Final Physics 9HB winter 2001

Use a law blue book. Closed book. Two 3"x5" note cards. PRINT your name on your blue book. To get credit, you must show your work. Be neat, clear, and organized. If we can't read it or figure it out, we can't give you any points. Also be sure to give your answers with appropriate units.

$k_B = 1.38\text{x}10^{-23}$J/K, $N_A = 6.02\text{x}10^{23}$/mole, R = 8.31 J/(mole K)

1. (20) A 1m (1m (1m box holds 40 moles of helium, an ideal gas with q=3 degrees of freedom and a mass per atom $m=4g/N_A$. The pressure is 10^5 N/m^2. The box of gas is in thermal equilibrium with a cubic meter of water.

a) What is the temperature of the water?

b) What is the average translational kinetic energy of a water molecule?

c) What is the rms speed of a helium atom?

d) The box is removed from contact with the water, insulated and is now surrounded by vacuum. One wall is slid to the side so that the box is open to the vacuum for 1 ms and then slid closed again. After a short time, the remaining molecules come to equilibrium. Are the gas molecules that remain in the box and the water still in thermal equilibrium? Explain.

2. (25) To make things a little simpler, let's suppose that air is 50% O_2 and 50% N_2 by number. Consider a small box that is divided in half. On the left half there is one O_2 molecule, and on the right half one N_2 molecule. The box is in thermal equilibrium with air at 300K. The partition between the two halves of this small box is removed for a few seconds and then replaced.

a) What is the probability that the left half now has one O_2 and the right one N_2?

b) Using our simplified air mixture, suppose that a partition were to drop from the ceiling and divide this room in half. Is there any appreciable probability that the left half contains all O_2 and the right all N_2? Explain your answer carefully including an explicit statement of any physical principle that you use. Include comments

on why your answer here differs from your answer to part a (if it does).
c) We saw that the entropy of an ideal gas has the form $S=k_B N \ln[CV/N]$ with C independent of V. Estimate the ratio of the probability of finding all O_2 on the left side and all N_2 on the right to the probability of the actual macrostate. Use one mole each of N_2 and O_2 .

3. (45) One mole of a monatomic ideal gas (q=3, (= 5/3) is initially at T_1 = 300K,
$P_1 = 10^5$ N/m^2, and V_1. All steps are quasistatic. In step 1, the gas is insulated, and it expands until the temperature is T_2 = 200K and V_2. In step 2, it is in equilibrium with a heat reservoir at 200K, and it is compressed back to its original volume. Finally in step 3, in contact with (but not necessarily in equilibrium with) a reservoir at 300K, it is heated at constant volume until it is in equilibrium with the 300K reservoir.

a) Draw the PV diagram (Is this a closed cycle?) and calculate V_1 and V_2.

b) Calculate the entropy change for the gas for each step. What is the net entropy change for the gas for the three steps combined? Explain your answer.

c) Calculate the entropy change of each of the two reservoirs and the combined entropy change for the two reservoirs?

d) What is the total entropy change of the universe for one cycle?

e) If a Carnot cycle operated between the same two reservoirs, what would the total entropy change of the universe be for one cycle?

f) Explain why your answers to d and e are either the same or different.

4. (over)

4) (10) The present cosmic microwave background radiation (CMB) temperature is 2.7K. At the time the radiation was emitted, the temperature was 3000K. The present value of the Hubble parameter is $H_0 = 1/(14 \times 10^9$ yrs). Let t_0 be the present time and t_1 be the time when the CMB was emitted.

a) By what factor has the universe expanded since time t_1 ?

b) For the period since t_1 , we can consider two cases. In the first, the universe is matter dominated and $R(t) = R_0 (t/t_0)^{2/3}$ with $t_0=2/(3 H_0)$. In the second case, it is dominated by vacuum energy and $R(t) = R_0 \exp[H_0 (t-t_0)]$. Both cases are arranged so that $R(t_0)=R_0$ and $H(t_0) = H_0$. In which case is the time difference $t_0 - t_1$, between the present and the time of CMB emission shorter? Explain.