Experiment 11

12 November 2019

Enthalpy of Neutralization

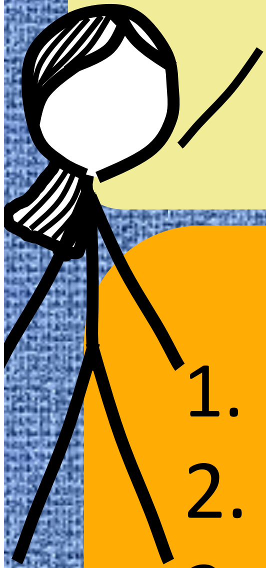
$H_3O^+ (aq) + OH^-(aq) \rightarrow 2\ H_2O(l) \quad \Delta H_{rxn} = ?$

$q_{surr} = c_{sol'n} \times m_{sol'n} \times \Delta T_{sol'n}$

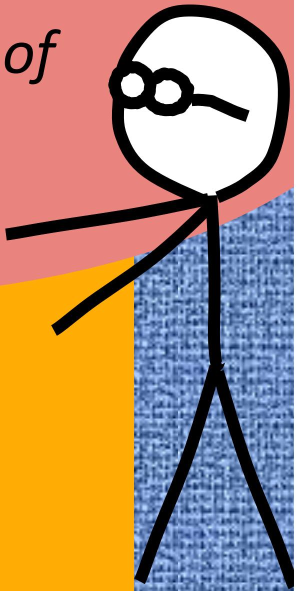
Oh! The things we will do. Oh! The things we will learn! And all in just three hours.

$q_{surr} = -q_{rxn}$

Objective: To use calorimetry to measure the heat released by a chemical reaction.



Today we will be measuring how much heat is released when a strong acid and a strong base are reacted.



The concept of measuring heat transferred can be extended to all sorts of situations.

Overview:

1. The reaction and ΔH_{rxn}
2. Measuring heat, q, by calorimetry
3. Data analysis and calculations
4. Procedure: What we do today
5. Your lab report

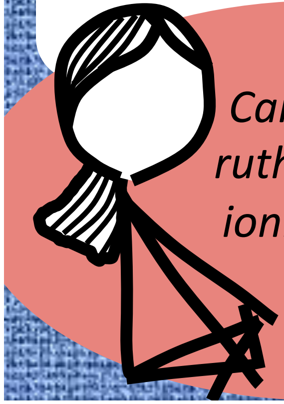
1. The reaction and ΔH_{rxn}

$$HClO_4(aq) + LiOH(aq) \rightarrow LiClO_4(aq) + H_2O(l) \quad \Delta H_{rxn} = ?$$

Here is a reaction similar to the one you are doing today. This is the overall reaction. If we break the strong acid and soluble salts into ions, we get the ionic equation, shown by my feet.

See how he made H^+ into H_3O^+? He had to add a water to the right side to keep things balanced.

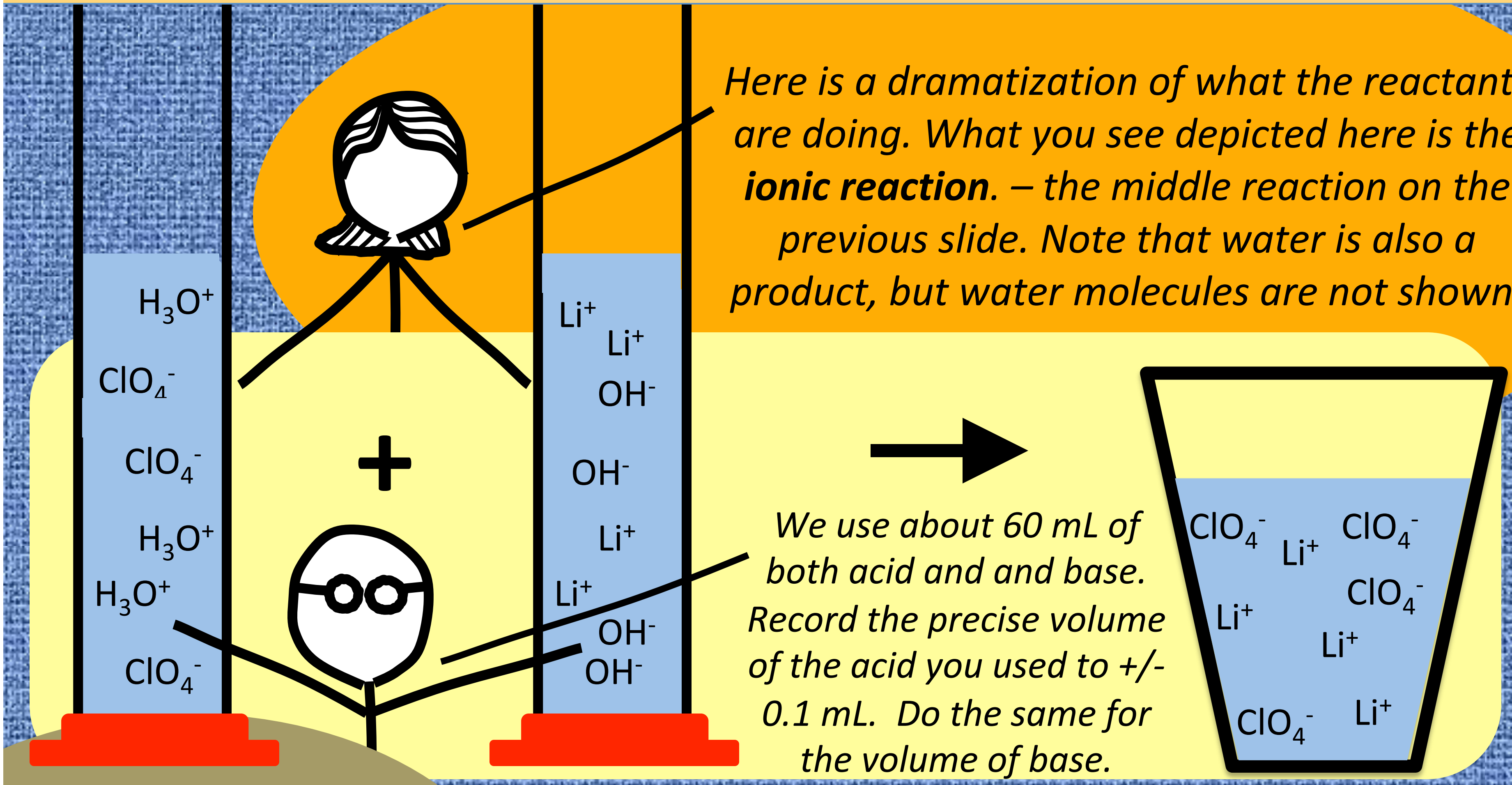
$$H_3O^+ (aq) + ClO_4^-(aq) + Li^+(aq) + OH^-(aq) \rightarrow$$
$$Li^+(aq) + ClO_4^-(aq) + 2\ H_2O(l) \quad \Delta H_{rxn} = ?$$



Cancel stuff! Be ruthless. The net ionic equation is simply…

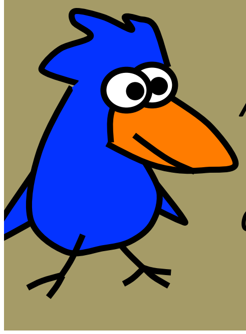
$$H_3O^+ (aq) + OH^-(aq) \rightarrow 2\ H_2O(l) \quad \Delta H_{rxn} = ?$$

1. The reaction and ΔH_{rxn}



Here is a dramatization of what the reactants are doing. What you see depicted here is the ***ionic reaction****. – the middle reaction on the previous slide. Note that water is also a product, but water molecules are not shown.*

We use about 60 mL of both acid and and base. Record the precise volume of the acid you used to +/- 0.1 mL. Do the same for the volume of base.

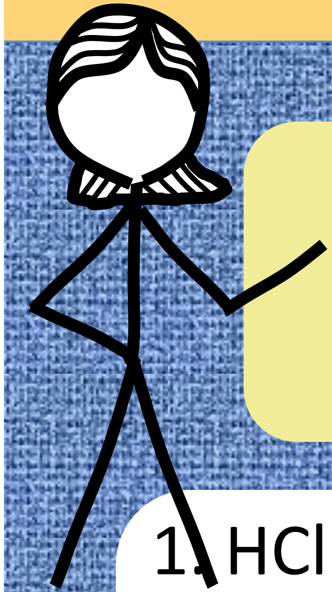


And here are the overall and net ionic equations

$$HClO_4(aq) + LiOH(aq) \rightarrow LiClO_4(aq) + H_2O(l)$$

$$H_3O^+(aq) + OH^-(aq) \rightarrow 2\,H_2O(l) \quad \Delta H_{rxn} = ?$$

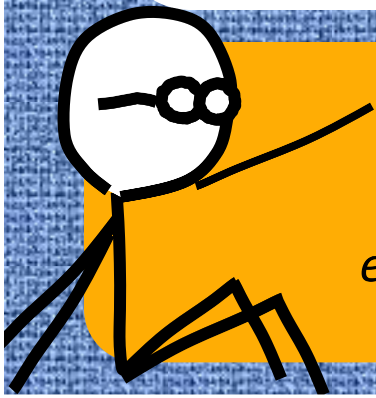
1. The reaction and ΔH_{rxn}



Your reaction will be one of these four – the two acids are ~2.0 M HCl(aq) and ~2.0 M HNO_3. The two bases are ~2.0 M NaOH(aq) and ~2.0 M KOH(aq).

Four combinations.

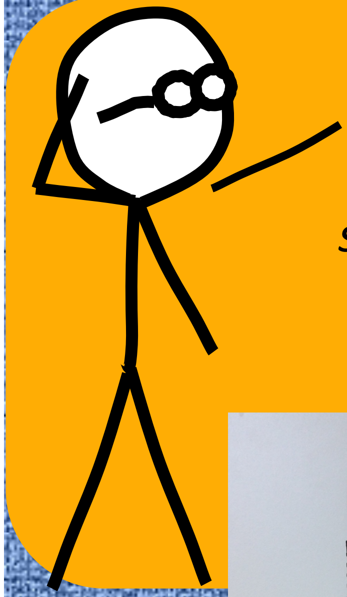
1. $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)\ \ \Delta H_{rxn} = ?$
2. $HCl(aq) + KOH(aq) \rightarrow KCl(aq) + H_2O(l)\ \ \Delta H_{rxn} = ?$
3. $HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)\ \ \Delta H_{rxn} = ?$
4. $HNO_3(aq) + KOH(aq) \rightarrow KNO_3(aq) + H_2O(l)\ \ \Delta H_{rxn} = ?$



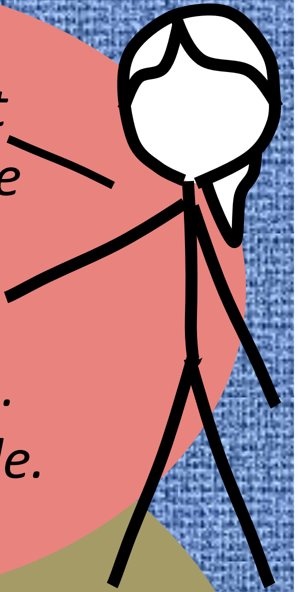
Not much room for me here and the drawing makes me look like a spider! Anyway, in your lab notebook, write the overall equation for your combination (one of the 4 given above), the ionic and net ionic equations for ***your*** *combination. Compare your answer with the other pairs around your station. What do the net ionics have in common?*

1. The reaction and ΔH_{rxn}

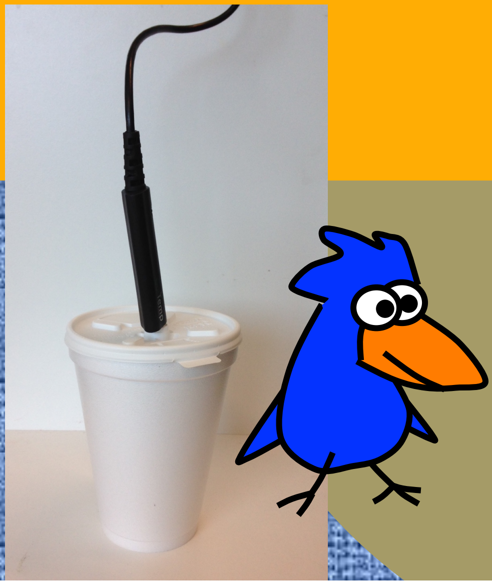
$$H_3O^+ (aq) + OH^-(aq) \rightarrow 2\ H_2O(l) \quad \Delta H_{rxn} = ?$$



Ok, zoom out for a second… Have you figured out that all these reactions give the very same net ionic equation? The other ions from the acid and the base are spectator ions.



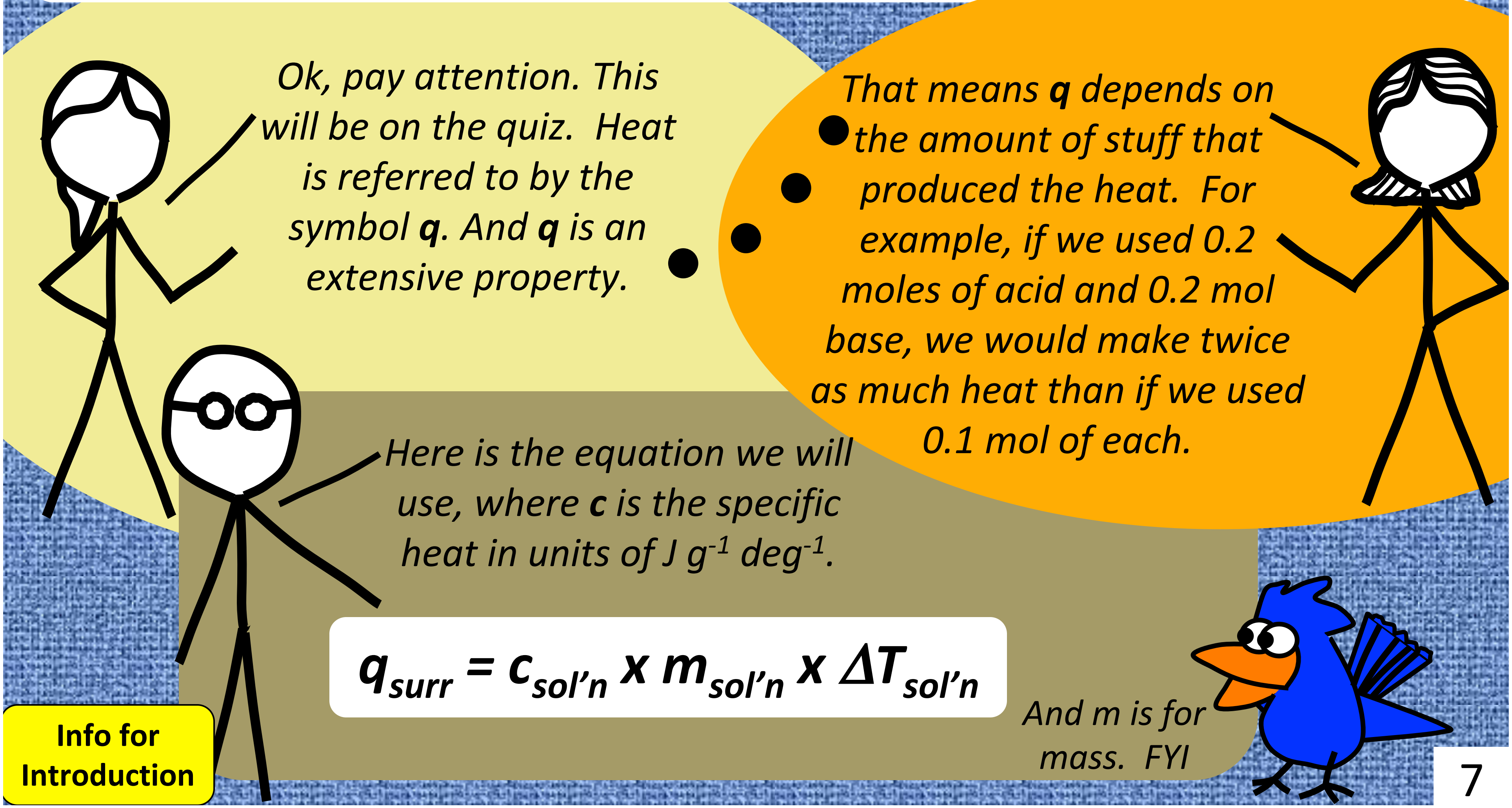
The only thing that produces heat is the acid-base reaction shown above. The spectator ions are… just along for the ride.



*To catch the heat, we are going to use a **calorimeter**. Calorimeters can be very expensive and extremely precise. But they don't have to be. The one we will use is right behind me here.*

2. Measuring heat, q, by calorimetry

$$H_3O^+ (aq) + OH^- (aq) \rightarrow 2\ H_2O(l) \quad \Delta H_{rxn} = ?$$



*Ok, pay attention. This will be on the quiz. Heat is referred to by the symbol **q**. And **q** is an extensive property.*

*That means **q** depends on the amount of stuff that produced the heat. For example, if we used 0.2 moles of acid and 0.2 mol base, we would make twice as much heat than if we used 0.1 mol of each.*

*Here is the equation we will use, where **c** is the specific heat in units of J g^{-1} deg^{-1}.*

$$q_{surr} = c_{sol'n} \times m_{sol'n} \times \Delta T_{sol'n}$$

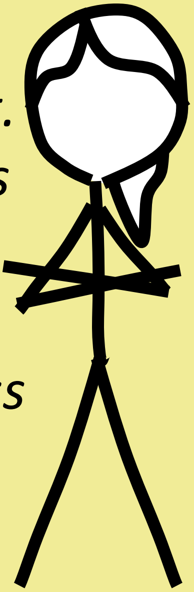
And m is for mass. FYI

Info for Introduction

2. Measuring heat, q, by calorimetry

This is the calorimeter! The thingy sticking out of it is the temperature probe and it is used with LoggerPro. We used it last week with the intermolecular forces lab.

The reaction produces the heat. The solution holds the heat and the calorimeter minimizes heat loss from dissipation.



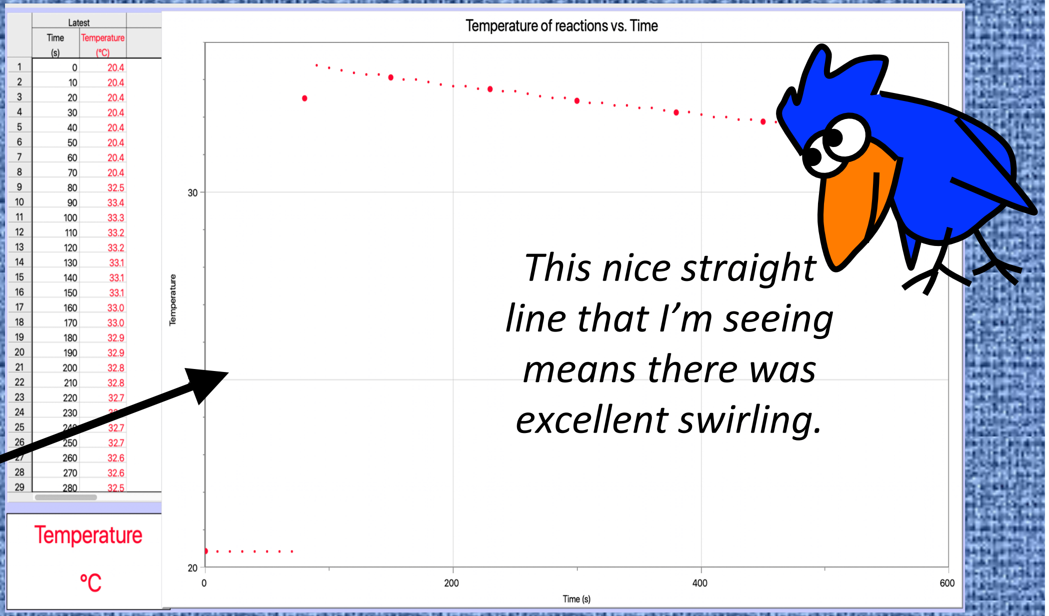
See q_{surr}*? The "surrounding" is the solution in the cup – errrr – calorimeter.*

$$q_{surr} = c_{sol'n} \times m_{sol'n} \times \Delta T_{sol'n}$$

You can call q_{surr} *"*q_{cal}*" or "*$q_{sol'n}$*" – it's all the same thing.*

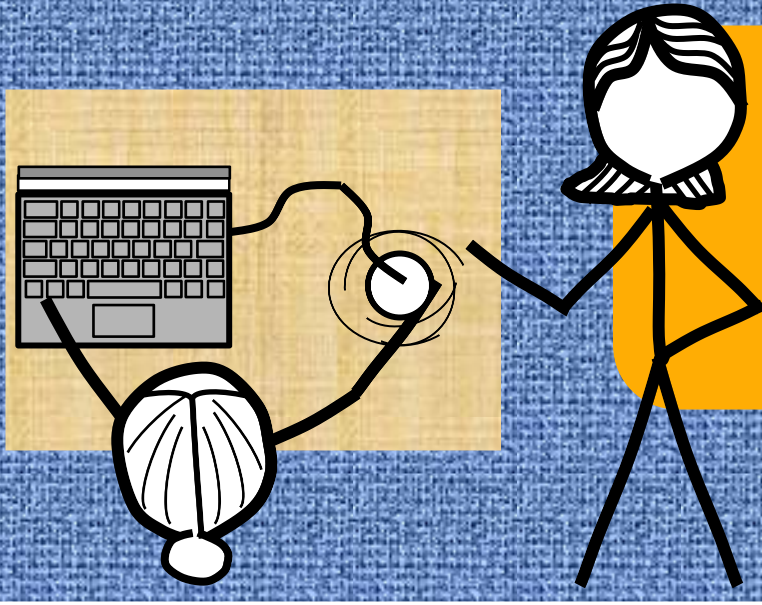
2. Measuring heat, q, by calorimetry

We'll use LoggerPro again. Plug in the probe and launch LoggerPro on your laptop.



	Latest	
	Time (s)	Temperature (°C)
1	0	20.4
2	10	20.4
3	20	20.4
4	30	20.4
5	40	20.4
6	50	20.4
7	60	20.4
8	70	20.4
9	80	32.5
10	90	33.4
11	100	33.3
12	110	33.2
13	120	33.2
14	130	33.1
15	140	33.1
16	150	33.1
17	160	33.0
18	170	33.0
19	180	32.9
20	190	32.9
21	200	32.8
22	210	32.8
23	220	32.7
24	230	[illegible]
25	240	32.7
26	250	32.7
27	260	32.6
28	270	32.6
29	280	32.5

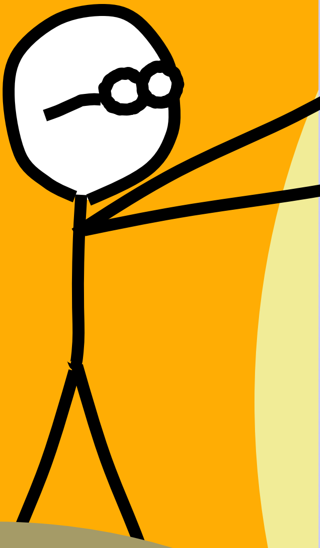
This nice straight line that I'm seeing means there was excellent swirling.

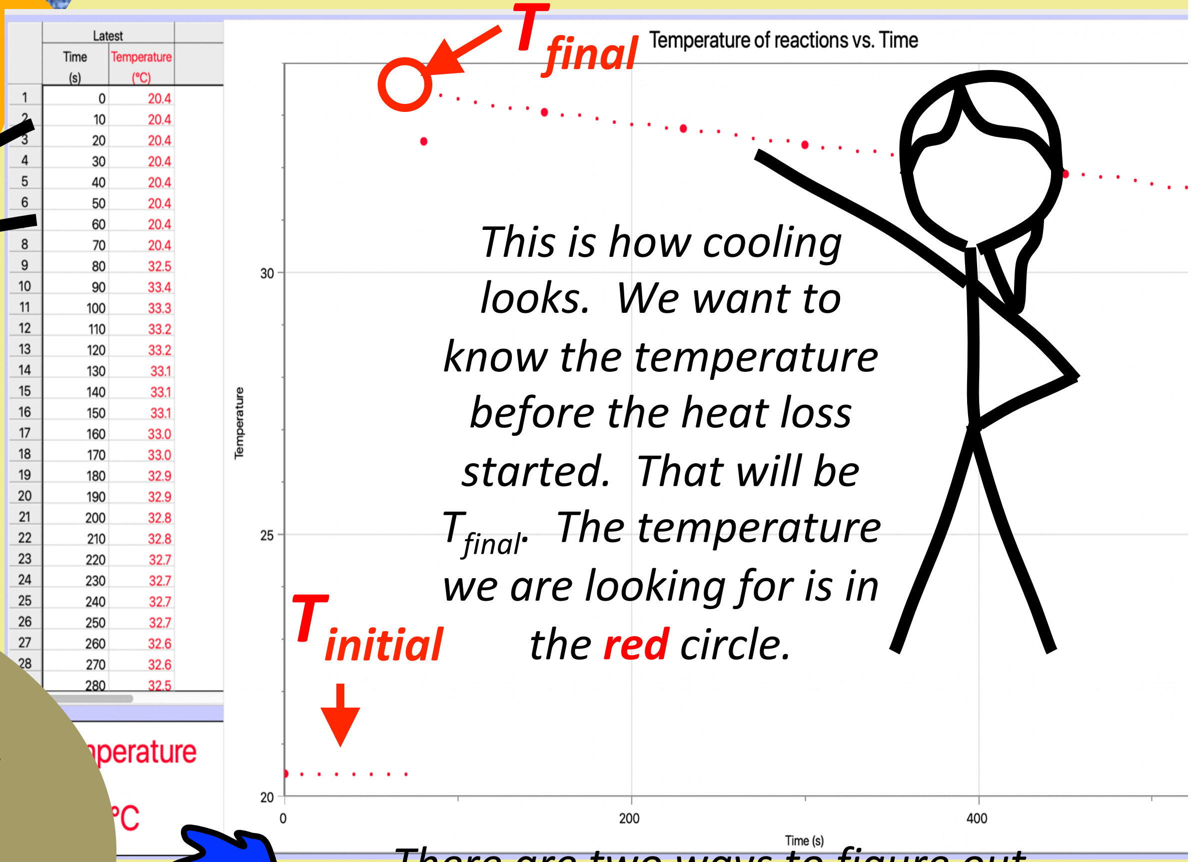


See how she is swirling the solution during data collection?

3. Data analysis and calculations

Here are the first data pairs from LoggerPro. You can see that $T_{initial}$ = 20.4 °C. See when the chemicals were added together.





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10	90	33.4
11	100	33.3
12	110	33.2
13	120	33.2
14	130	33.1
15	140	33.1
16	150	33.1
17	160	33.0
18	170	33.0
19	180	32.9
20	190	32.9
21	200	32.8
22	210	32.8
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24	230	32.7
25	240	32.7
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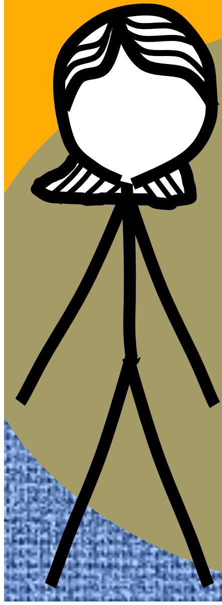
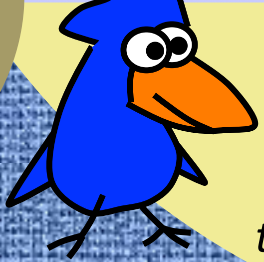
27	260	32.6
28	270	32.6
	280	32.5

This is how cooling looks. We want to know the temperature before the heat loss started. That will be T_{final}. The temperature we are looking for is in the ***red*** *circle.*

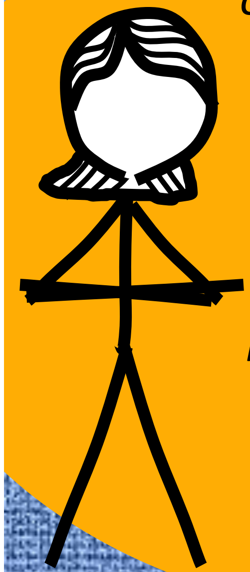


The ***precise time*** *the chemicals were added was 77 s, as measured with the stopwatch feature on a phone. The lab manual does not mention this in Step 5..*

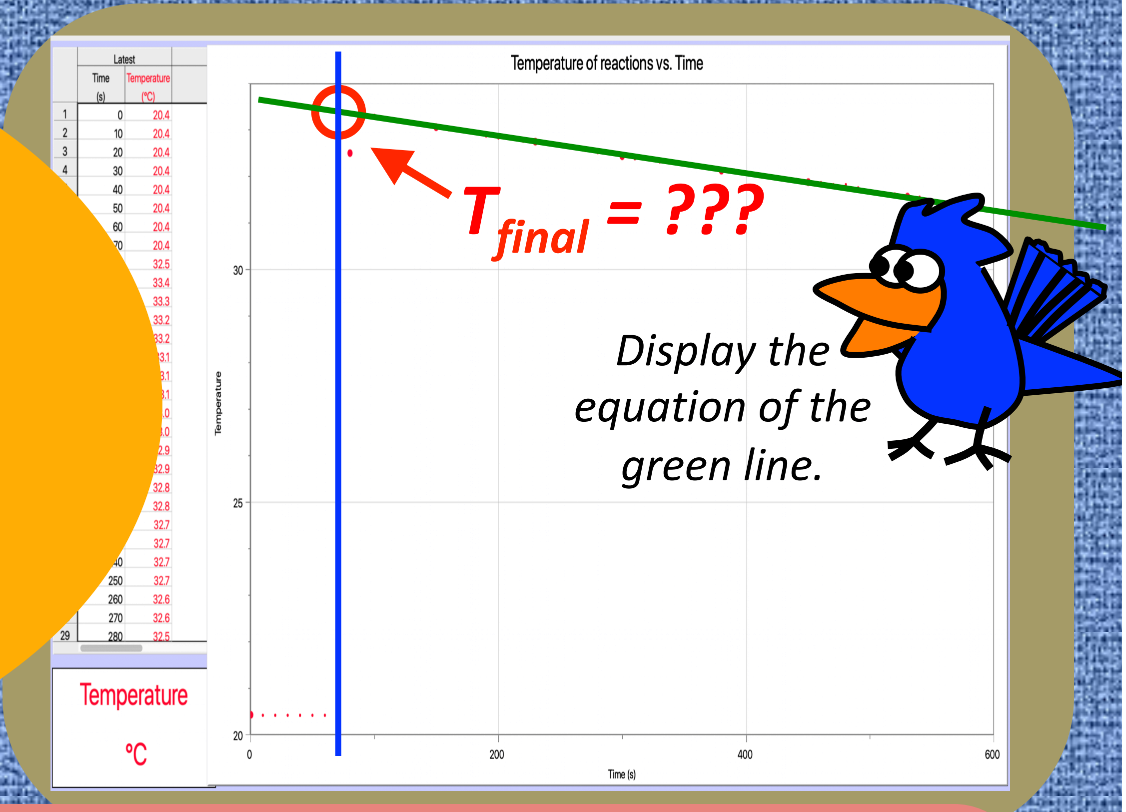


There are two ways to figure out T_{final}. Let's find out about them… You will need to know the exact time when you added the chemicals together and the reaction took place.

3. Data analysis and calculations



This isn't how we figured out T_{final} last week when we did intermolecular forces. This way is appropriate for situations in which the reaction is instantaneous upon mixing and followed by heat loss. Last week, we were watching a process that took several minutes.



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	50	20.4
	60	20.4
	70	20.4
		32.5
		33.4
		33.3
		33.2
		33.2
		3.1
		3.1
		.1
		.0
		3.0
		2.9
		32.9
		32.8
		32.8
		32.7
		32.7
	40	32.7
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	270	32.6
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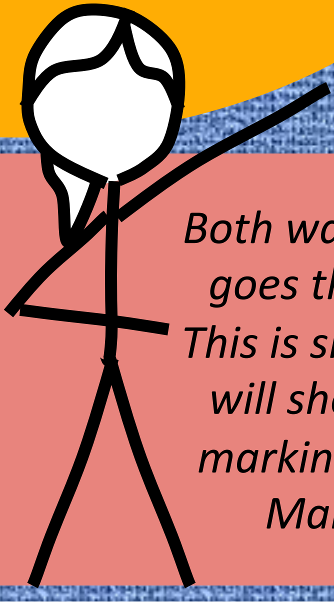
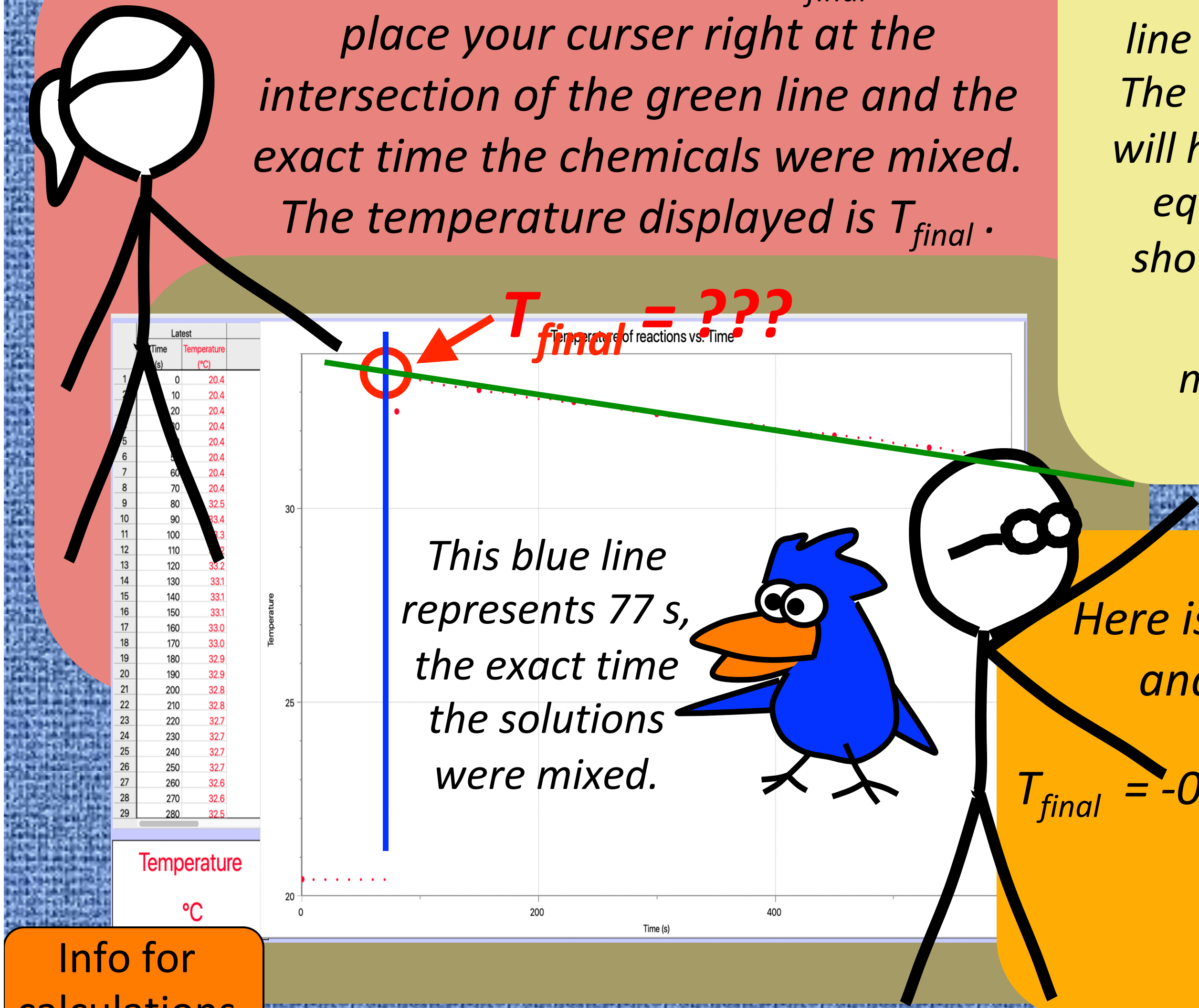
Display the equation of the green line.



Both ways of determining T_{final} require us to create a line that goes through the linear cooling curve portion of the graph. This is shown above with a green line. Your TA or Dr. Mattson will show you how to do this. We just imagine the blue line marking the time when the chemicals were added together. Make sure you record this time in your lab notebook.

3. Data analysis and calculations

One way to determine T_{final} is to place your curser right at the intersection of the green line and the exact time the chemicals were mixed. The temperature displayed is T_{final} .



	Latest	
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1	0	20.4
2	10	20.4
[illegible]	20	20.4
[illegible]	[illegible]	20.4
5	[illegible]	20.4
6	[illegible]	20.4
7	60	20.4
8	70	20.4
9	80	32.5
10	90	33.4
11	100	[illegible]
12	110	[illegible]
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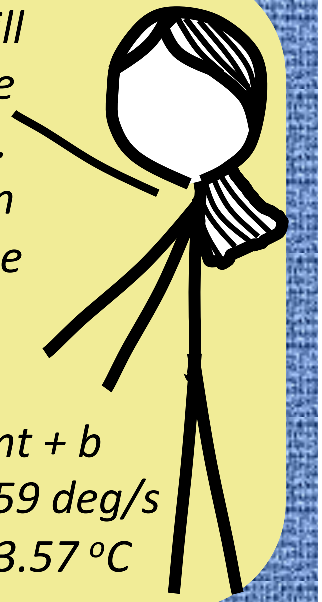
23	220	32.7
24	230	32.7
25	240	32.7
26	250	32.7
27	260	32.6
28	270	32.6
29	280	32.5

This blue line represents 77 s, the exact time the solutions were mixed.



Today, however, we will use the equation of the line to determine T_{final}. The TAs or Dr. Mattson will help you display the equation of the line shown in green. It is:

temperature = mt + b

m(slope) = -0.003759 deg/s

b(y-intercept) = 33.57 °C

Here is T_{final} from using the formula and plugging in 77 s for time:

T_{final} = -0.003759 x 77 + 33.57 °C

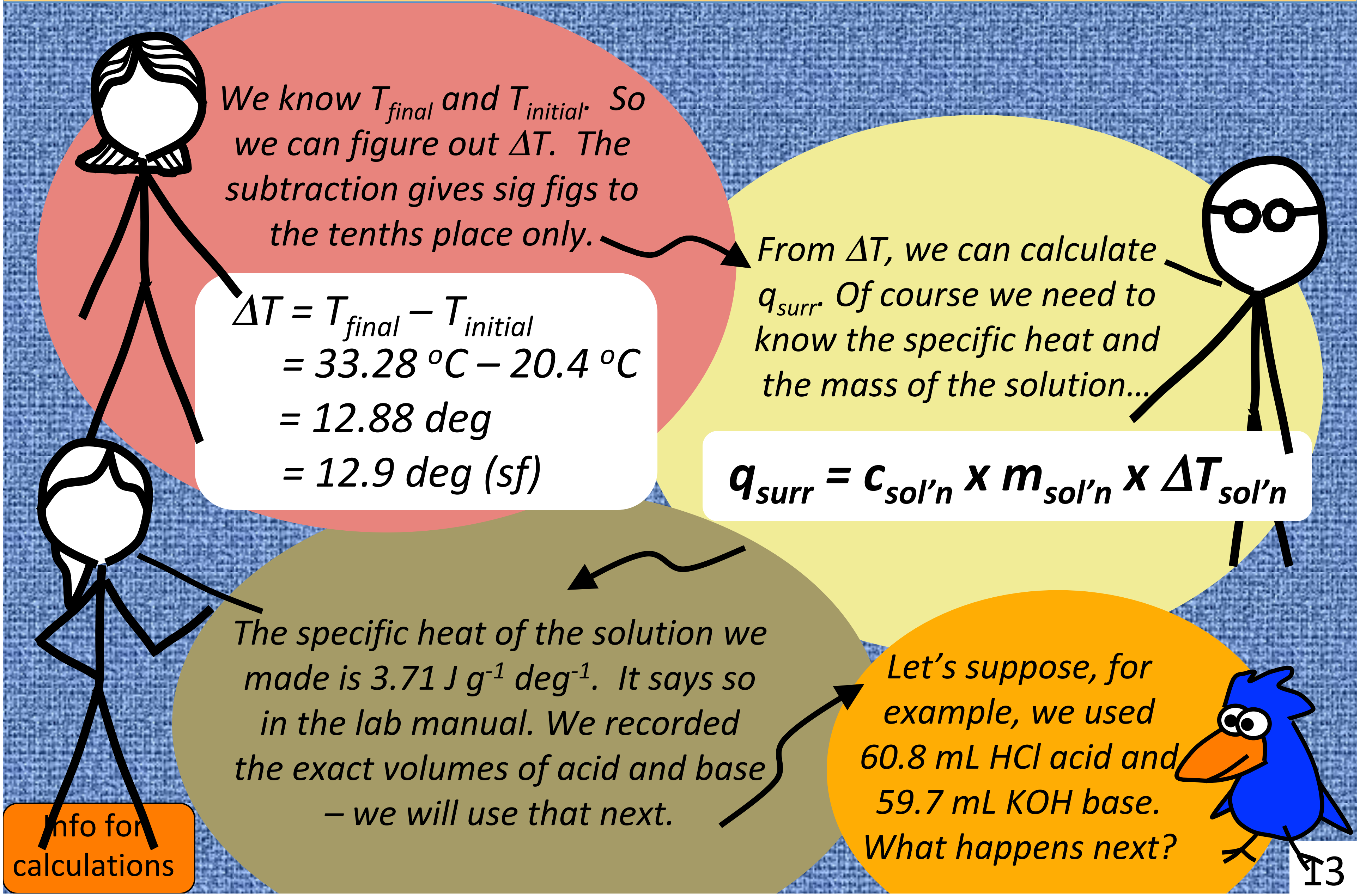
= -0.289443 deg + 33.57 °C

= -0.29 deg + 33.57 °C (sig fig)

= 33.28 °C (sig fig)

Info for calculations

3. Data analysis and calculations



We know T_{final} and $T_{initial}$. So we can figure out ΔT. The subtraction gives sig figs to the tenths place only.

$$\Delta T = T_{final} - T_{initial}$$
$$= 33.28\ ^{o}C - 20.4\ ^{o}C$$
$$= 12.88\ deg$$
$$= 12.9\ deg\ (sf)$$

From ΔT, we can calculate q_{surr}. Of course we need to know the specific heat and the mass of the solution…

$$q_{surr} = c_{sol'n} \times m_{sol'n} \times \Delta T_{sol'n}$$

The specific heat of the solution we made is 3.71 $J\ g^{-1}\ deg^{-1}$. It says so in the lab manual. We recorded the exact volumes of acid and base – we will use that next.

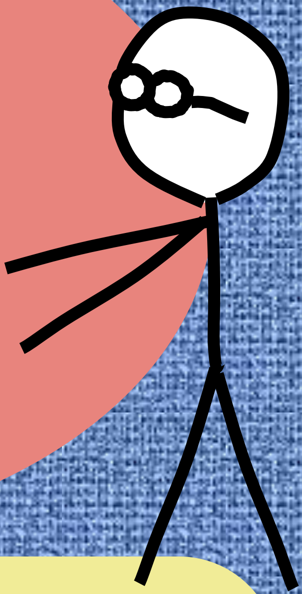
Let's suppose, for example, we used 60.8 mL HCl acid and 59.7 mL KOH base. What happens next?

Info for calculations

3. Data analysis and calculations

What was I saying? Oh, yeah. Let's suppose we used 60.8 mL HCl(aq) and 59.7 mL KOH(aq).

We need the mass of the solution next. The densities of the two acids and two bases are given in the table.



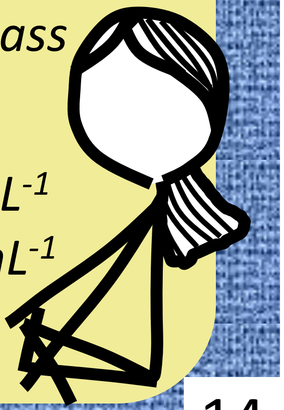
Densities of Our Acids and Bases

2.0 M HCl	**1.033 g mL^{-1}**
2.0 M HNO_3	**1.065 g mL^{-1}**
2.0 M NaOH	**1.079 g mL^{-1}**
2.0 M KOH	**1.093 g mL^{-1}**

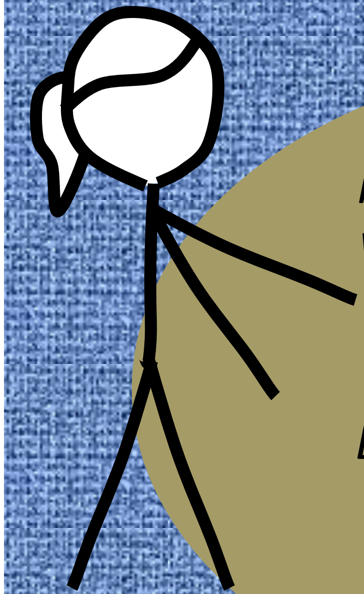
Info for calculations

Sooo… 60.8 mL of the HCl(aq) and 59.7 of the KOH would have a mass of…

60.8 mL x 1.033 g mL^{-1}
+ 59.7 mL x 1.093 g mL^{-1}
or 128.1 g



3. Data analysis and calculations



Now we're cooking! We have everything we need – specific heat, mass and ΔT! Let's be careful with the units.

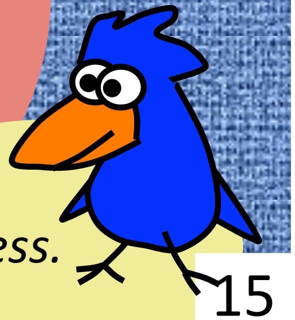
$$q_{surr} = c_{sol'n} \times m_{sol'n} \times \Delta T_{sol'n}$$

$$= \begin{array}{c|c|c} 3.71\ \text{J} & 128.1\ \text{g} & 12.88\ \text{deg} \\ \hline \text{g deg} & & \end{array}$$

$$= 6121.497595\ \text{J}$$

$$= 6120\ \text{J with 3 sig figs}$$

Remember, ΔT has only three significant figures, 12.9 deg (Slide 13), but we use the number obtained for all calculations and then at the end, adjust for significant figures.



Progress.

Info for calculations

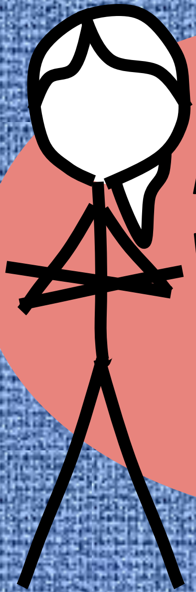
3. Data analysis and calculations

Ok, let's pull up here for a second and think what this means. Our coffee cup calorimeter collected 6120 J of heat.

$$q_{surr} = c_{sol'n} \times m_{sol'n} \times \Delta T_{sol'n}$$

Would we have collected more heat if we had used 50 mL of acid and 70 mL base instead of about 60 of each? Think limiting reagent...

We used ~2.0 M acid and ~2.0 M base. Would we have collected more heat if we had used 30 mL of 3.0 M acid and 60 mL of 1.5 M base? What else would have changed? (assume the specific heat is not changed much)



The value for q will increase or decrease with amount of stuff used. This is called an extensive property.

Ahhh, the distinct smell of a quiz question.

3. Data analysis and calculations

$$H_3O^+ (aq) + OH^-(aq) \rightarrow 2\ H_2O(l) \quad \Delta H_{rxn} = ?$$

So, the solution in the calorimeter collected 6120 J of heat. This heat came from our reaction – which we haven't seen since Slide 7! The calorimeter gained heat because the reaction released heat. The mathematical relationship is pretty simple:

$$q_{surr} = -q_{reaction}$$

We are getting close here. We can almost calculate ΔH, then clean up and go home.

Remember in our example how we used 60.8 mL acid and 59.7 mL base? We will be given the exact molarities of the acid and base. Suppose the acid was 2.040 M and the base was 1.962 M. Using ***n = MV****, we can calculate the moles of acid and moles of base:*

$$n_{acid} = 2.040\ mol\ L^{-1} \times 0.0608\ L = 0.1240\ mol\ H_3O^+$$

$$n_{base} = 1.962\ mol\ L^{-1} \times 0.0597\ L = 0.1171\ mol\ OH^-$$

Info for calculations

3. Data analysis and calculations

$$H_3O^+ (aq) + OH^-(aq) \rightarrow 2\ H_2O(l) \quad \Delta H_{rxn} = ?$$

The -6120 J from the reaction is associated with the limiting reagent – in our example, the base. From that we can calculate ΔH!

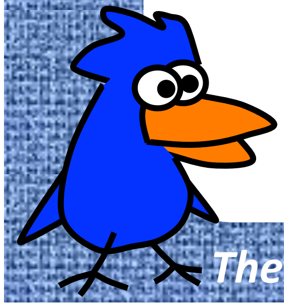
See how the equation features one OH^-? So ΔH has to be for one mole of OH^-.

$$\Delta H_{neutralization} = q_{rxn} / n_{LR}$$

$$= \frac{-6120\ J}{0.1171\ mol\ OH^-} \left| \frac{1 \times 10^{-3}\ kJ}{1\ J} \right.$$

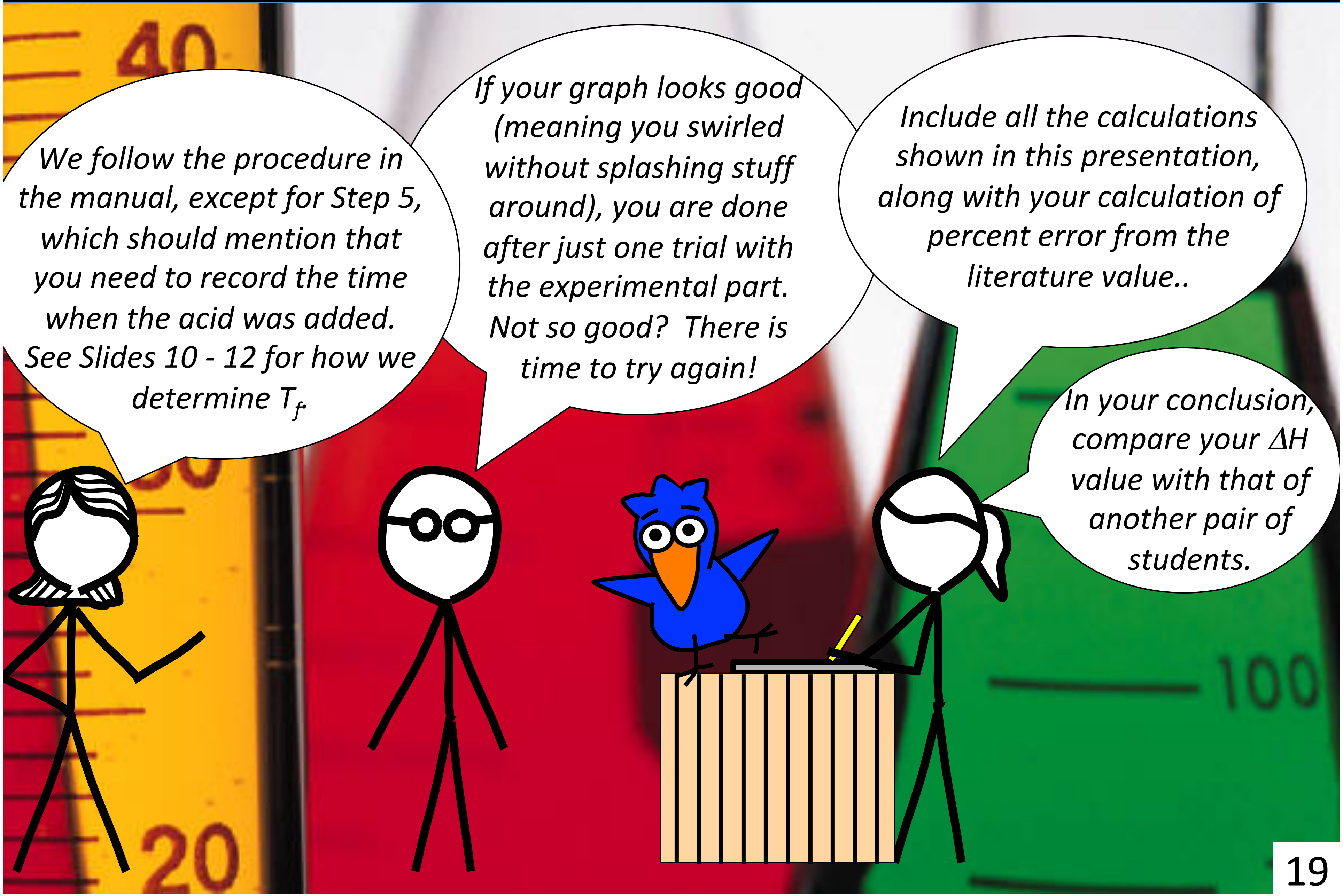
$$= -52.27581208\ kJ/mol$$

So… isn't that a lot of significant figures?



The literature value is -55.8 kJ/mol. Ooops.

4. Procedure: What to do today



5. Your lab report

① First, the cover page with TA initials.

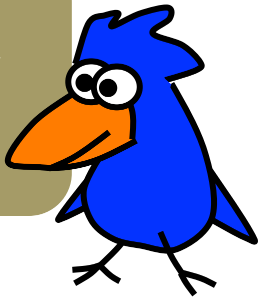
② Next, the trimmed copy pages from your lab notebook stapled together.

③ **On-line results** due at the end of class today. Late submissions are not graded – see the syllabus.

④ Your LoggerPro chart attached.

⑤ Turn in lab report ***today*** or ***before*** the start of class tomorrow. Late labs may not be graded – see the syllabus.

Dress for a mess – this week and for Experiment 12!



Stick people inspired by xkcd cartoons by Randall Munroe (www.xkcd.com)

Chem Lab with the Stick People and Bird *was created and produced by Dr. Bruce Mattson, Creighton Chemistry. Enjoy it and share it if you wish.*