PHYSICS 4E QUIZ 1 SPRING QUARTER 2009
PROF. HIRSCH APRIL 10

Formulas:

Relativistic energy - momentum relation $E = \sqrt{m^2c^4 + p^2c^2}$; $c = 3\times 10^8 m/s$

Electron rest mass : $m_e = 0.511\ MeV/c^2$;Proton : $m_p = 938.26\ MeV/c^2$;Neutron : $m_n = 939.55\ MeV/c^2$

Planck's law : $u(\lambda) = n(\lambda)\bar{E}(\lambda)$; $n(\lambda) = \frac{8\pi}{\lambda^4}$; $\bar{E}(\lambda) = \frac{hc}{\lambda}\frac{1}{e^{hc/\lambda k_B T} - 1}$

Energy in a mode/oscillator : $E_f = nhf$; probability $P(E) \propto e^{-E/k_B T}$

Stefan's law : $R = \sigma T^4$; $\sigma = 5.67\times 10^{-8} W/m^2K^4$; $R = cU/4$, $U = \int_0^\infty u(\lambda)d\lambda$

Wien's displacement law : $\lambda_m T = \frac{hc}{4.96 k_B}$

Photons : $E = pc$; $E = hf$; $p = h/\lambda$; $f = c/\lambda$

Photoelectric effect : $eV_0 = (\frac{1}{2}mv^2)_{\max} = hf - \phi$, $\phi \equiv$ work function

Compton scattering : $\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$

Rutherford scattering: $b = \frac{kq_\alpha Q}{m_\alpha v^2}\cot(\theta/2)$; $\Delta N \propto \frac{1}{\sin^4(\theta/2)}$

Constants : $hc = 12{,}400\ eV A$; $k_B = 1/11{,}600\ eV/K$; $ke^2 = 14.4 eVA$

Electrostatics : $F = \frac{kq_1q_2}{r^2}$ (force) ; $U = q_0V$ (potential energy) ; $V = \frac{kq}{r}$ (potential)

Hydrogen spectrum : $\frac{1}{\lambda} = R(\frac{1}{m^2} - \frac{1}{n^2})$; $R = 1.097\times 10^7\ m^{-1} = \frac{1}{911.3A}$

Bohr atom : $E_n = -\frac{ke^2Z}{2r_n} = -\frac{Z^2E_0}{n^2}$; $E_0 = \frac{ke^2}{2a_0} = \frac{mk^2e^4}{2\hbar^2} = 13.6eV$; $E_n = E_{kin} + E_{pot}, E_{kin} = -E_{pot}/2 = -E_n$

$hf = E_i - E_f$; $r_n = r_0 n^2$; $r_0 = \frac{a_0}{Z}$; $a_0 = \frac{\hbar^2}{mke^2} = 0.529A$; $L = mvr = n\hbar$ angular momentum

Justify all your answers to all problems

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Problem 1 (10 pts)
In a different universe, the energy of electromagnetic radiation is quantized according to the law
$E = nIf^2$
instead of Planck's law $E = nhf$. f is the frequency of the radiation, n is an integer, and I is the equivalent of Planck's constant h in that universe. The Boltzmann distribution, counting of modes, etc., are the same in that universe as in ours.
(a) The equivalent of Stefan's law in that universe is
$P = CT^{\alpha}$
where C and α are constants. Find α.
(b) The equivalent of Wien's displacement law in that universe is
$\lambda_m T^{\beta} = D$
where D and β are constants. Find β.
(c) What are the dimensions of the constant I, and what might it represent physically?

Problem 2 (10 pts)
In a Compton scattering experiment, incident photons have wavelength 1A and scattered electrons have kinetic energy 493 eV.
(a) Find the wavelength of the scattered photons, in A.
(b) Find the angle θ at which the photons are scattered, in degrees.
Hint: use energy conservation.

Problem 3 (10 pts)
(a) The emission line spectrum emitted by a hydrogen-like ion extends down to wavelengths smaller than 15 A. Clearly, this is not hydrogen (Z=1). What is the minimum Z that this ion has to have?
(b) A hydrogen-like ion has the electron orbiting at speed faster than 0.1c. What is the minimum Z that this ion has to have? (Hint: use angular momentum).
(c) A hydrogen-like ion has the electron in an orbit of radius 0.0529A. Give two possible values for the Z of this ion.

Justify all your answers to all problems