the first equivalence point, we reach one equivalent of conjugated acid and base, and then we are onto the next ionizable group which is protonated up to its own independent equivalence point where the conjugate base is dissociated.

***Step 5:* To determine the concentration of each phosphoric acid solution (solution “A” and “B”) divide the amount of mmoles solved in part (c) by the volume of the phosphoric solution that was titrated.**

- Phosphoric acid “A”: 4.06mmol ÷ .05L = 81.2 mM
- Phosphoric acid “B”: 2.08mmol ÷ .10L = 20.8 mM

Q-4. Compare the concentration of Phosphoric acid “A” with “B”. When comparing both titration curves, briefly point out the obvious similarities and differences between the two? What is causing the similarities and differences? Explain in terms of buffering regions and buffer capacity.

- To break it down simply, a buffer is a resistance in change, in titrations it’s the change in pH of our conjugated acid and base. Buffer capacity is the quantifiable amount of acid or base added to a buffer system that is able to resist significant pH change (Harris et al., 2011). When looking at Figure 1 and 2, some key differences would be the size of the buffering regions or buffer zones. This is the area of the graph that is plateaued where pH is not increasing very much when we continually add more mmol of OH-. Somewhere similar in both graphs is a smaller initial equivalence step followed by a second larger equivalence step. Both of these can be explained as a result of the strength of the conjugate acid and base. Buffer capacity is the number of moles added divided by the change in pH and because this was the same value for both titrations we are just looking at the concentration of the titrant, and for phosphoric acid “B” it was 4x stronger than phosphoric acid "a" which would indicate a larger buffer capacity or resistance to pH change, and that’s exactly what we see shown in Figure 2 vs Figure 1.

Q-5. **There are many ways for making a phosphate buffer. Depending on what is available in the lab, a phosphate buffer can be made from (i) phosphoric acid and a strong base, eg. H_3PO_4 / NaOH; (ii) a phosphate salt and the addition of either a strong acid or base, eg. NaH_2PO_4 / NaOH; (iii) the phosphate salt of both the conjugate acid and the conjugate base, eg. NaH_2PO_4 /Na_2HPO_4.; or (iv) or a combination of the reagents mentioned above. Most of the time we start with a solution of the salt form and then titrate with either a strong base or acid to obtain the pH that we desire. Determine the expected pH and the concentrations of the following solutions (Use the Henderson-Hasselbalch equation to help you and show your reasoning and calculations).**

(a) 4.80 g of NaH_2PO_4 (MW 120 g/mol), 4.8 ml of 4.0 M NaOH and enough water to make a final volume of 200 ml.

(b) 11.36 g of Na_2HPO_4 (MW 142 g/mol), 15 ml of 4.0 M HCl and enough water to make a final volume of 500 ml.

a) $pKa = 6.8$

$n_{salt} = m/M = 4.8\,g/120\,g/mol = .04$

$n_{NaOH} = C \times V = 4M \times .0048L = .0192$

$HA + H_2O \rightarrow H_3O + A^-$

HA	H_2O	A^-
.04	.0192	0
-.0192	-.0192	+.0192
=.04-.0192	0	.0192
=.0208		

$pH = pKa + \log(A^-/HA)$

$= 6.8 + \log(.0192/.0208)$

$pH = 6.77$

$C_{buffer} = \frac{n}{v} = n_{salt} + n_{NaOH} / V_T = .04 + .0192 / .2L$

$= .296\,M$

Con. B is now Con. A Con A is now Con. B

b) $pKa = 6.8$

$n_{salt} = m/M = 11.36g/142g/mol = .08\,mol$

$n_{HCl} = C \times V = 4M \times .015L = .06\,mol$

$A^- + HCl \rightarrow HA^2$

A^-	HCl	HA^2
.08	.06	0
-.06	-.06	+.06
.02	0	.06

$pH = pKa + \log([A^-]/[HA])$

$pH = 6.8 + \log(.06/.02)$

$= 7.28$

$C_{buffer} = n_T/V_1 = .08 + .06 / .5 = .28\,M$

(c) 4.80 g of NaH_2PO_4 (MW 120 g/mol) and 11.36 g Na_2HPO_4 (MW 142 g/mol) dissolved in a total volume of 1.00 litre of water.

c) $n_{acid} = m/M = 4.8g/120g/mol = .04$

$n_{base} = 11.36 \div 142 = .08$

$pH = pKa + \log(A^-/HA)$

$= 6.8 + \log(.08/.04)$

$pH = 7.1$

$C_{buffer} = n/v = .04 + .08 / 1L = .12\,M$

Q-6. You have **3.1 L of a 60 mM phosphate buffer, pH 6.8**. You need to increase the pH of this buffer to 7.4 by using 4 M NaOH.

(a) Determine mmoles of NaH_2PO_4 **and Na_2HPO_4 both at pH 6.8 and at the changed pH.**

(b) Determine the expected mmols of NaOH required to effect pH change.

(c) Determine the volume (mL) of the available (given) NaOH required.

(a) pKa buffer = 6.8 $\quad pH = pKa + \log([A^-]/[HA])$

$pH_1 = 6.8 \quad 7.4 = 6.8 + \log(A^-/HA)$

$pH_2 = 7.4 \quad 0.6 = \log(A^-/HA)$

$C_{PO_4} = 60$ mM $\quad 10^{0.6} = 10^{\log(A^-/HA)}$

$C_{NaOH} = 4$ M $\quad 3.98 = ([A^-]/[HA])$

① $[A^-] + [HA] = 60$ mM $\quad$ ② $[A^-] = 3.98[HA]$

$\rightarrow [A^-] = 47.96$ mM $= [Na_2HPO_4]$

sub ② → ①

$3.98[HA] + [HA] = 60$ mM

$[HA](3.98 + 1) = 60$ mM

$[HA] = 12.05$ mM $\therefore [NaH_2PO_4] = 12.05$ mM

Convert from mM → mmoles = C × V

47.96 mM × 3.1 L = 148.68 mmoles of Na_2HPO_4 @7.4

12.05 mM × 3.1 L = 37.36 mmoles of NaH_2PO_4 @7.4

→ $pH = pKa + \log([A^-]/[HA])$

$6.8 = 6.8 + \log(A^-/HA) \quad$ Total = 60 mM, $[A^-] = 30$ mM, $[HA] = 30$ mM

$0 = \log(A^-/HA) \quad$ mM → mmol

$10^0 = 10^{A^-/HA} \quad$ 30 mM × 3.1 L = 93 mmol

$1 = A^-/HA \quad \therefore Na_2HPO_4$ @ 6.8 = 93 mmol

$[HA] = [A^-] \quad \therefore NaH_2PO_4$ @ 6.8 = 93 mmol

b) $\Delta[A^-] = 148.68 - 93$

= 55.68 mmoles ∴ required amount of mmoles of NaOH to effect pH change.

c) Volume of NaOH = n/c

$= \frac{55.68 \text{ mmoles}}{4 \text{ M}} = 13.92$ mL

(d) At pH 7.4 will the phosphate buffer have a greater capacity to buffer the addition of a strong acid or strong base? Explain.

A pH of 7.4 is higher than the pKa of the phosphate buffer at 6.8 by .6pH units. With this we know that there will be more conjugate base present than conjugate acid so the buffer will be able to resist the addition of more acid vs the addition of more base. This is due to the greater number of moles of base present to neutralize the addition of the acid.

Work Cited

Harris, Justin. Preparation of Buffers and Buffer Capacity Measurement. Carmen Wiki. The Ohio State University. 11/18/11. Retrieved from <https://carmenwiki.osu.edu/download/attachments/26518655/Buffer+Lab.pdf?version=1&modificationDate=1301198124224>.

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