Physics 132-3 Final Exam

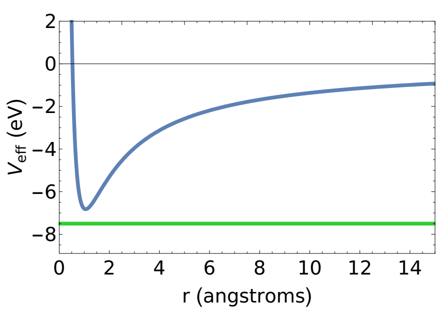
I pledge that I have neither given nor received unauthorized assistance during the completion of this work.

Signature ________________________________

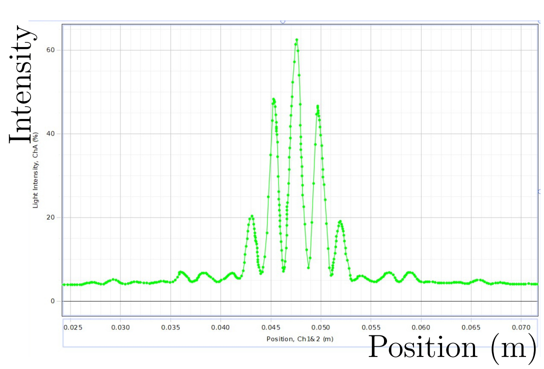
Questions (10 for 4 pts. apiece) Answer in complete, well-written sentences WITHIN the spaces provided.

1. 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. What is the photon energy for the $n = 5 \rightarrow n = 3$ transition? What is the wavelength of the light? Show your reasoning.

2. The figure shows the effective potential for a hydrogen atom. The green line represents the total energy of the atom. Does this result make sense? Explain.



3. Consider the intensity pattern shown below for two, identical, narrow slits. How would you determine the size of the slits?



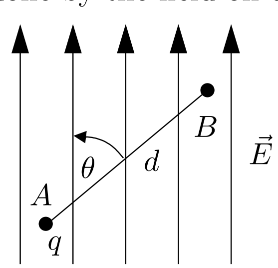
4. Recall the experiment where you determined the heat of vaporization of liquid nitrogen. Was the temperature of the liquid nitrogen changing during this experiment? Explain.

5. The table below shows a comparison between a calculation of the molar specific heat of elemental solids C_n in the third column and the expected value from measurement (second column). The solids are listed in the first column. Does the calculation work? Be quantitative in your answer.

Solid	Measured C_n (J/K-mole)	Calculated C_n (J/K-mole)
Lead	26.4 ± 0.7	24.9
Zinc	25.4 ± 0.6	24.9
Aluminum	26.4 ± 0.2	24.9

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

7. The charge $q > 0$ travels a distance d from point A to point B in a uniform electric field of magnitude E. The path lies at an angle θ to the field lines. What is the work done by the field on the charge? Explain your reasoning.



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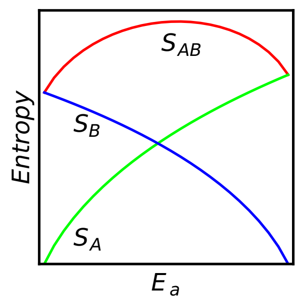
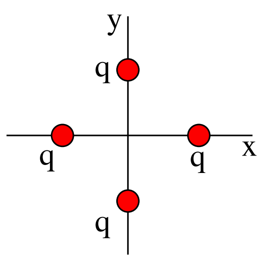
8. Suppose you were talking to a scientist from the mid-nineteenth century (when we were called natural philosophers) who thought atoms were a mathematical 'trick' and not real objects. Using knowledge you gained from this course, how would you convince someone in the existence of atoms?

9. Consider the plot below of the entropy of two Einstein solids S_A (green) and S_B (blue) and their combined entropy S_{total} (red) plotted as a function of the number of energy quanta q_A in solid A. On the plot label the equilibrium state of the combined Einstein solids. Explain your choice.



10. Consider the charge distribution below. Each charge q is a distance a from the origin. How does the electric field of this charge distribution depend on r, the distance from the origin for $r \gg a$? Explain your reasoning.



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

1. 8 pts. For what wavelength of light does a laser of power $P = 0.04\ J/s$ deliver 10^{17} photons per second?

2. 10 pts. Two hydrogen atoms collide head-on. The collision brings both atoms to a halt. Immediately after the collision, both atoms emit a $\lambda = 102.7\ nm$ photon. What was the speed of each atom just before the collision? If the final quantum state of each hydrogen atom is $n_f = 1$, what is the initial value n_i of the principle quantum number?

3. 10 pts. The Impressionist painter Georges Seurat created paintings with an enormous number of dots of pure pigment, each of which was approximately 2.5 mm in diameter. The idea was to have colors such as red and green next to each other to form a scintillating canvas (see figure). Outside what distance would one be unable to discern individual dots on the canvas? (Assume that $\lambda = 700\ nm$ and that the pupil diameter is $a = 5.0\ mm$.)

4. 10 pts. Imagine that the multiplicity of a certain substance is given by $\Omega(E, N) = Ne^{(NE/\hbar\omega)^{3/2}}$, where $\hbar\omega$ is some unit of energy. How would the energy of an object made out of this substance depend on its temperature? Would this be a 'normal' substance in our usual sense of temperature.

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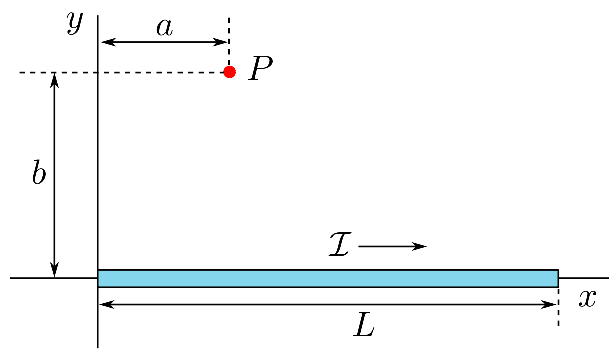
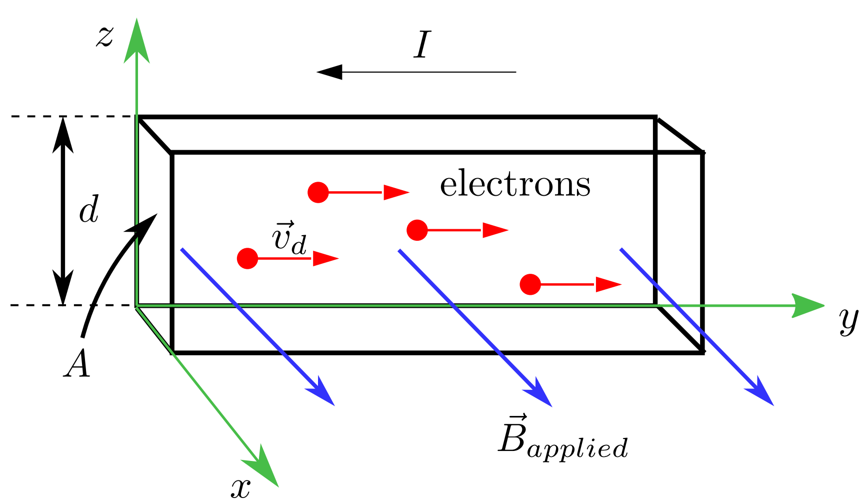
5. 10 pts. A current I in a thin wire of length L sits along the x-axis as shown below. Its left end is at the origin. Starting from the Biot-Savart Law for the magnetic field from a 'point' current, what is $\vec{B}$ at the point P where $\vec{P} = a\hat{i} + b\hat{j}$ in terms of I, a, b, L, and any other necessary constants?



6. 12 pts. Consider a wire with a square cross section of area $A = 5.5 \times 10^{-6}\ m^2$ and a number density $n = 8.46 \times 10^{28}\ electrons/m^3$. A current $i = 15\ A$ is flowing. A constant, uniform magnetic field transverse (*i.e.* perpendicular) to the motion of the electrons is suddenly turned on as shown in the figure below with $B_{applied} = 3.0\ T$. (a) What is the magnetic force on an individual electron due to the applied field and in what direction is the force? (b) The flow of electrons in the wire will be modified to balance the effect of the applied magnetic field by creating another electric field within the wire. What is the size and direction of the compensating electric field? (c) Sketch the distribution of electrons in the wire as a function of z after the transverse field is turned on. In 1985, Klaus von Klitzing received the Nobel Prize in physics for the use of this effect to understand conductivity and the behavior of charged particles in solids.



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

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.

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

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

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

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

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

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

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

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

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

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

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

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

$$\int \frac{1}{(x^2+a^2)^{3/2}}dx = \frac{x}{a^2\sqrt{x^2+a^2}} \quad \int \frac{x}{(x^2+a^2)^{3/2}}dx = \frac{-1}{\sqrt{x^2+a^2}}$$

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

$$\vec{A}\cdot\vec{B} = AB\cos\theta \quad |\vec{A} \times \vec{B}| = |AB\sin\theta|$$

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.