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

\[ x' = x - vt; \quad y' = y; \quad z' = z \]
\[ \beta = v/c \]
\[ \Delta t = \gamma \Delta t' \]
\[ (\Delta s)^2 = (c\Delta t)^2 - (\Delta x)^2 \]
\[ u'_x = (u_x - v)/[1 - (vu_x/c^2)] \]
\[ u'_z = u_z/\gamma [1 - (vu_x/c^2)] \]
\[ E = \gamma mc^2 \]
\[ E = mc^2 + T \]
\[ p = (E/c, p_x, p_y, p_z) \]
\[ E^2 = (mc^2)^2 + (pc)^2 \]
\[ \nu = c/\lambda \]
\[ R = \sigma T^4; \quad \sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{-K}^4 \]
\[ n(\lambda) = 8\pi \lambda^{-4} \]
\[ u(\lambda) = \frac{8\pi \lambda\hbar \lambda^{-5}}{\exp(hc/\lambda \kappa T) - 1} \]
\[ eV_{\text{stop}} = h\nu - \phi \]
\[ \lambda_c = \frac{\hbar}{mc} = 2.43 \times 10^{-12} \text{ m} \]
\[ \Delta N = \frac{L \lambda_{\text{eff}} n(\lambda) k^2 Z^2 e^2}{4E_k} \frac{1}{\sin^4(\theta/2)} \]
\[ \frac{d\sigma}{d\Omega} = \frac{k^2 Z^2 e^2}{4E_k} \frac{1}{\sin^4(\theta/2)} \]
\[ U_E = \frac{k q n Z^2 e^2}{r} \]
\[ \frac{1}{\lambda_{\text{N} n}} = Z^2 R \left( \frac{1}{N^2} - \frac{1}{n^2} \right) \]
\[ L = n\hbar \]
\[ c = 2.998 \times 10^8 \text{ m/s} \]
\[ \hbar = 1.054 \times 10^{-34} \text{ J-s} = 6.582 \times 10^{-16} \text{ eV-s} \]
\[ hc = 1240 \text{ eV-nm} \]
\[ e = 1.602 \times 10^{-19} \text{ C; } 1.602 \times 10^{-19} \text{ J per eV} \]
\[ ct' = \gamma(ct - \beta x); \quad x' = \gamma(x - \beta ct) \]
\[ \gamma = 1/\sqrt{1 - \beta^2} \]
\[ L = L_P/\gamma \]
\[ \Delta \tau = \Delta s/c \]
\[ u'_y = u_y/\gamma [1 - (vu_x/c^2)] \]
\[ \vec{p} = \gamma m\vec{v} \]
\[ E'/c = \gamma(E/c - \beta p_x); \quad p'_x = \gamma(p_x - \beta E/c) \]
\[ M = |p|/c; \quad |p|^2 = (E/c)^2 - p_x^2 - p_y^2 - p_z^2 \]
\[ pc = \beta E \]
\[ E = h\nu \]
\[ \lambda_{\text{max}}T = 2.898 \times 10^{-3} \text{ m-K} \]
\[ \overline{E} = kT \]
\[ \overline{E} = \frac{h\nu}{\exp(hc/\lambda\kappa T) - 1} \]
\[ \lambda_2 - \lambda_1 = \lambda_c(1 - \cos \theta) \]
\[ b = \frac{k^2 Z^2 e^2}{2E_k} \cot \frac{\theta}{2} \]
\[ d\Omega = \sin \theta d\theta d\phi \]
\[ r_d = \frac{k^2 Z^2 e^2}{E_k} \]
\[ E_n = -hcR Z^2 \]
\[ \mu = \frac{mM}{m + M} \]
\[ \sqrt{\nu} = A_n(Z - b) \]
\[ \hbar = \hbar/2\pi \]
\[ h = 6.626 \times 10^{-34} \text{ J-s} \]
\[ k = 1.381 \times 10^{-23} \text{ J/K} = 8.617 \times 10^{-5} \text{ eV/K} \]
\[ m_p = 938.3 \text{ MeV/c}^2 \]
\[ m_e = 5.110 \times 10^5 \text{ eV}/c^2 = 9.109 \times 10^{-31} \text{ kg} \]

\[ R_\infty = 1.097 \times 10^7 \text{ m}^{-1} \]

\[ a_0 = \frac{\hbar^2}{mke^2} = 0.0529 \text{ nm} \]

\[ k = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2 \text{ (electrostatic constant)} \]
PROBLEM 1 [25 PTS]
In a photoelectric effect experiment, light from the Balmer-β (n=4 to N=2) transition illu-
minates a photoemissive cathode. The stopping potential is found to be precisely 1 Volt.

a) What is the work function \( \phi \) 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 $\lambda_{\text{out}}$ of directly backscattered (180-degree scattered) X-rays is 1.5% longer than the wavelength $\lambda_{\text{in}}$ of the incident X-rays. What is the wavelength $\lambda_{\text{in}}$ of the incident X-rays?
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
\[ e^+ e^- \rightarrow N_0 \rightarrow \gamma \gamma \]
\[ e^+ e^- \rightarrow N_1 \rightarrow \gamma \gamma. \]
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
\[ \frac{d\sigma}{d\Omega} \mid_{N_0} = A_0 \]
\[ \frac{d\sigma}{d\Omega} \mid_{N_1} = \frac{A_0}{2} (1 + \cos^2 \theta) \]
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 $2\pi$ in $\phi$ and from 0 to $\pi$ in $\theta$.

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 $\mu$m and depth 10 $\mu$m (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?)