Physics 132-1 Final Exam

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

Signature ________________________________

Questions (10 for 4 pts. apiece) Answer in complete, well-written sentences WITHIN the spaces provided.

1. Recall the lab entitled *A Theory for the Hydrogen Atom*. Describe the motion of a quantum particle such as an electron in the hydrogen atom potential. What restrictions, if any, are there on the energy E of a quantum particle?

2. When you solve the Schrödinger equation you determine the wave function of the electron bound to the proton to form hydrogen. What happened to the wave function as the energy of the solution you found increased?

3. A piece of ice at T_0 is tossed into water in a calorimeter cup at room temperature T_1 and melts completely. The calorimeter cup is thermally isolated from its surroundings so no heat escapes. Suppose you knew all the masses (ice (m_i), water (m_w), cup(m_c)) at the start, specific heats (ice (c_i), water (c_w), cup(c_c)), and latent heats (ice (L_{f_i}, L_{vi}), water (L_{f_w}, L_{vw}), cup(L_{f_c}, L_{vc}),) What is the equation you would start from and solve in order to calculate the final temperature of the system? Make sure you clearly label each item in your answer.

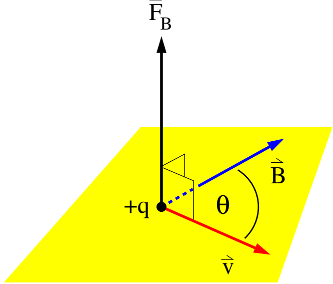
DO NOT WRITE BELOW THIS LINE.

4. Recall our investigation of the kinetic theory of ideal gases. If the collisions of the atoms or molecules with the wall perpendicular to the x direction are elastic, show that the force exerted on that wall for each collision is $F_x = 2mv_x/\Delta t_x$ where m is the mass of the particles and Δt_x is the mean interval between collisions with the wall. (Hint: Think of the form of Newtons second law in which force is defined in terms of the change in momentum per unit time so that $F = \Delta p/\Delta t$ where p refers to momentum not pressure.)

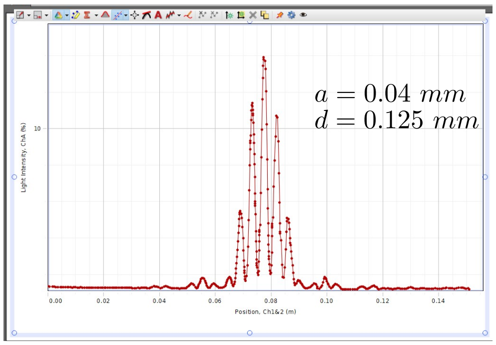
5. Recall the laboratory entitled *Einstein Solid*. When the system is in a macrostate far from the most probable one, what is the most likely thing to happen as energy or heat flows around the system? Explain.

6. Recall measuring the equipotential lines around a point charge near a conducting plate. If the potential at a point is zero, must the electric field be zero as well? Explain.

7. The figure below shows the relationship between $\vec{F}_B$, $\vec{v}$, and $\vec{B}$. How is the magnitude of the cross product $\vec{v} \times \vec{B}$ related to the magnitude of v, B, and θ the angle between $\vec{v}$ and $\vec{B}$? Describe the trajectory of the charged particle. Explain.



8. In lab you took data on the pattern of light created when you passed laser light through two slits of width a seperated by a distance d (see the figure). You then extracted and plotted the angular positions of the peaks (intensity versus angle). You used the positions of the minima in that second plot to determine which quantity a or d? Explain.



9. Suppose it was shown that the cosmic-ray intensity striking the Earth was much greater 10,000 years ago. How would this difference affect currently accepted values of radiocarbon-dated artifacts? Explain.

10. How can the motion of a moving, charged particle be used to distinguish between a magnetic field and an electric field? Don't assume you know the direction of either field.

Problems (6). Clearly show all reasoning for full credit. Use a separate sheet to show your work.

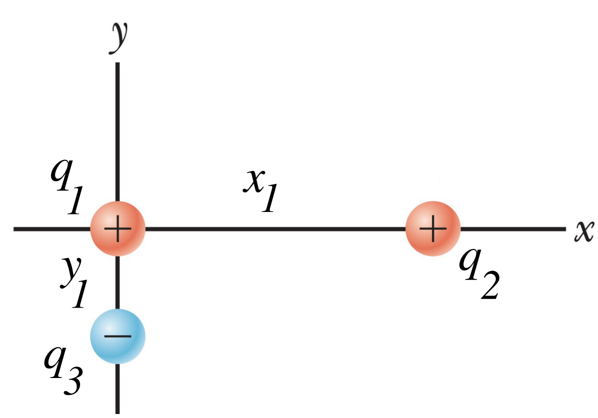
1. 10 pts. A beam of electrons is incident upon a gas of hydrogen atoms. What minimum speed v_0 must the electrons have to cause the emission of the $\lambda = 656\ nm$ light from the $3 \rightarrow 2$ transition of hydrogen?

2. 10 pts. A star with the mass ($M = 2.0 \times 10^{30} kg$) and size ($R = 7.0 \times 10^{8}\ m$) of our sun rotates once every $T_0 = 30\ days$. After undergoing gravitational collapse after its nuclear fuel is expended, the star collapses and forms a pulsar that is observed by astronomers to emit radio pulses every $T_1 = 0.10\ s$. What is the speed of a point on the equator of the pulsar?

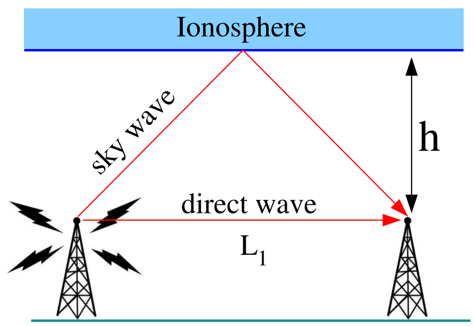
3. 10 pts. A certain macropartition of two Einstein solids has an entropy of $S_1 = 305.2k_B$. The next macropartition closer to the most probable one has an entropy of $S_2 = 335.5k_B$. If the system is initially in the first macropartition and we check it again later, how many times more likely is it to have moved to the other than to have stayed in the first?

4. 10 pts. A typical nuclear reactor generates $P_0 = 1000\ MW$ of electrical energy where P_0 is power (energy/time) and $1\ MW = 10^6 J/s$. In doing so, it produces $P_1 = 2000\ MW$ of waste heat that must be removed from the reactor to keep it from melting down. Many reactors are sited next to large bodies of water so that they can use the water for cooling. Consider a reactor where the intake water is at $T_0 = 18°C$. State regulations limit the temperature of the output water to $T_1 = 26°C$ so as not to harm aquatic organisms. How many liters of cooling water have to be pumped through the reactor each minute? The specific heat of water is $c_w = 4190\ J/kg\ K$. The latent heat of vaporization of water is $L_v = 22.6 \times 10^5\ J/kg$. the latent heat of fusion of water is $L_f = 3.33 \times 10^5\ J/kg$.

5. 10 pts. Three point charges are arranged as shown in the figure. What is the vector electric field that q_2 and q_3 create together at the origin? What is the force on q_1? Use the $\hat{i}$, $\hat{j}$, $\hat{k}$ notation to express your vectors.



6. 10 pts. The waves from a radio station can reach a home receiver by two paths shown in the figure. One is a direct, straight-line path from transmitter to home, a distance $L_1 = 30 \times 10^3\ m$. The second is by reflection from the ionosphere (a layer of ionized air molecules high in the atmosphere). Assume this reflection takes place at the midpoint between the transmitter and the receiver, the wavelength broadcast by the radio station is $\lambda = 350\ m$, and there is no phase change when the radio waves are reflected. What is the minimum height of the ionosphere that could produce destructive interference between the direct and the reflected beams? Neglect the height of the towers in the figure.



Physics 132-1 Constants

Avogadro's number (N_A)	6.022×10^{23}	Speed of light (c)	$3 \times 10^8\ m/s$
k_B	$1.38 \times 10^{-23}\ J/K$	proton/neutron mass	$1.67 \times 10^{-27}\ kg$
$1\ u$	$1.67 \times 10^{-27}\ kg$	g	$9.8\ m/s^2$
Gravitation constant	$6.67 \times 10^{-11}\ N - m^2/kg^2$	Earth's radius	$6.37 \times 10^6\ m$
Coulomb constant (k_e)	$8.99 \times 10^9 \frac{N-m^2}{C^2}$	Electron mass	$9.11 \times 10^{-31}\ kg$
Elementary charge (e)	$1.60 \times 10^{-19}\ C$	Proton/Neutron mass	$1.67 \times 10^{-27}\ kg$
Permittivity constant (ϵ_0)	$8.85 \times 10^{-12} \frac{kg^2}{N-m^2}$	1.0 eV	$1.6 \times 10^{-19}\ J$
1 MeV	$10^6\ eV$	atomic mass unit (u)	$1.66 \times 10^{-27}\ kg$
Planck's constant (h)	$6.626 \times 10^{-34}\ J - s$	Planck's constant (h)	$4.14 \times 10^{-15}\ eV - s$
Planck's constant 2 ($\hbar = h/2\pi$)	$1.0546 \times 10^{-34}\ J - s$	R	$6.58 \times 10^{-16} J/K - mole$
atomic mass unit (u)	$1.66 \times 10^{-27}\ kg$	Permittivity constant (ϵ_0)	$8.85 \times 10^{-12} \frac{kg^2}{N-m^2}$

Physics 132-1 Equation Sheet, Final

$$\vec{F} = m\vec{a} = \frac{d\vec{p}}{dt} \quad a_c = \frac{v^2}{r} \quad \vec{F}_c = -m\frac{v^2}{r}\hat{r} \qquad KE = \frac{1}{2}mv^2 \quad ME_0 = ME_1 = KE_1 + PE_1 \quad \vec{p} = m\vec{v} \quad \vec{p}_0 = \vec{p}_1$$

$$x = \frac{a}{2}t^2 + v_0 t + x_0 \quad v = at + v_0 \qquad Q = C\Delta T = cm\Delta T = nC_v\Delta T \quad Q_{f,v} = mL_{f,v}$$

$$\Delta E_{int} = Q + W \quad W = \int \vec{F}\cdot d\vec{s} \to P\Delta V \quad \langle\vec{F}\rangle = \frac{\Delta\vec{p}}{\Delta t} \quad P = \frac{|\vec{F}|}{A} \quad PV = Nk_BT = nRT$$

$$\vec{I} = \int \vec{F}dt = \langle\vec{F}\rangle\Delta t = \Delta\vec{p} \quad \langle KE\rangle = \langle E_{kin}\rangle = \frac{1}{2}m\overline{v^2} \quad \langle E_{kin}\rangle = \frac{3}{2}k_BT = \frac{1}{2}mv_{rms}^2 \quad E_{int} = N\langle E_{kin}\rangle = \frac{3}{2}Nk_BT$$

$$v_{rms} = \sqrt{\langle v^2\rangle} \quad C_V = \frac{f}{2}N_Ak_B \quad E_f = \frac{k_BT}{2} \quad E_{int} = \frac{f}{2}Nk_BT \quad f \equiv \text{number of degrees of freedom}$$

$$E_{atom} = (n_x + n_y + n_z + \frac{3}{2})\epsilon_i \quad E = \sum_{i=1}^{3N} n_i\epsilon_i = q\epsilon_i \quad \Omega(N,q) = \frac{(q+3N-1)!}{q!(3N-1)!} \quad S = k_B\ln\Omega$$

$$\frac{1}{T} = \frac{dS}{dE} \quad q = \frac{E}{\hbar\omega_0} \quad C = \frac{1}{n}\frac{dE}{dT} \quad E = 3Nk_BT$$

$$\vec{F}_G = -G\frac{m_1m_2}{r^2}\hat{r} \quad \vec{F}_C = k_e\frac{q_1q_2}{r^2}\hat{r} \quad \vec{E} \equiv \frac{\vec{F}}{q_0} \quad \vec{E} = k_e\sum_i\frac{q_i}{r_i^2}\hat{r}_i \quad \vec{E} = k_e\int\frac{dq}{r^2}\hat{r} \quad \vec{E}_{dipole} = k_e\frac{q(2a)}{(x^2+a^2)^{3/2}}\hat{j}$$

$$\vec{E}_{ring} = k_e\frac{qx}{(x^2+R^2)^{3/2}}\hat{i} \quad \vec{E}_{plane} = 2\pi k_e\eta\hat{k} = \frac{\eta}{2\epsilon_0}\hat{k} \quad \Delta V \equiv \frac{\Delta PE}{q_0} = -\int_A^B \vec{E}\cdot d\vec{s} \quad V = k_e\frac{q}{r} \quad PE = qV$$

$$V = k_e\sum_n\frac{q_n}{r_n} \quad V = k_e\int\frac{dq}{r} \quad V = Ed \quad I \equiv \frac{dQ}{dt} \quad V = IR \quad P = IV \quad R_{equiv} = \sum R_i$$

The algebraic sum of the potential changes across all the elements of a closed loop is zero.

$$I = nev_dA \quad \vec{F}_B = q\vec{v}\times\vec{B} \quad |\vec{F}_B| = |qvB\sin\theta|$$

$$\frac{dN}{dt} = -\lambda t \quad N = N_0e^{-\lambda t} \quad t_{1/2} = \frac{\ln 2}{\lambda} \quad y = A\sin(kx - \omega t + \phi) \quad k\lambda = 2\pi = \omega T \quad \frac{\lambda}{T} = c \quad f = \frac{1}{T}$$

$$E = E_m\sin(kx - \omega t) \quad B = B_m\sin(kx - \omega t) \quad \vec{S} = \frac{1}{\mu_0}\vec{E}\times\vec{B} \quad |\vec{S}| = I = \frac{E^2}{\mu_0 c} \quad \frac{E_m}{B_m} = c$$

$$I = 4I_0\cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right) \quad I = I_m\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2 \quad I = I_m\cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right)\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2$$

$$\delta = d\sin\theta = m\lambda \quad \delta = a\sin\theta = m\lambda \quad \phi = k\delta \quad \sin\theta_R = \frac{\lambda}{a}$$

$$L = I\omega = mv_tr \quad I = \sum m_ir_i^2 \quad I = I_{cm} + mR^2 \quad L_0 = L_1 \quad E = \frac{1}{2}mv_r^2 + \frac{L^2}{mr^2} - k_e\frac{e^2}{r}$$

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) \quad E_n = -\frac{13.6\ eV}{n^2} \quad E = hf = h\frac{c}{\lambda} \quad -\frac{\hbar^2}{2m}\left(\frac{d^2}{dr^2}\right)\Psi(r) + \frac{L^2}{2mr^2}\Psi(r) + V\Psi(r) = E\Psi(r)$$

$$\frac{df(x)}{dx} = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \quad \frac{dx^n}{dx} = nx^{n-1} \quad \frac{de^x}{dx} = e^x \quad \frac{df(u)}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx} f(x) \cdot g(x) = f\frac{dg}{dx} + g\frac{df}{dx} \quad \frac{d \ln x}{dx} = \frac{1}{x} \quad \frac{d}{dx}\cos ax = -a \sin ax \quad \frac{d}{dx} \sin ax = a \cos ax$$

$$\int_a^b f(x)dx = \lim_{\Delta x \to 0} \sum_{n=1}^{N} f(x)\Delta x \quad \int x^n dx = \frac{x^{n+1}}{n+1} \quad \int \sin^2(ax)dx = \frac{x}{2} - \frac{\sin(ax)}{4a}$$

$$\int e^x dx = e^x \quad \int \frac{1}{x} dx = \ln x \int \frac{1}{\sqrt{x^2+a^2}} dx = \ln\left[x + \sqrt{x^2+a^2}\right] \quad \int \frac{x}{\sqrt{x^2+a^2}} dx = \sqrt{x^2+a^2}$$

$$\int \frac{x^2}{\sqrt{x^2+a^2}} dx = \frac{1}{2}x\sqrt{x^2+a^2} - \frac{1}{2}a^2 \ln\left[x + \sqrt{x^2+a^2}\right] \quad \int \frac{x^3}{\sqrt{x^2+a^2}} dx = \frac{1}{3}(-2a^2+x^2)\sqrt{x^2+a^2}$$

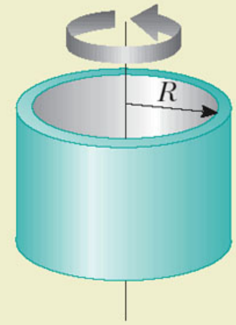
$$\langle x \rangle = \frac{1}{N}\sum_i x_i \quad \sigma = \sqrt{\frac{\sum_i \left(x_i - \langle x \rangle\right)^2}{N-1}} \quad N = \frac{b-a}{\Delta x} \quad A = 4\pi r^2 \quad V = Ah \quad V = \frac{4}{3}\pi r^3$$

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 **	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

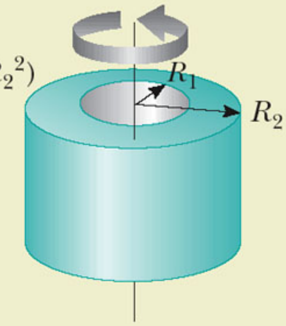
*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
**Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

TABLE 10.2 Moments of Inertia of Homogeneous Rigid Objects With Different Geometries

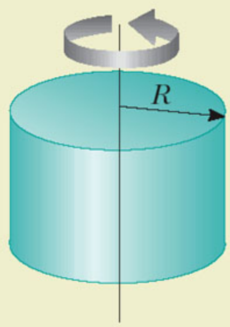
Hoop or thin cylindrical shell
$I_{CM} = MR^2$



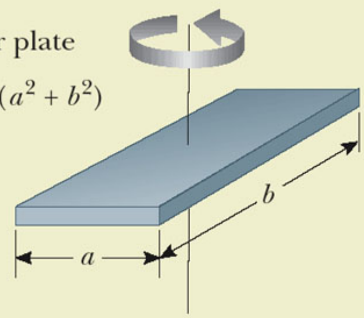
Hollow cylinder
$I_{CM} = \frac{1}{2}M(R_1^{\ 2} + R_2^{\ 2})$



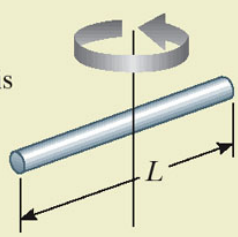
Solid cylinder or disk
$I_{CM} = \frac{1}{2}MR^2$



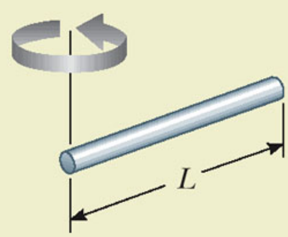
Rectangular plate
$I_{CM} = \frac{1}{12}M(a^2 + b^2)$



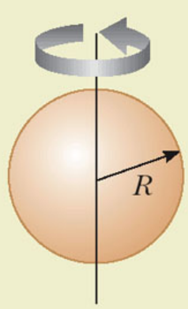
Long thin rod with rotation axis through center
$I_{CM} = \frac{1}{12}ML^2$



Long thin rod with rotation axis through end
$I = \frac{1}{3}ML^2$



Solid sphere
$I_{CM} = \frac{2}{5}MR^2$



Thin spherical shell
$I_{CM} = \frac{2}{3}MR^2$