Final Exam: Modern Physics 201
April 12, 2005

Duration: 2.5 hours. Text book and one double sided formula sheet. Point values are given with each question. Total exam is worth 60 points plus a 6 point bonus question. Maximum mark is still 100%.

1. (a) What technique was/is used to study energy levels in atoms? Comment on the stability of the hydrogen atom in classical physics. (4)

   (b) What was Bohr's assumption concerning quantization of angular momentum in the hydrogen atom? If angular momentum $L = mvr$ for circular orbits show how this is consistent with deBroglie's hypothesis that the wavelength of the electron is $\lambda = h/p$. (4)

   (c) The energy levels of the Bohr atom are given by

$$E_n = -\frac{me^4}{32\pi^2\epsilon_0^2\hbar^2}\frac{Z^2}{n^2} \tag{1}$$

   Calculate the wavelength of the light that comes from the $n = 5$ to $n = 2$ transition in hydrogen. (4)

2. If your one-dimensional wavefunction has the form $\psi(x)$ the position $\hat{x}$ and $\hat{p}_x$ momentum operators are

$$\hat{x} = x \tag{2}$$

$$\hat{p}_x = \frac{\hbar}{i}\frac{\partial}{\partial x}. \tag{3}$$

   (a) In terms of probability what does ψ represent? (same interpretation as Ψ in this case) (2)

   (b) Show that the electron plane wave $\psi(x) = Ae^{ikx}$ which is moving to the right is an eigenfunction of the momentum operator and give the eigenvalue. (2)

   (c) Suppose that the energy of the electron is 10 eV. What is the value of k? Is there any uncertainty associated with this value if the wavefunction is of the earlier form? (4)

   (d) Now suppose that this electron plane wave is incident on a barrier that is 12 eV high and 3 Å thick. What is the name of the phenomena that allows the electrons to traverse the barrier? What is the transmission probability? (4)

3. Monochromatic light with $\lambda = 500$ nm is incident on a photocathode. The work function of the cathode is 1.5 eV. (This is the energy required to liberate electrodes from the cathode.) What reverse bias is necessary to cut off the photocurrent? What is the intensity dependence of this value? (6)

4. (a) Give the relativistic definition of momentum and energy in terms of $\vec{V}$ the velocity of the particle measured in that frame. (2)

   (b) Calculate E, p_x, p_y, and p_z in "MeV" style units for an electron moving at $0.95c$ along the x-axis. $m_e = 0.511$ MeV$/c^2$ (2)

   (c) Numerically show that $E^2 + p^2c^2 = m^2c^4$ is satisfied for the above example. (2)

(d) What form should physical laws (such as conservation of momentum) take in order to be consistent with the postulates of relativity? (I am looking for a key phrase.) Group E and the components of p so that it is in this form. (3)

5. Matching question. Match the items in the two columns by giving a letter number pair. Two of the items in the first column match with the same one in the second column and one item of the second column doesn't match anything. In each case give one extra fact or statement on the topic. for example an item in column 1 like "broken conservation laws in beta decay" would match with "evidence for neutrino". Extra facts could include: "postulated by Pauli", "chargeless/ massless", "only affected by weak force", "lepton partner of electron in standard model", etc. You will receive 1 point for each correct match and 1.5 points for each fact. (21 points total, 9 matches and 8 facts, just give one fact for the "double")

1. trying to retrieve a trapped guitar pick	a) creation of virtual particles
2. 1 millisievert of beta radiation	b) field bosons
3. a wimpy or cream puff scatterer	c) 1 millisievert of gamma radiaton
4. cheating energy conservation	d) small ψ near the walls in infinite square well
5. leptons and quarks	e) failure of Rayleigh-Jeans law
6. photons, gluons, $W^{\pm}$ and Z	f) Thompson atom
7. feeling your way in the dark	g) alpha particle in nucleus prior to decay
8. standing waves on a string	h) 2.7 millisievert of gamma radiation
9. ultraviolet catastrophe	i) fermions of standard model

6. BONUS: What were Einstein's 3 significant contributions to the field of modern physics in 1905? (6)