Physics 322 Problem Set #3
(Relativistic Loose Ends and Particles of Light)

Due Friday, February 6 at 4:00 pm

ASSUMED READING: Before starting this homework, you should read Chapter 3 of Harris' *Modern Physics*. For the last problem, it may be helpful to review single-slit diffraction from Harris' *Classical Physics Review* (pages 27-29 of that document).

SCORING: There are 70 points possible on this Problem Set. Scoring per problem is indicated.

1. **[Harris 2.82 tweaked] (10 points)** A high-explosive material employing chemical reactions has an explosive yield of 10^6 J/kg, measured in Joules of energy released per kilogram of material.
   - **a.** By what fraction does its mass change when it explodes?
   - **b.** What is the explosive yield of a kilogram of material that produces energy via *nuclear* reactions in which its mass decreases by 1 part in 10,000?

2. **[Harris 3.3] (5 points)** You are conducting a photoelectric effect experiment by shining light of 500 nm wavelength at a piece of metal and determining the stopping potential. If, unbeknownst to you, your 500 nm light source actually contained a small amount of ultraviolet light, would it throw off your results by a small amount or by quite a bit? Explain.

3. **[Harris 3.9] (5 points)** A low-intensity beam of light is sent toward a narrow single slit. On the far side, individual flashes are seen sporadically at the detectors over a broad area that is orders of magnitude wider than the slit width. What aspects of the experiment suggest a wave nature for light, and what aspects suggest a particle nature?

4. **[Harris 3.11] (10 points)** For small z, e^z is approximately $1+z$.
   - **a.** Use this to show that Planck's spectral energy density (described by equation 3-1) agrees with the result of the classical wave theory (listed before equation 3-1 in the book) in the limit of small frequencies (low energy or long wavelength).
   - **b.** Show that, whereas the classical formula diverges at high frequencies – the so-called **ultraviolet catastrophe** of this theory – Planck's formula approaches 0.

5. **[Harris 3.25] (10 points)** You are an early 20th-Century experimental physicist and do not know the value of Planck's constant. By a suitable plot of the following data, and using Einstein's explanation of the photoelectric effect (KE = $hf - \varphi$ where h is *not* known), determine Planck's constant. **NOTE:** Just to clarify, if you want to use Excel or some other plotting package, that is OK, but you better <u>clearly</u> explain what you are doing!

Wavelength of Light (nm)	**Stopping Potential (V)**
550	0.060
500	0.286
450	0.563
400	0.908

6. **[Harris 3.32 tweaked] (10 points)** A 0.065 nm X-ray source is directed at a sample of carbon (which weakly holds on to its electrons, so you don't have to consider the binding energy of the electron to the carbon in this problem). Determine the maximum speed of the scattered electrons. **HINT:** You can determine the final kinetic energy of the electron through the application of conservation of energy. Assume the electron is moving a relativistic speed unless you can prove its not, just to be safe.

7. **[Harris 3.41 tweaked] (10 points)** A stationary muon μ^- annihilates with a stationary antimuon μ^+ (same mass, 1.88×10^{-28} kg, but opposite charge). The two disappear, replaced by electromagnetic radiation.
   - **a.** Clearly explain why is it not possible for a single photon to result? **HINT:** Think about momentum.
   - **b.** Suppose two photons result. Describe the possible directions of motion and the wavelengths.

8. **[Harris 3.45 tweaked] (10 points)** Electromagnetic "waves" strike a single slit of 1 μm width. Determine the *angular full width* (angle from first minimum on one side of the center to the first minimum on the other) in degrees of of the central diffraction maximum if the waves are
   - **a.** visible light of wavelength 500 nm and
   - **b.** X-rays of wavelength 0.05 nm.
   - **c.** Which more clearly demonstrates a wave nature? *Clearly explain why you have come to this conclusion.*