PHYSICS 101A FALL 2008
SAMPLE QUESTIONS FOR MIDTERM II

PUT YOUR NAME ON THE EXAM RIGHT AWAY!

PLEASE SHOW ALL OF YOUR WORK. You may use the back of the page if necessary. Please clearly mark all problems for which you have information on the back of the page that you would like to be considered during the grading of the exam.

EQUATIONS AND FORMULAE

$x' = x - vt$; $y' = y$; $z' = z$

$ct' = \gamma(ct - \beta x)$; $x' = \gamma(x - \beta ct)$

$\beta = v/c$

$\gamma = 1/\sqrt{1-\beta^2}$

$\Delta t = \gamma \Delta t'$

$L = L_P/\gamma$

$(\Delta s)^2 = (c\Delta t)^2 - (\Delta x)^2$

$\Delta\tau = \Delta s/c$

$u'_x = (u_x - v)/[1 - (vu_x/c^2)]$

$u'_y = u_y/\gamma[1 - (vu_x/c^2)]$

$u'_z = u_z/\gamma[1 - (vu_x/c^2)]$

$\vec{p} = \gamma m \vec{v}$

$E = \gamma mc^2$

$E'/c = \gamma(E/c - \beta p_x)$; $p'_x = \gamma(p_x - \beta E/c)$

$E = mc^2 + T$

$p = (E/c, p_x, p_y, p_z)$

$M = |p|/c$; $|p|^2 = (E/c)^2 - p_x^2 - p_y^2 - p_z^2$

$E^2 = (mc^2)^2 + (pc)^2$

$pc = \beta E$

$\nu = c/\lambda$

$E = h\nu$

$R = \sigma T^4$; $\quad \sigma = 5.67 \times 10^{-8}$ W/m^2-K^4

$\lambda_{max} T = 2.898 \times 10^{-3}$ m-K

$n(\lambda) = 8\pi\lambda^{-4}$

$\overline{E} = kT$

$u(\lambda) = \frac{8\pi hc\lambda^{-5}}{\exp(hc/\lambda kT)-1}$

$\overline{E} = \frac{h\nu}{\exp(hc/\lambda kT)-1}$

$eV_{stop} = h\nu - \phi$

$\lambda_2 - \lambda_1 = \lambda_c(1 - \cos\theta)$

$\lambda_c = \frac{h}{m_e c} = 2.43 \times 10^{-12}$ m

$b = \frac{kzZe^2}{2E_k} \cot\frac{\theta}{2}$

$\Delta N = \frac{I_0 A_{sc} nt}{r^2} \frac{kzZe^2}{4E_k}^2 \frac{1}{\sin^4(\theta/2)}$

$d\Omega = \sin\theta d\theta d\phi$

$\frac{d\sigma}{d\Omega} = \frac{kzZe^2}{4E_k}^2 \frac{1}{\sin^4(\theta/2)}$

$r_d = \frac{kzZe^2}{E_k}$

$U_E = \frac{kq_1q_2}{r}$

$E_n = -hcR\frac{Z^2}{n^2}$

$\frac{1}{\lambda_{Nn}} = Z^2 R\left(\frac{1}{N^2} - \frac{1}{n^2}\right)$

$\mu = \frac{mM}{m+M}$

$L = n\bar{h}$

$\sqrt{\nu} = A_n(Z - b)$

c $= 2.998 \times 10^8$ m/s

$\bar{h} = h/2\pi$

$\bar{h} = 1.054 \times 10^{-34}$ J-s $= 6.582 \times 10^{-16}$ eV-s

$h = 6.626 \times 10^{-34}$ J-s

$hc = 1240$ eV-nm

$k = 1.381 \times 10^{-23}$ J/K $= 8.617 \times 10^{-5}$ eV/K

$e = 1.602 \times 10^{-19}$ C; 1.602×10^{-19} J per eV

$m_p = 938.3$ MeV/c^2

$m_e = 5.110 \times 10^5$ eV/c^2 $= 9.109 \times 10^{-31}$ kg

$a_0 = \bar{h}^2/mke^2 = 0.0529$ nm

$R_\infty = 1.097 \times 10^7$ m^{-1}

$k = 8.99 \times 10^9$ N-m^2/C^2 (electrostatic constant)

PROBLEM 1 [25 PTS]

In a photoelectric effect experiment, light from the Balmer-β (n=4 to N=2) transition illuminates a photoemissive cathode. The stopping potential is found to be precisely 1 Volt.

a) What is the work function ϕ of the photoemissive material in the cathode, in units of eV?

b) Can any of the Paschen series lines (transitions to N=3) cause photoelectrons to be emitted from the photocathode? Why or why not?

PROBLEM 2 [25 PTS]

a) What is the *classical* expression for the energy density $u(\lambda)$ inside a blackbody cavity? In other words, what is the formula for $u(\lambda)$ assuming an average energy per mode of $\bar{E} = kT$, independent of the mode's wavelength? Don't plug any numbers in for this one – just show the formula.

b) For what wavelengths does Planck's quantum form for $u(\lambda)$ approaches the classical form: very long or very short? Why?

c) Show explicitly that Planck's $u(\lambda)$ approaches the classical form from a) in the limit that you chose as your answer to b).

PROBLEM 3 [25 PTS]

In a Compton scattering experiment with X-rays, it is found that the wavelength λ_{out} of directly backscattered (180-degree scattered) X-rays is 1.5% longer than the wavelength λ_{in} of the incident X-rays. What is the wavelength λ_{in} of the incident X-rays?

PROBLEM 4 [25 PTS]

The eminent British theoretical physicist Derek Noggins has predicted two new particles – the N_0 and N_1 – with mass around 1 TeV/c^2 (trillion eV/c^2), and which can be produced via electron-positron annihilation. These two new particles decay very rapidly into a pair of photons, yielding the reactions

$$e^+e^- \to N_0 \to \gamma\gamma$$

$$e^+e^- \to N_1 \to \gamma\gamma.$$

Thus, the N_0 and N_1 can be discovered by colliding electrons and positrons with cms energy equal to the N_0 or N_1 rest mass, and looking for photons from the subsequent N_0 and N_1 decay which enter a detector surrounding the collision point (see diagram).

According to Noggins, the differential cross section for producing photons via the N_0 and N_1 is given by

$$(\frac{d\sigma}{d\Omega})_{N_0} = A_0$$

$$(\frac{d\sigma}{d\Omega})_{N_1} = \frac{A_0}{2}(1 + \cos^2\theta)$$

with $A_0 = 1$ mbarn (10^{-31} m^2).

a) Doing the experiment with continuously colliding electron and positron beams, you indeed find that photons are observed in your detector when the electron/positron cms energy is tuned precisely to 1.012 TeV and 1.014 TeV. Seemingly, you have discovered the two Noggins particles – but which is the N_0 and which is the N_1? Looking back at your data, you notice that the rate of photons striking your detector is 50% higher at 1.012 TeV than at 1.014 TeV. Is the particle with mass 1.012 TeV/c^2 the N_0 or the N_1? Assume that your detector covers the full solid angle, from 0 to 2π in ϕ and from 0 to π in θ.

b) The electron and positron beams each consist of packets of 10^{10} particles which cross through each other 120 times per second. Each packet is a cylinder of radius 1 μm and depth 10 μm (see diagram). Your detector completely surrounds the collision point, so every photon pair that is produced is recorded in your detector.

On average, how many photon pair events are observed in your detector per second if the beam is tuned to the mass-energy of the N_0? (Hint: consider *one* electron passing through the packet of 10^{10} positrons, and then multiply by 10^{10}. Does the answer depend upon the depth of the cylinder?).