Physics H7B Fall 2014
Dr. Winoto - Midterm 1
Wed, October 1st, 2014

Instruction for the examination:
- In the front of your bluebook, next to your name, please write you SID.
- You may use a calculator without any wireless internet connection and one 8.5"x11" sheet of notes
- Topic covered: Kinetic Theory and Thermodynamics
- There are 5 problems, listed in the order of increasing difficulty (albeit approximate and subjective)
- Total points for the exam = 100 points for a perfect score
- You have exactly 120 minutes to complete the test
- **Show all your work!** Please outline and explain in details all your physical and mathematical reasonings in a clear, rational, step-by-step and logical manner.
- Cross out any parts of your written exam that you would like to discard and not considered as part of your answers.

1. (15 points)
Two reversible engines operates on Carnot cycles between the same minimum and maximum volume, the same maximum and minimum pressure, and the same maximum and minimum temperature. One engine (Engine 1) uses Helium (mass number A=4) as the working substance, the other (Engine 2) uses Argon (mass number A=40). Which engine delivers more work per cycle? Please give physical justification for every single step of your reasoning.

2. (20 points)
Using the techniques of laser cooling and atom trapping, it is possible to use laser lights to confine an ideal gas of atoms in two dimensions (2D). Now suppose, initially, you have a gas of Cesium (monoatomic) with N number of particle confined in 2D with temperature T. Some time later, you abruptly turn off the laser field, so suddenly the atoms find themselves in a 3D space; (so this is a bit like a Joule free expansion that you are familiar with). And for simplicity, assume that somehow the atoms will now be freely moving in 3D but confined with walls on all side, so that they don't run away to infinity (this can actually be arranged experimentally).
(a). Express the Maxwell distribution of the atomic speed when the atoms are in 2D initially. Please give detail explanation, not just the formula.
(b). Using equipartition theorem, calculate the v_{rms} of the atomic speed.
After the atoms thermalize in 3D:
(c). Calculate the new temperature T_{3d}
(d). Express the new Maxwell distribution of the atomic speed in 3D. Again, please give detail explanation, not just the formula.

3. (20 points)
Translate the ideal Carnot cycle (abcd) on a P-V diagram (see figure 1) operating between T_H and T_L, with a=(P_a,V_a), b=(P_b,V_b), c=(P_c,V_c), d=(P_d,V_d) into:
(a). a T-S diagram with corresponding points (abcd). Give a functional form of each segment ab, bc, cd, and da.
(b). a V-S diagram with corresponding points (abcd). Give a functional form of each segment ab, bc, cd, and da.

4. (20 points)
In a cavity with a gas of electromagnetic field, the thermal energy of the the gas is given by the following function:

$U(V,T) = \sigma V T^4$, where σ is the Stefan-Boltzmann constant, V is the volume of the cavity, and T is the temperature of the cavity.
Also, $P V = (\gamma - 1) U$.
(a). Calculate the heat capacity at constant volume C_V of the gas, $C_V = C_V(V,T)$
(b). Using the first law of thermodynamics for reversible process, please calculate the entropy S of the gas, S=S(V,T). You may assume that the entropy of the gas at T=0K is equal to 0.
(c). In an adiabatic expansion of the gas $\Delta S=0$. Please express the relationship between V and T for an adiabatic process for this gas.
(d). Also, calculate the relationship between P and V in an adiabatic process.
(e). (1 points) Based on your result for (d), please give your brief thought about the compressibility of the electromagnetic gas.

5. (25 points)

Two identical materials M_1 and M_2 of constant heat capacity C_p, originally at temperatures T_1 and T_2 are used as reservoirs for a Carnot engine operating in infinitesimal reversible cycles (see figure 2). The reservoirs are under constant pressure and at all times, and do not undergo any phase-transition. Eventually, after many cycles, the engine comes to rest when the temperatures of M_1 and M_2 come to a thermal equilibrium of T_f.
(a). (13 points) Calculate T_f.
Of course, if there were no Carnot engine, if M_1 and M_2 were just in a simple thermal contact, then the final temperature T_f would just be equal to $(T_1+T_2)/2$. However, in our case, we are exploiting the temperature difference T_1 and T_2 to do work by way of a Carnot engine! So, things are a little more involved, so now you know that $T_f=(T_1+T_2)/2$ is definitely a wrong answer.
(b). (6 points) Calculate the total amount of work W done by the engine.
(c). (6 points) Calculate the total entropy change for M1, M2, for the Carnot engine itself, and for the whole system (M1 + M2 + Carnot engine)