Name: ______________________________

PH122 — Exam 1 — February 28, 2020

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.

<u>High Level of Understanding Demonstrated</u>

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

<u>Partial Understanding Demonstrated</u>

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

<u>Little to No Understanding Demonstrated</u>

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

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. You don't usually hear people discuss thermal expansion coefficients for ideal gases, probably because you can figure them out on your own. Not surprisingly, they are process dependent.

   (a) Write out and explain the definition of the coefficient of volume expansion, β, for any arbitrary object (for example, a solid as you might have seen in notes and homework).
   (b) Consider an ideal gas that is heated isobarically. Determine the coefficient of volume expansion for the gas in terms of other thermodynamic quantities.
   (c) Can one define a similar volume expansion coefficient for gases undergoing isochoric (isovolumic) or isothermal changes? Explain why or why not with a careful analysis of these types of processes.

2. In class I showed you a *Stirling engine*, which took heat from a cup of hot water and converted some of it to work (the work being turning a propeller against air resistance). The engine works by taking n moles of an ideal gas through the following four process cycle:

   A. Isothermal expansion from state (P_1, V_1, T_1) to state (P_2, V_2, T_2).
   B. Isovolumic (isochoric) cooling from state (P_2, V_2, T_2) to state (P_3, V_3, T_3).
   C. Isothermal compression from state (P_3, V_3, T_3) to state (P_4, V_4, T_4).
   D. Isovolumic (isochoric) heating from state (P_4, V_4, T_4) to state (P_1, V_1, T_1).

   (a) Draw this cycle on a PV diagram.
   (b) For each step in the process, A through D, *explain* whether heat is added to or removed from the gas, whether work is done on the gas or by the gas, and whether the total thermal energy of the gas increases or decreases. Make sure to justify your answers with a thorough discussion.
   (c) Suppose that $V_2 = 2V_1$, and $P_1 = 2P_4$. Write down every pressure, volume, and temperature at the "corners" of the gas cycle as appropriate multiples of P_1, V_1, and T_1. (For example, write $P_3 = 35\,P_1$, $T_4 = 2.718\,T_1$, etc., although these are not the correct answers.)
   (d) Argue whether the engine operating as in (c) above will be more efficient if the gas is *monatomic* or *diatomic*. You will need to point specifically to which part(s) of the cycle are affected by the molecular structure and how this leads to greater or lesser efficiency.

3. Your favorite physics professor enjoys two main culinary hobbies: brewing beer and cooking barbecue. Carefully tracking temperatures is important in both of these processes. It is so I possess a custom-built thermometer marked in a special temperature scale, °R (for "Rupright", not "Rankine"). The Rupright temperature scale is constructed around two points: 0 °R (22 °C) is an ideal temperature to "pitch" yeast and begin fermentation, while 100 °R (110 °C) is an ideal smoking temperature for barbecue. Construct formulas for converting temperatures from °C to °R and from °R to °C. Using these formulas determine the temperatures of absolute zero (−273 °C), the freezing temperature of water (0 °C), and human body temperature (37 °C) on the Rupright scale.

   Is the Rupright scale absolute? Absolutely not! That's why Dr. Pontius invented the Pontius scale. The difference between two temperatures on the Pontius scale is equal to the difference between two temperatures on the Rupright scale, but 0 °P really is absolute zero. Construct a formula relating temperatures on the Pontius scale to temperatures on the Kelvin scale.

4. You have done a number of “calorimetry” problems which involved mixing ice/water/hot metals, etc. together in a sealed, thermally insulated container. In these problems we ignored an important source of error: as the materials inside the container heat and cool, the walls of the container and the thermometer also heat and cool. Strictly speaking, we must take such factors into account. Lab apparatus manufacturers are compassionate. Realizing that the most common substance used in calorimeters is water, they often report the heat capacity of the container and thermometer in terms of a “water equivalent” — the amount (mass) of water that has a heat capacity equivalent to the heat capacity of the container.

   Now use your knowledge of physics to determine the specific heat of an unknown material in a hypothetical experiment. You have a metal ball (mass 75 g) that has been heated in a 300 °C oven for a long time. You also have a calorimeter and thermometer (which together have a heat capacity equivalent to 30 g of water). These are initially in thermal equilibrium with 200 g of water at 20 °C. You drop the ball into the water, seal the container, and allow enough time for everything to come to thermal equilibrium, after which you measure the final temperature of the system to be 28.2 °C. What is the specific heat of the metal? By what percentage would your answer have been wrong if you had not taken the heat capacity of the calorimeter and thermometer into account?

5. Deuterium is an isotope of hydrogen with one proton and one neutron. At room temperature pure deuterium is a *diatomic* gas with a molecular weight of around 4 grams/mole. Helium, on the other hand, is a *monatomic* gas with the same molecular weight as deuterium. Let's say you have one mole of each gas in identical containers at room temperature. Compare each of the following quantities for the two gases: (a) pressure, (b) total translational kinetic energy, (b) total internal (thermal) energy, (c) average (RMS) molecular speed, (d) constant-volume molar heat capacity, and constant-pressure molar heat capacity. I want a good explanation for each answer. If the quantities are equal for the two gases, I want to know why they're equal. If the quantities are different, I want to know which gas has the greater value and why. These comparisons are very easy if you just write down equations, but that's not what I'm looking for. I want to know the physical explanation for each answer!

   Now imagine that I add the same amount of heat to the gases four different ways: (i) deuterium at constant volume, (ii) helium at constant volume, (iii) deuterium at constant pressure, and (iv) helium at constant pressure. Rank these four cases from smallest temperature increase to greatest temperature increase. If any answers are equal, point out which ones. If you answered the above questions well, this should be straightforward.

6. A sealed aluminum container with a volume of 1 liter contains an ideal gas with a pressure of 1 atmosphere at a temperature of 27 °C. The canister is immersed in a bath of boiling water and brought to thermal equilibrium with the boiling water.

   (a) Compute the final pressure of the gas, assuming the volume is fixed.
   (b) As with our homework problems involving heating ideal gases in containers, in the above calculation we ignored the expansion of the cylinder itself. Re-calculate the final pressure of the gas, taking into account the volume expansion of the aluminum container.
   (c) Are we usually justified in ignoring the volume expansion of the container in these kinds of problems? Explain your reasoning.