Physics 7C Section 1
Fall Semester 2001
Final Examination

December 13, 2001 (8:00-11:00 am)

Instructions

1. This is a **closed book** exam. You are allowed to bring along only one 8'x11' "cheat sheet", pens, pencils, scientific calculator, and blue books.
2. **Write your name, Discussion Section # and SID#** on the top of all materials you intend to hand in and want to be graded.
3. Read all questions carefully before attempting them. Questions do not carry equal points. Try the questions you find easier first. Partially credits will be given for equations only if you can indicate how they can be used to solve the problem.
4. While cleanliness and legibility of your hand-writing will not get your extra credit, they will help to make sure that your answers get the credit they deserve. In case you make mistakes be sure to cross them out so they will not be mistaken as your answer. It helps to underline your final answers. Always give your answers in the proper units.

You are provided with the following 2 tables of constants for your reference. There is no guarantee that they will all be required in solving the problems.

Fundamental Constants

Quantity	Symbol	Approximate Value
Speed of light in vacuum	c	3.00×10^8 m/s
Gravitational constant	G	6.67×10^{-11} N·m²/kg²
Avogadro's number	N_A	6.02×10^{23} mol^{-1}
Gas constant	R	8.315 J/mol·K = 1.99 cal/mol·K = 0.082 atm·liter/mol·K
Boltzmann's constant	k	1.38×10^{-23} J/K
Charge on electron	e	1.60×10^{-19} C
Stefan-Boltzmann constant	σ	5.67×10^{-8} W/m²·K⁴
Permittivity of free space	$\epsilon_0 = (1/c^2\mu_0)$	8.85×10^{-12} C²/N·m²
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T·m/A
Planck's constant	h	6.63×10^{-34} J·s
Electron rest mass	m_e	9.11×10^{-31} kg = 0.000549 u = 0.511 MeV/c^2
Proton rest mass	m_p	1.6726×10^{-27} kg = 1.00728 u = 938.3 MeV/c^2
Neutron rest mass	m_n	1.6749×10^{-27} kg = 1.008665 u = 939.6 MeV/c^2
Atomic mass unit (1 u)		1.6605×10^{-27} kg = 931.5 MeV/c^2

(1) Atomic Number Z	(2) Element	(3) Symbol	(4) Mass Number A	(5) Atomic Mass*	(6) % Abundance (or Radioactive Decay Mode)	(7) Half-life (if radioactive)
43	Technetium	Tc	98	97.907216	β^-, γ	4.2×10^6 yr
44	Ruthenium	Ru	102	101.904349	31.6%	
45	Rhodium	Rh	103	102.905504	100%	
46	Palladium	Pd	106	105.903483	27.33%	
47	Silver	Ag	107	106.905093	51.839%	
			109	108.904756	48.161%	
48	Cadmium	Cd	114	113.903358	28.73%	
49	Indium	In	115	114.903878	95.7%; β^-, γ	4.41×10^{14} yr
50	Tin	Sn	120	119.902197	32.59%	
51	Antimony	Sb	121	120.903818	57.36%	
52	Tellurium	Te	130	129.906223	33.80%	7.9×10^{20} yr
53	Iodine	I	127	126.904468	100%	
			131	130.906124	β^-, γ	8.0207 days
54	Xenon	Xe	132	131.904154	26.9%	
			136	135.907220	8.9%	
55	Cesium	Cs	133	132.905446	100%	
56	Barium	Ba	137	136.905821	11.23%	
			138	137.905241	71.70%	
57	Lanthanum	La	139	138.906348	99.9098%	
58	Cerium	Ce	140	139.905434	88.48%	
59	Praseodymium	Pr	141	140.907647	100%	
60	Neodymium	Nd	142	141.907718	27.13%	
61	Promethium	Pm	145	144.912744	EC, γ, α	17.7 yr
62	Samarium	Sm	152	151.919728	26.7%	
63	Europium	Eu	153	152.921226	52.2%	
64	Gadolinium	Gd	158	157.924101	24.84%	
65	Terbium	Tb	159	158.925343	100%	
66	Dysprosium	Dy	164	163.929171	28.2%	
67	Holmium	Ho	165	164.930319	100%	
68	Erbium	Er	166	165.930290	33.6%	
69	Thulium	Tm	169	168.934211	100%	
70	Ytterbium	Yb	174	173.938858	31.8%	
71	Lutecium	Lu	175	174.940767	97.4%	
72	Hafnium	Hf	180	179.946549	35.100%	
73	Tantalum	Ta	181	180.947996	99.988%	
74	Tungsten (wolfram)	W	184	183.950933	30.67%	
75	Rhenium	Re	187	186.955751	62.60%; β^-	4.35×10^{10} yr
76	Osmium	Os	191	190.960927	β^-, γ	15.4 days
			192	191.961479	41.0%	
77	Iridium	Ir	191	190.960591	37.3%	
			193	192.962923	62.7%	
78	Platinum	Pt	195	194.964774	33.8%	

*The masses given in column (5) are those for the neutral atom, including the Z electrons.

Question 1 (12 Points)

You are given the following information about the eyeball of a cataract patient (someone whose natural lens has become opaque and has to be replaced by an artificial lens). The radius of curvature of the cornea is 0.8 cm. The thickness of the cornea is negligible and therefore it is not necessary to worry about its refractive index. The refractive index of the liquid (known as aqueous humor) behind the cornea is 1.336. To make the calculation easier we will assume that this liquid fills the eye. In real eyes the liquid behind the lens is known as vitreous humor and has a slightly different refractive index.

(a) (4 Points) After the natural lens of this patient's eye has been removed where will be the location of the image (say, measured from the front of the eyeball) inside the aqueous humor for an object located 25 cm outside the eye in air?

(b) (8 Points) A surgeon implants an artificial lens of refractive index 1.35 into the patient's eye at a distance of 0.2 cm behind the cornea. Suppose this lens has a focal length of 0.2 cm *in air* where will be location of the image now?

In the above calculations you can use the paraxial approximation and assume that the lens is thin.

Question 2 (8 Points)

Suppose you want to determine the spacing between the grooves on a compact disc (CD).

(a) (4 Points) You use the yellow light from a sodium vapor lamp (wavelength=589 nm) to illuminate the CD at normal incidence and found that several diffraction spots are produced on a screen 100 cm away. The separation of the first order diffraction spot is 25 cm from the central reflected spot. What is the spacing between the grooves?

(b) (4 Points) Suppose you now illuminate the CD with another laser with wavelength=1.06 μm. What will be the locations of the second and third order diffraction spots on the same screen?

Question 3 (total: 13 Points)

In quantum mechanics the probability of finding a particle with wave function $\Psi(x,y,z)$ within a volume $\Delta x\Delta y\Delta z$ is given by $\{|\Psi|^2\Delta x\Delta y\Delta z\}/\{\int|\Psi|^2 dxdydz\}$.

(a) (3 Points) What is the probability of find a particle moving in a spherical potential within a ring of radius r and width Δr?

(b) (3 Points) The wave function of the electron in the 2s state of the hydrogen atom as a function of the radius r from the proton is given by:

$$\Psi_{200} = \frac{1}{\sqrt{32\pi r_o^3}}\left(2-\frac{r}{r_0}\right)e^{-\frac{r}{2r_0}}$$ where r_0 is the Bohr radius.

Find *all* the values of r where there is zero probability of finding the electron.

(c) (7 Points) Let us label those values of r you obtained in part (b) as r_1, r_2, r_3 etc. What is the probability of finding the electron between r_1 and r_2? (Hint: you may find the following integral useful: $\int x^2 e^{-x} dx = -e^{-x}(x^2+2x+2)$)

Question 4 (total: 15 Points)

(a) (5 Points) An electron in the hydrogen atom is in the 3s state. When a magnetic field of 1 Tesla is applied to this electron what will be the energies of the resultant levels? The Bohr magneton (μ_B) has the value of 9.27×10^{-24} J/T.

(b) (5 Points) Suppose we can "turn off" the spin of the electron and the electron is placed in the 3d state of the hydrogen atom, how will the degenerate 3d levels of this electron be split in the presence of the applied magnetic field? You should label these levels according to their magnetic quantum numbers and give their separations.

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(c) (5 points) A beam of atoms of unknown chemical identity is allowed to pass through an inhomogeneous magnetic field in a Stern-Gerlach experiment. The beam is found to split up into 4 beams after passing through the inhomogeneous magnetic field. What is the *total angular momentum* (J) of these unknown atoms? Suppose these atoms are in some excited state with only *one electron* in the outermost unfilled shell, what is the angular momentum (l) of this electron?

Question 5 (total: 12 Points)

The bond length between the hydrogen and chlorine atom in the HCl molecule is 1.3×10^{-10} m. The mass of the chlorine atom is 35 atomic units.

(a) (4 Points) What is the moment of inertia of the HCl molecule?

(b) (2 Points) What is the *rotational angular momentum* (L) selection rule for optical absorption by the HCl molecule?

(c) (6 points) Suppose the energy of an absorption peak due to the excitation of an electron in HCl is hv. Calculate the energies (relative to hv) of the series of neighboring absorption peaks due to the *simultaneous* excitation of the electron in the HCl molecule and of rotations of the molecule. Given your answers in units of meV. You can assume that the molecules are maintained at a non-zero temperature that is high enough for L to both *increase or decreases*.

Question 6 (total: 15 Points)

The electronic configuration in Ag is: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^1$. The density of Ag is 1.05×10^4 Kg/m^3.

(a) (5 Points) What is the Fermi energy of Ag in electron volts (eV)?

(b) (3 Points) What is the *average* energy of a free electron in Ag?

(c) (7 points) What is the number of electronic states per cm^3 per eV at the Fermi energy in Ag?

Question 7 (total: 15 Points)

David and Daniel are two identical twins. The maximum force F_o they can apply is the same. They decide to test the time dilation result predicted by the special theory of relativity. They obtain two identical springs of spring constant k_o and attach to them to two identical balls of rest mass m_o=1 Kg to form two identical clocks. When they pull the balls to cause them to oscillate both balls oscillate with the same period T_o of exactly 1 sec.