Final - Modern Physics for Engineers

December 6, 1999

Test Number: ____________________

Name: ____________________

S.S. No.: ____________________

Do all work in this exam booklet. Use the backs of the sheets if necessary. An equation sheet is provided as the second page of this exam. You may use your calculators to evaluate answers if necessary. Note that some questions in this exam require answers that have the integrals evaluated. The integrals that you will need may be on the equation page. If not, there is a table of integrals in the front of the class.

Good luck.

Enjoy the Holidays!!!

EQUATION SHEET

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad \beta = \frac{v}{c} \qquad f\lambda = c$$

$$x' = \gamma(x + \beta ct) \qquad p' = \gamma(p + \beta E/c)$$

$$t' = \gamma(t + \beta x/c) \qquad E' = \gamma(E + \beta cp)$$

$$E^2 = p^2c^2 + m^2c^4 \qquad KE = E - mc^2$$

$$\vec{p}_i = \vec{p}_f \qquad f' = f\sqrt{\frac{1-\beta}{1+\beta}}$$

$$E_i = E_f \qquad v' = \frac{v+u}{1+uv/c^2}$$

$$\int_{-\infty}^{\infty} e^{-\frac{x^2}{2\sigma^2}}\, dx = \sqrt{2\pi}\sigma \qquad \int_{-\infty}^{\infty} x^2 e^{-\frac{x^2}{2\sigma^2}}\, dx = \sqrt{2\pi}\sigma^3$$

$$\int_0^{\pi} \sin^2 x\, dx = \frac{\pi}{2} \qquad \int_0^{\pi} x^2 \sin^2 x\, dx = \frac{4\pi^3}{3} - \frac{\pi}{2} \qquad \int_0^{\pi} \sin x \cos x\, dx = 0$$

$$E = (n + \frac{1}{2})\hbar\omega \qquad E = \frac{\hbar^2\pi^2 n^2}{2mL^2} \qquad E = \frac{\hbar^2 l(l+1)}{2I_{cm}} \qquad E = -\frac{ke^2}{2a_0 n^2}$$

$$V = \frac{1}{2}m\omega^2 x^2 \qquad V = -\frac{kq^2}{r}$$

$$\hbar = 1.055 \times 10^{-34}\ \mathrm{J \cdot s} = 4.136 \times 10^{-15}\ \mathrm{eVsec}$$

$$x_{op} = x \qquad p_{op} = i\hbar\frac{\partial}{\partial x} \qquad E_{op} = \frac{\hbar}{i}\frac{\partial}{\partial t}$$

u	c	t
d	s	b
e^-	μ^-	τ^-
ν_e	ν_μ	ν_τ

Problem 1 - (**40 points**)

A Λ_b decays via the weak interactions to a neutron and D^0. The quark content of the Λ_b, neutron, and D^0 are (udb), (udd), and $(\bar{u}c)$, respectively. Their masses are 5624 MeV/c^2, 940 MeV/c^2, and 1865 MeV/c^2.

Part A: (**10 points**) Draw the quark line diagram that represents this decay.

Part B: (**20 points**) Calculate the energy and the momentum of both the neutron and the D^0 after the decay if the Λ_b is initially at rest in the laboratory.

Problem 1 (Continued)

Part B: (continued)

Part C: (**10 points**) If the D^0 has a lifetime of 4×10^{-13} seconds, how far will it travel in the laboratory before it decays?

Problem 2 - (**40 points**)

The wave function for the ground state of a simple harmonic oscillator (potential $V(x) = \frac{1}{2}m\omega^2 x^2$) is given by

$$\psi(x) = Ae^{-ax^2}.$$

For reference:

$$\int_{-\infty}^{\infty} x^n e^{-\alpha x^2} = \begin{cases} 0 & n \text{ odd} \\ \sqrt{\frac{\pi}{\alpha}} & n = 0 \\ \frac{\sqrt{\pi}}{a^{\frac{n+1}{2}}}\frac{(n-1)!!}{2^{\frac{n}{2}}} & n > 0 \text{ and even.} \end{cases}$$

where $n!! = n \cdot (n-2) \cdot (n-4) \cdots 1$.

Part A - (**10 points**): Find explicitly (including doing the integrations) the value of A in terms of a.

Problem 2 (continued)

Part B - (**15 points**): What does the value of a and E have to be such that Schrödinger's equation is satisfied?

Problem 2 (continued)

Part C - (**15 points**): Find explicitly (including doing the integrals) the average value of the kinetic energy, *i.e.*, $\left\langle \frac{p^2}{2m} \right\rangle$.

Short Answer Problems - (**80 points**) - 10 points each.

Problem 1) A certain nucleus behaves like a rigid rotator. What is its moment of inertia if a photon of energy 170 keV is given off in the transition from the $\ell = 3$ to the $\ell = 2$ energy level?

Problem 2) Write out explicity the quantum numbers of the seven electrons of a nitrogen atom.

Problem 3) Thorium (Th_{90}^{228}) beta decays to protactium (Po) which in turn alpha decays to actinium (Ac). Write out these two decay reactions including putting the nucleon number and number of protons (or the charge) on each of the products.

Problem 4) How much energy is released when 1 gm of U_{92}^{235} (mass = 235.043922 u) alpha decays to Th_{90}^{231} (mass = 231.036402 u) and an alpha particle (mass = 4.002603 u).

Problem 5) Electrons and photons with 100 keV/c momentum give the same diffraction pattern when scattering off of a crystal. Does this show that they are both waves, both particles, or that the electron is a wave and the photon is a particle? Why?

Problem 6) If you localize an electron to be within an atom ($\Delta x \approx .05$ nm), what is its minimum kinetic energy? (Remember $\langle KE \rangle = \frac{\langle p^2 \rangle}{2m}$). The mass of an electron is 9.1×10^{-31} kg.

Problem 7) Name three pieces of evidence that are consistent with the “Big Bang” theory of the universe.

Problem 8) You built the starship Enterprise according to specifications which says that it is supposed to be 1 km long. However, Captain Kirk flies the ship past you at .9995 c (on the way to warp 3). How long do you measure the ship to be now?