University of Kentucky, Physics 361
EXAM 1, 2010-02-10 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.

[4 pts] 2. a) Draw two blackbody spectra at different temperatures, and indicate features illustrating the Stefan-Boltzmann and Wein's displacement laws.

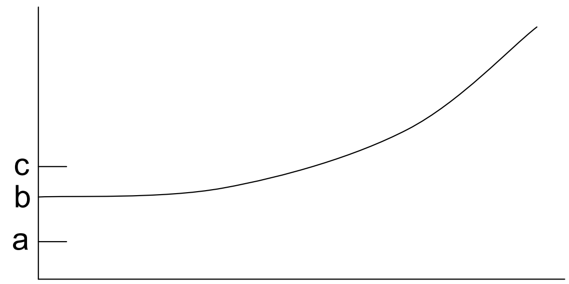
[2 pts] b) Why is blackbody radiation suppressed at long wavelengths?

[2 pts] c) Why is blackbody radiation suppressed at short wavelengths?

[3 pts] 3. Why are two crystals needed to measure the Compton effect?

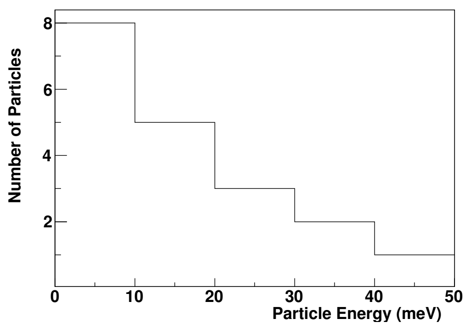
[3 pts] 4. What was de Broglie's interpretation of Bohr's quantization condition $L = n\hbar$?

[6 pts] 5. In the following diagram, label the impact parameter and scattering angle. Draw the scattering trajectories starting at a) and c). Show the location of nucleus with an '×'. Draw a detector and label the corresponding $d\sigma$ and $d\Omega$.



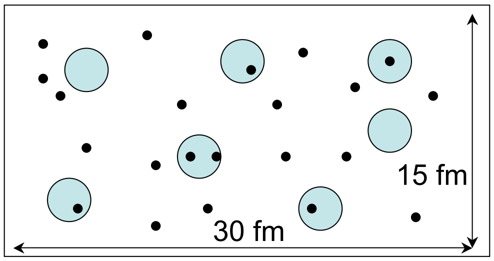
Part II—Calculation

[10 pts] 6. Given the following distribution of energy in a system of particles, a) how many particles are there? b) what is the total energy? c) what is the average energy? [Ignore $g(E)$].



[10 pts] 7. The smallest scattering angle of X-rays from a crystal with 0.2 nm lattice spacing is 5°. a) What is the corresponding wavelength? b) What voltage was applied to the X-ray tube?

[10 pts] 8. Suppose Rutherford were able to peek at alpha 'bullet-holes' in his gold sample, and saw the result below. Using ratio of areas, What would he measure for the cross section σ?



[10 pts] 9. Calculate the wavelength of a proton with energy 1 MeV.

[10 pts bonus] 10. Starting from E_n in the Bohr model, derive the value of R in the Rydberg-Ritz formula.

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	$u(\lambda) = 8\pi hc\lambda^{-5}/(e^{hc/\lambda kT} - 1); \qquad E_n = n\,hf$
Photoelectric effect	$eV_0 = hf - \phi$
Bragg diffraction	$m\lambda = 2d \sin\theta$
Compton effect	$\lambda_2 - \lambda_1 = \lambda_c(1 - \cos\theta)$
Rydberg-Ritz formula	$\frac{1}{\lambda_{mn}} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right), n > m$
Impact parameter	$b = \frac{k_e q_\alpha Q}{m_\alpha v^2} \cot\frac{\theta}{2}$
Differential cross section	$\frac{d\sigma}{d\Omega} = \frac{2\pi b\, db}{2\pi \sin\theta\, d\theta} = \frac{\Delta N}{I_0\, nt} \frac{r^2}{A_{sc}}$
α scattering	$\frac{d\sigma}{d\Omega} = \left(\frac{2Zk_e e^2}{4E_k}\right)^2 \frac{1}{\sin^4\frac{\theta}{2}}$
Size of nucleus	$r_d = \frac{k_e q_\alpha Q}{\frac{1}{2} m_\alpha v^2}$
Bohr's postulates	$L = n\hbar; \qquad hf = E_n - E_m$
Atomic energy levels	$E_n = -Z^2 E_0/n^2$ 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	$n\lambda = D \sin\phi$