Thermo-chem diary

Thermo-chemistry is the study of how heat (energy) plays a role in chemical reactions and physical changes (phase changes). Heat can be released or absorbed by chemical reactions (exothermic or endothermic). All substances can go through different phase changes. The exact amounts of energy required to be absorbed or released is measurable and predictable.

Thermo-chem is a lot more complicated than anything that we will do. There are the three heat formulas listed on your reference table to become familiar with, and Table B, which are the three physical constants for water. We'll have the two labs, the SPECIFIC HEAT OF COPPER (C of Cu) and the HEAT CONTENT OF A DORITO'S CHIP. We have to be able to convert between calories and Calories and Joules and kilo-joules and back again. We need to pay attention to WHEN to use the different formulas, and we need to watch all of our significant figures.

Vocabulary

calorie	The amount of energy required to increase the temperature of exactly 1.0 grams of pure water by exactly 1.0 Kelvin
Calorie	This is a "food calorie", equal to 1000 calories (also called kilo-calorie)
Joule	The metric unit of energy. 4.18 Joules = 1.0 calorie
Kilo-Joule	1000 Joules
Specific Heat Capacity	It is the energy required to make 1.0 grams of a substance change temperature by 1.0 K. This is a constant for any substance. ("C" value)
Specific Heat	This is the energy change required to change a substance by 1.0 K. It is not a constant, because it concerns a sample of stuff (for example, NOT 1.0 grams of water, but a whole pot of water). It's tied to the specific heat capacity of the substance AND how much of it you have.
Specific Heat for Water *from table B*	"abbreviated" from specific heat capacity= 4.18 J/g·K which means it takes 4.18 Joule of energy added to make one gram of water 1.0 K hotter (or that many joules need to be removed to make one gram of pure water 1.0 K colder). Don't forget that 4.18 J = 1.0 calories.
Heat of Fusion for Water (H_F) *from table B*	The amount heat needed to turn 1.0 grams of solid ice water to a liquid at the freezing point. NO TEMPERATURE CHANGE. All substances have a H_F Also the reverse, the same amount of energy would be removed to freeze 1.0 grams of liquid water into solid ice. The constant for water H_F = 334 Joules/gram
Heat of Vaporization for Water (H_V) *from table B*	The amount heat needed to turn 1.0 grams of liquid water to a gas at the boiling point. NO TEMPERATURE CHANGE. All substances have a H_V Also the reverse, the same amount of energy would be removed to condense 1.0 grams of gas vapor into liquid water. The constant for water H_V =2240 Joules/gram
Calorimeter	A device used to measure heat loss by a sample of matter (or food). Also called a bomb calorimeter. These are highly sophisticated and exact, unlike our high school "calorimeters" made up of 2 styro-foam cups.

Energy Conversion Problems

Remembering the conversion factors is primary here. 4.18 Joules = 1 calorie (lower case "c")
1000 calories = 1 Calorie (capital "C", this is a FOOD CALORIE). 1000 calories is also called a kilo-calorie. Always use your units

Ex 1 Convert 556 Calories into Joules and calories.

$$\frac{556\text{ Calories}}{1} \times \frac{1000\text{ calories}}{1\text{ Calorie}} = 556{,}000\text{ calories}$$

$$\frac{556{,}000\text{ calories}}{1} \times \frac{4.18\text{ Joules}}{1\text{ calorie}} = 2{,}324{,}080\text{ Joules} \quad = 2{,}320{,}000\text{ J} \quad \text{(3SF)}$$

Ex 2 Convert 1,000,002 Joules into calories and Calories

$$\frac{1{,}000{,}002\text{ Joules}}{1} \times \frac{1\text{ calories}}{4.18\text{ Joules}} = 239{,}234.9\text{ calories}$$

$$\frac{239{,}234.9\text{ calories}}{1} \times \frac{1\text{ Calorie}}{1000\text{ calories}} = 239.2349\text{ Calories}$$

The Heat Formulas

On the reference table back page, under "HEAT" there are three thermo-chem heat formulas, used at different times. ***Each one is EASY*** to use, but recognizing when to use them (during temperature changes, or the cold or hot phase changes) takes a bit of practice.

The **BASIC HEAT FORMULA**, is

$$q = mC\Delta T$$

Where q is the amount of heat in joules
m is the mass in grams of the substance you are examining
C is the specific heat capacity, which is a constant for every substance,
with the unusual unit of J/g·K
ΔT is read as DELTA-T, and means the change in temperature, in Kelvin

This formula is used when ever there is a temperature change (NOT for phase changes).

You can solve for any part of the equation, energy, mass, specific heat capacity or temperature change, if you know the rest of the numbers.

Ex 3 How many grams of water can change temperature from 299.0 K to 304.2 K with the removal of exactly 499 Joules of energy?

$q = mC\Delta T$ Substitute in what you have, and solve for the unknown.

499 J = (m) (4.18 J/g·K) (5.20 K) ***[now, solve for m]***

$\frac{499 \text{ Joules}}{21.736 \text{ J/g}}$ = m *= 22.957... grams of water*

m = 23.0 grams of water (with 3 sf)

The COLD PHASE CHANGE HEAT FORMULA,
the 2nd one on the reference table, is

$$q = mH_F$$

Which is used only during the cold phase change, when $\Delta T = 0$. Using the $q = mC\Delta T$ formula when there is no temperature change is silly, it would always work out to zero.

The H_F or heat of fusion is the energy associated with "fusing" of water into a solid, or "unfusing" a solid into a liquid.

The formula has q again, the amount of heat in Joules, equal to m again, the mass in grams, times, a new constant, H_F. This constant is 334 Joules/gram, which is how much energy it takes to melt 1.00 grams of water from solid to liquid with NO TEMPERATURE CHANGE, at the freezing point.

Ex 4 How much energy is needed to melt 722 grams of ice at 273 K to liquid water at the same temperature?

$q = mH_F$ so, fill in what you know,
q = (722 grams) (334 J/g) = 241,000 Joules (with 3 sf)

Ex 5 How much energy is needed to freeze 722 grams of liquid water into solid ice at 273 K?

$q = mH_F$ so, fill in what you know,
q = (722 grams) (334 J/g) = 241,000 Joules (with 3 sf)

In thermo-chemistry, the EXACT same amounts of energy affect water in
BOTH TEMPERATURE DIRECTIONS.
It doesn't matter if water is cooling or heating, the CONSTANTS are CONSTANT.

The HOT PHASE CHANGE HEAT FORMULA, the 3rd one on the reference table, is

$$q = mH_V$$

Which is used only during the hot phase change, when $\Delta T = 0$. Using the $q = mC\Delta T$ formula if there is no temperature change is silly: it would always work out mathematically to zero.

The H_V or heat of vaporization is the energy associated with "vaporizing" of water into a gas, or the reverse, un-vaporizing it "condensing" a gas into a liquid.

The formula has q again, the amount of heat in Joules, equal to m again, the mass in grams, times, a new constant, H_V. This constant is 2240 Joules/gram, which means it takes 2240 Joules of energy to vaporize 1.0 grams of water from liquid to gas with NO TEMPERATURE CHANGE, from 373 K liquid to 373 K gas.

Ex 6 How much energy is needed to vaporize 722 grams of water at 373 K to steam at the same temperature?

$q = mH_V$ so, fill in what you know:

q = (722 grams) (2240 J/g) = 1,617,280 Joules

1,620,000 J (with 3 sf)

Ex 7 How much energy is needed to condense 722 grams of steam at the condensing point to liquid water at the same temperature?

$q = mH_V$ so, fill in what you know:
q = (722 grams) (2240 J/g) = 1,617,280 Joules

1,620,000 J (with 3 sf)

In thermo-chemistry, the EXACT same amounts of energy affect water in
BOTH PHASE CHANGE DIRECTIONS - increasing or decreasing energy.
It doesn't matter if H_2O is freezing or melting, or vaporizing or condensing,
the CONSTANTS are CONSTANT.

Let's look again at the answers to example 3, 4, 5, and 6.
Whether you freeze or melt, during the cold phase change, the amount of energy to get a certain amount of water through the phase change is the same (except that energy is removed to freeze and it's added to melt).

During the hot phase change, it also takes the SAME AMOUNT of energy in either temperature direction, condensing removes the same energy it took to vaporize the 722 grams of water.

FINALLY NOTE: There is a major difference between the hot and cold phase changes here concerning energy. The same 722 grams of H_2O: Melting took ONLY 241,000 Joules compared to vaporizing which took a whopping 1,620,00 Joules.

with a constant mass of water 722 grams of water	energy needed to be removed to 722 grams of H_2O	energy needed to be added to 722 grams of H_2O
the COLD phase change	241,000 Joules (freeze)	241,000 Joules (melt)
Hot phase change	1,620,000 J (condense)	1,620,000 J (vaporize)

It's almost a 7X difference in energy. That is clear on TABLE B, the heat of fusion is only 334 J/g while the heat of vaporization is 2240 Joules/gram.

Multiple Phase Change problems

Measuring energy in water phase changes requires all three formulas above. Imagine this problem, you have 4048 grams of ice at 273 K and you vaporize it to 373 K gas. How much energy would be required for this?

Rather than do this problem, let's take it apart.

1. First, determine the heat needed to phase change 4048 grams of H_2O from ice to liquid at the freezing point. Save this answer in Joules.

2. Determine the heat needed to warm 4048 grams water from 273 K to 373 K. Save this answer in Joules as well.

3. Determine the heat needed to phase change 4048 grams of water from liquid to gas, at the boiling point. Save this answer in Joules as well.

4. Last, add the three amounts of Joules of energy to get a TOTAL NUMBER OF JOULES. Each step takes a certain amount of energy.

   All the steps take ALL THE ENERGY ADDED TOGETHER. The right answer is the sum of all the energy added to make all the steps of the process occur.

Rather than doing a lot of calculating, <u>let's do a lot of thinking</u>. Don't do the math, just tell what formulas are required to determine the answer. Write, cold phase change, basic heat, or hot phase change formulas. Answers at the bottom of the page in red.

Ex 8 Water at 275 K is warmed to exactly 373 K but it remains liquid. How many joules are needed to be absorbed?

Ex 9 Steam at 373 K is cooled all the way to 273 K liquid. How many joules of energy are released?

Ex 10 Steam condenses from 373 K until ice forms at 273 K. How many joules are released?

Ex 11 Ice at 273 K is melted then warmed to 295 K which is room temperature. How many joules are absorbed?

The Thermo-Chemistry Labs…

C of Cu Lab

Measuring the specific heat capacity constant of copper indirectly by measuring the amount of the heat gained by a known sample of water.

To do the math, imagine that there are 2 sets of heat formulas problems to do. The HEAT GAINED BY THE WATER IN THE CUP is done first.

Since you know the mass of the water, the specific heat capacity of water is a known constant, and you can measure the temperature gained with a thermometer which means you can calculate the ΔT, you can solve for the number of Joules of energy gained by this water which is the q.

The second part of the calculations will arrive us to the measured value for the C of Cu. The heat gained by the water ONLY came from the hot copper pellets. So, since the heat gained by the water equals the heat lost by the copper, then the number of Joules gained by the water in the cup is in fact equal to the number of Joules of energy lost by the copper pellets.

Answers:
Ex 8: just the basic heat formula.
Ex 9: Hot phase change, basic heat formula
Ex 10: hot phase change, basic heat, and cold phase change formulas.
Ex 11: cold phase change, basic heat formula.

Now, insert this number of joules energy gained into the second heat formula equation to calculate the specific heat capacity for copper.

Your number of joules is equal to the mass of copper, times the unknown in this lab "C", times the temperature change for the copper pellets.

Here's a bit of tricky thinking! The copper hot temp is easy, you measured it already. The LOWEST TEMP that the copper goes down to is also the HIGHEST TEMP the water in the cup goes to in the first equation above. Use that same temperature in BOTH equations. Solve for the "C" of Cu, the specific heat capacity of copper.

The C of Cu is a constant = 0.39 J/g·K. That's the actual value. How close you come to that will be measured during your % Error calculation. Closer is better, but you knew that!

The rest of the lab is just basic heat formula, or hot and cold phase change formula math practice.

The HEAT CONTENT OF A DORITO'S CHIP LAB

This lab is another, bigger, thermo-chem lab. We'll be using Doritos chips (one per team) to measure how much energy is in them, PER GRAM.

Since we know how to measure heat gain by water from the C of Cu lab, we'll do the same again. Using the set up as shown in class, we will burn a chip of known mass under a can of deionized water of known mass. The burning of the chip releases the energy stored in it. How much energy gained by the water is how much energy lost by the chip by burning.

The chips also come with a nutritional label, clearly stating the number of Calories (food calories) per serving, and the serving size in grams. We'll do some math to figure out how many Calories per gram they are, and convert that to Joules per gram. Then we'll measure how many joules pre gram the burning chips released, and compare our results with the bag label.

This lab is great practice with the basic heat formula, and utilizing our brains. But, there is a major heat loss into the air that is unavoidable. A percent error of 50% will NOT be uncommon. It's hard to measure energy stored in food using a small piece of aluminum foil and a used diet coke can. Getting a good answer is not the point, thinking through the process, learning the connection between food calories and joules, and how energy/food can affect ourselves, now that is a good lesson.

For the regents, that particular lesson will be overlooked, but you will be expected to calculate using these formulas in an academic way! **You've got to own it like a dog.**

Table I: The Heats of Reaction

This is page 8 already, and I don't feel too close to the end yet. It's big and important. Nibble at it, don't be a snake and attempt to swallow this all at once.

Table I shows us 25 exothermic and endothermic reactions, and the exact ΔH associated with each one, at standard pressure and room temperature 298K.

The balanced chemical reactions have mole ratios associated with them, remember STOICH? Now we include the energy gain or release as well, and those amounts of energy (in kilo-Joules) is also in a Stoichiometric ratio, just like the moles.

Look at the first reaction (here), methane combusts:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + 890.4\ kJ$$

This means that one mole of methane needs 2 moles oxygen to form one mole carbon dioxide plus 2 moles of water, and it releases 890.4 kJ of energy in an Exothermic reaction. A negative "delta H" (-ΔH) means heat is given off.

You remember Stoichiometry, the mole ratios work mole:mole only. If you have grams, liters, or numbers of particles, you must FIRST convert to moles to do the Stoichiometry. NOW the energy is included into this ratio.

The WHOLE Mole Ratio for this reaction is

$1_{mole} : 2_{mole} : 1_{mole} : 2_{mole} : \mathit{890.4}\ _{kJ}$

The energy is now included in the mole ratio.

Table I lets use see exothermic reactions with their negative ΔH, and also the endothermic reactions with their positive ΔH. This is just a list of 25, there are thousands of thermo-chem reactions in the universe.

Note that from a stoich point of view, in reaction 3 on table I, as the octane combusts, it starts with 2 moles of octane to produce the 10943 kJ of energy release. The mole ratio there is 2:25:16:18:*10943kJ*

The **most endothermic** reaction on table I is
$C_2H_{4(G)}$ forms, and takes in 227.4 kJ of energy.

The **most exothermic** reaction by far is when octane combustion and releases energy. It takes 2 moles octane produce 10943 kJ; one mole octane would release half that amount of energy or 5471.5 kJ is released.

Imagine a heating pad put onto your achy elbow. The pad undergoes a chemical reaction that is exothermic (-ΔH), releasing heat. The heat, or kinetic energy goes from the pad into your elbow. You feel good.

If you rather a cold pad, those reactions that undergo endothermic reactions (+ΔH), and the pad is cold. Place it on your twisted ankle. The pad does not "send" cold to your ankle, rather the heat from your ankle is transferred to the pad.

Ex 12 How much heat is absorbed when 2.50 moles of NaOH is dissolved into water?

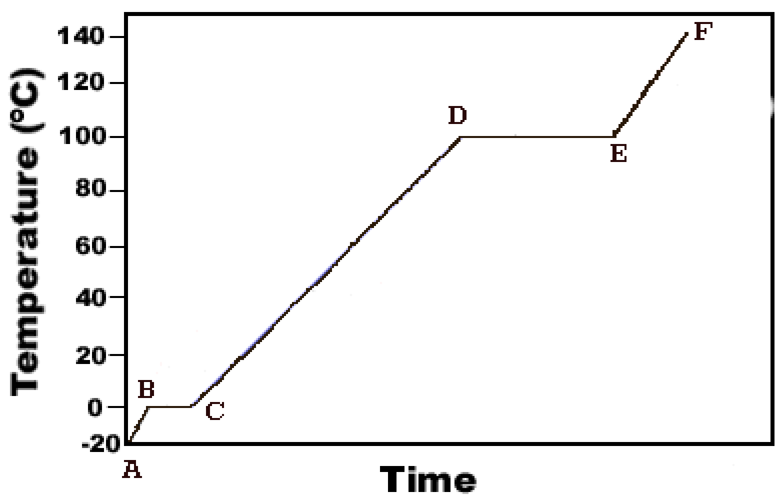
The ΔH for this reaction on Table I for NaOH dissolving into water is +44.51 kJ. That is for ONE MOLE of sodium hydroxide. The mole ratio is when one mole NaOH is dissolved into water it absorbs that many kilojoules of energy. You have 2.50 moles here. The ratio would be this way:

1 $\frac{\text{1 mole NaOH}}{\text{44.51 kJ}}$	2 $\frac{\text{2.50 moles NaOH}}{\text{X kJ}}$	3 Cross multiply and solve for X kilojoules of energy
4 X = (44.51kJ)(2.50)	5 X = 111.275 kJ	6 With 3 SF: 111 kJ energy absorbed

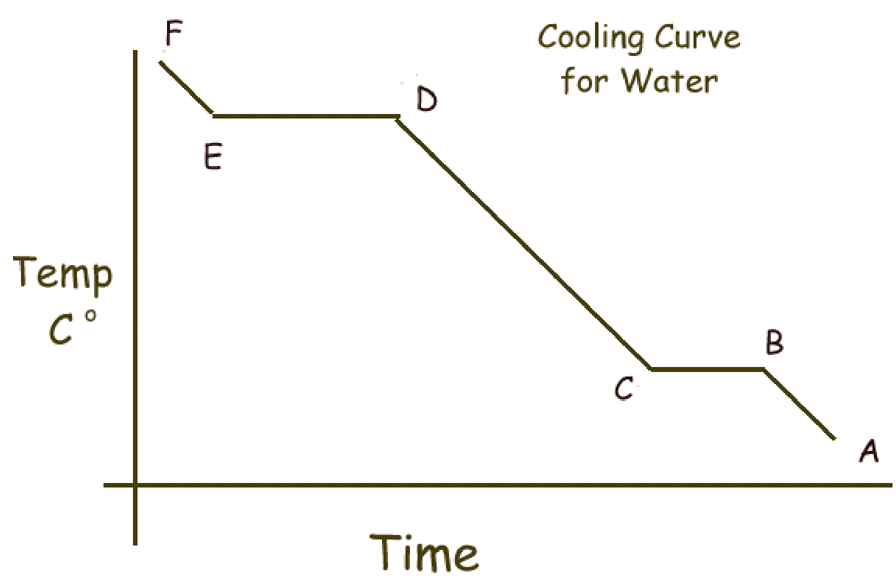
Heat Formulas and Cooling Curves or Heating Curves

Below are diagrams of both the heating curve and cooling curves for water. The cooling curve is the REVERSE, with the **same corresponding points at ABCDEF**. The points BC represent the cold phase change while the points EF represent the hot phase change. CD is the liquid water phase. AB is solid ice only, and EF is totally the gas phase. This chart outlines all values for Temp, KE, PE, and formulas needed to do any energy calculations for that section of each graph.
NOTE: TEMP & KINETIC ENERGY ALWAYS CHANGE TOGETHER,
POTENTIAL ENERGY IS DIFFERENT

The Heating Curve for Water



The Cooling Curve for Water



Choosing the right formulas… If your problem concerns just one part of the heating or cooling curve, just use the one correct formula...

AB	ice changes temp, getting hotter or colder	$q = mC\Delta T$
BC	Cold phase change Liquid to solid or solid to liquid	$q = mH_F$
CD	water temp changes, getting hotter or colder	$q = mC\Delta T$
DE	Hot phase change Liquid to gas or gas to liquid	$q = mH_V$
EF	steam changing temp, getting hotter or colder	$q = mC\Delta T$

If you have a problem that phase change and a temperature change, combine more than one step, and combine the total number of joules together to get one answer.

Examples of multi-step thermo-chem problems follow.

Think really hard now:

Ex 12+1 A complex problem would go like this, 99 grams of ice at 270. K is vaporized until the steam is 378 K. How much energy would that take?

1st: warm ice with basic heat formula and use
C = 2.10 J/g·°K (the specific heat capacity for ice)

2nd: cold phase change with heat of fusion formula

3rd: warm water to boiling point, basic heat formula using the specific heat capacity of 4.18J/g·°K

4th: hot phase change with heat of vaporization formula

5th: warm the steam up with the basic heat formula and use
(C = 1.7 J/g·°K which is the specific heat capacity for steam)

6th: add up 1 + 2 + 3 + 4 + 5 steps to get TOTAL JOULES NEEDED.

This is not hard, just a very long problem. Be sure to watch what phase you are in, and that you use the proper "C" values along the way.

Heat Formulas with ICE and STEAM changing temperatures too

We will not have to do math like this, but, it is important to note that since all substances have a constant called specific heat capacity, so would steam and ice. They are different forms of water, not liquid, and have their own "C" values. Ice has a specific heat capacity of 2.10 J/g·K, and the specific heat capacity for steam is 1.7 J/g·K.

When 45 grams of ice warms, say from 268 K to 273 K, but still remains solid ice, there is a real temperature change. You would use the basic heat formula, $q=mC\Delta T$, but instead of the specific heat capacity constant for water from Table B, you'd use the specific heat capacity for ice instead, like this:

$q=mC\Delta T$ so,

q= (45 g)(2.10 J/g·K)(5.00 K) = 473 Joules energy gained by the ice

All heat formulas work in both temperature directions, getting hotter, or colder. Both use the same amount of energy to move a certain amount of grams a certain temperature, just that energy would be absorbed or released, depending.

See you next year in AP CHEM, okay?