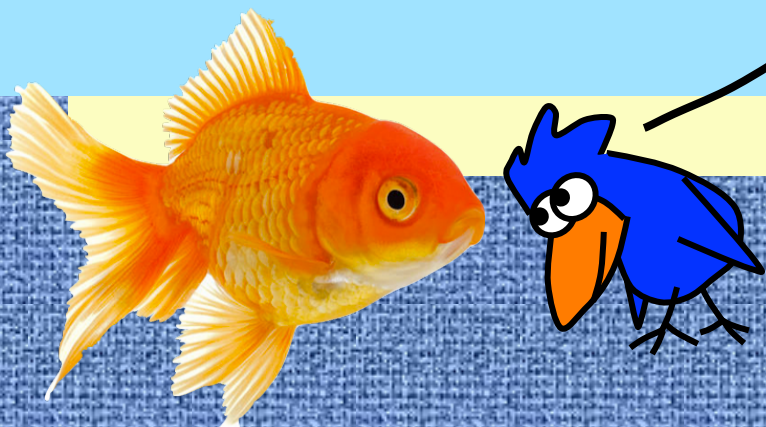


Experiment 6

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.



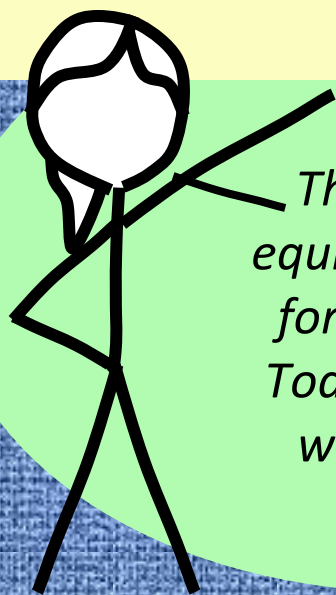
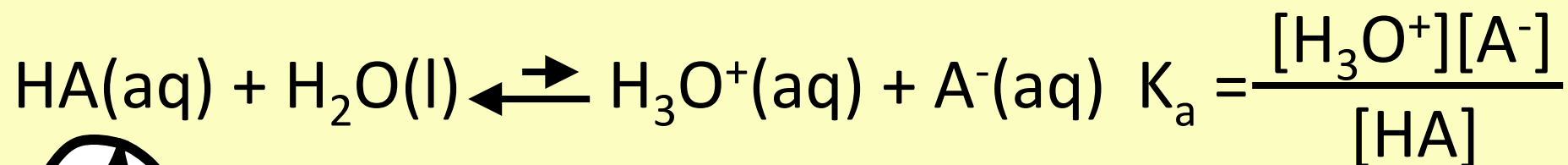
Overview:

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?

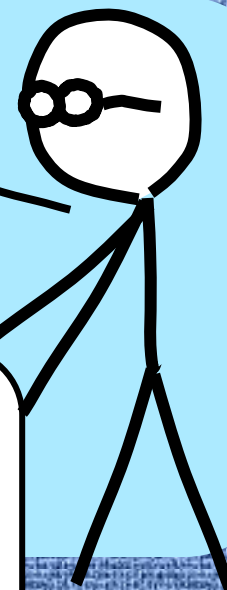


1. Introduction and Overview



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 .



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

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

Just in case you forgot...

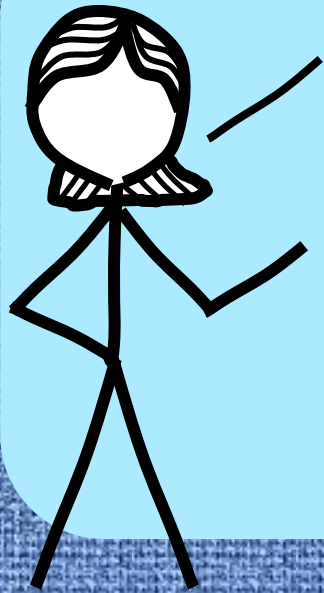
$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$[\text{H}_3\text{O}^+] = 10^{-\text{pH}}$$

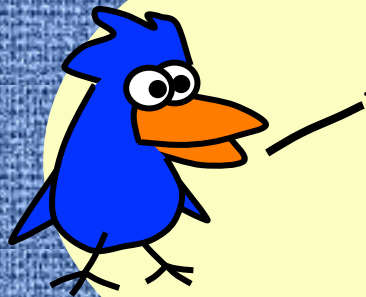


Info for
Introduction

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.



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

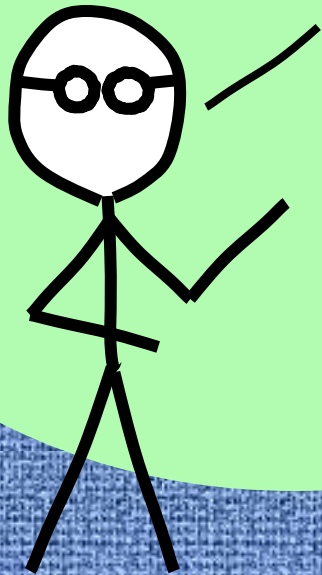
	A	B
1	Volume (mL)	pH
2	0.00	2.57
3	0.72	2.83
4	1.01	2.91
5	1.41	3.12
6	1.78	3.26
7	2.05	3.32
8	2.31	3.38
9	2.68	3.48
10	3.01	3.60
11	3.31	3.67
12	3.61	3.75
13	3.99	3.87
14	4.29	3.92
15	5.00	4.02
16	5.32	4.03
17	5.69	4.07
18	6.59	4.19
19	6.93	4.24
20	7.41	4.30

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

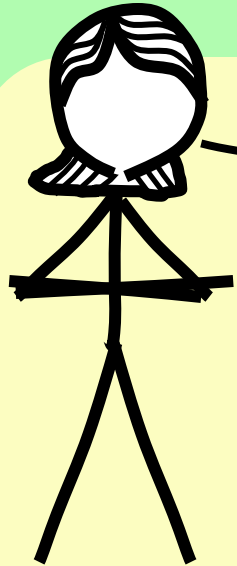


2. Collect data

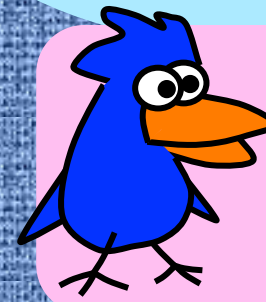
Early in the titration we can add the sodium hydroxide about 1 mL at a time until the pH reaches 5-ish.



Then sloooow way down and collect more data. Maybe every 0.5 mL or even 0.2 mL.



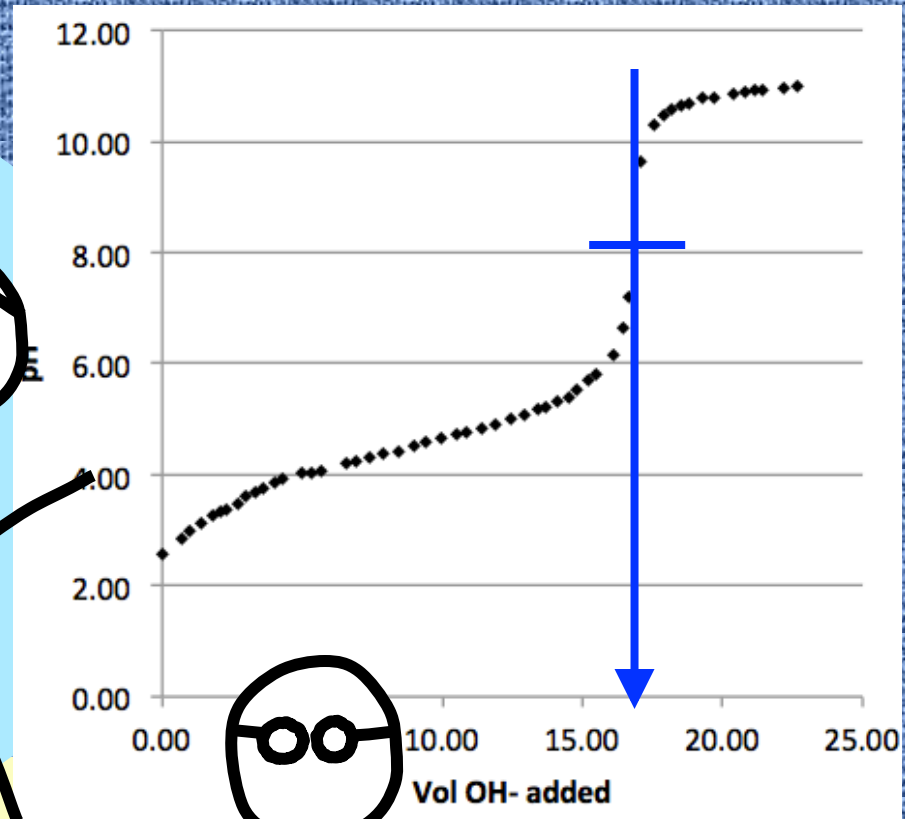
Try to collect the data so that the pH never jumps more than half of a pH unit at a time between pH 5 and 9.



You can go back to adding 1 mL after the pH gets to 9.

3. Making the titration graphs

The equivalence point is shown with the blue cross. Our goal is to know the volume associated with the equivalence point.



It is (a) not pH 7 and (b) very hard to estimate from this graph.

Is there anything we can do?

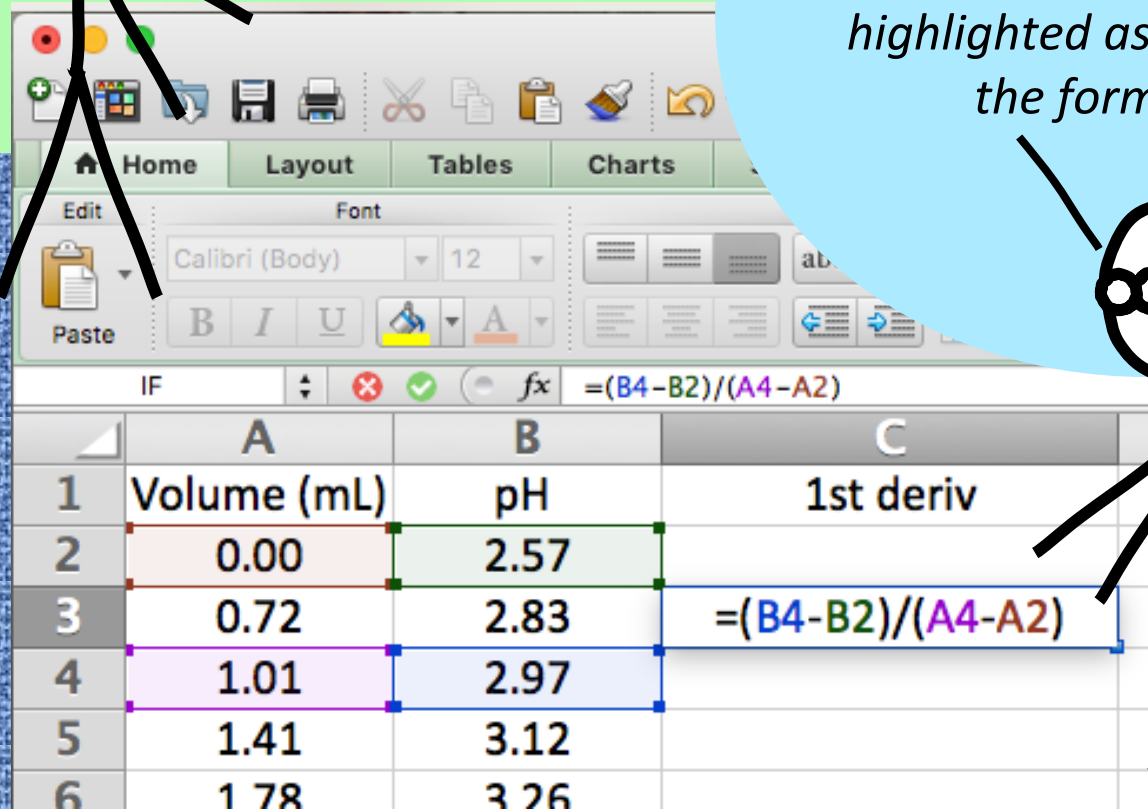


3. Making the titration graphs

We can make measuring the equivalence point easier by taking the first derivative.

So... in Cell C3, enter the formula as shown. Note the cells typed in are highlighted as you enter the formula.

Isn't this the slope, $\Delta y / \Delta x$?



The screenshot shows a spreadsheet with the following data:

	A	B	C
1	Volume (mL)	pH	1st deriv
2	0.00	2.57	
3	0.72	2.83	$=(B4-B2)/(A4-A2)$
4	1.01	2.97	
5	1.41	3.12	
6	1.78	3.26	

The formula bar shows the formula $=(B4-B2)/(A4-A2)$ and the formula is entered into cell C3. The cells B2, B4, A2, and A4 are highlighted in the spreadsheet.



3. Making the titration graphs

Then copy
Cell C3...

... and paste it
from Cell C4 to
the end. Voila!
It knows what you
want.

	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	D
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	
15	5.00	4.00	0.127	

3. Making the titration graphs

Next we will calculate the second derivative. See how it is similar to how we did the first derivative?



Notice we still divide by ΔVol



The screenshot shows an Excel spreadsheet titled "Expt 6 Data.xlsx". The spreadsheet has columns A, B, C, and D. Row 1 contains headers: "Volume (mL)", "pH", "1st deriv", and "2nd deriv". Rows 2 through 8 contain data. The formula bar shows the formula $= (C5 - C3) / (A5 - A3)$. The spreadsheet is showing the calculation of the second derivative in column D.

	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	

Then do the copy-and-paste thingy like we did for the first derivative data.



3. Making the titration graphs

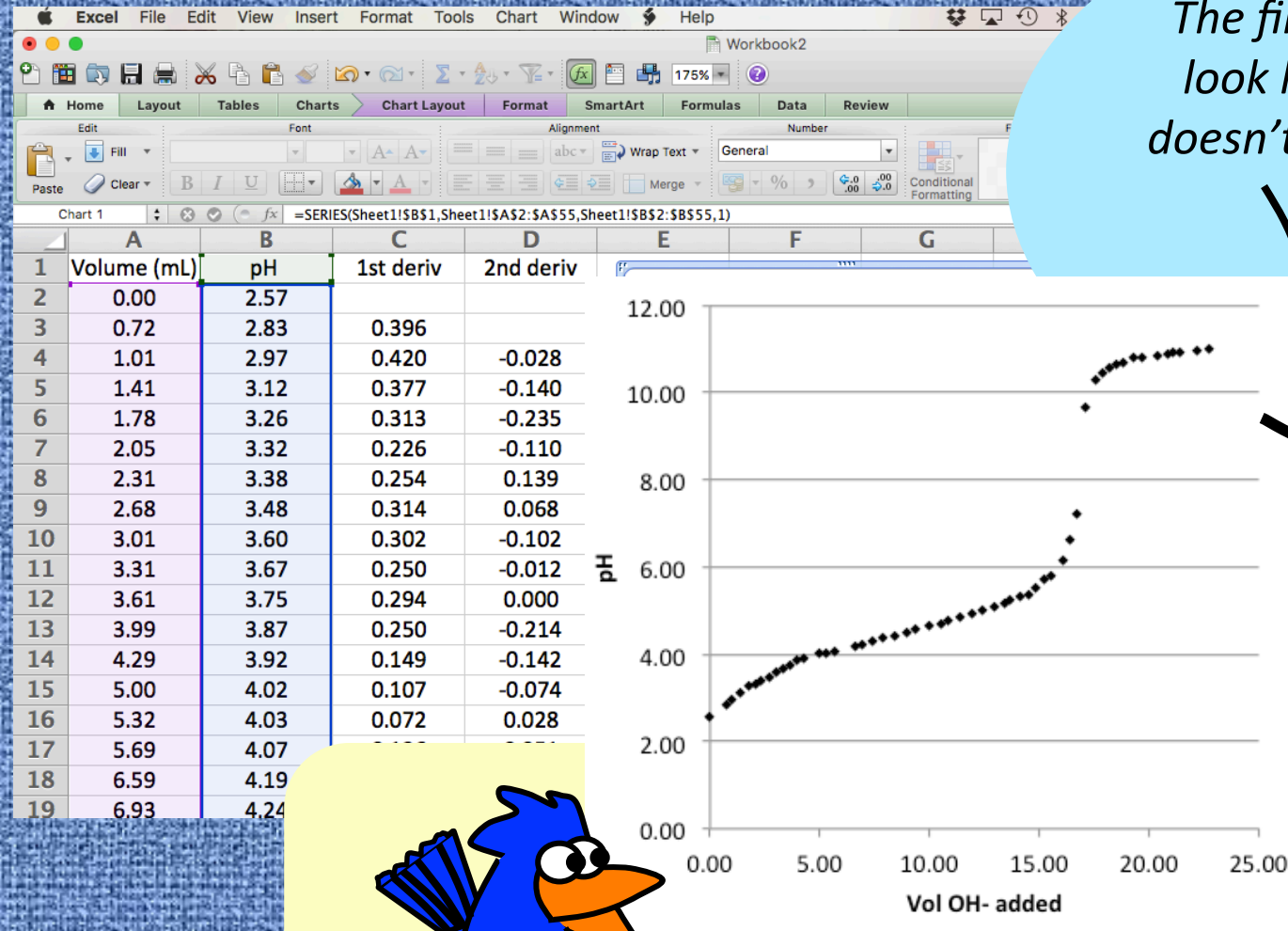
We are going to make three scatter graphs. In each case we start by highlighting the columns of data we want plotted. Here we see Columns A and B are highlighted.

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

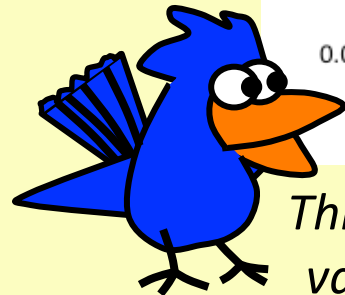
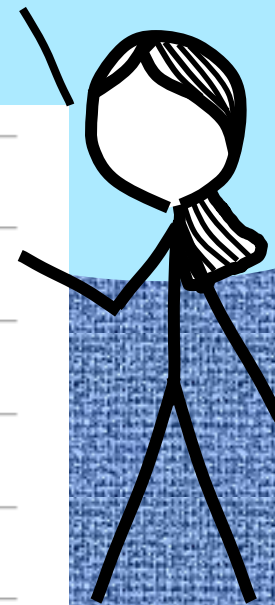
The screenshot shows the Microsoft Excel interface. The 'Insert' tab is active, and the 'Charts' group is expanded to show the 'Scatter' chart type. The spreadsheet data is visible in the background, with columns A and B highlighted. The data in column A is 'Volume (ml)' and the data in column B is 'pH'. The 'Scatter' menu is open, showing five options: 'Marked Scatter', 'Smooth Marked Scatter', 'Smooth Lined Scatter', 'Straight Marked Scatter', and 'Straight Lined Scatter'. The 'Marked Scatter' option is selected.

	A	B	C	D
1	Volume (ml)			2nd deriv
2	0.00			
3	0.72			
4	1.01			
5	1.41			
6	1.78			
7	2.05			
8	2.31			
9	2.68			
10	3.01			
11	3.31			
12	3.61			

3. Making the titration graphs



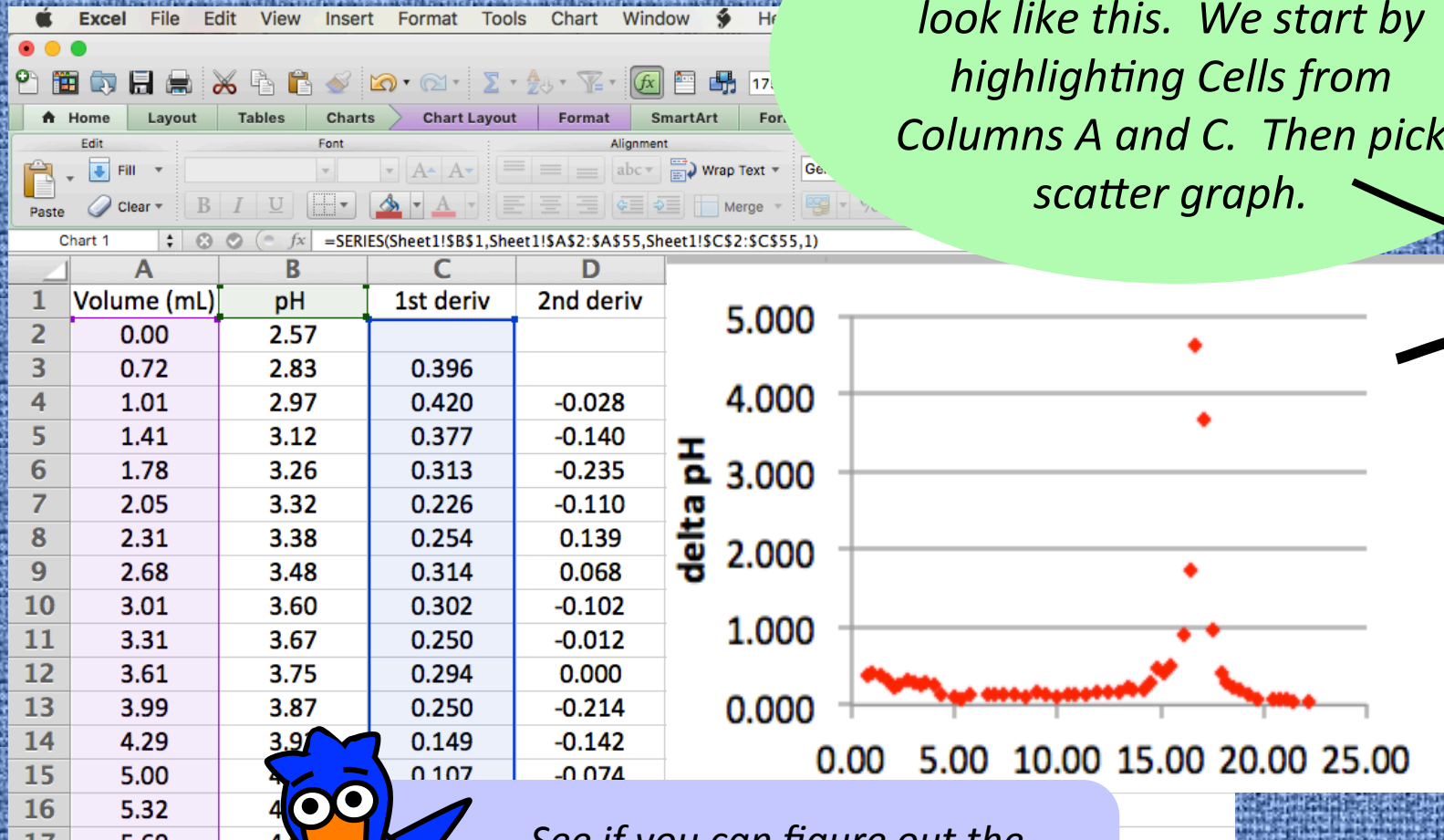
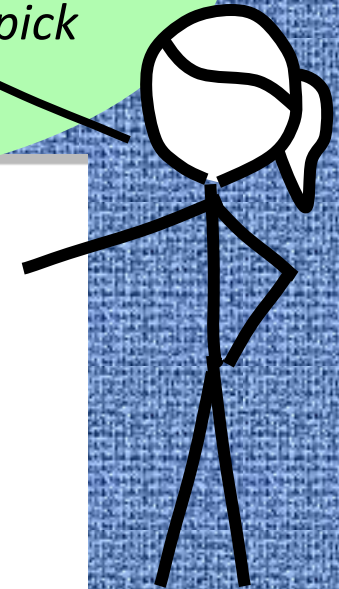
The first graph will look like this. If it doesn't, ask for help!



This is your basic, garden variety titration curve...

3. Making the titration graphs

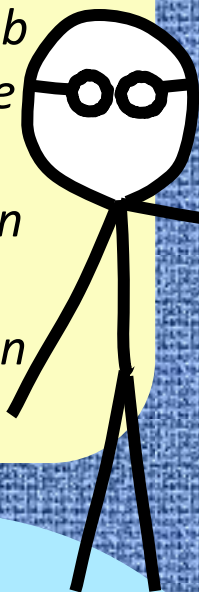
The first derivative graph will look like this. We start by highlighting Cells from Columns A and C. Then pick scatter graph.



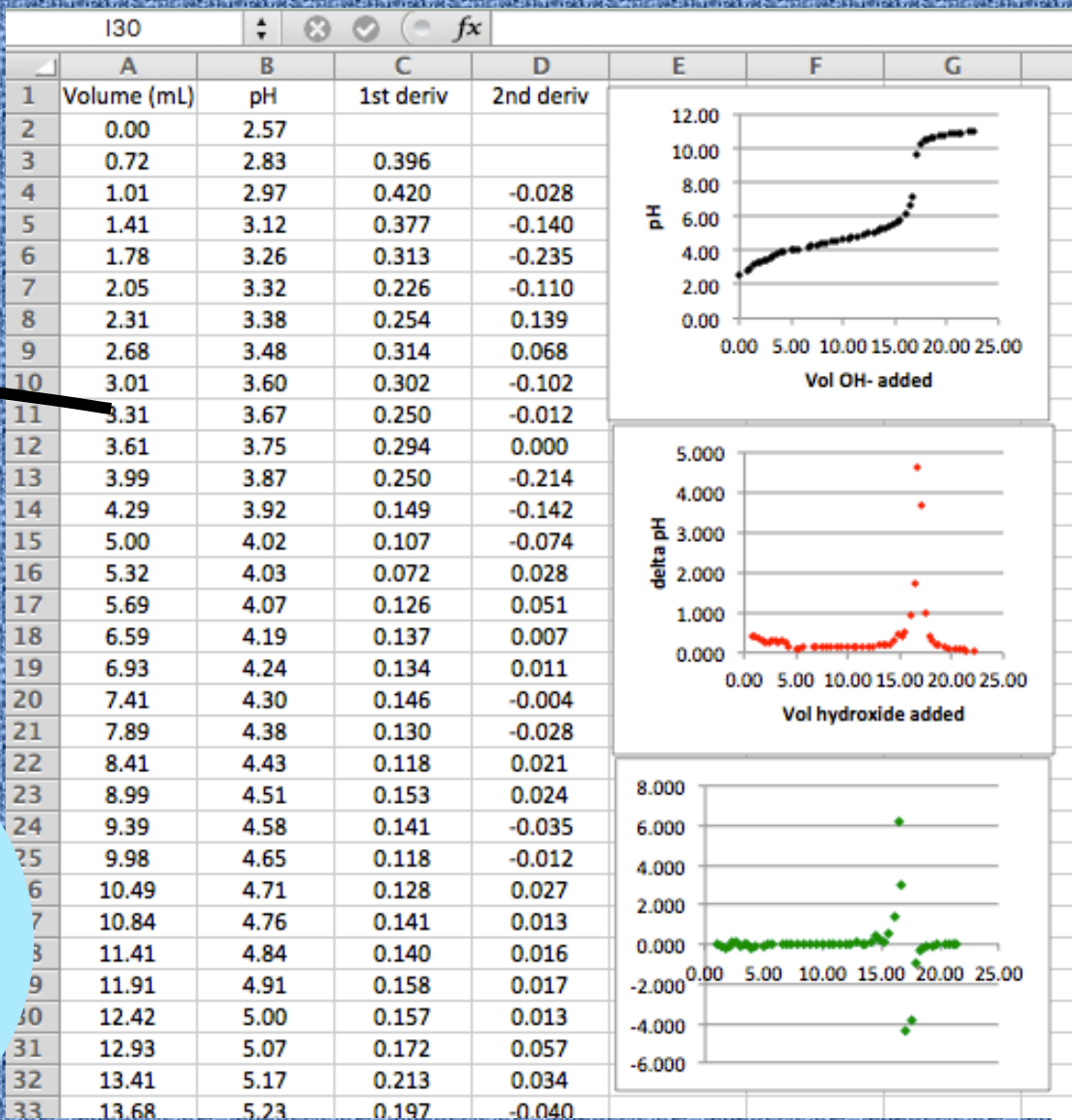
See if you can figure out the second derivative graph – hint: Use stuff from Columns A and D.

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.



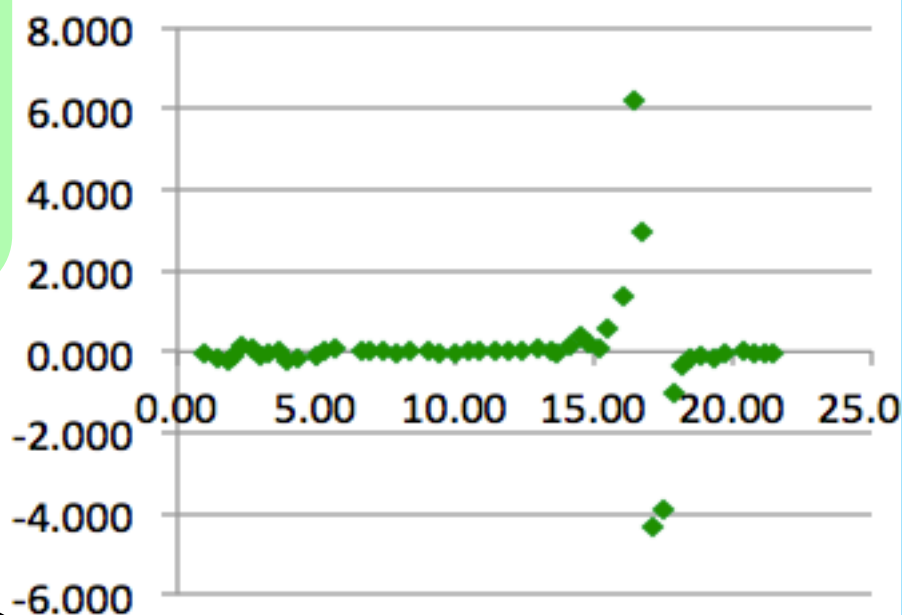
If you need to use a second page, that's fine.



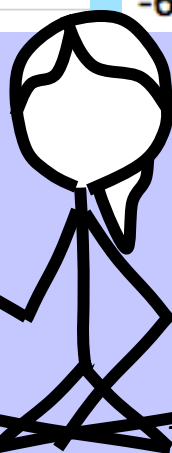
4. Interpolation for equivalence point and for pK_a



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	



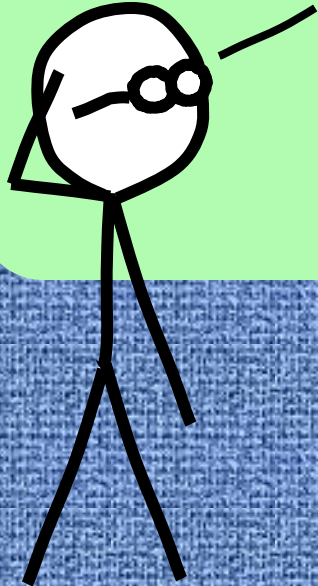
See how the second derivative data goes from large and positive to large and negative? Somewhere in between these two volumes, 16.69 mL and 17.07 mL, the 2nd derivative goes through zero – the equivalence point!

I'm guessing this is where we interpolate...

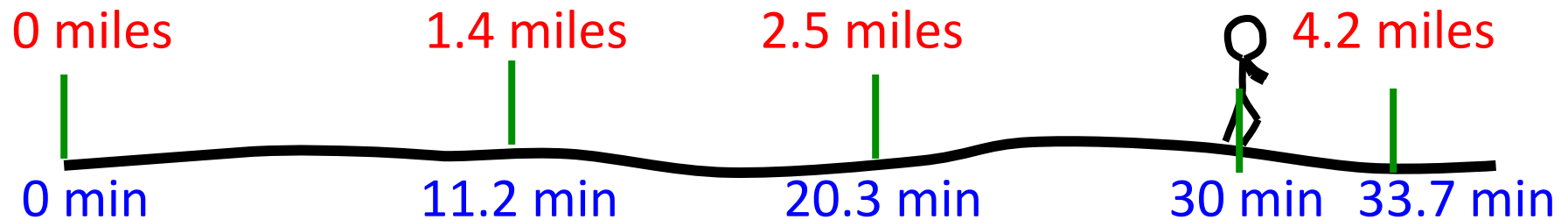
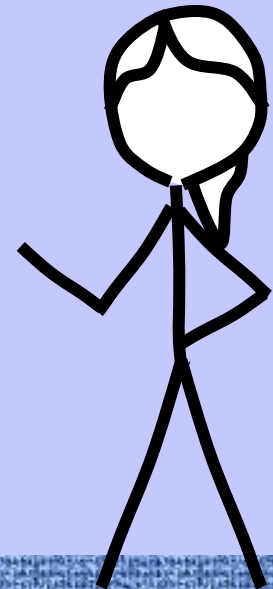


4. Interpolation for equivalence point and for pK_a

Wait, what is interpolation again?

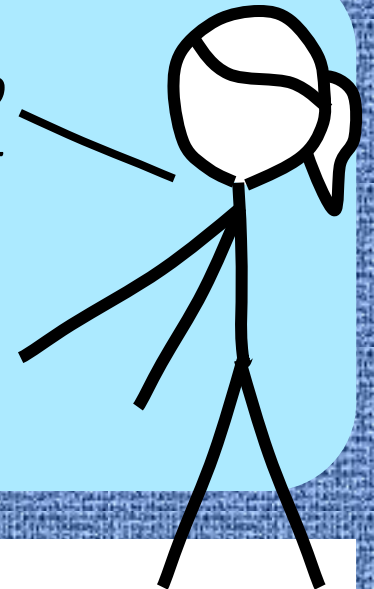
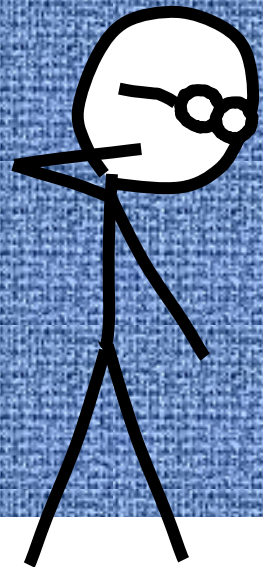


Ok, so imagine you're jogging along like in the picture. You've passed some reference points as shown. If we want to know how far you've gone after 30 minutes, we use the closest data pairs on each side of 30 minutes.



4. Interpolation for equivalence point and for pK_a

See how you are closer to 4.2 miles than to 2.5 miles? You've covered 9.7 minutes out of 13.4 minutes in this segment of 1.7 miles. That's 0.724 or 72.4% of the 1.7 miles.



2.5 miles

4.2 miles

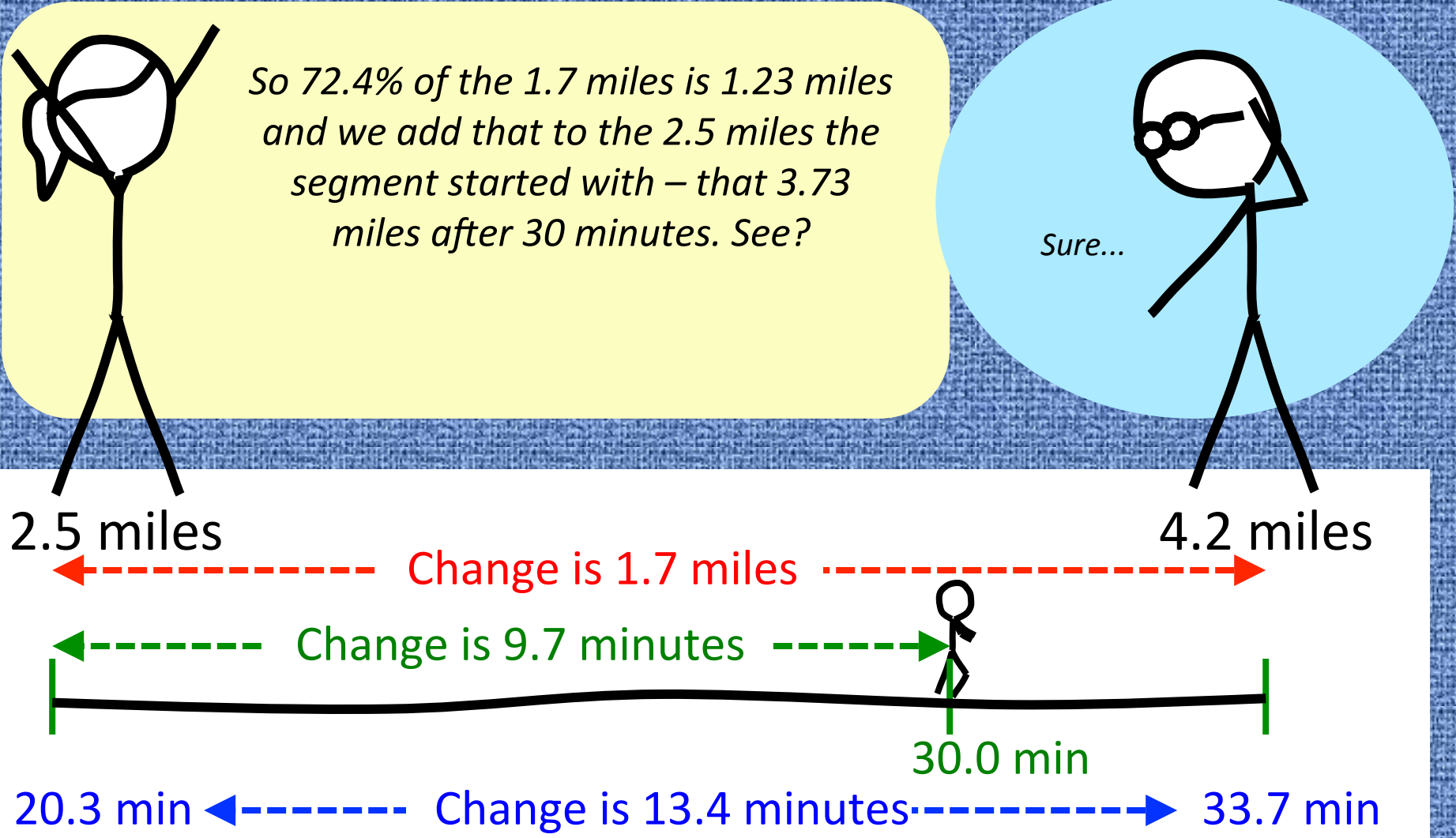
Change is 1.7 miles

Change is 9.7 minutes

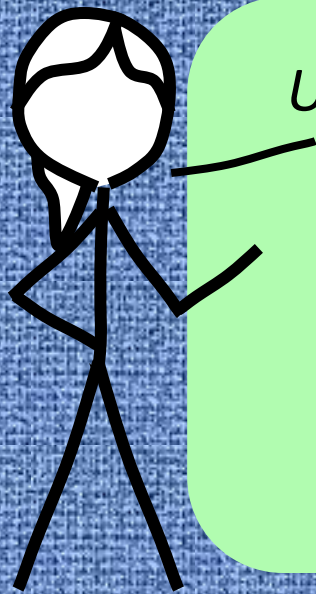
30.0 min

20.3 min Change is 13.4 minutes 33.7 min

4. Interpolation for equivalence point and for pK_a



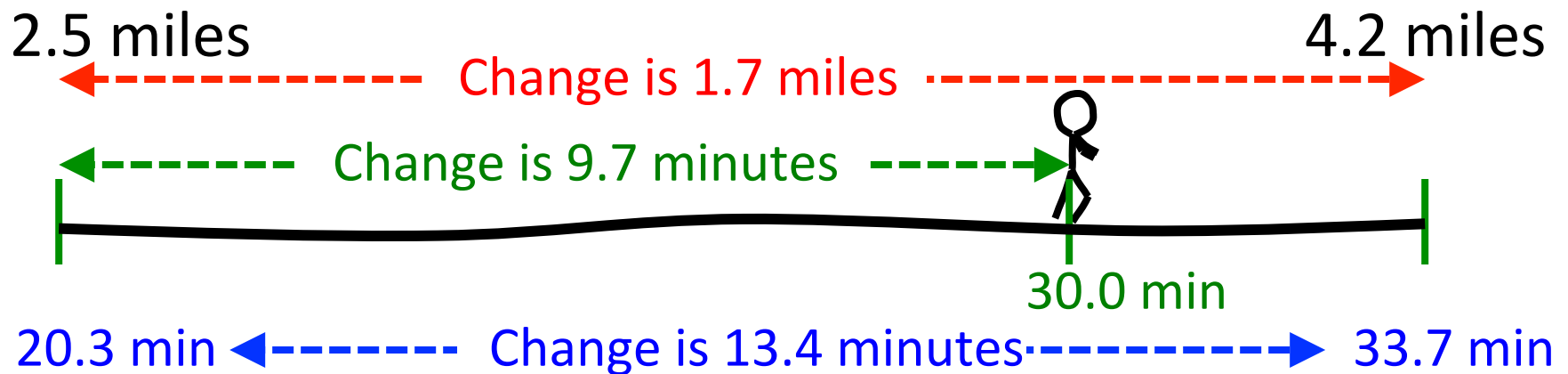
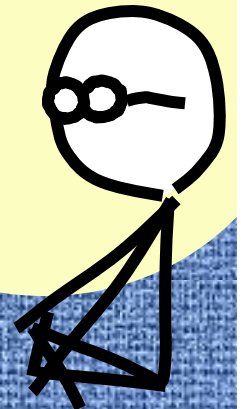
4. Interpolation for equivalence point and for pK_a



Using math, it looks like...

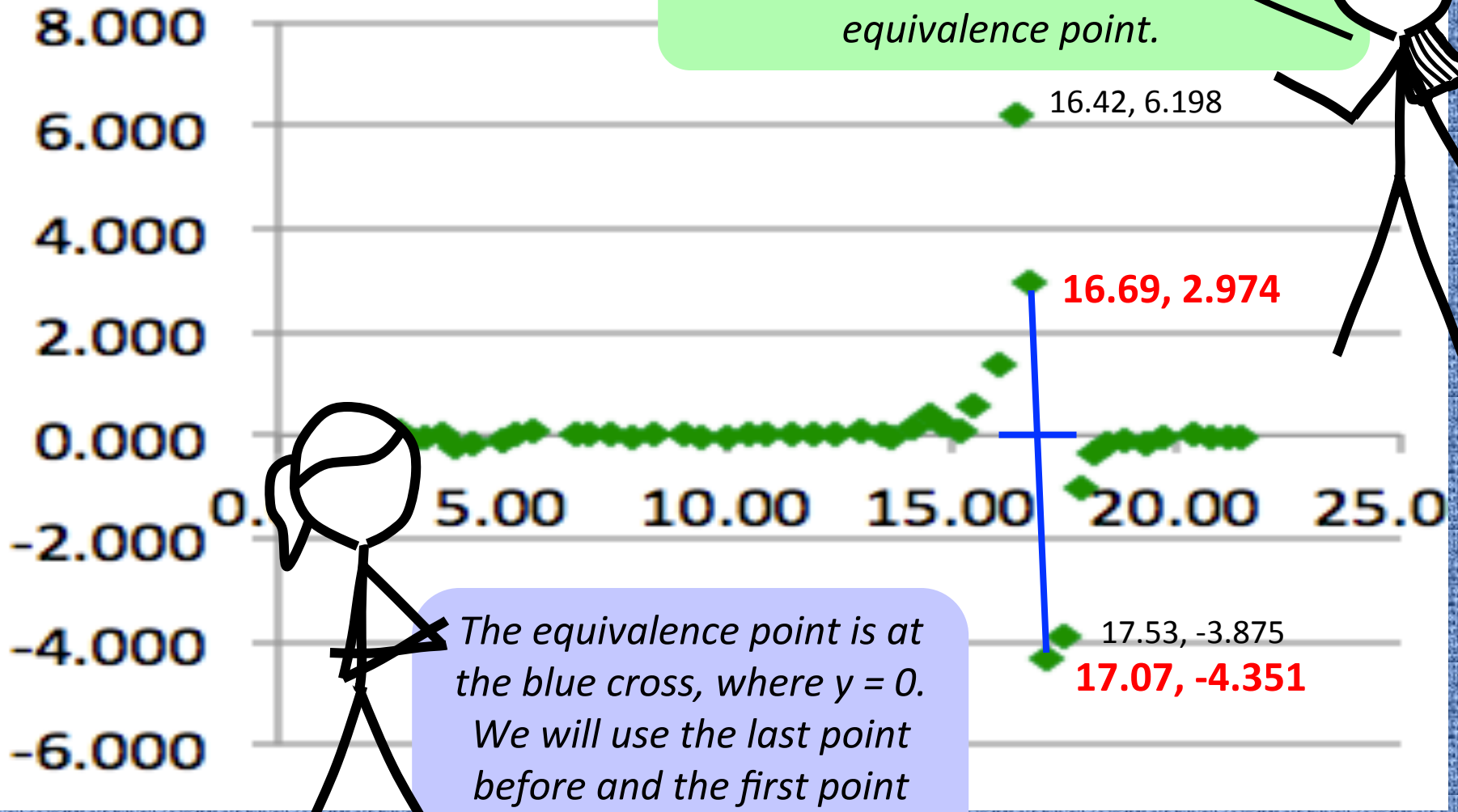
$$\begin{aligned} &= 2.5 + \frac{(30.0 - 20.3)}{(33.7 - 20.3)} \times (4.2 - 2.5) \\ &= 2.5 + \frac{(9.7)}{(13.4)} \times (1.7) = 3.73 \text{ miles} \end{aligned}$$

Sweet!



4. Interpolation for equivalence point and for pK_a

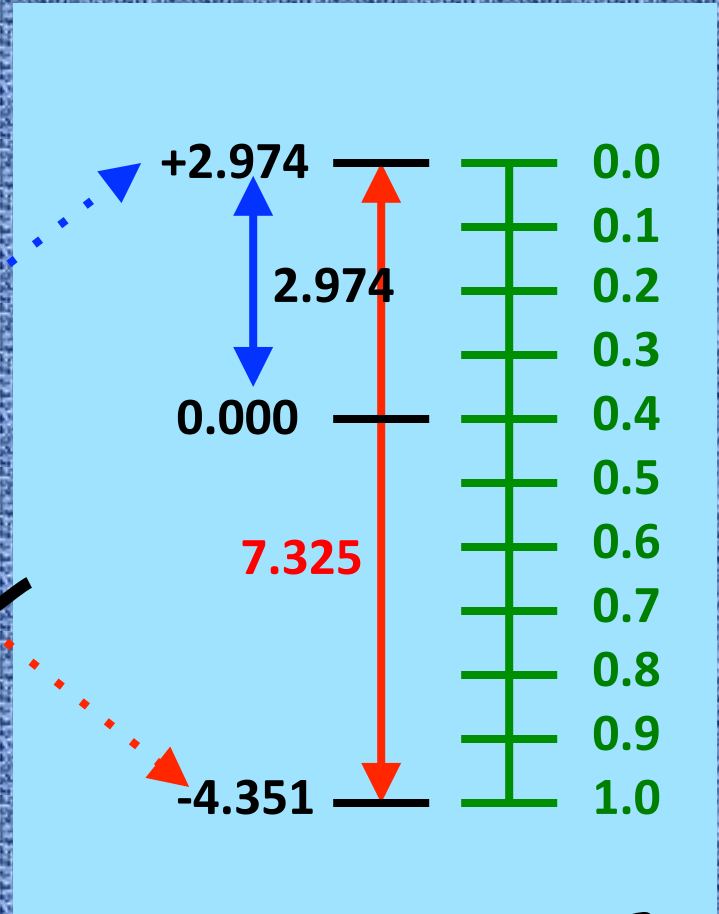
We will use the 2nd derivative and interpolation to find the equivalence point.



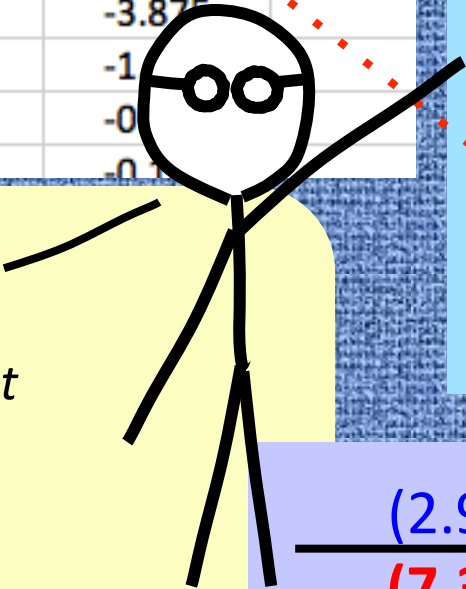
The equivalence point is at the blue cross, where $y = 0$. We will use the last point before and the first point after.

4. Interpolation for equivalence point and for pK_a

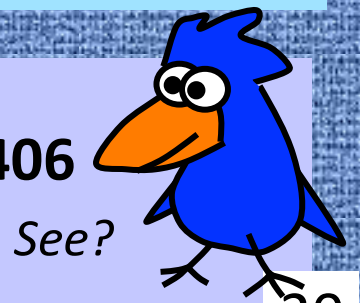
	A	B	C	D	E
1	Volume (mL)	pH	1st deriv	2nd deriv	
37	15.18	5.70	0.414	0.060	
38	15.51	5.80	0.505	0.547	
39	16.09	6.16	0.912	1.349	
40	16.42	6.63	1.733	6.198	
41	16.69	7.20	4.631	2.974	
42	17.07	9.64	3.667	-4.351	
43	17.53	10.28	0.976	-3.875	
44	17.91	10.46	0.412	-1.111	
45	18.21	10.56	0.293	-0.333	
46	18.49	10.63	0.217	-0.111	



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.



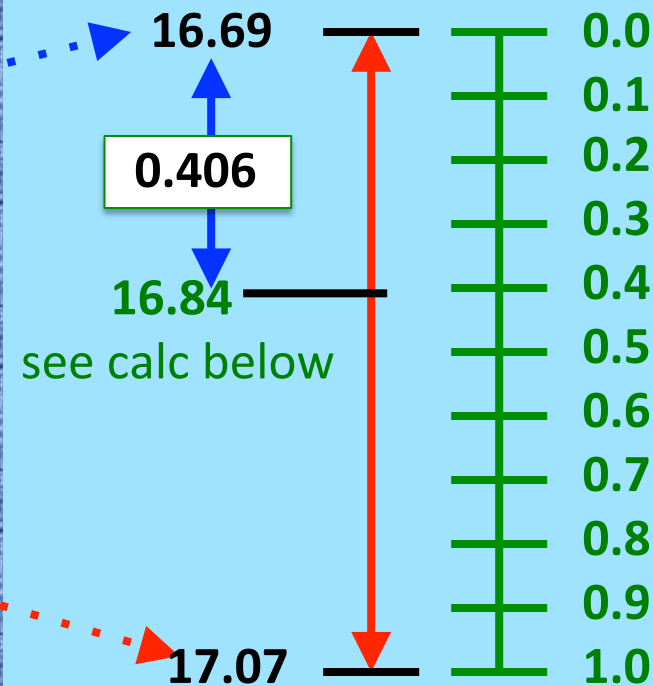
$$\frac{(2.974)}{(7.325)} = 0.406$$



See?

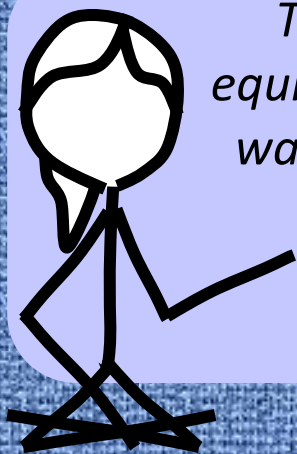
4. Interpolation for equivalence point and for pK_a

	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	



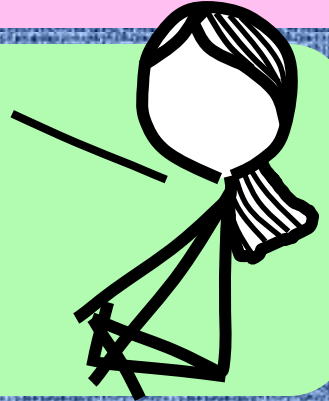
The volume of $[OH^-]$ at the equivalence point is 0.406 of the way between 16.69 and 17.07

$$= 16.69 + 0.406 \times (17.07 - 16.69) = 16.84 \text{ mL}$$



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)



$$16.84/2 = 8.42$$

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

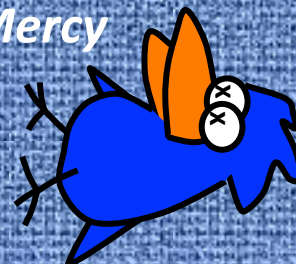
	A	B	C	D
1	Volume (mL)	pH	1st deriv	2nd deriv
18	6.59	4.19	0.137	0.007
19	6.93	4.24	0.134	0.011
20	7.41	4.30	0.146	-
21	7.89	4.38	0.130	-0.028
22	8.41	4.43	0.118	0.021
23	8.99	4.51	0.153	0.024
24	9.39	4.58	0.141	-0.035

Difference in pH

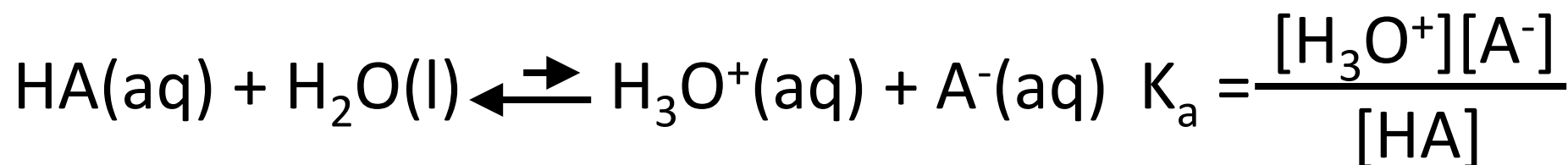
The lower pH

We need to fix the sig figs (4.43)

Mercy



4. Interpolation for equivalence point and for pK_a



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



$$\begin{aligned} pK_a &= 4.43138 \\ K_a &= 10^{-4.43138} \\ &= 3.7 \times 10^{-5} \end{aligned}$$

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

Today we follow the procedure as described in the lab manual starting on page 39 except for...

Step 4. You can record the volume and pH data pairs directly into Excel without copying it into your lab notebook.

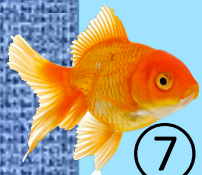
Then come back for the Analysis part and follow along starting on Slide 6.

Interpolating is sooooo... exhausting.

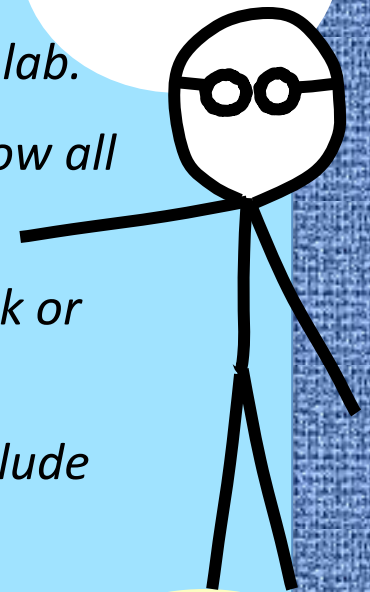
zzzzzzzz

5. Procedure: What we do today

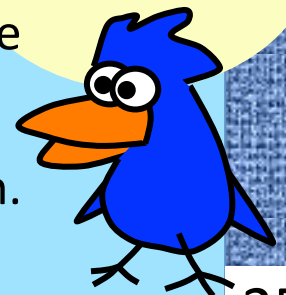
- ① *Wear your safety glasses. Dress for a mess.*
- ② *Take time writing an introduction in your own words before lab.*
- ③ *Record observations and details as carefully as possible. Show all of your calculations involving interpolation.*
- ④ *Compare your K_a with the literature value (from our textbook 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.*



A few details for today...



A little off-roading here.



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.**

