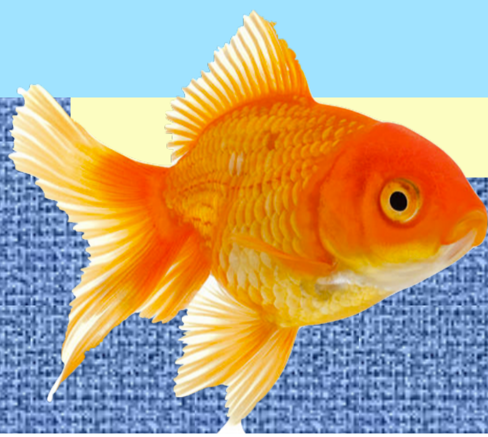
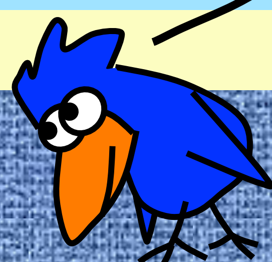
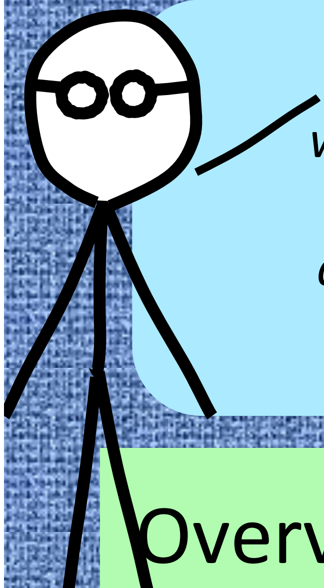
Experiment 6
pK_a and K_a of Acetic Acid
27 February 2020





Umm... Why is there a large fish in this presentation.

Objective: To determine the pK_a and K_a of acetic acid (ethanoic acid).



We have been learning about weak acids in lecture these days. Today in lab we will actually determine a K_a value for a weak acid. Amazing.

So, we will learn how to interpolate data in order to estimate a value between two other values.

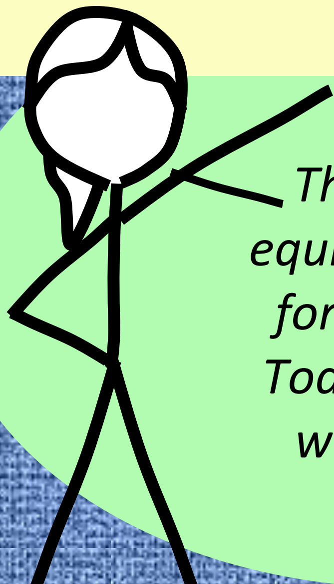
Overview:

1. Introduction and Overview
2. Collect data
3. Making the titration graphs
4. Interpolation for equivalence point and for pK_a
5. Procedure: What we do today
6. Your lab report

We will be interpolating?

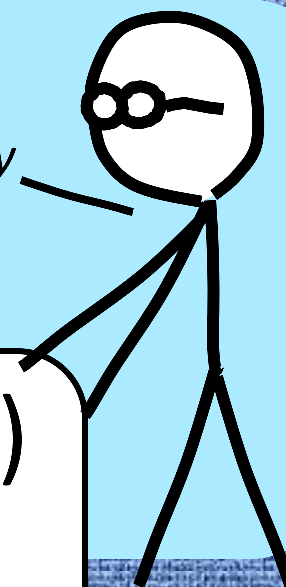
1. Introduction and Overview

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq) \quad K_a = \frac{[H_3O^+][A^-]}{[HA]}$$



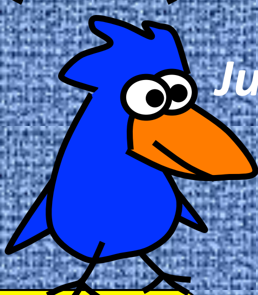
This is our familiar equilibrium expression for every weak acid. Today, our weak acid will be acetic acid.

We will measure pK_a in this experiment. It is mathematically just like pH. Our objective is to determine K_a.



$$pK_a = -\log(K_a)$$

$$K_a = 10^{-pKa}$$



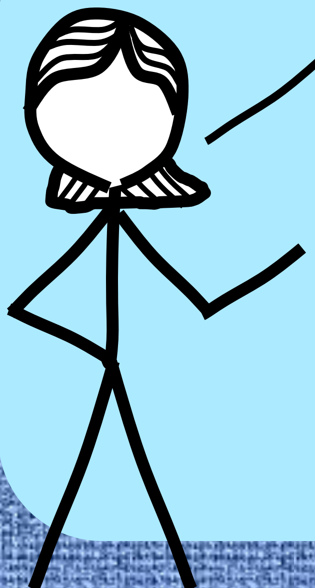
Just in case you forgot...

$$pH = -\log[H_3O^+]$$

$$[H_3O^+] = 10^{-pH}$$

Info for Introduction

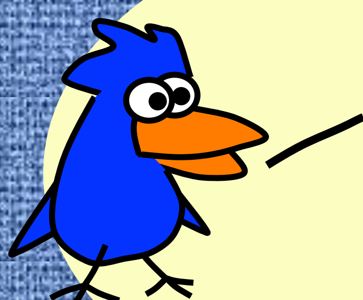
2. Collect data



Launch Excel and record the data directly into your Excel spreadsheet. There is no need to copy the data into your lab notebook, but you must print the Excel data as part of your lab report.

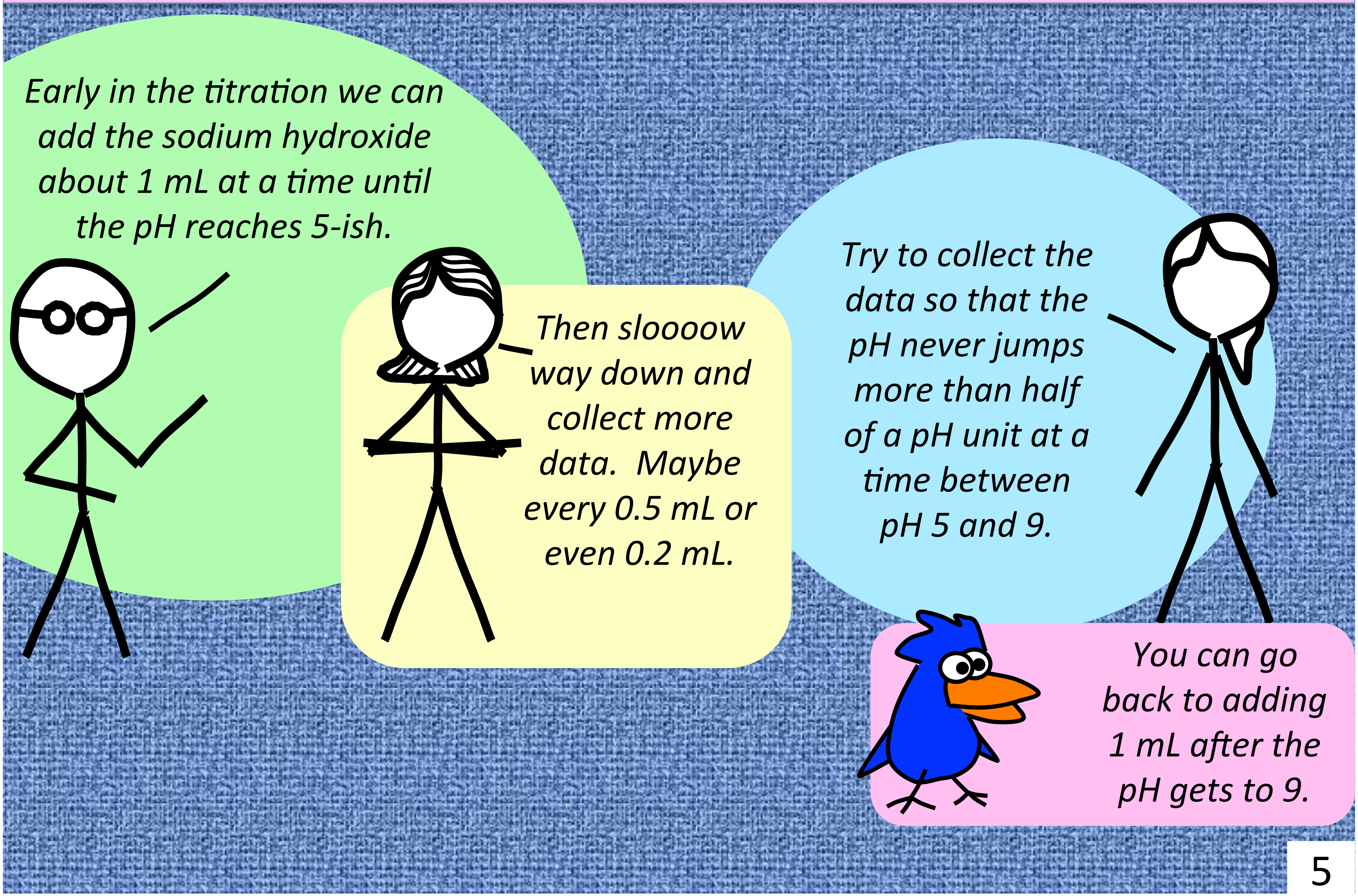
	A	B
1	Volume (mL)	pH
2	0.00	2.57
3	0.72	2.8[illegible]
4	1.01	2.9[illegible]
5	1.41	3.1[illegible]
6	1.78	3.26
7	2.05	3.32
8	2.31	3.38
9	2.68	3.48
10	3.01	3.60
11	3.31	3.67
12	3.61	3.75
13	3.99	3.87
14	4.29	3.92
15	5.00	4.02
16	5.32	4.03
17	5.69	4.07
18	6.59	4.19
19	6.93	4.24

Enter the data as it is obtained. This is sorta what it should look like…

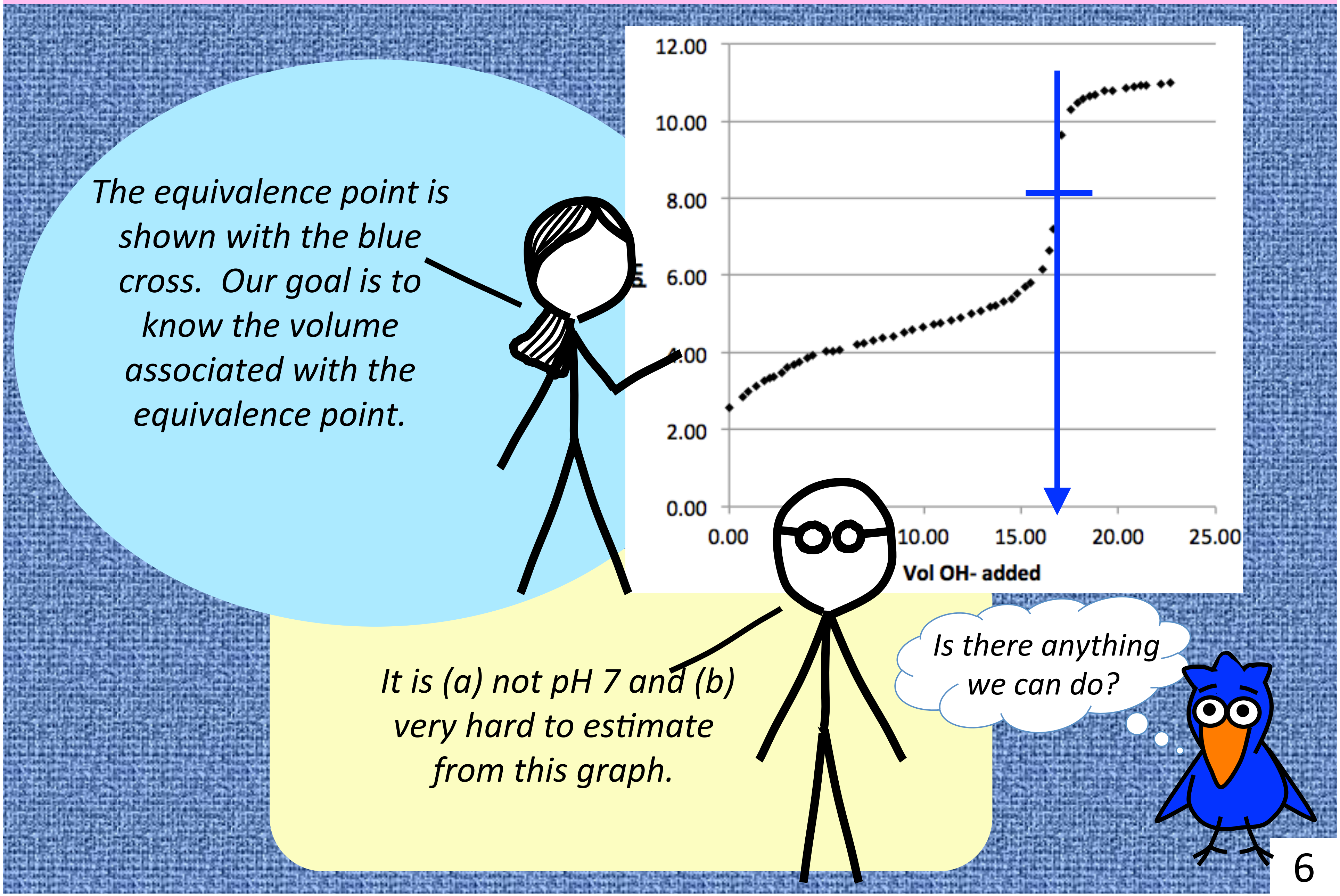


This is different from what the lab manual says. We will have to note that in our lab report…

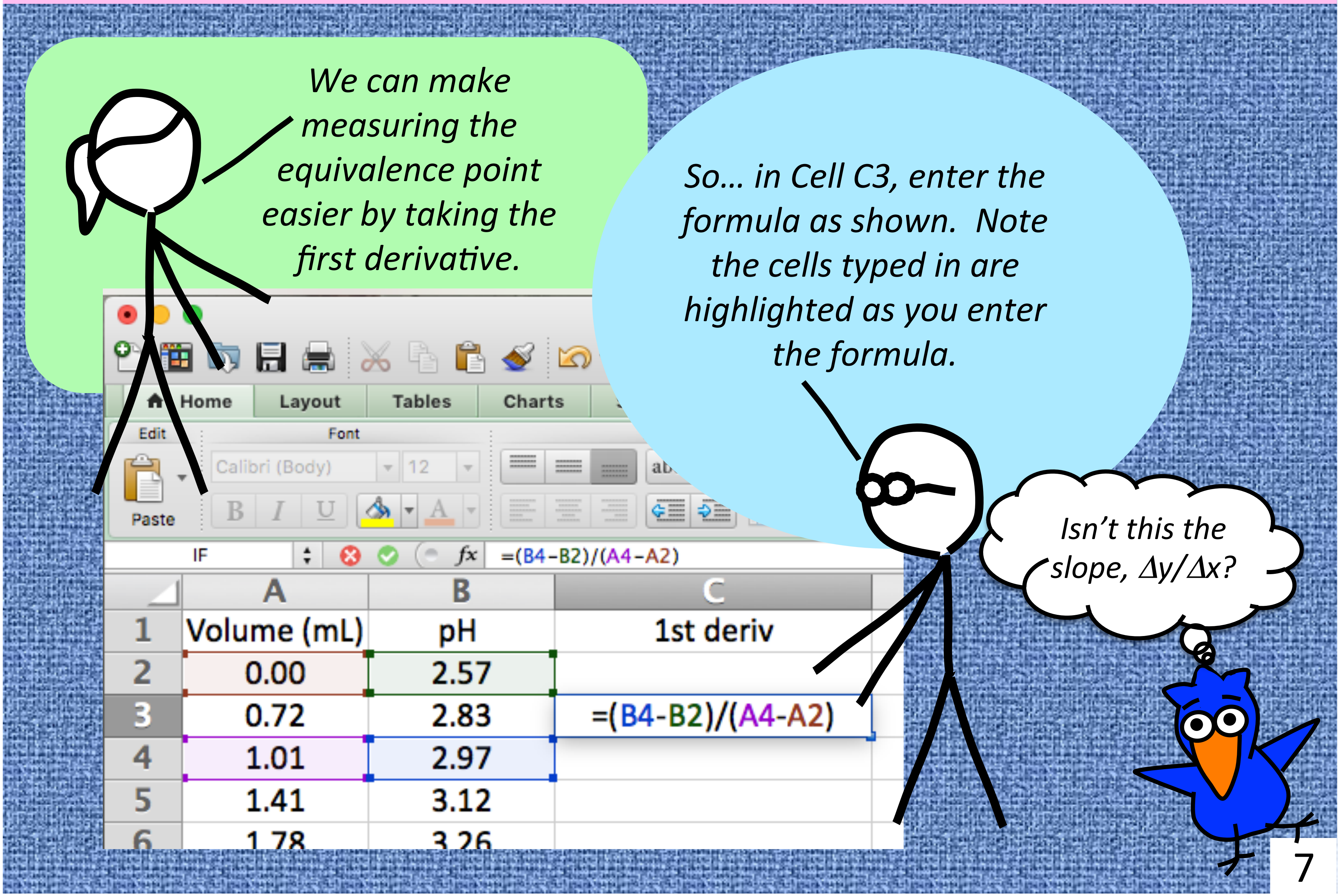
2. Collect data



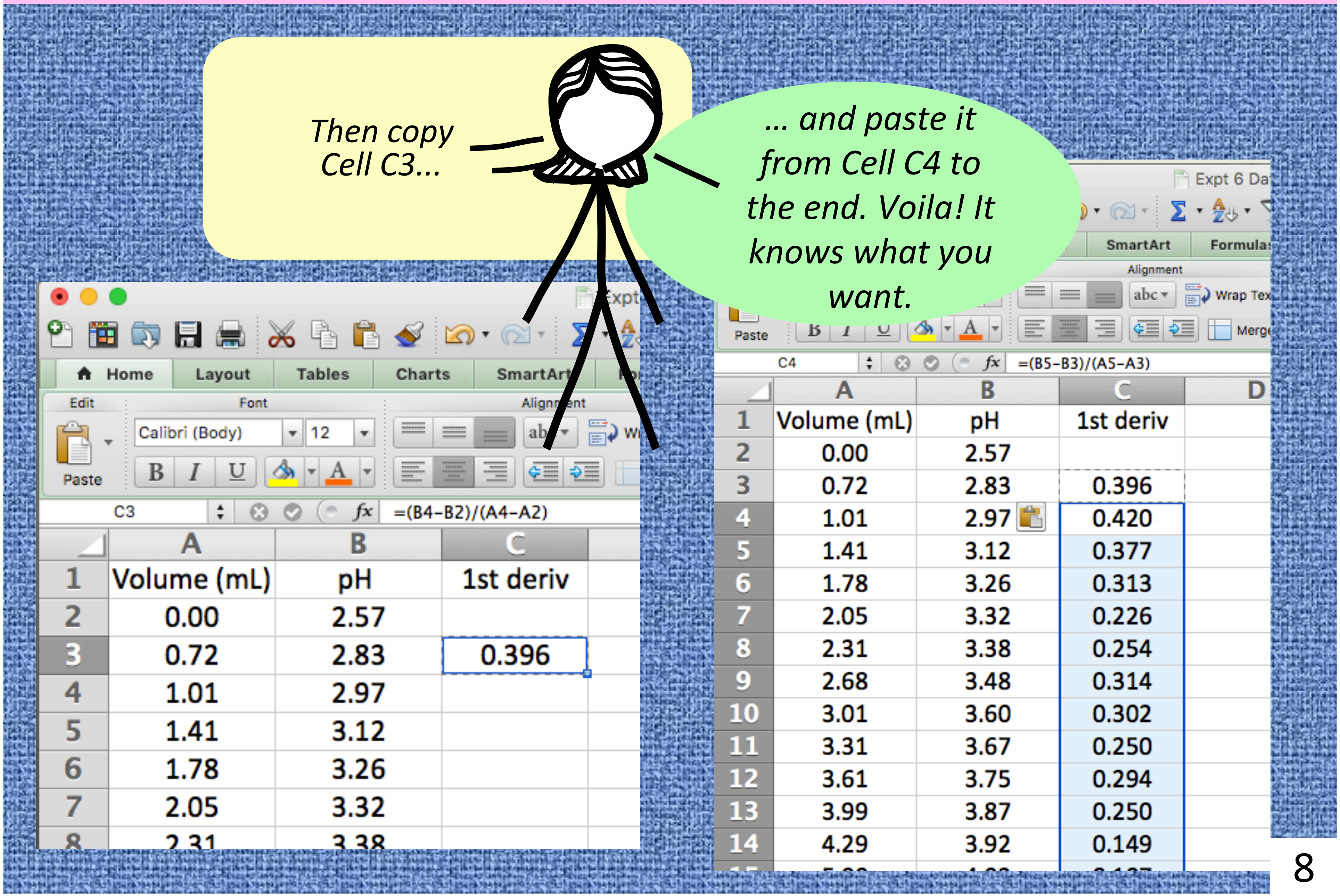
3. Making the titration graphs



3. Making the titration graphs



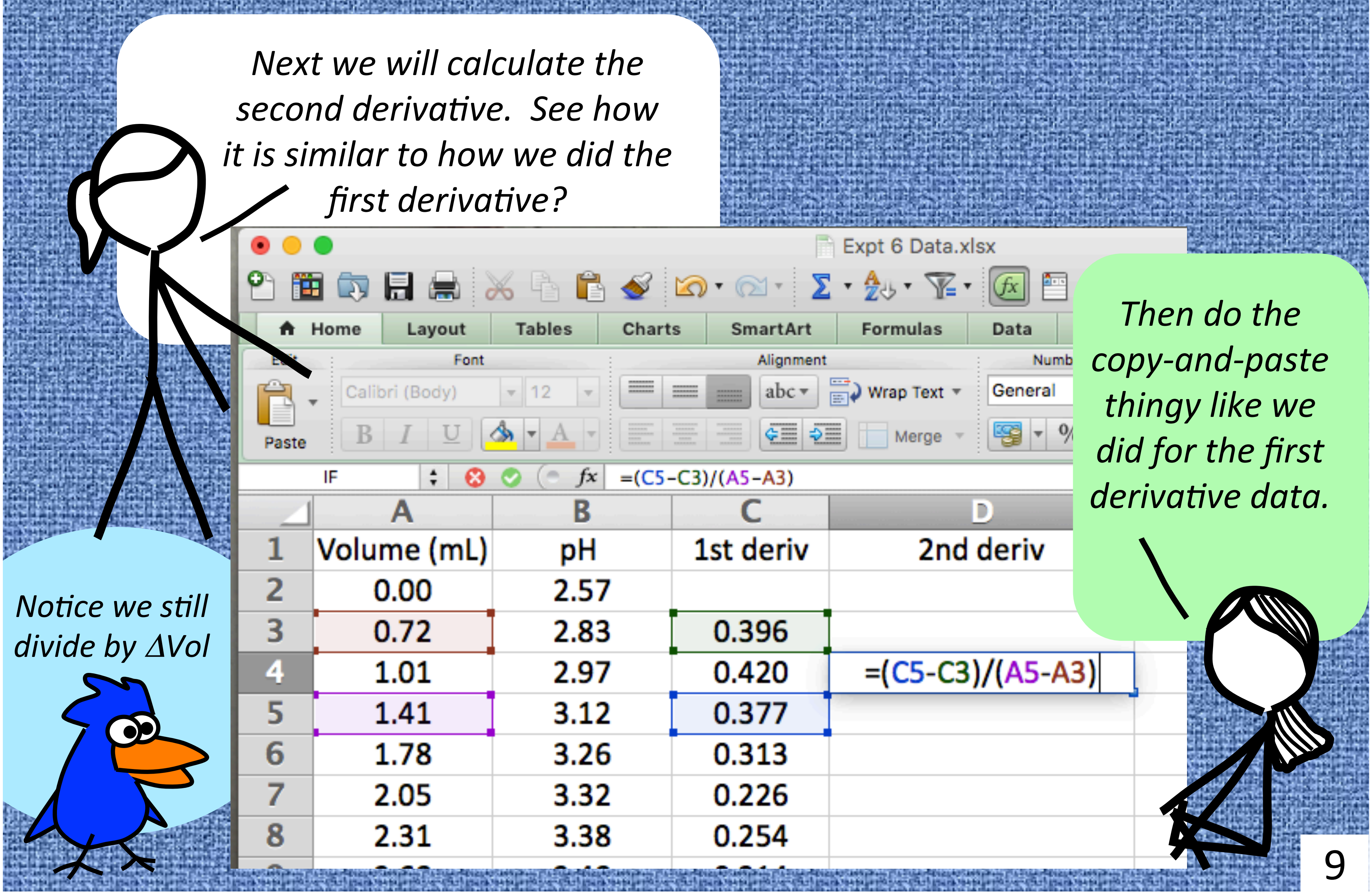
3. Making the titration graphs



	A	B	C
1	Volume (mL)	pH	1st deriv
2	0.00	2.57	
3	0.72	2.83	0.396
4	1.01	2.97	
5	1.41	3.12	
6	1.78	3.26	
7	2.05	3.32	
8	2.31	3.38	

	A	B	C
1	Volume (mL)	pH	1st deriv
2	0.00	2.57	
3	0.72	2.83	0.396
4	1.01	2.97	0.420
5	1.41	3.12	0.377
6	1.78	3.26	0.313
7	2.05	3.32	0.226
8	2.31	3.38	0.254
9	2.68	3.48	0.314
10	3.01	3.60	0.302
11	3.31	3.67	0.250
12	3.61	3.75	0.294
13	3.99	3.87	0.250
14	4.29	3.92	0.149

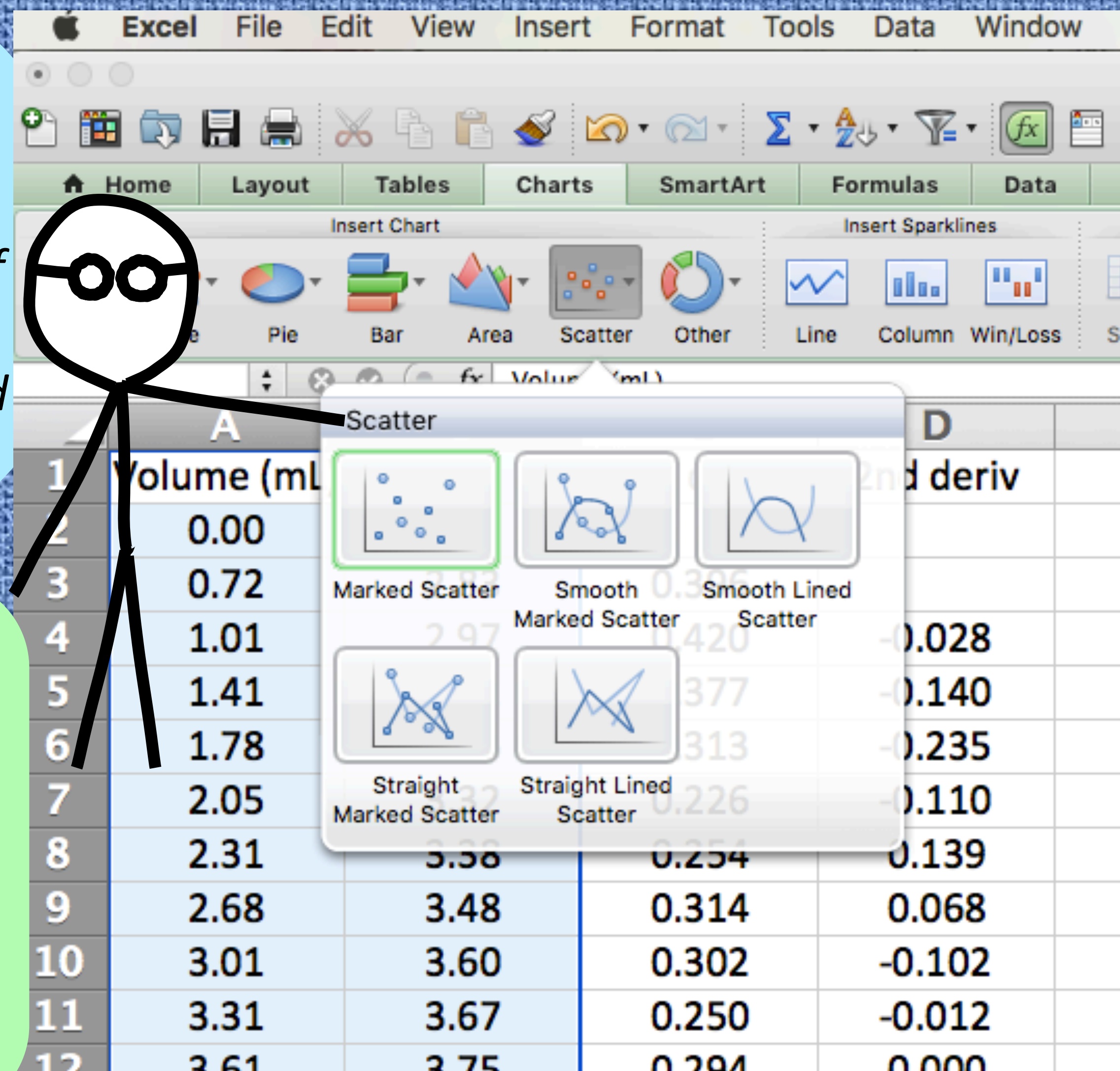
3. Making the titration graphs



	A	B	C	D
1	Volume (mL)	pH	1st deriv	2nd deriv
2	0.00	2.57		
3	0.72	2.83	0.396	
4	1.01	2.97	0.420	=(C5-C3)/(A5-A3)
5	1.41	3.12	0.377	
6	1.78	3.26	0.313	
7	2.05	3.32	0.226	
8	2.31	3.38	0.254	

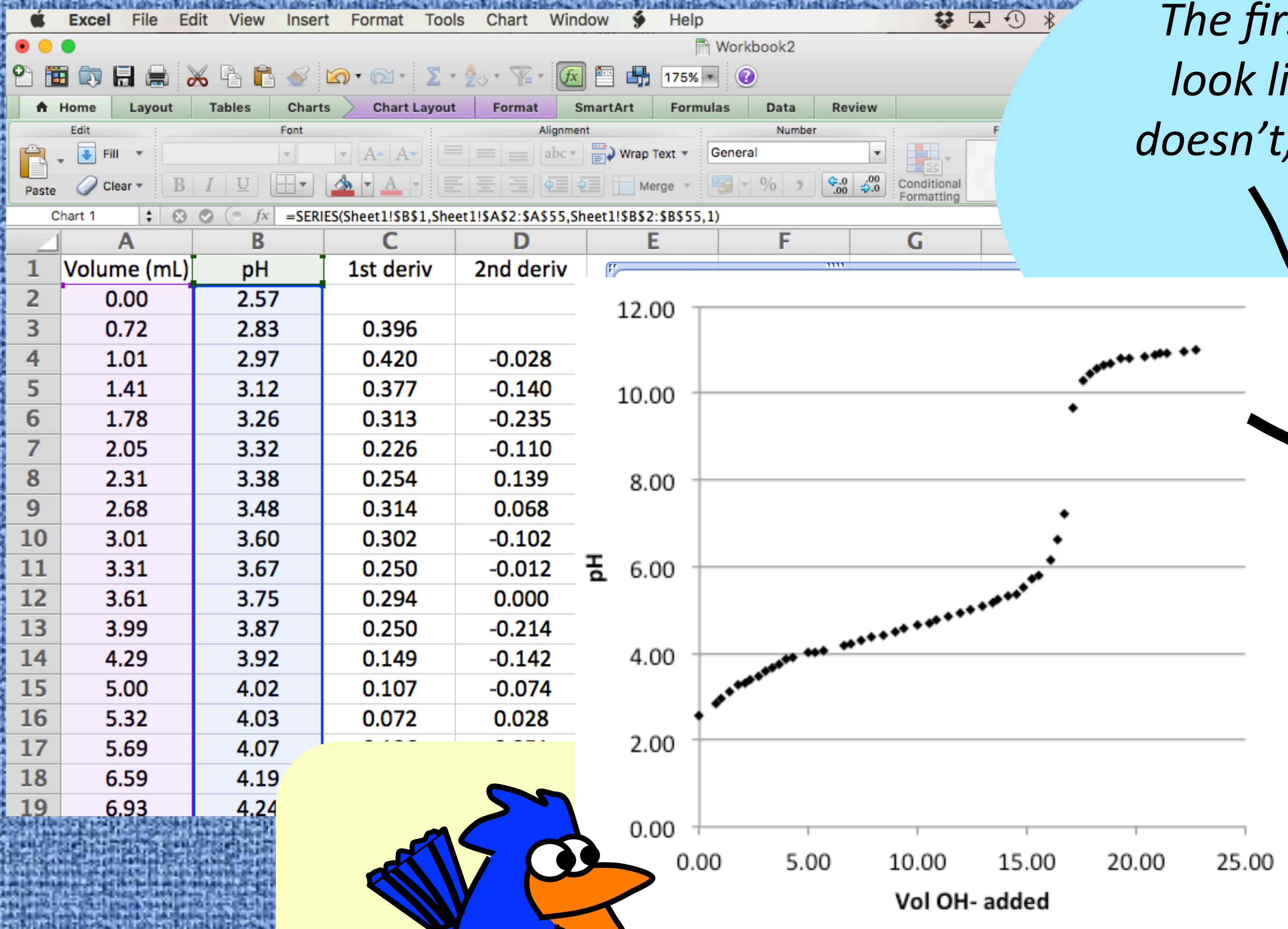
3. Making the titration graphs

We are going to make three scatter graphs. In each case we start by highlighting the columns of data we want plotted. Here we see Columns A and B are highlighted.

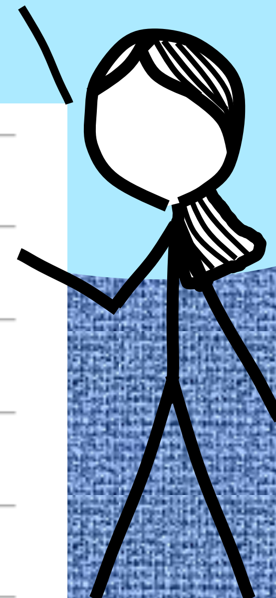


Then pick Scatter graph from the Chart menu. Every version of Excel is a bit different.

3. Making the titration graphs



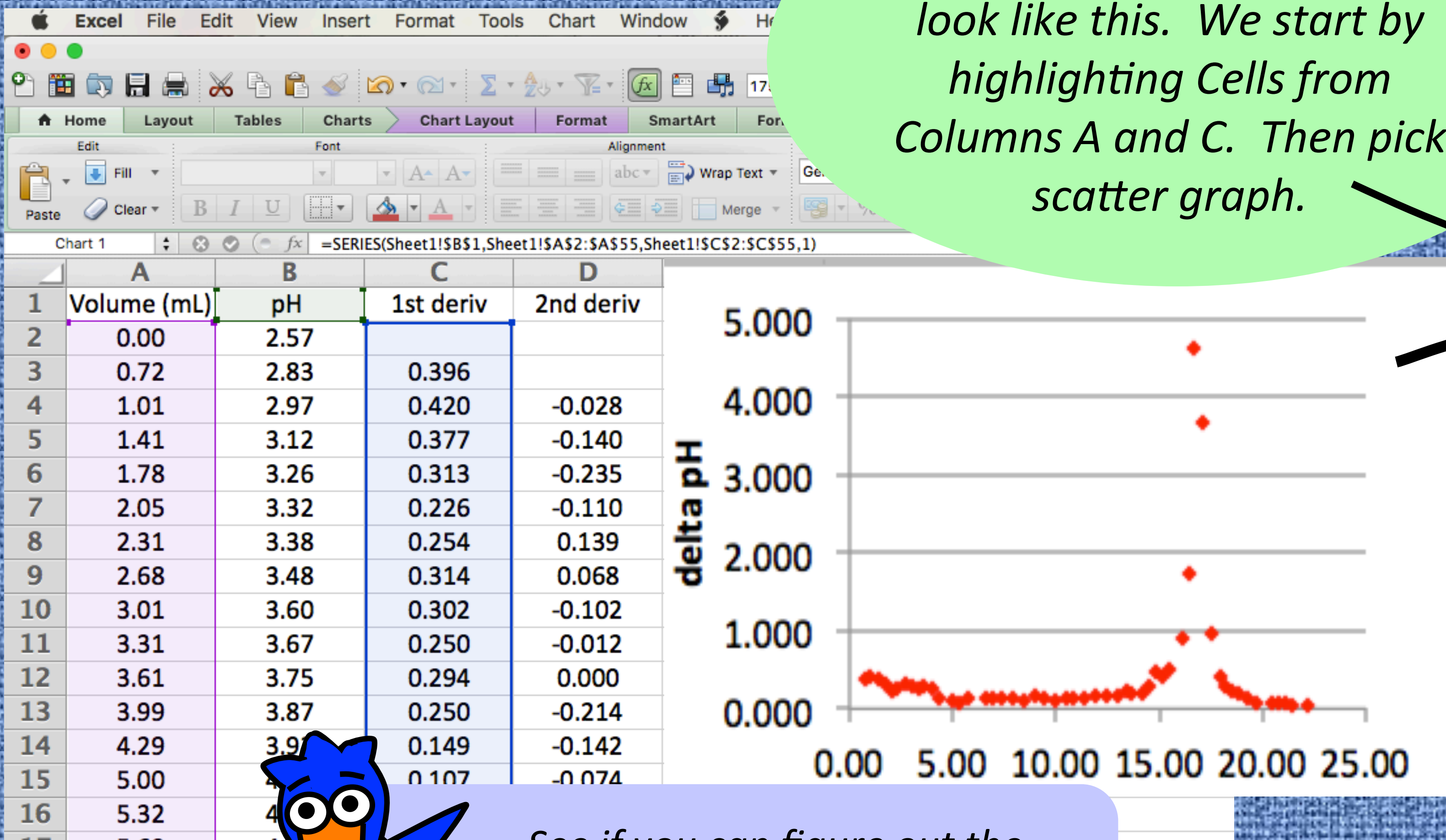
	A	B	C	D
1	Volume (mL)	pH	1st deriv	2nd deriv
2	0.00	2.57		
3	0.72	2.83	0.396	
4	1.01	2.97	0.420	-0.028
5	1.41	3.12	0.377	-0.140
6	1.78	3.26	0.313	-0.235
7	2.05	3.32	0.226	-0.110
8	2.31	3.38	0.254	0.139
9	2.68	3.48	0.314	0.068
10	3.01	3.60	0.302	-0.102
11	3.31	3.67	0.250	-0.012
12	3.61	3.75	0.294	0.000
13	3.99	3.87	0.250	-0.214
14	4.29	3.92	0.149	-0.142
15	5.00	4.02	0.107	-0.074
16	5.32	4.03	0.072	0.028
17	5.69	4.07		
18	6.59	4.19		
19	6.93	4.24		



The first graph will look like this. If it doesn't, ask for help!

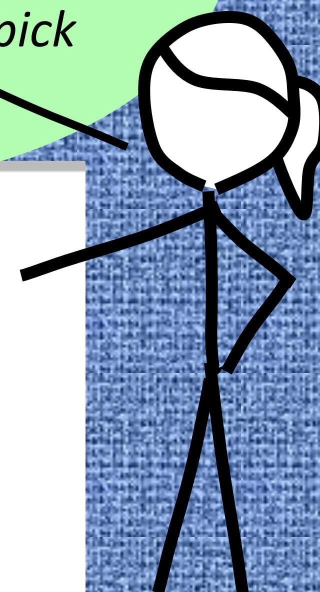
This is your basic, garden variety titration curve…

3. Making the titration graphs



	A	B	C	D
1	Volume (mL)	pH	1st deriv	2nd deriv
2	0.00	2.57		
3	0.72	2.83	0.396	
4	1.01	2.97	0.420	-0.028
5	1.41	3.12	0.377	-0.140
6	1.78	3.26	0.313	-0.235
7	2.05	3.32	0.226	-0.110
8	2.31	3.38	0.254	0.139
9	2.68	3.48	0.314	0.068
10	3.01	3.60	0.302	-0.102
11	3.31	3.67	0.250	-0.012
12	3.61	3.75	0.294	0.000
13	3.99	3.87	0.250	-0.214
14	4.29	[illegible]	0.149	-0.142
15	5.00	[illegible]	0.107	-0.074
16	5.32	[illegible]		

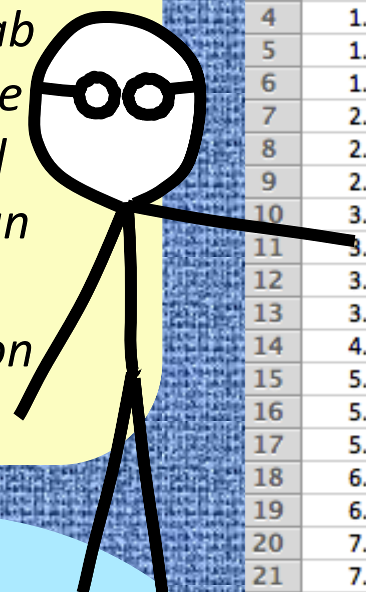
The first derivative graph will look like this. We start by highlighting Cells from Columns A and C. Then pick scatter graph.



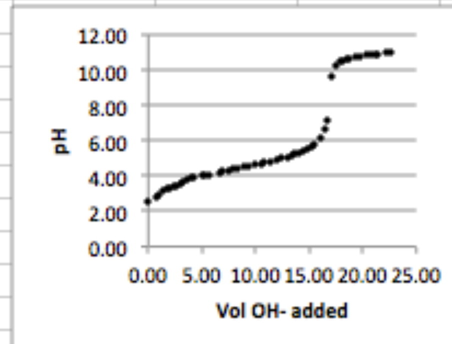
See if you can figure out the second derivative graph – hint: Use stuff from Columns A and D.

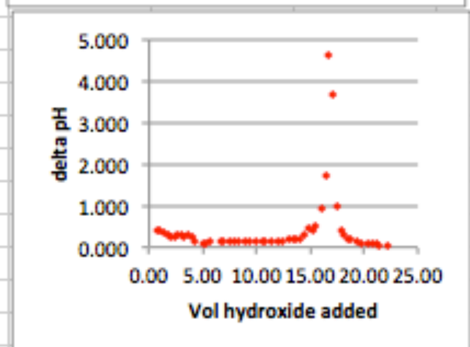
3. Making the titration graphs

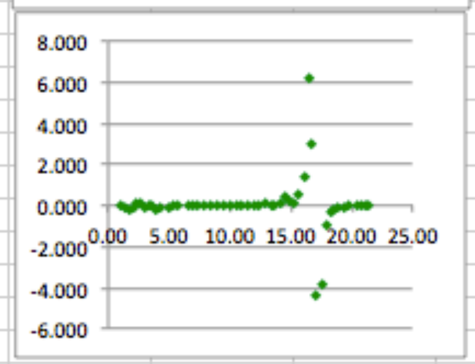
This is how graphs should look for submitting with lab report. Adjust the font size and cell size so that we can read all of your data, preferably on one page.

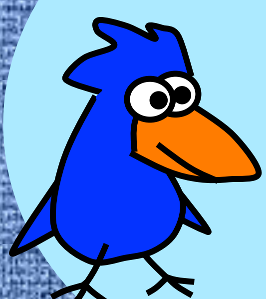


	A	B	C	D
1	Volume (mL)	pH	1st deriv	2nd deriv
2	0.00	2.57		
3	0.72	2.83	0.396	
4	1.01	2.97	0.420	-0.028
5	1.41	3.12	0.377	-0.140
6	1.78	3.26	0.313	-0.235
7	2.05	3.32	0.226	-0.110
8	2.31	3.38	0.254	0.139
9	2.68	3.48	0.314	0.068
10	3.01	3.60	0.302	-0.102
11	3.31	3.67	0.250	-0.012
12	3.61	3.75	0.294	0.000
13	3.99	3.87	0.250	-0.214
14	4.29	3.92	0.149	-0.142
15	5.00	4.02	0.107	-0.074
16	5.32	4.03	0.072	0.028
17	5.69	4.07	0.126	0.051
18	6.59	4.19	0.137	0.007
19	6.93	4.24	0.134	0.011
20	7.41	4.30	0.146	-0.004
21	7.89	4.38	0.130	-0.028
22	8.41	4.43	0.118	0.021
23	8.99	4.51	0.153	0.024
24	9.39	4.58	0.141	-0.035
25	9.98	4.65	0.118	-0.012
26	10.49	4.71	0.128	0.027
27	10.84	4.76	0.141	0.013
28	11.41	4.84	0.140	0.016
29	11.91	4.91	0.158	0.017
30	12.42	5.00	0.157	0.013
31	12.93	5.07	0.172	0.057
32	13.41	5.17	0.213	0.034
33	13.68	5.23	0.197	-0.040





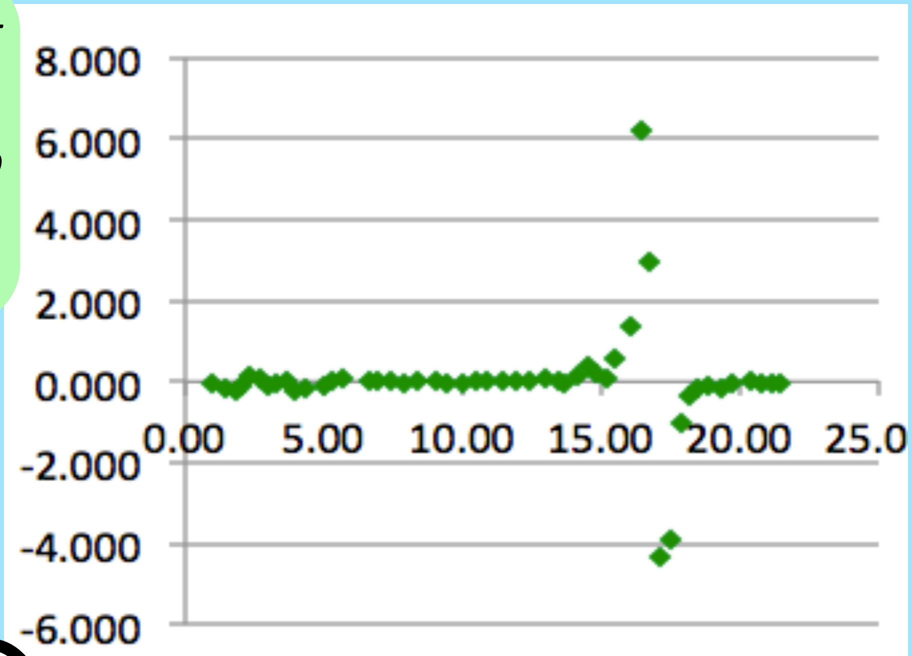




If you need to use a second page, that's fine.

4. Interpolation for equivalence point and for pK_a

So this is the 2nd derivative plot and data. We want to know where the positive values go to negative values – that is the equivalence point.

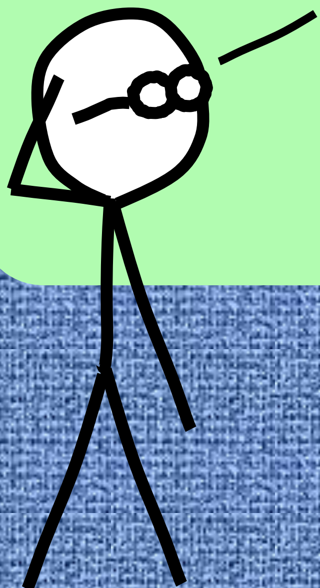


	A	B	C	D	E
31	12.93	5.07	0.172	0.057	
32	13.41	5.17	0.213	0.034	
33	13.68	5.23	0.197	-0.040	
34	14.12	5.31	0.185	0.114	
35	14.49	5.38	0.290	0.404	
36	14.81	5.51	0.464	0.180	
37	15.18	5.70	0.414	0.060	
38	15.51	5.80	0.505	0.547	
39	16.09	6.16	0.912	1.349	
40	16.42	6.63	1.733	6.198	
41	16.69	7.20	4.631	2.974	
42	17.07	9.64	3.667	-4.351	
43	17.53	10.28	0.976	-3.875	
44	17.91	10.46	0.412	-1.005	
45	18.21	10.56	0.293	-0.336	
46	18.49	10.63	0.217	-0.184	
47	18.81	10.69	0.183	-0.112	
48	19.31	10.78	0.125	-0.136	

See how the second derivative data goes from large and positive to large and negative? Somewhere in between these two volumes, 16.69 mL and 17.07 mL, the 2nd derivative goes through zero – the equivalence point!

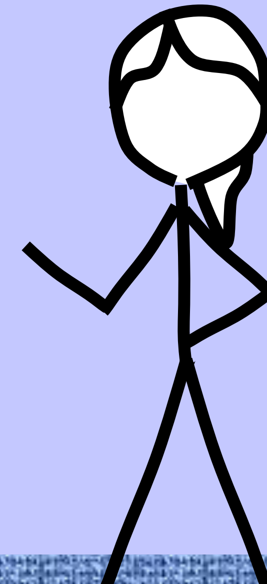
I'm guessing this is where we interpolate…

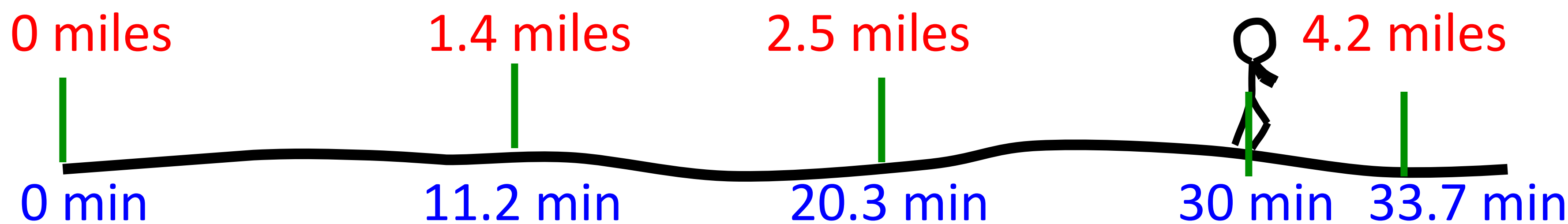
4. Interpolation for equivalence point and for pK_a



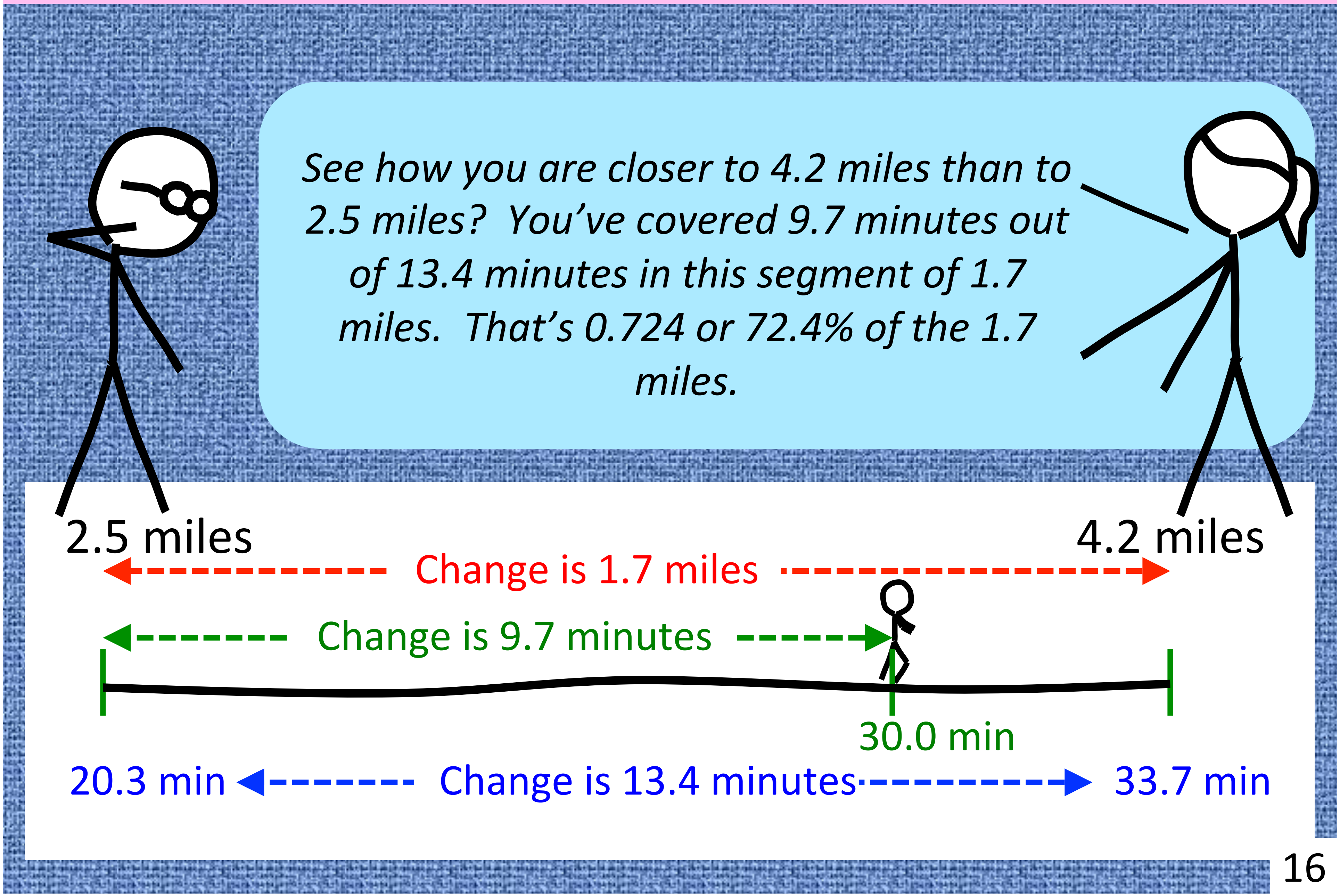
Wait, what is interpolation again?

Ok, so imagine you're jogging along like in the picture. You've passed some reference points as shown. If we want to know how far you've gone after 30 minutes, we use the closest data pairs on each side of 30 minutes.

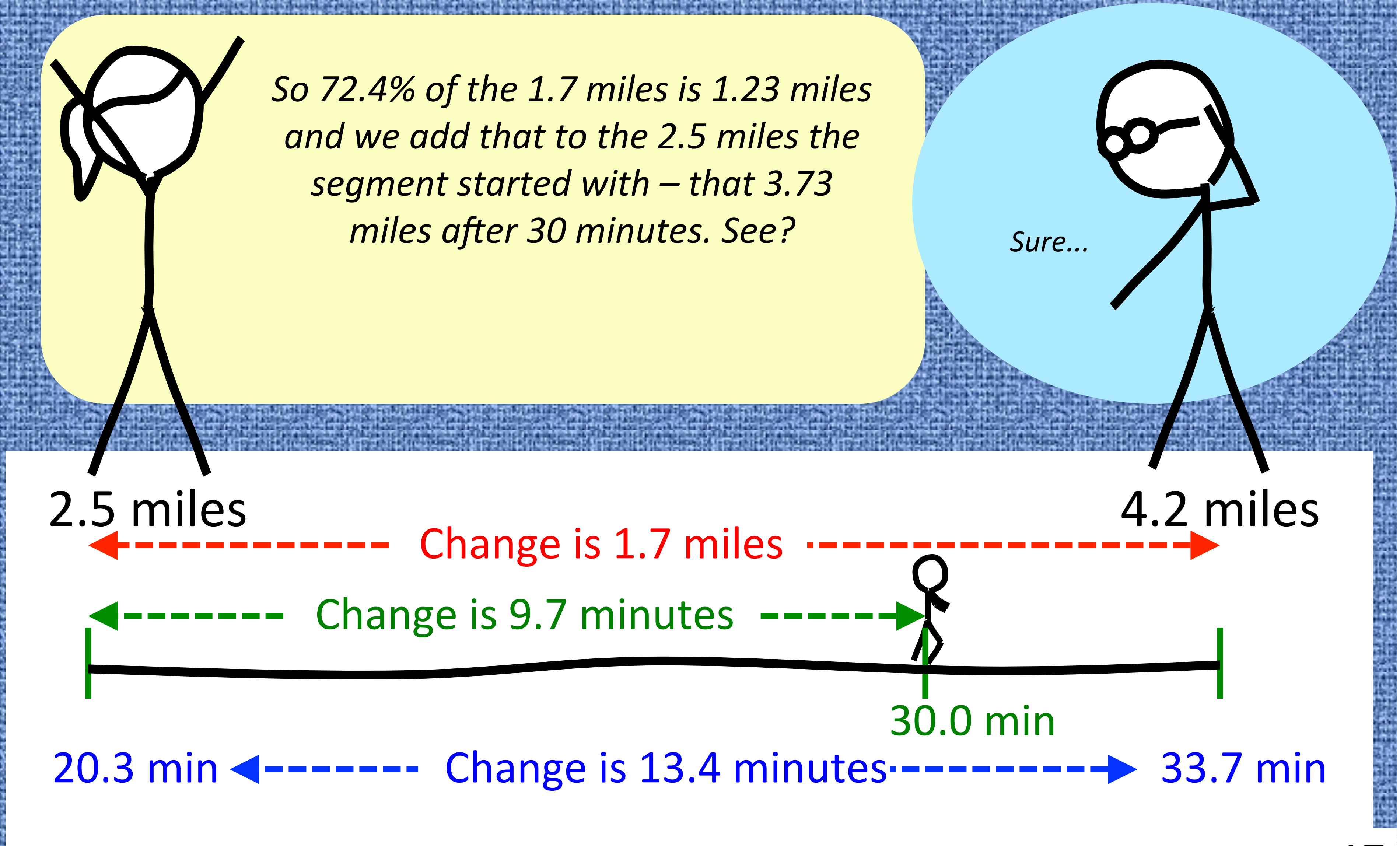




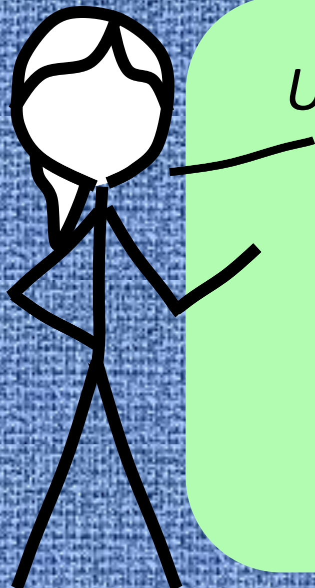
4. Interpolation for equivalence point and for pK_a



4. Interpolation for equivalence point and for pK_a



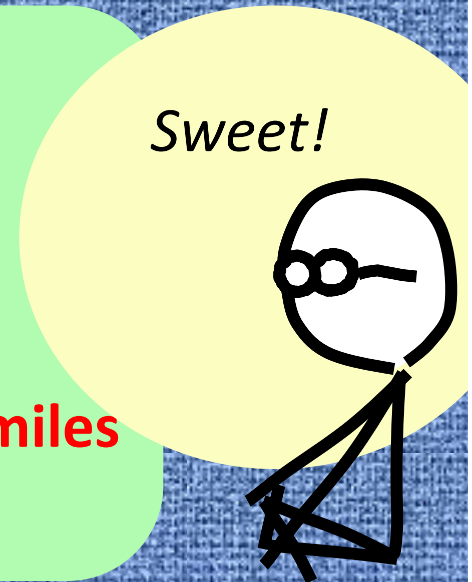
4. Interpolation for equivalence point and for pK_a

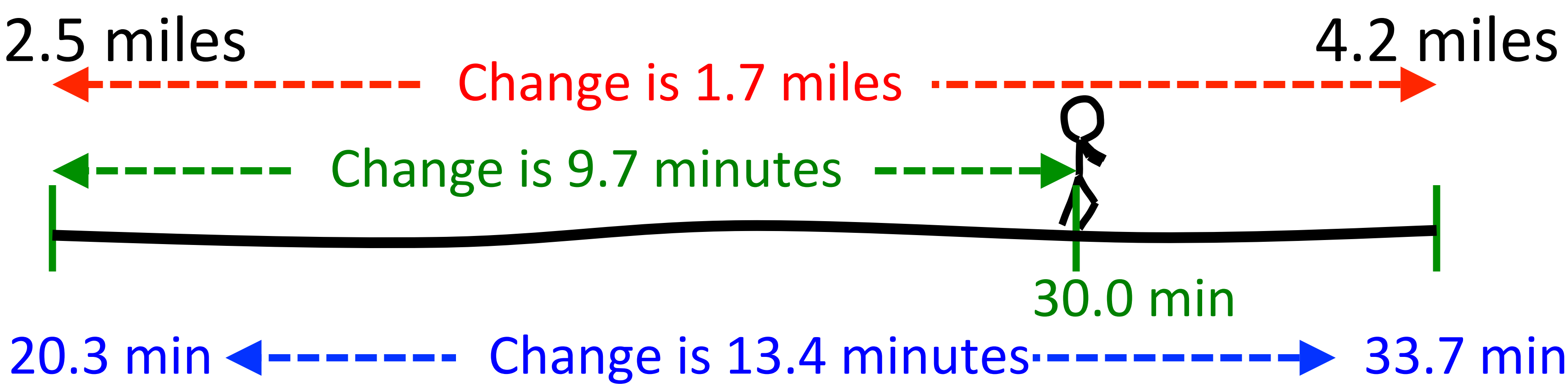


Using math, it looks like...

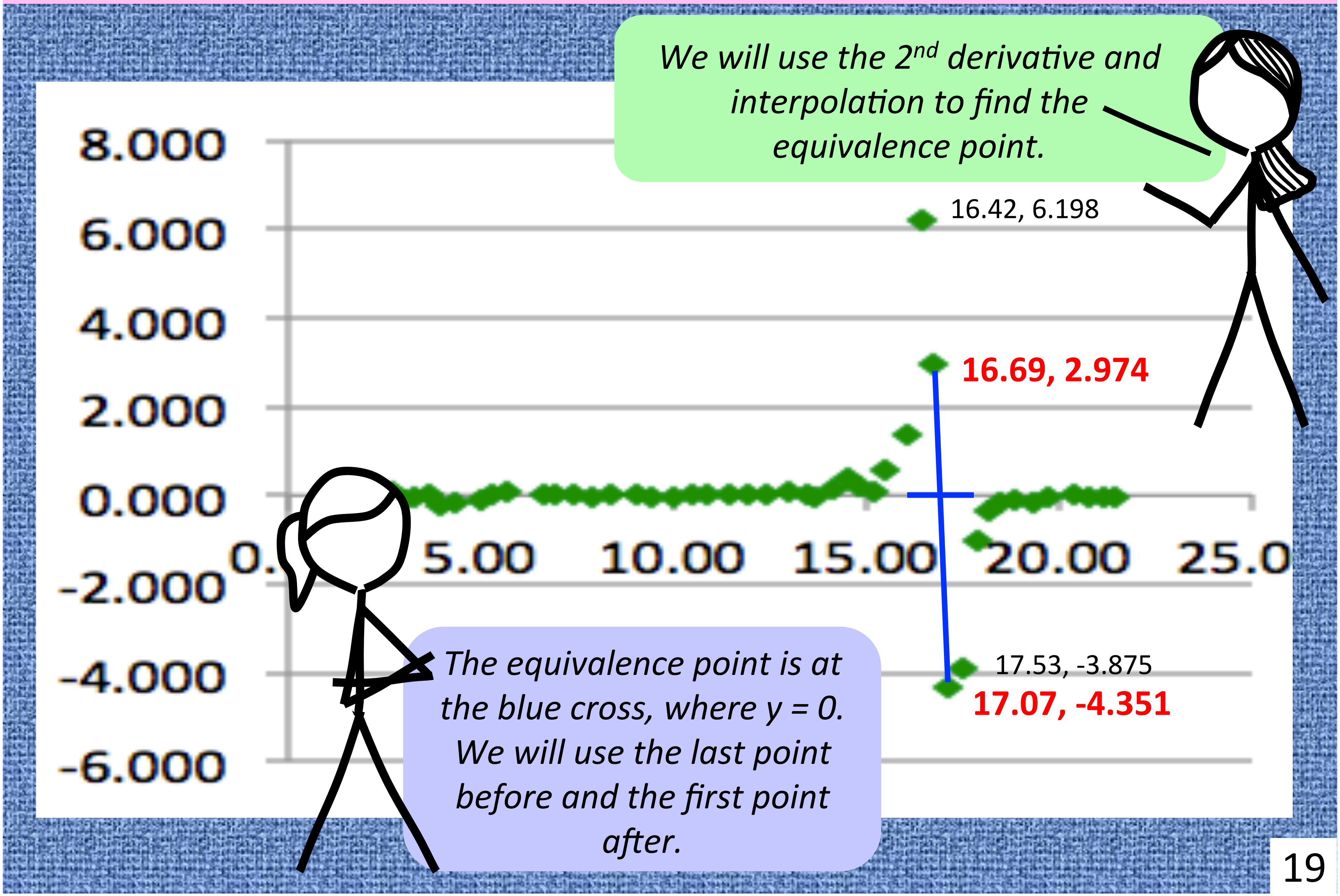
$$= 2.5 + \frac{(30.0 - 20.3)}{(33.7 - 20.3)} \times (4.2 - 2.5)$$

$$= 2.5 + \frac{(9.7)}{(13.4)} \times (1.7) = 3.73 \text{ miles}$$



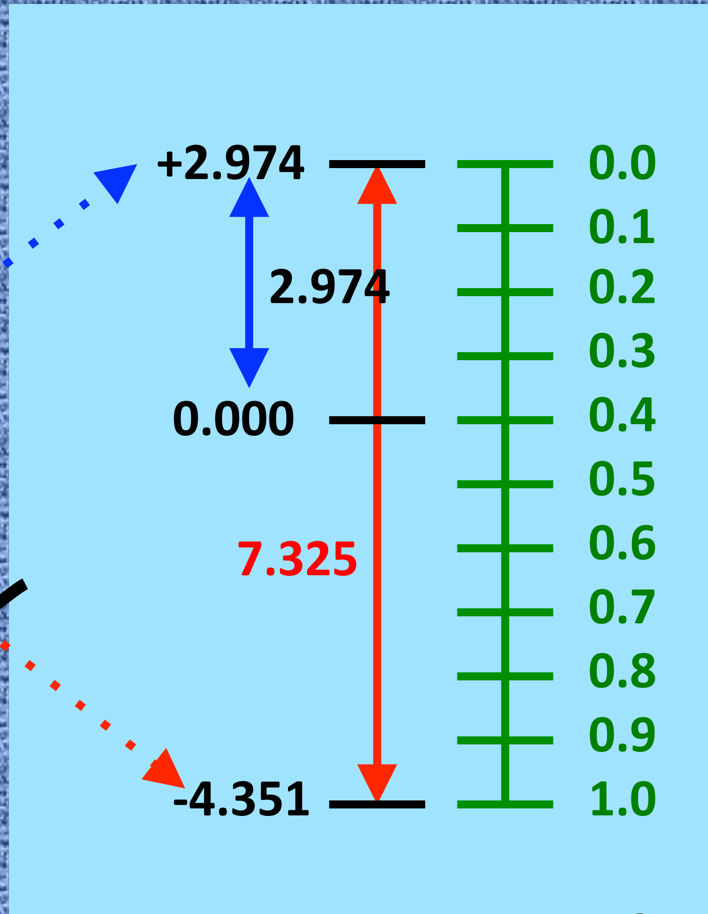


4. Interpolation for equivalence point and for pK_a



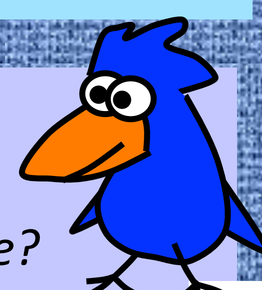
4. Interpolation for equivalence point and for pK_a

	A	B	C	D	E
1	Volume (mL)	pH	1st deriv	2nd deriv	
37	15.18	5.70	0.414	0.060	
38	15.51	5.80	0.505	0.547	
39	16.09	6.16	0.912	1.349	
40	16.42	6.63	1.733	6.198	
41	16.69	7.20	4.631	2.974	
42	17.07	9.64	3.667	-4.351	
43	17.53	10.28	0.976	-3.87[illegible]	
44	17.91	10.46	0.412	-1[illegible]	
45	18.21	10.56	0.293	-0[illegible]	
46	18.49	10.63	0.217	-0.1[illegible]	



The 2nd derivative goes from +2.974 to -4.351 (crossing through zero, but closer to +2.974). Specifically, it is 0.406 of the distance between the two values.

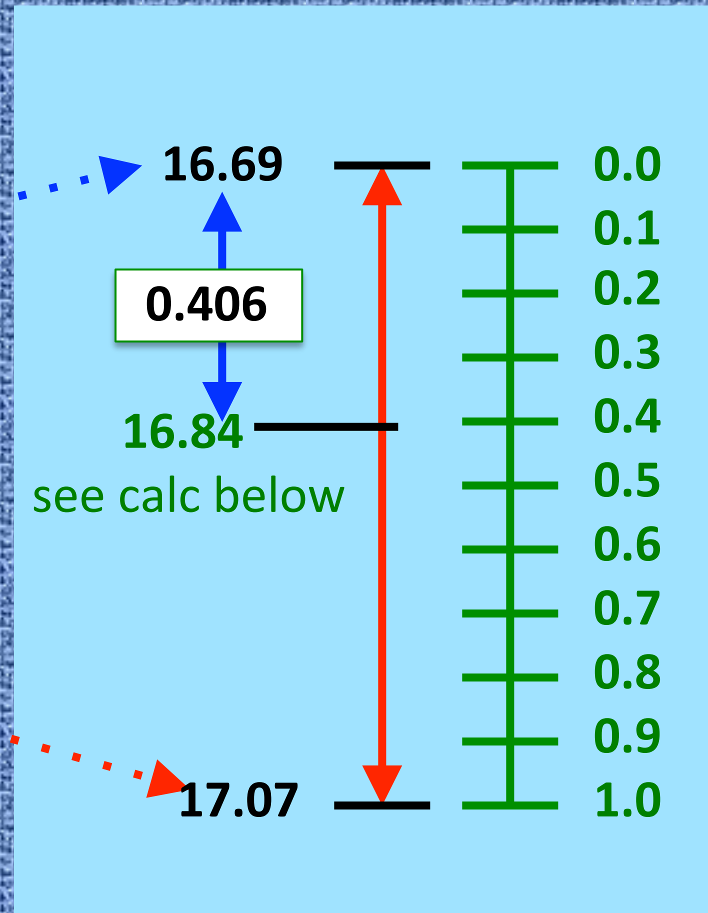
$$\frac{(2.974)}{(7.325)} = 0.406$$

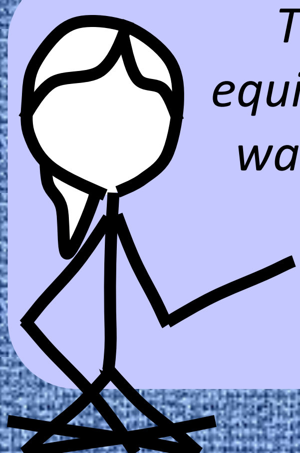


See?

4. Interpolation for equivalence point and for pK_a

	A	B	C	D	E
1	Volume (mL)	pH	1st deriv	2nd deriv	
37	15.18	5.70	0.414	0.060	
38	15.51	5.80	0.505	0.547	
39	16.09	6.16	0.912	1.349	
40	16.42	6.63	1.733	6.198	
41	16.69	7.20	4.631	2.974	
42	17.07	9.64	3.667	-4.351	
43	17.53	10.28	0.976	-3.875	
44	17.91	10.46	0.412	-1.005	
45	18.21	10.56	0.293	-0.336	
46	18.49	10.63	0.217	-0.184	



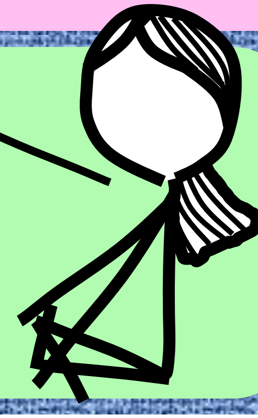


The volume of $[OH^-]$ at the equivalence point is 0.406 of the way between 16.69 and 17.07

= 16.69 + 0.406 x (17.07 – 16.69) = **16.84 mL**

4. Interpolation for equivalence point and for pK_a

The second interpolation is to find pK_a. As we shall see in lecture next week… ***the pK_a = pH at half-way to equivalence point*** *(half of 16.84 mL)*



16.84/2 = 8.42

$$\text{Interpolated pH} = 4.43 + \frac{(8.42 - 8.41)}{(8.99 - 8.41)} \times (4.51 - 4.43) = 4.43138$$

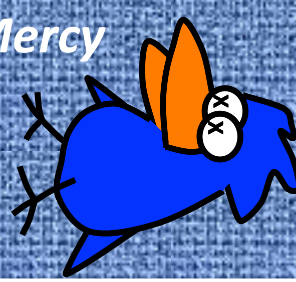
	A	B	C	D
1	Volume (mL)	pH	1st deriv	2nd deriv
18	6.59	4.19	0.137	0.007
19	6.93	4.24	0.134	0.011
20	7.41	4.30	0.146	-
21	7.89	4.38	0.130	-0.028
22	**8.41**	**4.43**	0.118	0.021
23	**8.99**	**4.51**	0.153	0.024
24	9.39	4.58	0.141	-0.035

The lower pH

Difference in pH

We need to fix the sig figs (4.43)

Mercy



4. Interpolation for equivalence point and for pK_a

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq) \quad K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

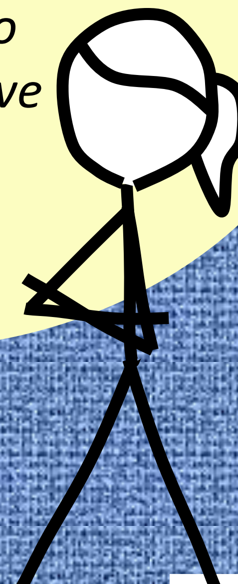
So now we are just about done! Just convert pK_a to K_a!

$$pK_a = 4.43138$$

$$K_a = 10^{-4.43138}$$

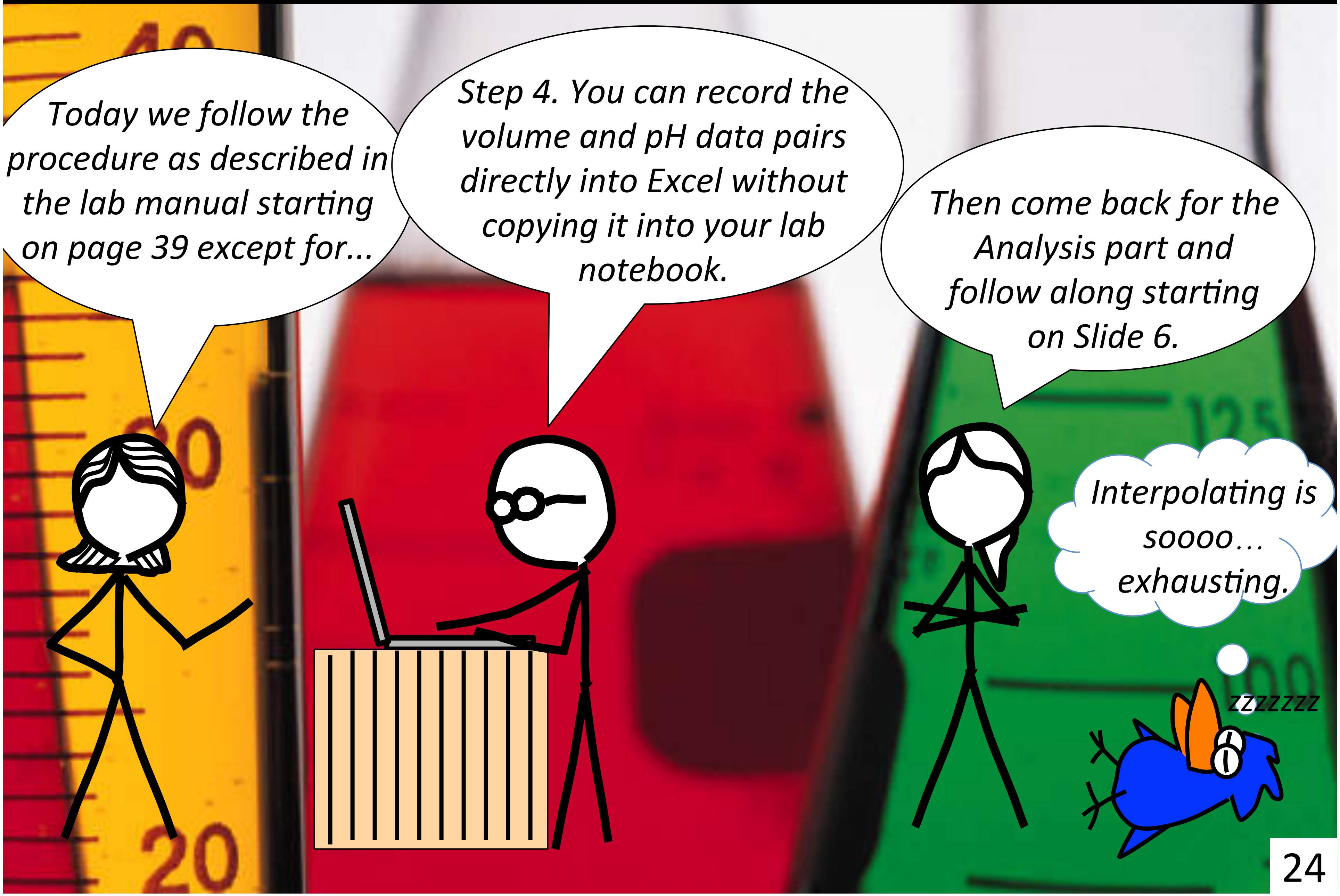
$$= 3.7 \times 10^{-5}$$

So pK_a = 4.43 has TWO significant figures (just the numbers to the right of the decimal), so our answer can have only two sig figs.

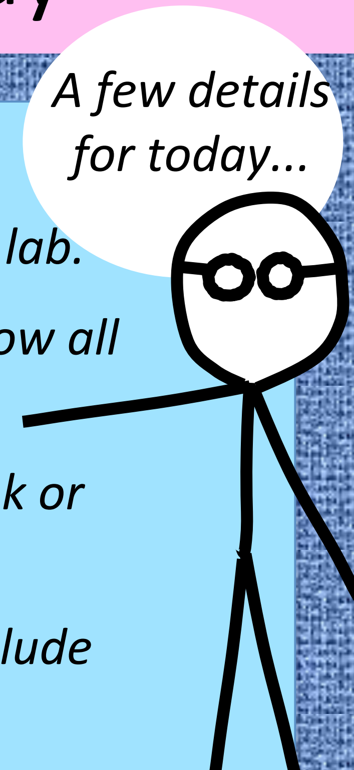


In case you were wondering, the 4 to the left of the decimal in 4.43 represents the exponent for base 10 (the 10^{-5} part) and is not counted as a significant figure

5. Procedure: What we do today



5. Procedure: What we do today



① *Wear your safety glasses. Dress for a mess.*

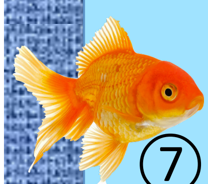
② *Take time writing an introduction in your own words before lab.*

③ *Record observations and details as carefully as possible. Show all of your calculations involving interpolation.*

④ *Compare your K_a with the literature value (from our textbook or the internet). Cite your reference.*

⑤ *The cover sheet summarizes everything that you need to include with your report.*

⑥ The pH probes are like goldfish – they work better if kept in water – always. The pH meters are inaccurate below pH = 2 and above 11.5.

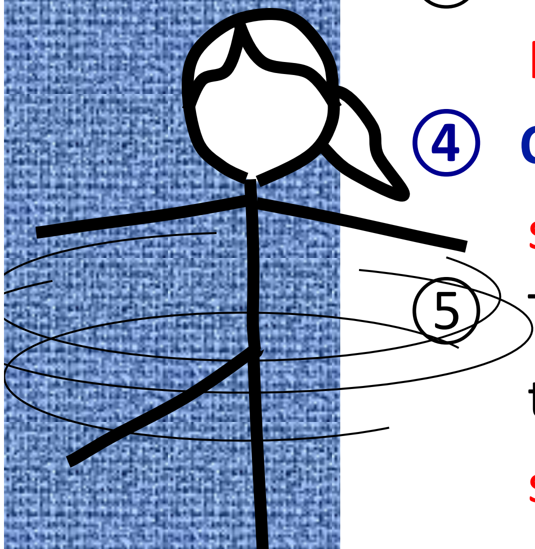


⑦ Work in pairs. Do one titration and if it looks good, you're done collecting data.

⑧ Use this presentation (or internet) to understand interpolation.

⑨ Put thought into writing your conclusion.

6. Your Lab Report



1. First, the cover page with TA initials.
2. Next, the trimmed copy pages from your lab notebook.
3. Attach graphs and data today. Staple all together. Reports without graphs will not be graded.
4. **On-line results** due at the end of class today. Late submissions are not graded – see the syllabus.
5. Turn in lab report today or ***before*** the start of class tomorrow. Late labs may not be graded – see the syllabus.