University of California, Berkeley
Physics 7C Professor Freedman Spring 2010
Second Midterm Examination Tuesday, 6 April, 6:00 – 8:00 PM

Print Name ______________________________Discussion Section # _______________

Signature _____________________________Discussion Section GSI ________________

Student ID# ______________________________

- You have 110 minutes.
- You may use both sides of the paper. Make sure the work for each problem is clearly identified with the particular problem. If you use additional paper make sure it is stapled to you exam. Ask the GSI to use the stapler when you hand in your exam.
- This exam is closed book, but you are allowed one 3" x 5" (double-sided) card of handwritten notes or equations.
- You may use a calculator, however NO wireless devices are allowed.
- To get partial credit your work must be clear. Work out formulas symbolically before evaluating them numerically.
- Put a box around the final symbolic and the final numerical result.
- Each problem is worth 20 points.

Some Numerical Information

Planck's Constant $h = 6.63 \times 10^{-34}$ J·s
Rydberg's Constant $R = 1.1 \times 10^{-2}$ nm^{-1}
Speed of Light $c = 3.0 \times 10^{8}$ m·s^{-1}

1	/20
2	/20
3	/20
4	/20
5	/20
Total	/100

1. 20 points. Traveling Twins

Bonnie boards a spaceship and travels away from Earth at a constant velocity $0.45c$ towards Betelgeuse (a red giant star in the constellation Orion). One year later on Earth clocks, Bonnie's twin, Clyde, boards a second spaceship and follows her at a constant velocity of $0.95c$ in the same direction.

a. Draw a space-time diagram from the point of view of an observer on the earth showing the world lines of Bonnie and Clyde. Determine the space-time coordinate of the event of Clyde catching up to Bonnie in the Earth frame.

b. When Clyde catches up with Bonnie, what will be the difference in their ages?

c. Which of the two is really the oldest at the event of their reunion (the brief reunion is the instant when Clyde catches up Bonnie)? Briefly explain the logic that leads you to this answer. Will Bonnie and Clyde agree about their relative age?

2. 20 points. Creating the Antiproton.

An antiproton $\overline{p}$ has the same rest energy as a proton. It was first created at Berkeley using a reaction (similar to) $p + p \rightarrow p + p + p + \overline{p}$. In the experiment the target proton was at rest in the laboratory and the beam was incident with kinetic energy E_k, which was chosen to be large enough so that some of the kinetic energy could be converted into rest energy $2mc^2$, which is sufficient to produce another proton and one antiproton. In the zero-momentum frame (sometimes called the center-of-momentum frame) the two protons (beam and target) move toward each other with speed u so that enough kinetic energy is available for the required additional rest energy.

a. Find the speed of each proton u so that the total kinetic energy in the zero-momentum frame is $2mc^2$.

b. Find the value of the kinetic energy E_k of the proton in the incident beam required to cause the reaction to proceed. (You should express your answer in terms of multiples of the proton rest energy.)

c. Describe the motion (in the laboratory frame) of the proton and antiproton produced in the reaction. What is their speed and direction in the laboratory?

3. 20 points. Black Body Radiation

Hint: $u(\lambda) = \dfrac{8\pi hc\lambda^{-5}}{e^{hc/\lambda kT} - 1}$

a. Find the ratio of the increase in the values for λ_m, the wavelength of the point with maximum intensity on the blackbody spectrum between $T = 3K$ and $T = 300K$.

b. The temperature of a blackbody radiator is changed from $T = 3K$ to $T = 300K$ by what factor will the total emitted power increase?

c. What is the expression for the average energy per mode used by Planck based on his hypothesis of quantization? (Hint: look for it hidden in the expression for the energy density $u(\lambda)$ provided in the helpful information above.)

d. Evaluate Planck's expression for the average energy per mode for temperature $T = \frac{hf}{k}$. Briefly explain the difference from what you would expect from the classical theory and how Planck's expression solves the problem of the ultraviolet catastrophe.

4. 20 points Photon absorption

Take the rest mass of a carbon nucleus is 12 u = 12 x 931.494 MeV/c^2
You approximate this at 12 GeV/c^2. Other approximations may be appropriate (for example the non-relativistic approximation) but you should note any approximations you make in obtaining numerical solutions.

a. Show that a 15-MeV photon cannot be absorbed by the carbon nucleus unless it can have internal energy (i.e. an excited state).

b. A photon can be absorbed by a system that can have internal energy. Assume that a 15-MeV photon can is absorbed by a carbon nucleus initially at rest. What must the momentum of the carbon nucleus be immediately after the photon is absorbed?

c. What is the energy of the carbon nucleus just after the photon is absorbed. Obtain a non-relativistic expression for the energy.

d. The carbon nucleus is brought to rest by some external process and the internal energy is released by the emission of a photon. What is the energy of the photon emitted by the carbon?

5. 20 points. Some Questions about Atomic Spectra

a. Explain why you don't expect to see the Balmer's series is in the of lines for atomic hydrogen in the absorption spectra of the Sun. (Hint: think about the Bohr quantum number *m*, which is, for the final state in the Balmer series.)

b. The hydrogen series of lines with $m = 4$ is called the Brackett's series. Compute the wavelengths of the first two lines of Brackett's series. (You can neglect reduced mass effects.)

c. Explain why the absorption spectrum of sodium is much simpler than the emission spectrum and has similarities to the absorption spectrum of hydrogen. Explain what differences you would expect.

d. Ions are atoms with some of their atomic electrons removed. Why should you expect the spectra of atoms with only one electron left to be similar to the spectrum of atomic hydrogen? Give a rough expression for how the wavelengths of the emission spectrum will change for different elements relative to hydrogen.