University of Kentucky, Physics 361
EXAM 1, 2008-02-08 11:00–11:50

Instructions: The exam is closed book and timed (50 minutes), so pace yourself. Problems will be graded on both technique and answer, so show your work. A formula sheet is on the last page.

Part I—Short Answer

[3 pts] 1. a) List three phenomena demonstrating the particle nature of light.

[2 pts] b) List two phenomena demonstrating the wave nature of matter.

[2 pts] c) List two examples of quantization of energy states.

[3 pts] 2. a) Why is Compton scattering non-classical?

[5 pts] b) List two ways in which the Bohr model of the atom is non-classical.

[5 pts] 3. a) What is the relationship between Planck's law and the Stefan-Boltzmann law?

[5 pts] b) What is the relationship between Planck's law and Wein's displacement law?

[5 pts] 4. What is the significance of negative energy states of the hydrogen atom?
(i.e. Why are there not any positive energy states in Bohr's formula for E_n?)

[5 pts] 5. a) Why do α-scattering data disagree with the Rutherford formula at large scattering angle for very large α-particle energies?

[5 pts] b) Why do the data disagree with the Rutherford formula at very small scattering angles? (hint: think about the Moseley b-parameter)

Part II—Calculation

[10 pts] 6. The luminosity (total power radiated) of the sun is 3.85×10^{26} W.
What is the surface temperature of the sun? (radius $r = 6.955 \times 10^8$ m, surface area $= 4\pi r^2$)
What is the most intense wavelength of sunlight? [0 pts] What color is it?

[10 pts] 7. A red ($\lambda = 600$ nm) laser pointer with 5 mW of power shines on Cesium, with a work function of 1.9 eV. What is the stopping voltage? What is the maximum possible photo-current (in mA)?

[10 pts] 8. Calculate the wavelength of an electron of energy 54 eV.

[10 pts] 9. At what momentum (in MeV/c) does the de Broglie wavelength of the proton equal its Compton wavelength?

Part III—Derivation

[10 pts] 10. Show that de Broglie's hypothesis of electrons forming standing waves around their orbitals is equivalent to Bohr's quantization of angular momentum.

Physical Constants and Useful Combinations:

Speed of light	c	3.00×10^8 m/s	
Planck's constant	h	6.63×10^{-34} J s;	$hc = 1240$ eV nm
	$\hbar = h/2\pi$	1.05×10^{-34} J s;	$\hbar c = 197$ eV nm
Coulomb force constant	$k_e = 1/4\pi\epsilon_0$	8.99×10^9 Nm^2/C;	$k_e e^2 = 1.44$ eVnm
Elementary charge	e	1.602×10^{-19} C;	1 eV $= 1.602 \times 10^{-19}$ J
Fine structure constant	$\alpha = k_e e^2/\hbar c$	$0.0730 \approx 1/137$	
Permeability of vacuum	μ_0	$4\pi \times 10^7$ N/A^2 $= 4\pi$ mm G/A;	1 T $= 10^4$ G
Gravitational constant	G	6.67×10^{-11} N m^2/kg^2	
Avogadro's number	N_A	6.02×10^{23}/mol	
Boltzman's constant	k	1.38×10^{-23} J/K $= 25$ meV/293 K	
Gas constant	$R = N_A k$	8.31 J/mol K	
Compton wavelength	$\lambda_c = h/m_e c$	0.00243 nm	
Bohr radius	$a_0 = \hbar^2/m_e k_e e^2$	0.529 Å	
Ionization energy of H	$E_0 = m_e k_e^2 e^2/2\hbar^2$	13.6 eV	
Bohr magneton	$\mu_B = e\hbar/2m_e$	9.27×10^{-24} J/T	
Unified mass unit	u	1.66×10^{-27} kg $=$ 931 MeV/c^2	
Mass of electron	m_e	9.11×10^{-31} kg $=$ 0.511 MeV/c^2	
proton	m_p	1.67×10^{-27} kg $=$ 938 MeV/c^2	
α-particle	m_α	6.64×10^{-27} kg $=$ 3727 MeV/c^2	

Formulas:

Stefan-Boltzmann law	$R = \sigma T^4 \qquad \sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4
Wein's displacement law	$\lambda_m T = 2.898 \times 10^{-3}$ m K
Rayleigh-Jeans formula	$u(\lambda) = 8\pi k T \lambda^{-4}$
Planck's radiation law	$u(\lambda) = \frac{8\pi hc\lambda^{-5}}{e^{hc/\lambda kT} - 1}; \qquad E_n = n\,hf = n\,hc/\lambda$
Photoelectric effect	$eV_0 = hf - \phi$
Bragg diffraction	$m\lambda = 2d\sin\theta$
Compton effect	$\lambda_2 - \lambda_1 = \lambda_c(1-\cos\theta); \qquad \lambda_c = \frac{h}{m_e c}$
Rydberg-Ritz formula	$\frac{1}{\lambda_{mn}} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right), n > m$
Impact parameter	$b = \frac{k_e q_\alpha Q}{m_\alpha v^2}\cot\frac{\theta}{2}$
Scattered fraction f	$f = \pi b^2 nt$
Number of scattered α's observed	$\Delta N = \left(\frac{I_0 A_{sc} nt}{r^2}\right)\left(\frac{Zk_e e^2}{2E_k}\right)^2 \frac{1}{\sin^4\frac{\theta}{2}}$
Size of nucleus	$r_d = \frac{k_e q_\alpha Q}{\frac{1}{2}m_\alpha v^2}$
Bohr's postulates	$L = n\hbar$ for integer n; $\qquad hf = E_n - E_m$
atomic energy levels	$E_n = -\frac{Z^2 E_0}{n^2}$ where $E_0 = \frac{m_e k_e^2 e^2}{2\hbar^2} = 13.6$ eV
atomic orbital radii	$r_n = \frac{n^2 a_0}{Z}$ where $a_0 = \frac{\hbar^2}{m_e k_e e^2} = 0.529$ Å
reduced mass	$\mu = \frac{mM}{m+M}$
Moseley equation	$f^{1/2} = A_n(Z-b)$
De Broglie relations	$f = E/h$ and $\lambda = h/p$
Davisson and Germer diffraction	$n\lambda = D\sin\phi$