Physics 132-3 Test 1

I pledge that I have neither given nor received unauthorized assistance during the completion of this work.

Signature ______________________________

Questions (6 for 7 pts. apiece) Answer in complete, well-written sentences WITHIN the spaces provided.

1. In the measurement of the heat of vaporization of liquid nitrogen L_V you subtracted the average of the absolute values of the two slopes when power was off from the absolute value of the slope when power was on. Why?

2. The table below shows pressure P and temperature T data for a gas. Describe how you would extract absolute zero from these data.

T [deg]	P [10^5 N/m^2]
37.39	1.05
50.09	1.09
61.35	1.12
74.25	1.16
85.44	1.2
98.14	1.24

3. Recall your one-particle 'gas' of mass m bouncing around in a cube of side ℓ. If the x-component of the particle velocity is v_x, what is the x-component of the average force $\langle F_x \rangle$ exerted by the 'gas' on one of the sides of the cube in terms of the parameters listed here? Start from the definition of $\langle F_x \rangle$ in terms of the change in momentum and show all steps.

DO NOT WRITE BELOW THIS LINE.

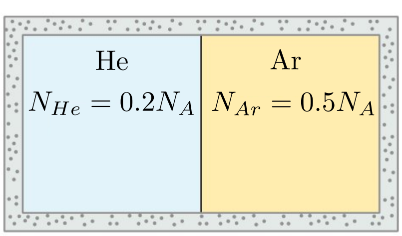
4. The kinetic theory model of an ideal gas requires that $PV = 2N\langle E_{kin}\rangle/3$. We have determined experimentally the ideal gas law $PV = Nk_BT$. Starting from these two results what can we say about the average kinetic energy per molecule for an ideal gas?

5. The table below has the results of a calculation of the multiplicities of an Einstein solid with $N_A = 20$, $N_B = 30$, and $q = 14$. What is the probability P_1 there are no energy quanta in solid B? What is the ratio of this probability to the most probable macrostate P_{max}? Is this result related to the notion of irreversibility? Explain.

U(A)	U(B)	Omega(A)	Omega(B)	Omega(AB)	Fraction of states
0	14	1	6.881e+16	6.881e+16	0.00114*
1	13	60	9.353e+15	5.612e+17	0.00930*
2	12	1,830	1.192e+15	2.181e+18	0.03614*
3	11	37,820	1.416e+14	5.356e+18	0.08874*
4	10	595,665	1.558e+13	9.280e+18	0.15374*
5	9	7,624,512	1.574e+12	1.200e+19	0.19877*
6	8	82,598,880	1.445e+11	1.194e+19	0.19776*
7	7	778,789,440	1.192e+10	9.283e+18	0.15378*
8	6	6.522e+9	869,107,785	5.669e+18	0.09391*
9	5	4.928e+10	54,891,018	2.705e+18	0.04481*
10	4	3.400e+11	2,919,735	9.928e+17	0.01645*
11	3	2.164e+12	125,580	2.717e+17	0.00450*
12	2	1.280e+13	4,095	5.243e+16	0.00087*
13	1	7.091e+13	90	6.382e+15	0.00011*
14	0	3.697e+14	1	3.697e+14	6.13e-6

Total number of microstates: 6.036e+19

6. The two gases shown in the figure are in thermal equilibrium with each other and well insulated from the environment. The helium has a molecular mass $m_{He} = 4\ u$. The argon has molecular mass $m_{Ar} = 40\ u$. Does the helium have more thermal energy, less thermal energy, or the same amount of thermal energy as the argon? Explain. (Hint: An equation or two might be helpful.)



Problems (3). Clearly show all reasoning for full credit. Use a separate sheet to show your work.

1. 10 pts. Consider a system consisting of a pair of Einstein solids in thermal contact. Suppose it is initially in a macropartition with multiplicity $\Omega_1 = 4.0 \times 10^{207}$. The adjacent macrostate closer to the equilibrium macrostate has multiplicity $\Omega_2 = 8.0 \times 10^{1034}$. If we look at the system later, how likely is it to have moved to the second macropartition Ω_2 than to have stayed with the first Ω_1?

2. 20 pts. A rigid tank having a volume of $V_t = 0.1\ m^3$ contains helium gas at a pressure $P_t = 94\ atm$. How many balloons can be inflated by opening the valve at the top of the tank? Each filled balloon is a sphere with radius $r_b = 0.12\ m$ at an absolute pressure of $P_b = 1.2\ atm$. The gas is at the same temperature throughout.

3. 28 pts. Suppose an ideal diatomic gas with $n = 4\ moles$ and molecular rotation but no vibration is heated so $\Delta T = 60\ K$ under constant pressure P. The gas is in a cylinder with a movable piston held down by air pressure. The specific heat here C_P is different because the pressure is constant and the volume can change. We studied the specific heat under constant volume C_V in lab. The relationship between the two is $C_P = C_V + N_A k_B$. (a) How much heat Q was added to the gas? (b) How much did the internal energy of the gas ΔE_{int} change? (c) How much work W was done by the gas? (d) How much did the translational kinetic energy of the gas increase? Clearly show your reasoning for full credit.

Physics 132-1 Constants

$T_{boiling}$ (N_2)	$77\ K$	$T_{freezing}$ (N_2)	$63\ K$
$T_{boiling}$ (water)	$373\ K$ or 100°C	$T_{freezing}$ (water)	$273\ K$ or 0°C
L_v(water)	$2.26 \times 10^6\ J/kg$	L_f (water)	$3.33 \times 10^5\ J/kg$
L_v(N_2)	$2.01 \times 10^5\ J/kg$	c (copper)	$3.87 \times 10^2\ J/kg -^\circ$ C
c (water)	$4.19 \times 10^3\ J/kg - K$	c (steam)	$0.69\ J/kg - K$
c (iron)	$4.5 \times 10^2\ J/kg - k$	c (aluminum)	$9.0 \times 10^2\ J/kg - K$
ρ (water)	$1.0 \times 10^3 kg/m^3$	P_{atm}	$1.01 \times 10^5\ N/m^2$
k_B	$1.38 \times 10^{-23}\ J/K$	proton/neutron mass	$1.67 \times 10^{-27}\ kg$
R	$8.31 J/K - mole$	g	$9.8\ m/s^2$
$0\ K$	-273° C	$1\ u$	$1.67 \times 10^{-27}\ kg$
Gravitation constant	$6.67 \times 10^{-11}\ N - m^2/kg^2$	Earth's radius	$6.37 \times 10^6\ m$
e electronic charge	$1.6 \times 10^{-19}\ C$	$k_e = 1/4\pi\epsilon_0$	$8.99 \times 10^9\ N - m^2/C^2$

Physics 132-1 Equations

$$\vec{F} = m\vec{a} = \frac{d\vec{p}}{dt} \qquad KE = \frac{1}{2}mv^2 \qquad ME_0 = ME_1 \qquad \vec{p} = m\vec{v} \qquad \vec{p}_0 = \vec{p}_1$$

$$Q = C\Delta T = cm\Delta T = nC_v\Delta T \qquad Q_{f,v} = mL_{f,v}$$

$$\Delta E_{int} = Q + W \qquad W = \text{force}\times\text{distance} = \int \vec{F}\cdot d\vec{s} \rightarrow P\Delta V \qquad \vec{F} = m\vec{a} = \frac{d\vec{p}}{dt} \qquad \langle\vec{F}\rangle = \frac{\Delta\vec{p}}{\Delta t}$$

$$\vec{I} = \int \vec{F}dt = \langle\vec{F}\rangle\Delta t = \Delta\vec{p} \qquad P = \frac{|\vec{F}|}{A} \qquad PV = Nk_BT = nRT$$

$$\langle KE\rangle = \langle E_{kin}\rangle = \frac{1}{2}m\overline{v^2} \qquad \langle E_{kin}\rangle = \frac{3}{2}k_BT \qquad E_{int} = N\langle E_{kin}\rangle = \frac{3}{2}Nk_BT$$

$$v_{rms} = \sqrt{\overline{v^2}} \qquad C_V = \frac{f}{2}N_Ak_B \qquad E_f = \frac{k_BT}{2} \qquad E_{int} = \frac{f}{2}Nk_BT$$

$f \equiv$ number of degrees of freedom

$$E_{atom} = (n_x + n_y + n_z + \frac{3}{2})\hbar\omega_0 \qquad E = \sum_{i=1}^{3N} n_i\epsilon = q\hbar\omega_0 \qquad \Omega(N,q) = \frac{(q+3N-1)!}{q!(3N-1)!}$$

$$S = k_B \ln\Omega \qquad \frac{1}{T} = \frac{dS}{dE} \qquad q = \frac{E}{\hbar\omega_0} \qquad C = \frac{1}{n}\frac{dE}{dT} \qquad E = 3Nk_BT$$

$$\langle x\rangle = \frac{1}{N}\sum_i x_i \qquad \sigma = \sqrt{\frac{\sum_i (x_i - \langle x\rangle)^2}{N-1}}$$

$$A = 4\pi r^2 \qquad V = Ah \qquad V = \frac{4}{3}\pi r^3 \qquad \frac{d}{dx}x^n = nx^{n-1} \qquad \frac{d}{dx}(u\cdot v) = u\frac{dv}{dx} + v\frac{du}{dx} \qquad \frac{d}{dx}\ln x = \frac{1}{x}$$

$$\frac{df(x)}{dx} = \lim_{\Delta x\to 0}\frac{f(x+\Delta x) - f(x)}{\Delta x} \qquad \int_a^b f(x)dx = \lim_{\Delta x\to 0}\sum_{n=1}^{N} f(x)\Delta x \qquad \frac{d}{dy}f(x) = \frac{df}{dx}\frac{dx}{dy}$$