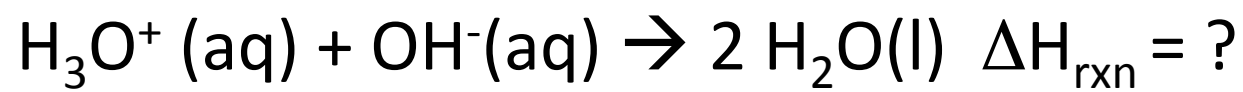


# Experiment 11

## 13 November 2018

### Enthalpy of Neutralization

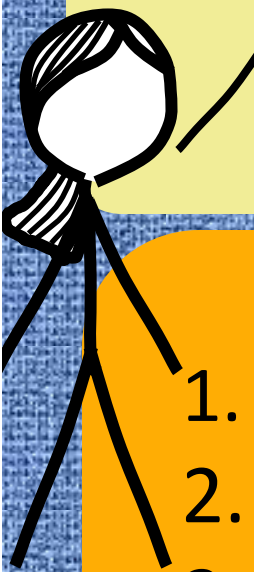


*Oh! The things we will do. Oh!  
The things we will learn! And  
all in just three hours.*

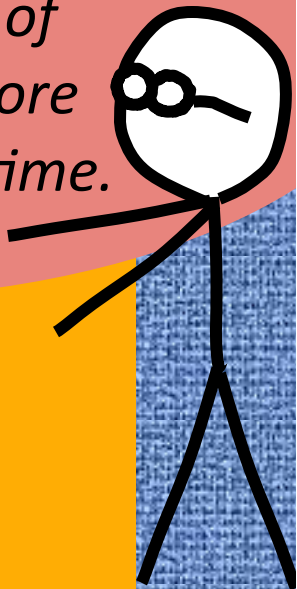
$$q_{\text{surr}} = c_{\text{sol'n}} \times m_{\text{sol'n}} \times \Delta T_{\text{sol'n}}$$

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

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. We'll explore another reaction next time.*

### **Overview:**

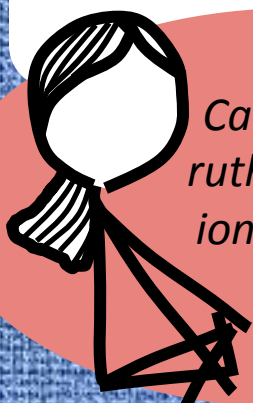
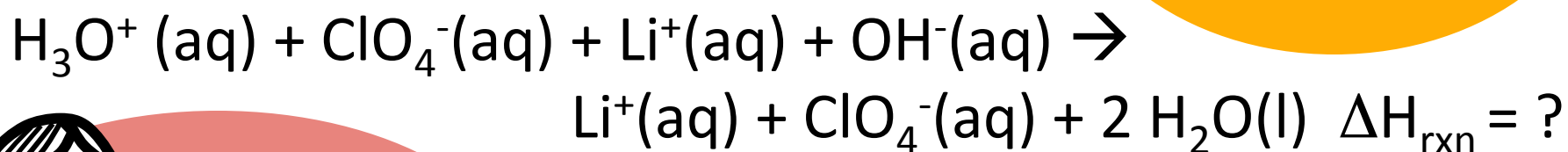
1. The reaction and  $\Delta H_{\text{rxn}}$
2. Measuring heat,  $q$ , by calorimetry
3. Data analysis and calculations
4. Procedure: What we do today
5. Your lab report

# 1. The reaction and $\Delta H_{\text{rxn}}$

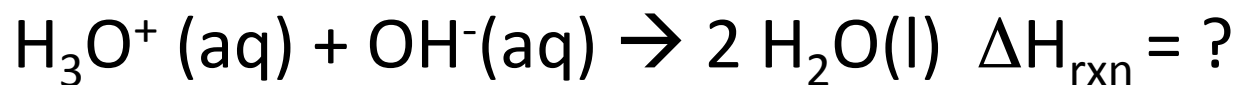


*Here is a reaction similar to the one you are doing today. This is the overall reaction. If we break the strong acid and soluble salts into ions, we get the ionic equation, shown by my feet.*

*See how he made  $\text{H}^+$  into  $\text{H}_3\text{O}^+$ ? He had to add a water to the right side to keep things balanced.*



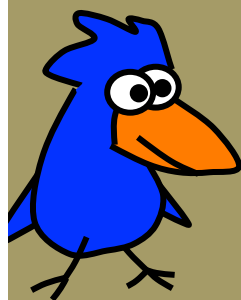
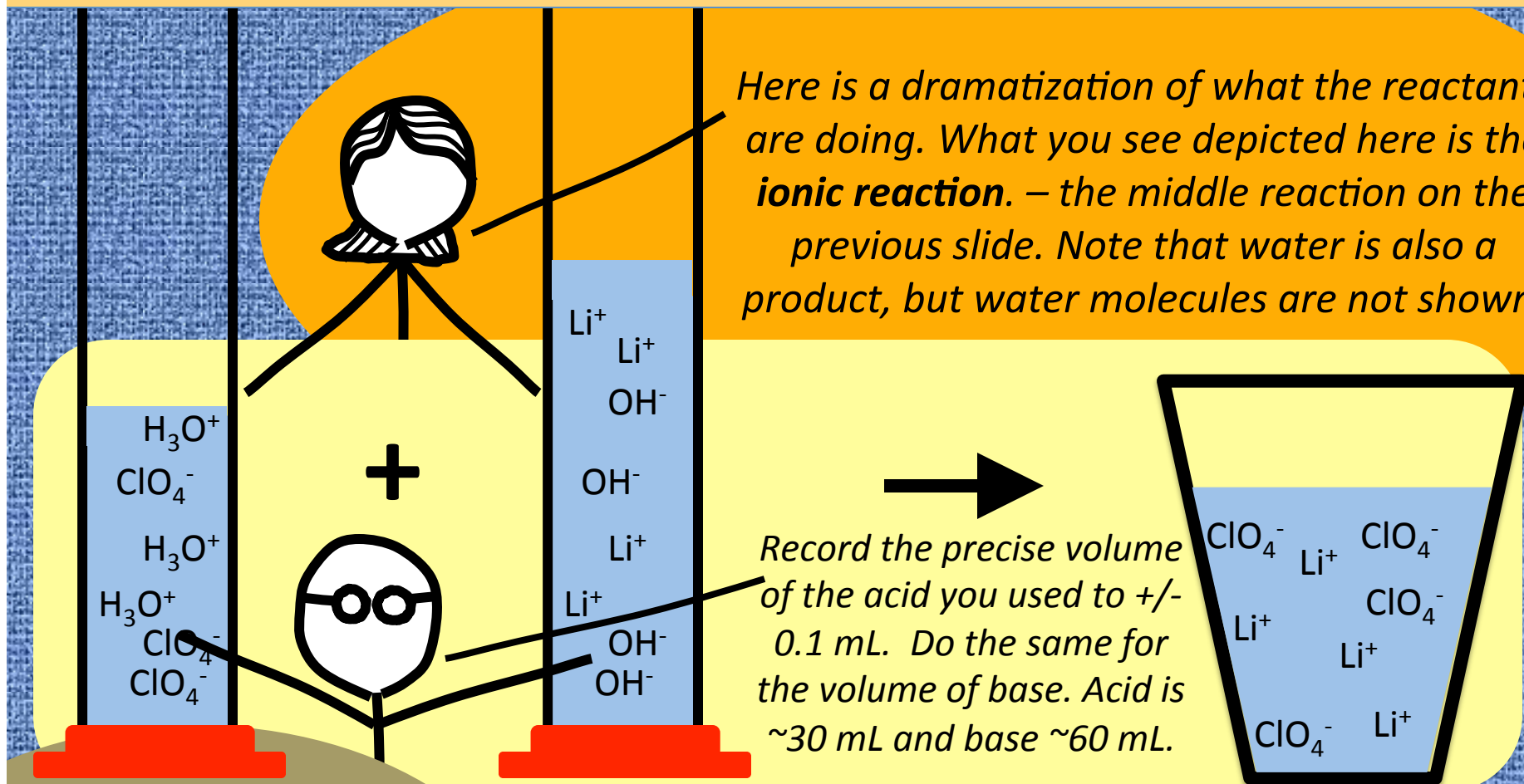
*Cancel stuff! Be ruthless. The net ionic equation is simply...*



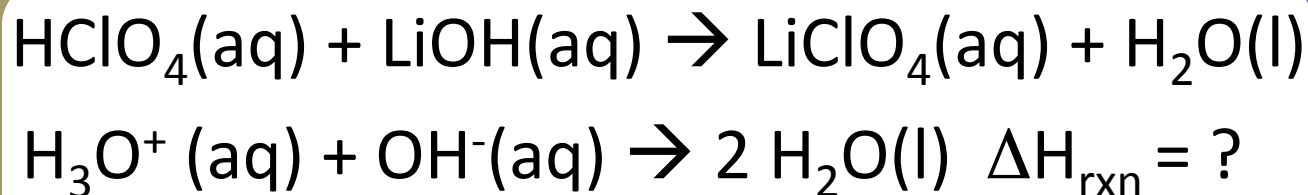
# 1. The reaction and $\Delta H_{\text{rxn}}$

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.

Record the precise volume of the acid you used to +/- 0.1 mL. Do the same for the volume of base. Acid is ~30 mL and base ~60 mL.



And here are the overall and net ionic equations

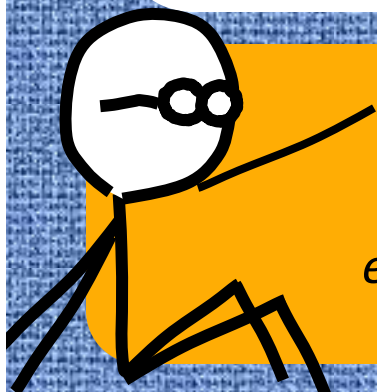


# 1. The reaction and $\Delta H_{\text{rxn}}$



Your reaction will be one of these four – the two acids are  $\sim 2.0 \text{ M HCl(aq)}$  and  $\sim 2.0 \text{ M HNO}_3$ . The two bases are  $\sim 1.0 \text{ M NaOH(aq)}$  and  $\sim 1.0 \text{ M KOH(aq)}$ .

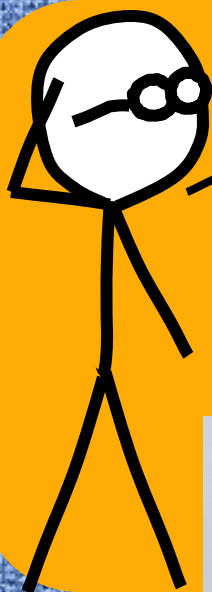
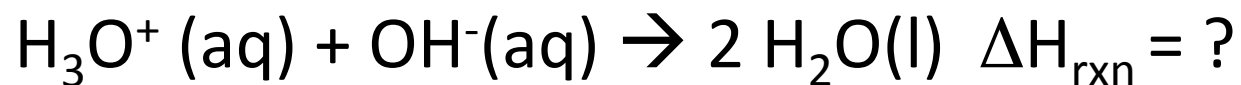
Four combinations.



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?

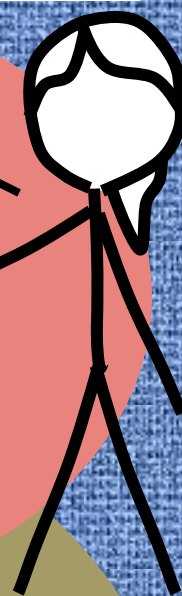


# 1. The reaction and $\Delta H_{\text{rxn}}$



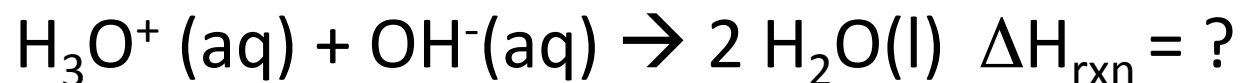
*Ok, zoom out for a second... Have you figured out that all these reactions give the very same net ionic equation? The other ions from the acid and the base are spectator ions.*

*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



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

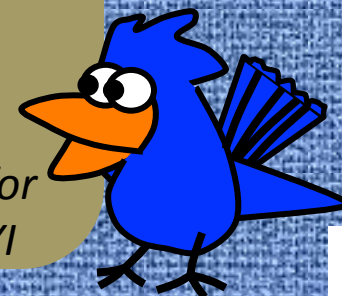
- the amount of stuff that produced the heat. For example, if we used 0.2 moles of acid and 0.2 mol base, we would make twice as much heat than if we used 0.1 mol of each.

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

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

Info for  
Introduction

And  $m$  is for  
mass. FYI

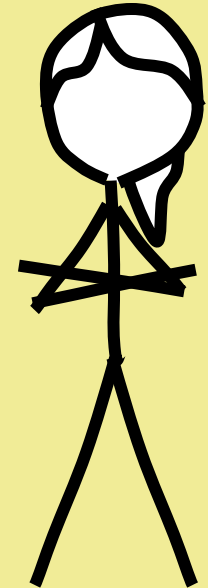


## 2. Measuring heat, $q$ , by calorimetry

*This is the calorimeter! The thingy sticking out of it is the temperature probe and it is used with LoggerPro.*



*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.*



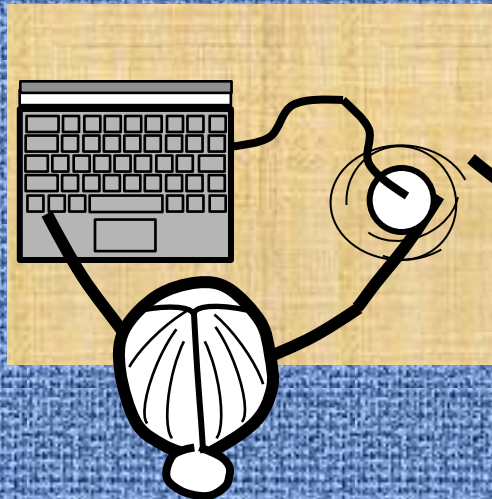
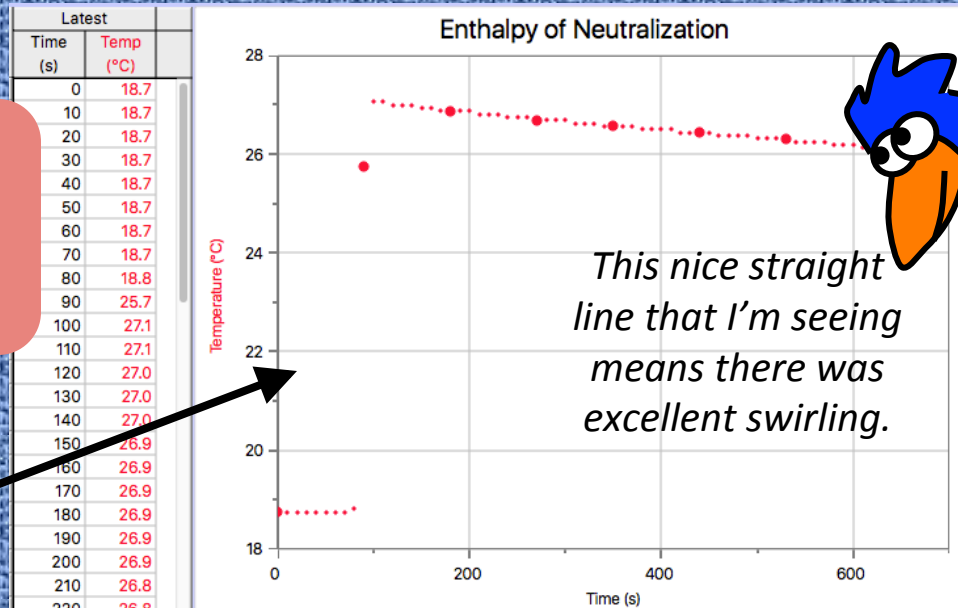
*You can call  $q_{surr}$  “ $q_{cal}$ ” or “ $q_{sol'n}$ ” – it’s all the same thing.*

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



## 2. Measuring heat, $q$ , by calorimetry

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

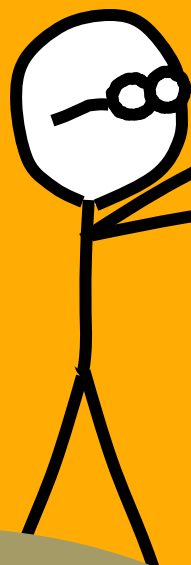


*See how she is swirling the solution during data collection?*

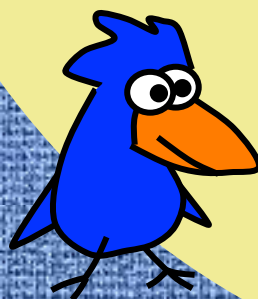
### 3. Data analysis and calculations

Here are the first data pairs from LoggerPro. You can see that  $T_{initial} = 18.7$ . See when the chemicals were added together.

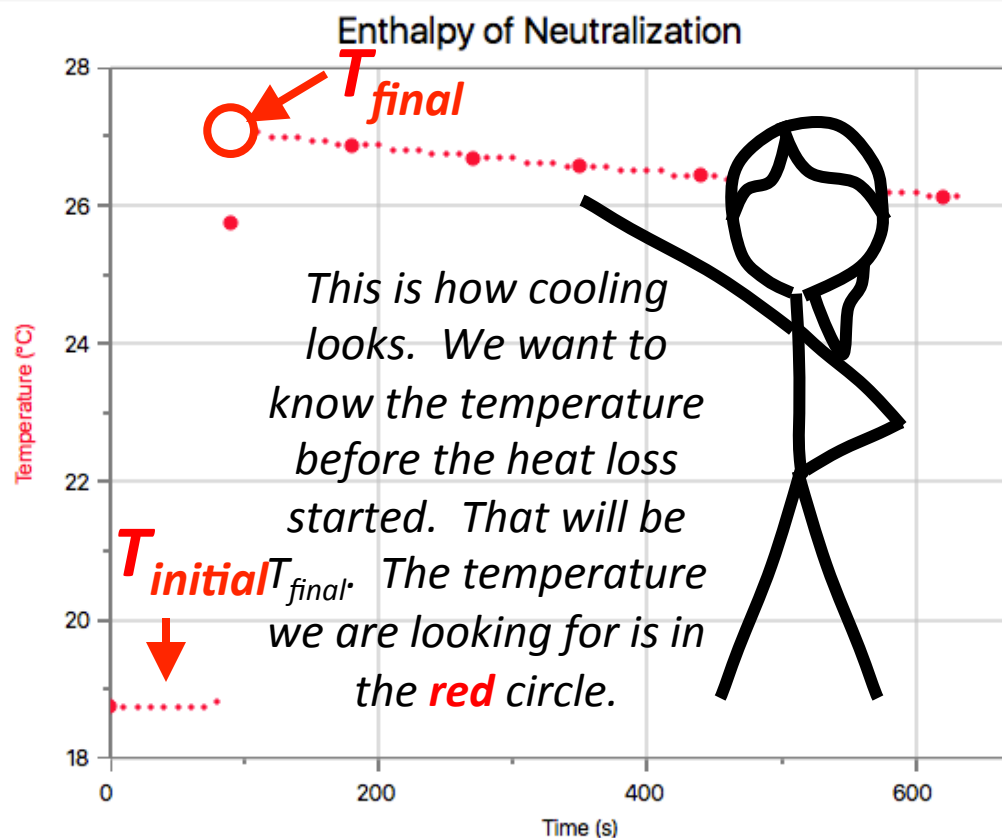
Latest	
Time (s)	Temp (°C)
0	18.7
10	18.7
20	18.7
30	18.7
40	18.7
50	18.7
60	18.7
70	18.7
80	18.8
90	25.7
100	27.1
110	27.1
120	27.0
130	27.0
140	27.0
150	26.9
160	26.9
170	26.9
180	26.9
190	26.9
200	26.9
210	26.8
220	26.8



The precise time the chemicals were added was 81 s, as measured with the stopwatch feature on a phone.

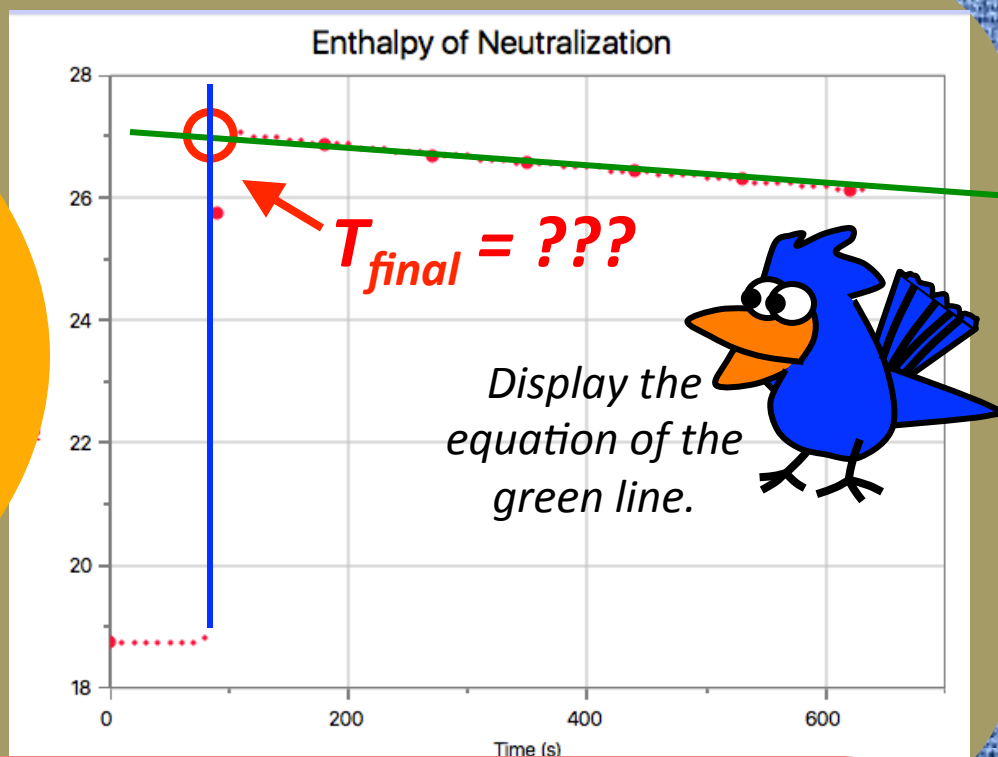


There are two ways to figure out  $T_{final}$ . Let's find out about them... You will need to know the exact time when you added the chemicals together and the reaction took place.



### 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.*



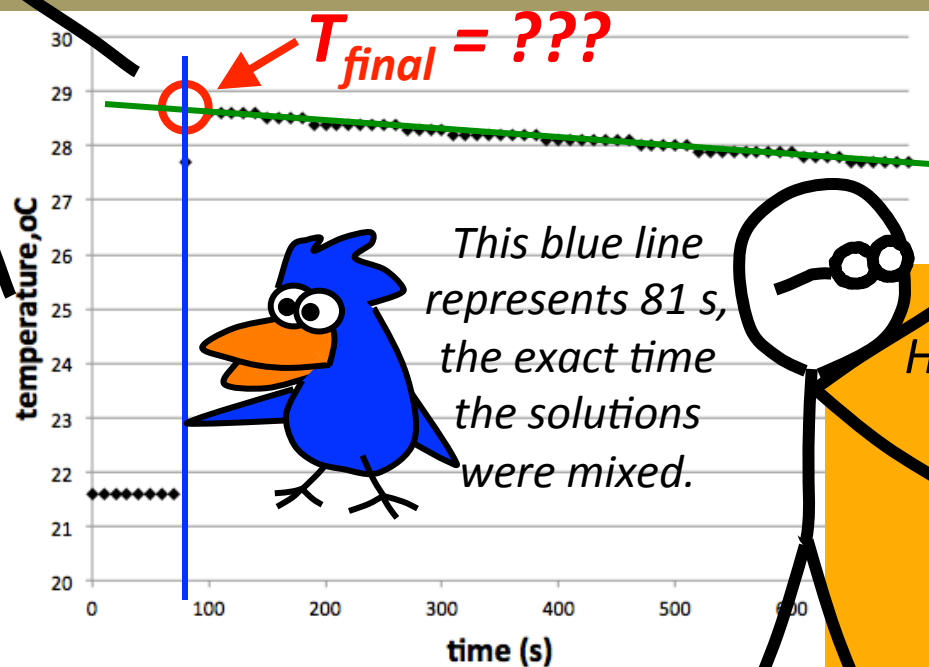
*Both ways of determining  $T_{final}$  require us to create a line that goes through the linear cooling curve portion of the graph. This is shown above with a green line. Your TA or Dr. Mattson will show you how to do this. We just imagine the blue line marking the time when the chemicals were added 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 cursor right at the intersection of the green line and the exact time the chemicals were mixed. The temperature displayed is  $T_{final}$ .

To use the equation of the line, the TAs or Dr. Mattson will help you display the equation of the line shown in green. It is:

$$\begin{aligned} \text{temperature} &= mt + b \\ m(\text{slope}) &= -0.001687 \text{ deg/s} \\ b(\text{y-intercept}) &= 27.17 \text{ }^\circ\text{C} \end{aligned}$$



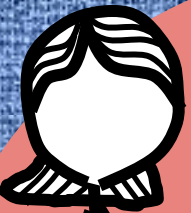
Here is  $T_{final}$  from using the formula and plugging in 81 s for time:

$$\begin{aligned} T_{final} &= -0.001687t + 27.17 \text{ }^\circ\text{C} \\ &= 27.03 \text{ }^\circ\text{C} \end{aligned}$$

Info for calculations

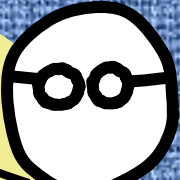


### 3. Data analysis and calculations




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

$$\begin{aligned}\Delta T &= T_{final} - T_{initial} \\ &= 27.03\text{ }^{\circ}\text{C} - 18.70\text{ }^{\circ}\text{C} \\ &= 8.33\text{ deg}\end{aligned}$$




From  $\Delta T$ , we can calculate  $q_{surr}$ . Of course we need to know the specific heat and the mass of the solution...

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



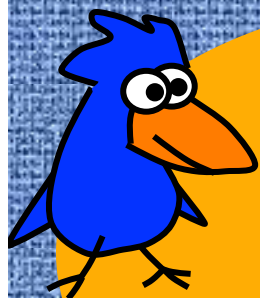
The specific heat of the solution we made is  $3.71\text{ J g}^{-1}\text{ deg}^{-1}$ . It says so in the lab manual. We recorded the exact volumes of acid and base – we will use that next.



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

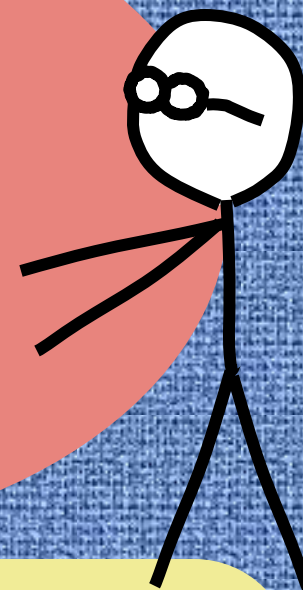
Info for calculations

### 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.



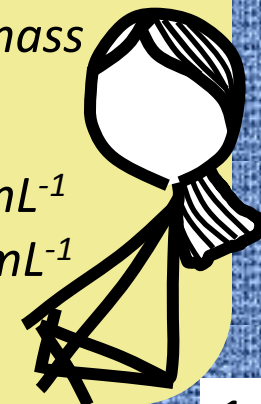
#### Densities of Our Acids and Bases

<b>2.0 M HCl</b>	<b>1.033 g mL<sup>-1</sup></b>
<b>2.0 M HNO<sub>3</sub></b>	<b>1.065 g mL<sup>-1</sup></b>
<b>2.0 M NaOH</b>	<b>1.079 g mL<sup>-1</sup></b>
<b>2.0 M KOH</b>	<b>1.093 g mL<sup>-1</sup></b>

Info for  
calculations

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

$$60.8 \text{ mL} \times 1.033 \text{ g mL}^{-1} \\ + 59.7 \text{ mL} \times 1.093 \text{ g mL}^{-1} \\ \text{or } 128.1 \text{ g}$$



### 3. Data analysis and calculations



*Now we're cooking!  
We have everything  
we need – specific  
heat, mass and  $\Delta T$ !  
Let's be careful with  
the units.*

$$\begin{aligned} q_{\text{surr}} &= c_{\text{sol'n}} \times m_{\text{sol'n}} \times \Delta T_{\text{sol'n}} \\ &= \frac{3.71 \text{ J}}{\text{g deg}} \mid \frac{128.1 \text{ g}}{\text{g deg}} \mid \frac{8.33 \text{ deg}}{\text{g deg}} \\ &= 3957.5583 \text{ J} \\ &= 3960 \text{ J with 3 sig figs} \end{aligned}$$



*We've made some  
changes from last year.  
With 2.0 M acids, our  $\Delta T$   
values should be >10  
degrees. That will get us  
three significant figures.*

Info for  
calculations

Progress.



### 3. Data analysis and calculations



*Ok, let's pull up here for a second and think what this means. Our coffee cup calorimeter collected 3960 J of heat.*

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

*Would we have collected more heat if we had used 50 mL of acid and 70 mL base instead of about 60 of each? Referring to the equation, justify your answer.*

*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)*




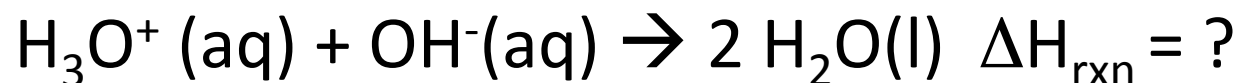
*The value for  $q$  will increase or decrease with amount of stuff used. This is called an extensive property.*



*Ahhh, the distinct smell of a quiz question.*



### 3. Data analysis and calculations

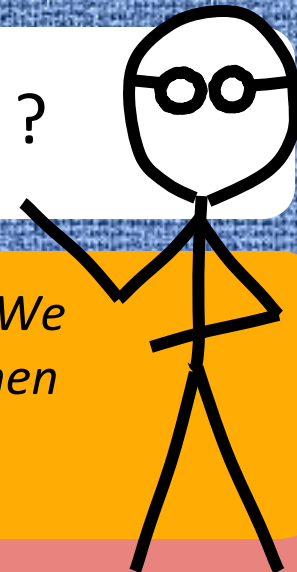


So, the solution in the calorimeter collected 3960 J of heat. This heat came from our reaction – which we haven't seen since Slide 7! The calorimeter gained heat because the reaction released heat. The mathematical relationship is pretty simple:

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

Info for  
calculations

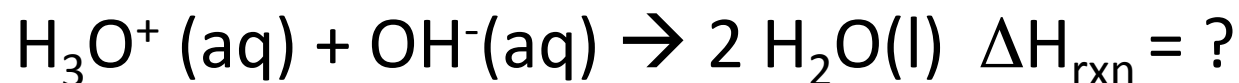
$$n_{\text{acid}} = 2.040 \text{ mol L}^{-1} \times 0.0608 \text{ L} = 0.1240 \text{ mol H}_3\text{O}^+$$
$$n_{\text{base}} = 1.962 \text{ mol L}^{-1} \times 0.0597 \text{ L} = 0.1171 \text{ mol OH}^-$$



We are getting close here. We can almost calculate  $\Delta H$ , 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:

### 3. Data analysis and calculations



The -3960 J from the reaction is associated with the limiting reagent – in our example, the base. From that we can calculate  $\Delta H$ !

See how the equation features one  $\text{OH}^-$ ? So  $\Delta H$  has to be for one mole of  $\text{OH}^-$ .

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

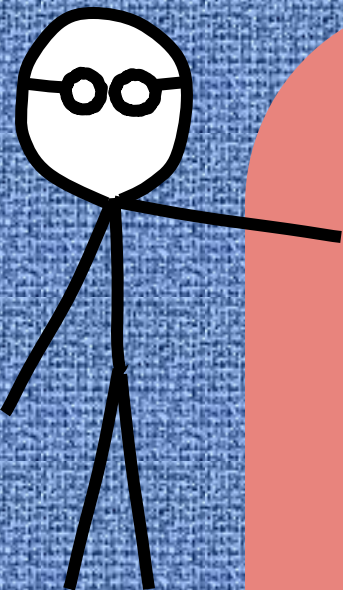
$$= \frac{-3960 \text{ J}}{0.1171 \text{ mol OH}^-} \left| \frac{1 \times 10^{-3} \text{ kJ}}{1 \text{ J}} \right.$$

$$= -33.81725021 \text{ kJ/mol}$$

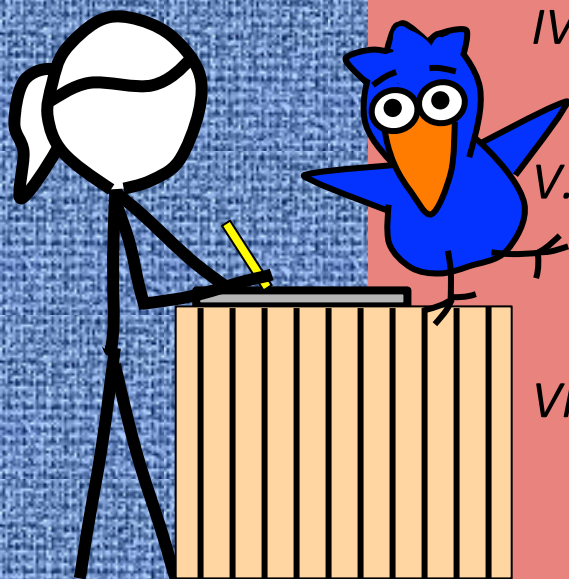
So... isn't that a lot of significant figures?

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

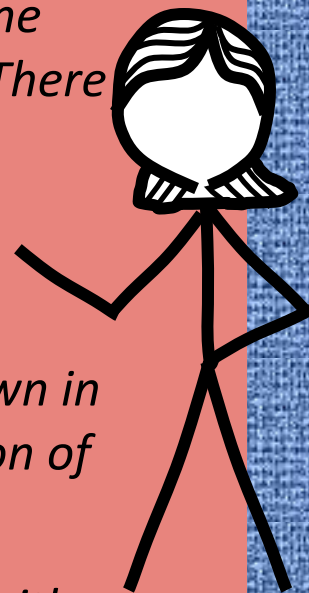
## 4. Procedure: What to do today



- I. *Wear your safety glasses today. And we need to dress for a mess.*
- II. *We follow the procedure in the manual carefully.*
- III. *If your graph looks good (meaning you swirled without splashing stuff around), you are done with the experimental part. Not so good? There is time to try again!*



- IV. *As usual, record observations and details as carefully as possible.*
- V. *Your report will include the calculations shown in this presentation, along with your calculation of percent error from the literature value.*
- VI. *In your conclusion, compare your  $\Delta H$  value with that of another pair of students.*

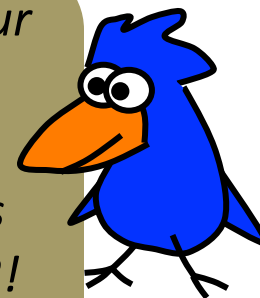


# 5. Your lab report

- 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.**

*LoggerPro will be used for our last experiment.*

*Also, dress for a mess – this week and for Experiment 12!*





*Happy  
Thanksgiving!!!*

*Be safe.  
Have fun!*

*See you in  
two weeks!*

