Name: ______________________________

PH122 – Exam 1 – May 11, 2018

Time Started ________ Time Ended ________ Place Taken ________

Instructions and Notes – You will lose points if you do not comply.

- You are only allowed three hours (or a pre-arranged accommodation) to take this exam. Pay careful attention to time! If you go over time, I will deduct points in proportion to how much time you go over the allotted amount.
- You are allowed one 8.5 inch by 11 inch piece of paper, with whatever information you choose to include on the front and back, as your only source of information outside of this exam paper. You may not consult your textbook, notes, or any other source of information.
- You are allowed to use a scientific calculator, but it must not be programmed with course-specific information. You may not use a cell phone as a calculator, but you can use it as a clock. (Keep it silent!)
- Unless you have made other arrangements, you will take the exam in one of the general physics laboratories (SSC111 or SSC115).
- Answer all questions on your own loose-leaf paper (not torn out of a spiral notebook).
- You may use only the front side of each sheet to answer the questions. If your answer goes longer than one page, continue on the front of a new sheet of paper and indicate that it is a continuation of that question's answer.
- Answers to each question (not each question part) must start on a new sheet of paper.
- Your answers should be clear, well explained, and legible. It is your job, not mine, to ensure that I understand your answer. If you have a muddled answer and time remains at the end of the test, re-write it neatly on a new sheet of paper and submit the clear answer.
- Box final answers to calculation/symbolic questions so I can easily locate your answer.
- The grading rubric is listed on the back of this page. You must demonstrate that you understand the physics involved in the problem in order to receive full credit. A correct answer is not sufficient. You must show how you obtained that answer.
- Show enough detail in algebraic manipulations to ensure I can follow your work.
- Include units in all calculations and include them through all steps of a calculation. I will deduct points for correct solutions for which you do not include units with numerical values through every step of the solution!!!
- When you finish the exam, arrange all answer sheets in order and staple them together with these exam sheets on top.

Sign That You Have Upheld
The Honor Code During This Exam: ______________________________

Grading Rubric

Each problem will be graded on a 10-point scale. The table below shows examples of how I will assign points.

High Level of Understanding Demonstrated

- 10 points: correct answer and explanation
- 9 points: correct reasoning with a reasonable answer but minor computational errors

Partial Understanding Demonstrated

- 7 points: physics errors (or correct setup but incomplete execution)
- 5 points: major physics errors (or partial justification provided even if answer is correct)

Little to No Understanding Demonstrated

- 3 points: little relevant work (or no justification provided even if the answer is correct)
- 1 point: very little relevant work
- 0 points: no relevant work, recopy of the problem statement with no additional work

Constants and Unit Conversions

$R = 8.314$ J/mol·K $= 0.08206$ L·atm/mol·K 1 atm $= 101\,325$ Pa $k_B = 1.38 \times 10^{-23}$ J/K

$N_A = 6.02 \times 10^{23}$ 1 kcal $= 4184$ J 1 m^3 $= 1000$ L $k_e = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}$

$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}$ $e = 1.6 \times 10^{-19}$ C $m_e = 9.11 \times 10^{-31}$ kg $m_p = 1.67 \times 10^{-27}$ kg

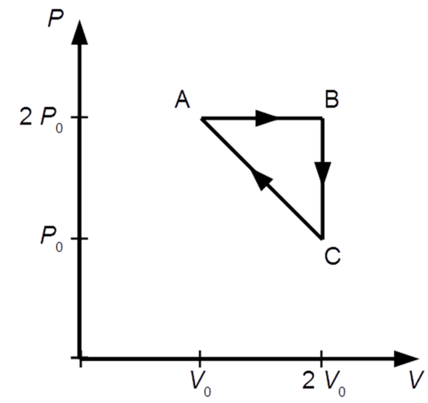
$\mu_0 = 4\pi \times 10^{-7}$ T·m/A $n_{\mathrm{water}} = 1.33$ $n_{\mathrm{glass}} = 1.5$

Thermal Properties of Materials

	Linear Expansion: α (K^{-1})	Specific Heat: c (J/kg·K)
Aluminum	24×10^{-6}	910
Lead	29×10^{-6}	128
Copper	17×10^{-6}	390
Concrete	12×10^{-6}	387
Iron	11×10^{-6}	448
Steel	13×10^{-6}	500
Mercury	61×10^{-6}	140
Glass	3×10^{-6}	840
Water	---	4186
Ice	---	2050

Latent Heats	Fusion: L_f (J/kg)	Vaporization: L_v (J/kg)
Water	3.34×10^5	2.26×10^6
Oxygen	2.55×10^4	2.13×10^5
Aluminum	3.7×10^5	1.14×10^7
Copper	1.34×10^5	5.07×10^6

1. Two moles of a *monatomic* ideal gas are confined to a cylinder with a moveable piston. The gas taken through the following closed cycle (diagram on the right):
   a. Isobaric expansion from A to B that doubles the volume.
   b. Isovolumetric cooling from B to C that cuts the pressure in half.
   c. Compression from C to A such that the pressure and volume are linearly related, as shown. (There is no simple name for this process.)



   For each of the steps above, compute the work done *by* the gas, the change in the total energy of the gas, and the heat *added to* the gas. Now imagine that the cycle represents a heat engine in which the total work done by the gas is the work output by the engine. Compute the efficiency of this engine. Remember, people have trouble with signs in these problems, so *be sure to express all answers above in words*, to make it clear whether energy is entering or leaving the system through heat, work, etc.

2. Two identical bubbles of gas form at the bottom of a lake, then rise to the surface. Because the pressure is much lower at the surface than at the bottom, both bubbles will expand as they rise. However, bubble A rises very quickly, so that no appreciable amount of heat is exchanged between it in the water during the time it rises. Bubble B, on the other hand, is impeded by a tangle of seaweed and rises slowly such that it always remains in thermal equilibrium with the water (which has the same temperature everywhere). Which of the two bubbles is larger when it reaches the surface? In answering this question, make a clear and careful argument that takes into account all the relevant quantities that change or stay the same in these two thermodynamic processes. I am not asking for a formal calculation of their relative sizes. You will probably drown in the math and there won't be enough air in either bubble to save you.

3. A glass bowl is filled to the very brim with 100 cm^3 of water at 10°C. How much water will overflow when the temperature of the filled bowl is raised to 50°C? (The volume expansion coefficient of water is 23 times that of glass.)

4. One day in class I lamented my own poor education in introductory physics, particularly in thermodynamics. When I was faced with a question about the "law of Dulong and Petit" on the physics GRE exam, I was completely flummoxed. Luckily, you are the beneficiary of a better physics education, so you recall that the Dulong-Petit law states that the molar heat capacity for all solids (at sufficiently high temperatures) is the same: $C_V \approx 25$ J/mol·K.

   Okay, even if you didn't remember the name of the law, prove to me that you understand the result. Explain first what the quantity C_V physically is for *any system*, not just a solid. (What does it mean? What quantities does it relate to each other?) Next, explain why we expect C_V to be the same for all solids at high enough temperatures. Why does it have the value it does? Finally, what happens to the value of C_V at lower temperatures? Why? Explain all answers thoroughly in words, not just equations, and identify any symbols you use.

5. Kidnapped by aliens, you find yourself on a trip to the planet Magrathea, where your impressive coloration and superior hacky-sack skills are sure to make you the star attraction at *Slartibartfast's Exofauna Circus Extravaganza*.

   On the trip to your new home, you pass the time in the ship's physics lab. There you find a "constant-volume gas thermometer" (CVGT). This device consists of a sealed metal canister of fixed volume with a fixed amount of an unknown ideal gas inside it. Attached to the canister is a gauge that measures the absolute pressure of the gas inside the canister. Of course the pressure gauge, and all other equipment available to you are marked in alien units. For example, the gauge indicates absolute pressures in K'Paxore's, which we'll just call "pressure units" (PU), while the thermometers read temperatures in Okjuc Zoquanii, which we'll call "temperature units" (TU).

   You don't have freezing or boiling water at your disposal to help relate TU to Celsius, but you do have an oil bath you can set to any desired temperature in TU. You first adjust the temperature of your oil bath until it feels "to the touch" to be equal to your body temperature (37°C). According to your thermometer, the bath has a temperature of 10 TU. When you immerse the canister of the CVGT in this oil bath and allow it to come to thermal equilibrium, the gauge reads a gas pressure of 31 PU inside the canister. Next, you heat the oil to a temperature of 20 TU, according to your thermometer. At that temperature, the gauge tells you that the gas in the canister has a pressure of 62 PU.

   Determine the value of absolute zero on the Temperature Unit (TU) scale. Also derive a formula relating the TU and Celsius scales. As usual, explain your reasoning as you go through both calculations.

6. *We went to the Philly Pizza Company and ordered some hot tea.*
   The waitress said, "well no, we only have it iced."
   So we jumped up on the table and shouted, "anarchy!"
   And someone played a Beach Boys song on the jukebox.
   It was "California Dreamin'", so we started screamin'
   "On such a winter's day!"

   —"Punk Rock Girl" by the Dead Milkmen

   No need to get all worked up about the iced tea, folks. You can just heat it up. Luckily, along with the car in which she was rollin', your Mohawk-coiffed companion has also stolen an immersion heater, an electrical coil you plug into the wall and put into a cup of liquid to heat it up (image above, right). Just order a small iced tea in a coffee mug and drop in the heater, which puts out heat at a rate of 300 J/s when plugged in.

   Your waitress obliges and brings out a cup with 200 grams of cold tea in thermal equilibrium with an additional 50 grams of ice. You can use the heater to melt the ice and heat up the tea. Unfortunately, you will end up with 250 grams of weak tea. To concentrate it back to its original strength, you're going to have to boil away the extra 50 grams of water that came from the ice.

   Determine how long it will take to get 200 grams of boiling tea. (Tea and water have the same specific heat. Ignore the specific heat of the cup and assume that no heat escapes.)