Physics 101A

Homework Assignment #4

Due in class, Thursday, February 4 100 points total

I will accept the homework late up until noon Friday, February 5, in my office.

All problems, 10 points each.
1) Suppose that after a Compton collision between a photon and an electron initially at rest, the photon and the electron emerge symmetrically, that is, at equal and opposite angles $\theta$ with respect to the direction of incidence. If the initial photon energy is 30 keV, what is the angle $\theta$ that corresponds to such symmetric scattering, and what are the final photon energy and the final electron energy?

2) An $\eta'$ meson decays to a $\rho^0$ meson and a photon about 30% of the time: $\eta' \rightarrow \rho^0 \gamma$.
   a) Derive an equation that gives in the $\eta'$ rest frame the energy of the $\gamma$ in terms of the particle masses and the speed of light. Use the symbols $m_{\eta'}$ and $m_{\rho^0}$ to denote the masses.
   b) Using the values $m_{\eta'}=958 \text{ MeV}/c^2$, $m_{\rho^0}=768 \text{ MeV}/c^2$, calculate the energies of the $\rho^0$ and $\gamma$ in the $\eta'$ rest frame.

3) The first conclusive evidence for a gravitational redshift was observed in the spectrum of light from Sirius B, the white-dwarf companion of Sirius, the dog star (brightest star in the sky, but the companion can only be resolved with a powerful telescope). What fractional frequency shift $\Delta \nu/\nu$ would you expect in light reaching us from the surface of Sirius B, assuming that it has the same mass as the Sun but the radius of the Earth? Recall from lecture that the time dilation factor for such a case is $\gamma = \frac{1}{\sqrt{1 - 2\phi/c^2}}$

$\phi$ is the gravitational potential (potential energy per unit mass) at the surface of the star (we can ignore the effect of the much smaller potential at the surface of Earth).

4) At the top of the Earth's atmosphere, the power from sunlight incident on a square meter surface directly facing the sun is $1.37 \times 10^3$ Watts. Assume that the Earth radiates like a black body at uniform temperature and calculate the equilibrium temperature of Earth (where the amount of energy radiated equals that absorbed). How does your result compare with your expectations? Try to explain qualitatively any differences.

5) Problem 1-15 from Eisberg and Resnick. Understanding the mean of a continuous distribution versus that of a discrete distribution.

6) Show that if $kT \gg h \nu$, Planck's formula for the average energy of an oscillator gives approximately $\bar{E} = kT$. Then, derive the Stefan-Boltzmann law for the radiancy from Planck's radiation law (Problem 1-17 of Eisberg and Resnick).

7) Answer Questions 2-2 and 2-3 from Eisberg and Resnick.
8) From Planck’s equation for black-body radiation, the classical result can be obtained by taking the limit in which $h \to 0$. Can you use this device to obtain classical results from quantum results in the case of the photoelectric effect? Explain.

9) The energy flux in the starlight reaching us from a sixth-magnitude star (approximately the faintest that can be seen by the naked eye) is $1.4 \times 10^{-10}$ W/m$^2$. If you are looking at such a star, how many photons per second enter your eye? Assume that the diameter of your dark-adapted pupil is 0.70 cm. Assume that the light has a wavelength of 500 nm.

10) Problem 2-5 from Eisberg and Resnick.

**Required Reading:** Eisberg and Resnick, Chapters 1 and 2. Note that Chapter 1 goes into more detail in the statistical-mechanics calculations leading up to Planck’s formula than was done in lecture. If you find the calculations too difficult, don’t worry. I don’t expect you to have an understanding of statistical mechanics at this point. We will go into it more next quarter.

**Recommended Reading:**

If you would like to read a little about General Relativity, without getting into the difficult mathematics, there is a short, non-technical book written by Einstein himself that is widely available in paperback in bookstores, as well as the library. I modeled my lecture on the subject after his explanations. The book is *Relativity, The Special and the General Theory*, by Albert Einstein. I’ve seen it available from more than one publisher, but my copy is from Three Rivers Press, New York. This subject will not be featured on the exams in this course, however.