Physics 132-3 Final Exam

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

Name ______________________ Signature ______________________

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

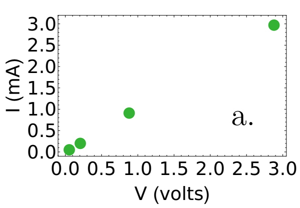
1. The energy levels of hydrogen can be described by the equation

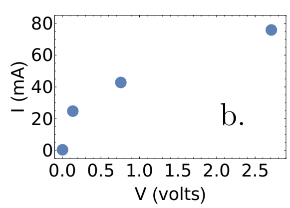
$$E_n = -\frac{13.6\ eV}{n^2}$$

where n is called the principal quantum number. How did you use this equation to compare with your measurements of the wavelengths of emission lines from hydrogen for the lab entitled 'The Optical Spectrum of Hydrogen'.

2. What is the difference between diffraction and interference? Explain.

3. The plots below show data from measurements of the voltage drop across two electrical devices (a and b) as a function of the electric current. Which device is ohmic, *i.e.* follows Ohm's Law. Explain.





DO NOT WRITE BELOW THIS LINE.

4. Consider the mathematical steps shown below in the calculation of the electric potential at a fixed point along the axis of a charged ring. Is the final step legal? Why or why not?

$$V = k\int \frac{dq}{r} = k\int \frac{dq}{\sqrt{x^2+a^2}} = \frac{k}{\sqrt{x^2+a^2}}\int dq$$

5. One day in class we did a demonstration where I dropped a metal cylinder down an aluminum tube. The cylinder fell through the tube at a normal rate. I then surreptitiously switched to a high-magnetic-field, cylindrical magnet of the same size and appearance. When I dropped that cylinder down the tube it fell very, very slowly. Why? Explain. This is an example of Lenz's Law.

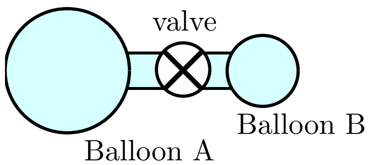
6. How does a mass spectrometer work?

7. Will ^{14}C dating work on anything? Explain.

8. Nobel-prize-winning physicist Richard Feynman once said 'the most powerful assumption of all, which leads one on and on in an attempt to understand life, it is that all things are made of atoms, and that everything that living things do can be understood in terms of the jigglings and wigglings of atoms.' Using things you learned from this course, how would you convince someone in the existence of atoms?

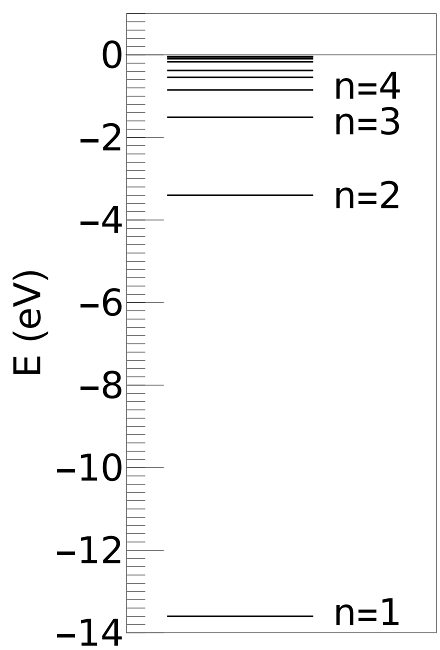
9. Where do electric fields come from? Cite evidence. Explain.

10. Consider two, air-filled balloons that are connected by a straight tube with a closed valve as shown in the figure. If the valve is now opened what will happen to the sizes of each balloon and the air in them? Explain. Hint: The elastic force of the balloon is stronger when the curvature of the balloon is large (*i.e* when the radius is smaller).

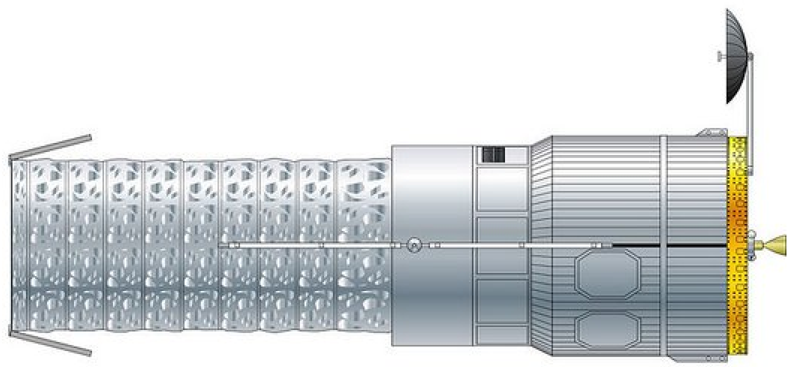


Problems (6). Clearly show all reasoning for full credit. Use a separate sheet to show your work.

1. 8 pts. Two hydrogen atoms collide head-on. The collision brings both atoms to a halt. Immediately after the collision, both atoms emit a 104.5 nm photon. What was the speed of each atom just before the collision? Why did both atoms come to a halt? The figure shows the hydrogen atom energy levels with the first few states labeled.



2. 10 pts. A spy satellite, military, commercial or otherwise, like the KH-11 satellite shown here (based on the Hubble Space Telescope) consists of a large-diameter concave mirror forming an image on a digital sensor. It is an astronomical telescope looking down instead of up. The KH-11 telescope may have an aperture of size $a = 0.70\ m$ and orbited the Earth at an altitude of $L = 681\ km$. Could the camera be used to read a license plate on Earth? The range of visible light is $\lambda = 400 - 700 \times 10^{-9}\ m$. Show your reasoning.



SIDE VIEW

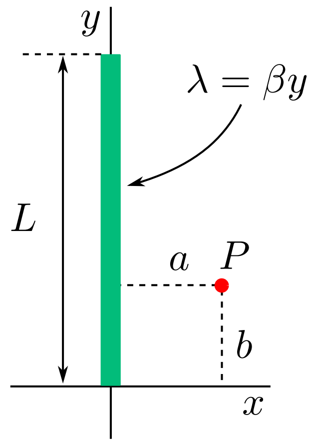
3. 10 pts. A newly-created material has a multiplicity

$$\Omega = \alpha N E^{5/2}$$

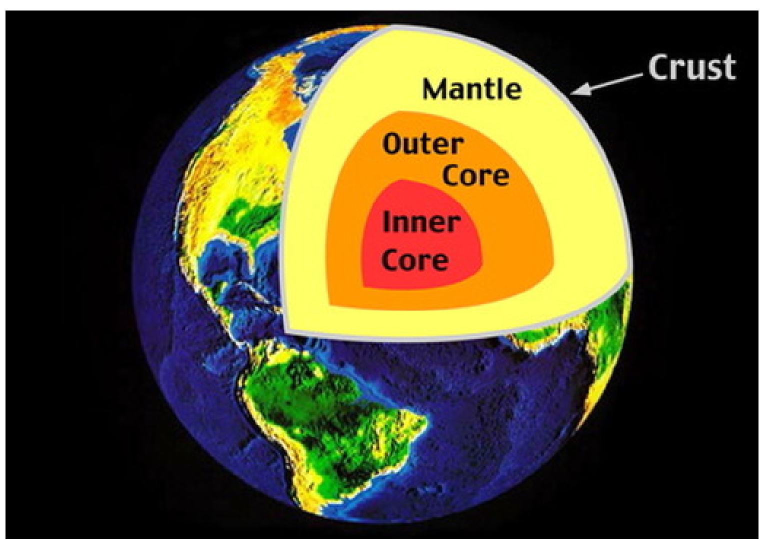
where N is the number of atoms in the solid, E is the total internal energy in the solid, and α is a constant. How is the energy E of the material related to the temperature T? What is the molar specific heat? Does this result make sense? Explain.

4. 10 pts. After the sudden release of radioactivity from the Chernobyl nuclear reactor accident in 1986, the radioactivity of milk in Poland rose to 1500 Bq/liter due to iodine-131 present in the grass eaten by dairy cattle (1 Bq = 1 Becquerel = 1 decay/s). Radioactive iodine, with half-life $t_I = 8.04\ days$, is particularly hazardous because the thyroid gland concentrates iodine. The Chernobyl accident caused a measurable increase in thyroid cancers among children in Belarus. For comparison, find the activity of milk due to potassium. Assume that one liter of milk contains a mass $m_K = 2.5\ g$ of potassium, of which a fraction $f = 0.0117\%$ is the isotope ^{40}K with half-life $t_K = 1.28 \times 10^9\ yr$.

5. 10 pts. A rod of length L (see figure) lies along the y axis with its bottom end at the origin. It has a nonuniform charge density $\lambda = \beta y$, where β is a positive constant. (a) What are the units of β? (b) What is the electric potential at the point P located at $\vec{r} = a\hat{i} + b\hat{j}$? Give your answer in terms of λ, β, L, a, b, and any other necessary constants.



6. 12 pts. At the North Magnetic Pole the Earth's magnetic field is vertical and has a strength $|\vec{B}| = 6.2 \times 10^{-5}\ T$. Suppose this field is created by the flow of electrons in the equatorial region of the iron-rich core of the Earth. The radius of the Earth's iron core is $r_c = 3.6 \times 10^{6}\ m$. The radius of the Earth is $r_E = 6.37 \times 10^{6}\ m$. How large a current flowing around the equatorial region of the core would be needed to create a field of this strength at the North Magnetic Pole? In what direction does the current flow? Remember the north end of a compass points toward the Arctic.



Physics 132-3 Constants and Conversions

Avogadro's number (N_A)	6.022×10^{23}	Speed of light (c)	$3 \times 10^8\ m/s$
Boltzmann constant (k_B)	$1.38 \times 10^{-23}\ J/K$	proton/neutron mass	$1.67 \times 10^{-27}\ kg$
atomic mass unit (u)	$1.66 \times 10^{-27}\ kg$	g	$9.8\ m/s^2$
Gravitation constant (G)	$6.67 \times 10^{-11}\ N - m^2/kg^2$	Earth's radius	$6.37 \times 10^6\ m$
Coulomb constant (k_e)	$8.99 \times 10^9 \frac{N-m^2}{C^2}$	Earth's mass	$5.98 \times 10^{24}\ kg$
Electron mass	$9.11 \times 10^{-31}\ kg$	Earth-Sun distance	$1.5 \times 10^{11}\ m$
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 ($\hbar = h/2\pi$)	$1.0546 \times 10^{-34}\ J - s$	Gas constant R	$8.315\ J/K - mol$
Planck's constant 2 ($\hbar = h/2\pi$)	$6.58 \times 10^{-16} J/K - mole$	Rydberg constant (R)	$1.097 \times 10^7\ m^{-1}$
Permittivity constant (ϵ_0)	$8.85 \times 10^{-12} \frac{kg^2}{N-m^2}$	Absolute Zero	-273.2°C
Permeability constant (μ_0)	$1.26 \times 10^{-6}\ T - m/A$	Becquerel (Bq)	$1\ decay/s$

Physics 132-3 Equation Sheet, Final

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

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

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

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

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

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

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

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

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

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

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

$$\vec{F}_B = q\vec{v} \times \vec{B} \quad |\vec{F}_B| = |qvB \sin\alpha| \quad \vec{B} = k_m \int \frac{Id\vec{s} \times \hat{r}}{r^2} \quad k_m = \frac{\mu_0}{4\pi} \quad \vec{B}_{ring} = \frac{\mu_o I R^2}{2} \frac{1}{(x^2 + R^2)^{3/2}} \hat{\imath}$$

$$\frac{dN}{dt} = -\lambda N \quad N = N_0 e^{-\lambda t} \quad t_{1/2} = \frac{\ln 2}{\lambda} \quad y = A \sin(kx - \omega t + \phi) \quad k\lambda = 2\pi = \omega T \quad \frac{\lambda}{T} = c \quad f = \frac{1}{T}$$

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

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

$$\delta = d \sin\theta = m\lambda \quad \delta = a \sin\theta = m\lambda \quad \phi = k\delta \quad \sin\theta_R = \frac{\lambda}{a} \quad \sin A + \sin B = 2 \sin\left(\frac{A+B}{2}\right) \cos\left(\frac{A-B}{2}\right)$$

$$\sin\theta \approx \theta \quad \sin\theta \approx \frac{y}{L} \quad L = I\omega = mv_t r \quad L_0 = L_1 \quad E = \frac{1}{2} m \left(v_r^2 + v_t^2\right) - k_e \frac{e^2}{r} = \frac{1}{2} m v_r^2 + \frac{L^2}{mr^2} - k_e \frac{e^2}{r}$$

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \quad E_n = -\frac{13.6\ eV}{n^2} \quad E = hf = h\frac{c}{\lambda}$$

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

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

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

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

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

$$\int \frac{1}{(x^2 + a^2)^{3/2}} dx = \frac{x}{a^2 \sqrt{x^2 + a^2}} \quad \int \frac{x}{(x^2 + a^2)^{3/2}} dx = \frac{-1}{\sqrt{x^2 + a^2}} \quad A = 4\pi r^2 \quad V = Ah \quad V = \frac{4}{3} \pi r^3$$

$$\langle x \rangle = \frac{1}{N} \sum_i x_i \quad \sigma = \sqrt{\frac{\sum_i (x_i - \langle x \rangle)^2}{N - 1}} \quad \vec{A} \cdot \vec{B} = AB \cos\theta = A_x B_x + A_y B_y + A_z B_z$$

$$\vec{A} \times \vec{B} = (A_y B_z - A_z B_y)\hat{\imath} - (A_x B_z - A_z B_x)\hat{\jmath} + (A_x B_y - A_y B_x)\hat{k} = |\vec{A}||\vec{B}| \sin\alpha \text{ (right-hand-rule direction)}$$

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]

The Periodic Chart.