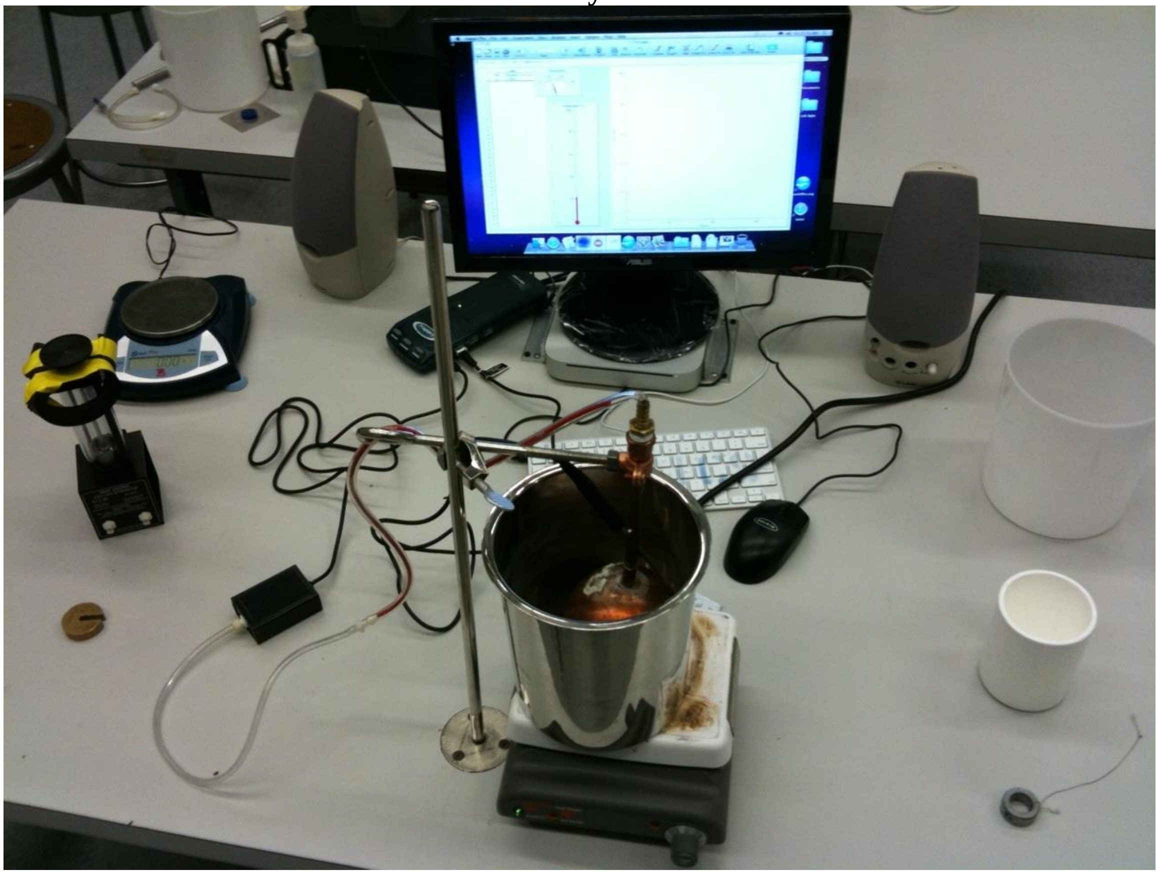
Thermodynamics



Objective: To investigate the zeroth and first laws of thermodynamics. To calculate properties such as specific heat. To investigate the ideal gas law. To become familiar with basic P-V diagrams.

Apparatus: Gas bulb, hot plate, hot water (from heating stainless steel bucket of water with hot plate), Pasco Gas Law piston, tubing, blue valve in tubing, **temperature probe, pressure probe**, glass or oven thermometer, tap water, styrofoam cup (non-disposable), metal block, scale, paper towels, ice (from cooler in Room 209 or ice machine in Room 210), white plastic bucket (for transporting ice), ring stand, 100g or 200g mass.

Theory:

We can summarize the four laws of thermodynamics as follows:

0th Law If you have two objects of the same *temperature* in physical contact with each other, they will exchange no heat and are said to be in *thermal equilibrium*.

1st Law The change in energy of a system is equal to the heat gained by the system minus the work done by the system: $\Delta U = Q - W$

2nd Law	This law places constraints on the *direction of the transfer of heat* and *efficiencies* of heat engines. It also introduces the concept of *entropy*, a measure of the amount of disorder of a system, and states that only *reversible, adiabatic processes* result in the conservation of this quantity; *irreversible processes* are ones where this quantity always increases.
3rd Law	You can approach *absolute zero* arbitrarily closely, but you can never attain it in reality.

In this lab we will examine and test consequences of the 0th law and the 1st law. One example of the combination of the zeroth and first law is this problem:

Calculate the final equilibrium temperature when a a 0.1 kg block of copper at 5^0C is dropped into 1.0 kg of water at 80^0C :

English	***Math***
The internal energy of the system (block + water) should remain the same since no energy or work is done on (or by) the system.	$\Delta U_{system} = \Delta U_{block} + \Delta U_{water} = 0$
The change in internal energy of the block should equal negative the change in internal energy of the water.	$\Delta U_{block} = -\Delta U_{water}$
Since there is no work done on (or by) the block or water, the heat gained by the block is equal to the heat lost by the water.	$\Delta Q_{block} = -\Delta Q_{water}$
The heat gained (or lost) by either is the product of its mass, specific heat, and change in temperature.	%$m_{block} c_{block} \Delta T_{block} = -m_{water} c_{water} \Delta T_{water}$

English	***Math***
The block and water eventually reach thermal equilibrium, which means that they reach a common temperature.	$\Delta T_{block} = T_{final} - (T_{block})_{initial}$ $\Delta T_{water} = T_{final} - (T_{water})_{initial}$
We can find the common temperature from combining the zeroth and first laws.	$m_{block} c_{block} \left(T_{final} - (T_{block})_{initial}\right) = - m_{water} c_{water} \left(T_{final} - (T_{water})_{initial}\right)$ or $(0.1kg)\left(390 \frac{J}{(kg^0 K)}\right)\left(T_{final} - 5^0 C\right) =$ $-(1.0kg)\left(4200 \frac{J}{(kg^0 K)}\right)\left(T_{final} - 80^0 C\right)$ $Therefore\text{:}\ \ T_{final} = 7.5^0 C$

You may recall from your textbook (and there is at least one example problem there) that whenever there is a change of phase (e.g., from water to water vapor, or from ice to water), additional heat is required, as in the Latent Heat of Vaporization or the Latent Heat of Fusion. For example, just to melt ice into water, at the same temperature (0ºC), you would need mL_{fusion} amount of heat. Values for these are also given in your textbook.

The *Ideal Gas Law* relates the pressure, volume temperature of a quantity of a gas in which the molecules do not interact with each other; they interact with the walls of the container with which they undergo perfectly elastic collisions. Mathematically it is expressed as:

$PV = nRT$

Here P is pressure, V is volume, T is the temperature of the gas in Kelvins, n is the number of moles of the gas, and R is the universal gas constant, 8.3145 J/mol K. Again, there are numerous examples of ideal gas law problems in your textbook; an important key in working out such problems is identifying which of the above variables change during the given process, and which ones do not. For processes of constant pressure, the quantity W in the First Law can be gotten from Newtonian Mechanics and can be expressed simply as:

$W = P\Delta V$

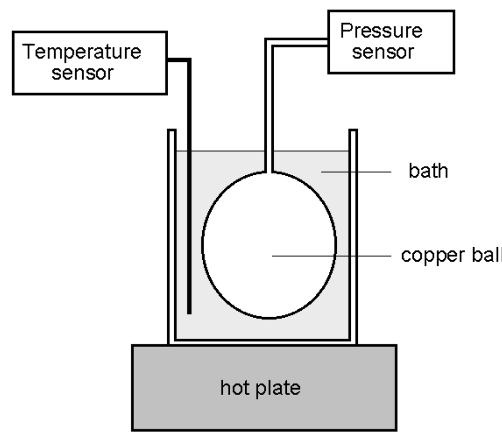
Here W can equate to work done by or on the gas as it expands or contracts, and relates to the Newtonian formulation of work you are familiar with: $W = Force x Distance$.
Activities

1. Ideal Gas Law (30 pts)

As usual, write your lab report in Google Docs and share it with lab partner(s), TA and LA.

You have:

- A gas bulb with an ideal gas inside.
- Thermometer and pressure probes; the thermometer lies just *outside* the gas bulb while the pressure sensor is connected via tube to the gas bulb.
- Ability to make temperature baths (for example, 0^{o} C, 100^{o} C, room temperature air, and so forth).
- Graphical and numerical data collected by Logger Pro



FOR THIS PART OF THE LAB YOU WILL USE THE TEMPERATURE PROBE AND THE PRESSURE PROBE – Open “Temp - Press.CMBL”, which is a Logger Pro template file in the same folder as this write-up.

If the temperature probe is not inserted in its holder next to the gas bulb, insert it now. **Make sure the probe cable does not touch the hot plate or the metal bucket!**

Using the Logger Pro template you just opened, which will run for about 30 minutes and record Temperature as a function of Pressure, perform an experiment to test how the pressure of an ideal gas depends on the absolute temperature when the volume of gas is held constant. You should start off with cold or tap water and heat it until it is hot (**but the boiling point need not be reached – the temperature should level off at somewhere in the 80 degree range, at which point you can conclude the experiment**), the software will take simultaneous readings of T and P along the way, one pair of data points per minute. A plot will automatically be generated; you will:

a) analyze the data with the appropriate curve fit. Then, you will:

b) explain the significance of extrapolating (extending your data mathematically) your plot to zero pressure and discuss the importance of the temperature at this point (which is the Y-intercept of your plot).

Make sure that neither the gas bulb nor the thermometer is touching the walls of your temperature bath. (30 points for **a** and **b** in total)

IMPORTANT:

• During the first 5 minutes of the experiment that the water bath is heating the gas bulb, check that both T and P are rising on the Logger Pro plot (there should be a trace going both upward and rightward; if there is instead a horizontal plot, there could be leak in the tubing – have your TA examine it.

• The part of the gas bulb tube that attaches to the pressure sensor should be screwed-in tightly by hand – make sure you ask your TA to confirm that it is tight enough so no gas leaks. See graphic below:

2. Calorimetry using the First Law of Thermodynamics (25 pts)

FOR THIS PART OF THE LAB YOU WILL USE THE GLASS OR OVEN THERMOMETER, since the temperature probe is likely being used for Part 2 (Ideal Gas Law) of the lab.

A. Predict the amount of ice (in grams) that you should add to a cup of hot water (roughly 100g, at about 60ºC) in order that the ice and water reach a final temperature that is half the initial Celsius temperature of the hot water. (10 pts) After your prediction, check with the instructor. Then do the experiment using the styrofoam cup, and record your results; how close was your experimental mass to your theoretical mass? (5 pts)

NOTE: Your ice might not be at 0 ◦C, so pour some water on it and let it sit for a few minutes. The water-ice solution will reach a temperature of 0^0 C. Then pour off the water, and quickly pat the ice dry with a paper towel and weight the desired amount. Remember that you can obtain hot water from your previous Ideal Gas experiment.

B. Find the heat capacity of a block of unknown material. (10 pts) You will immerse the block, with its temperature known, into a known quantity of water, which is at a very different temperature than the block. After they reach equilibrium, they will be at the same final temperature. From the change of temperature of both, calculate the block's heat capacity. **REMEMBER NOT TO THROW AWAY THE STYROFOAM CUP AS THE NEXT SECTION WILL RE-USE IT!**

NOTE: You can heat up or cool the block using hot water or ice water.

<u>3. Qualitative explanations of piston/gas bulb apparatus (45 pts)</u>

Note the foam protecting the fragile glass-walled piston; please do not remove this!

WARNING – DO NOT EXERT TOO MUCH FORCE ON THE PISTON PLUNGER, EITHER PULLING OR PUSHING, OR YOU MAY SHATTER THE PISTON GLASS!

A. Remove the gas bulb from the hot water and let it cool down for a few minutes. <u>Disconnect (unscrew) the gas bulb's tube from the pressure sensor</u>. Look at the piston apparatus. The piston/plunger part itself is effectively air-tight, but there are two pathways for gas to get in or out – through the **two tubes at the bottom** that connect to the two white ports. There are already two short tubes connected to each port, one with a blue or white valve on its end. <u>Connect the gas bulb's tube to tube with the valve on the piston/plunger</u>. Then, <u>connect the piston/plunger's valve-less tube to the pressure sensor</u>; this will stop gas from flowing past the sensor (and allow monitoring of pressure). Note that turning the blue (or clear) valve knob on the other tube will similarly allow (blue/clear knob **parallel** to tube – open valve) or prevent (blue/clear knob **perpendicular** to tube – closed valve) gas from reaching the gas bulb:

	
Blue Valve closed (piston closed to bulb) ❌	Blue Valve open (piston open to bulb) ✅

In our case, we want gas to flow freely between the gas bulb and the piston, with the pressure sensor tube attached to stop any airflow through that port.

Before you start your experiment with the piston/plunger and gas bulb, first make sure the piston screw near the top of the apparatus is loosened (counterclockwise). **Temporarily** disconnect one of the two short tubes from the piston/plunger so that air can enter/leave the closed system. Then, loosen the piston screw (counterclockwise), and and move the piston to approximately the mid-position of its travel range. While maintaining the plunger's mid-position, reconnect the short tube that you had disconnected from the piston/plunger to allow the piston/plunger and gas bulb to exchange gas. Finally, **open the valve** on the other short tube. **The closed system you have configured will ensure that the contiguous volume of gas – inside the bulb, piston and tubing connecting them – does not escape.**

If you find that the connector you're trying to attach to a tube or port doesn't seem to be compatible, please ask your TA for help.

Predict what will happen to the position of the piston:

(i) When the gas bulb is immersed in a hot bath (you can use the hot water in stainless steel bucket) (5 pts)

(ii) When the gas bulb is immersed in a cold bath (you can use ice water in white plastic bucket) (5 pts)

Do both experiments and explain your results in terms of the ideal gas law. Also, watch the pressure *as* the piston moves up or down – does it change? Would you expect it to change? Recall that the gas in the bulb, piston and tubing is one contiguous volume - is this a constant pressure or constant volume process? Does your pressure reading support your answer? (5 questions x 5 pts each = 25 pts)

B. Make sure the piston screw is still loosened (counterclockwise). Move the piston to the lowest position possible by releasing the air by disconnecting the pressure sensor tube, then re-attaching. Now put a 100g or 200g mass on top of the piston platform and predict what will happen when you immerse the gas bulb in hot water. Do the experiment, note the results and explain them in terms of the First Law and the work done on or by the mass. Again, think of whether this process is a constant pressure or constant volume one. (10 pts)

When done, please unplug remove the tubing (originating from the pressure sensor) from the piston housing, such that the setup resembles what you saw before using the piston - thanks.