University of the Witwatersrand
Physics IIE (Engineering) : PHYS284 - 2004
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Class Test 1 **60 min. and 60 marks**

Special Relativity & Intro to Quantum Mechanics

1. A muon is created in the upper atmosphere at a typical altitude of 6 km, due to cosmic ray interactions with the nuclei of atoms in the atmosphere. The velocity of the muon is about $v = 0.995c$. The lifetime of the muon is 2.2 μs. Show the following :

   (a) Non-relativistic analysis leads to the conclusion that very few muons would survive long enough to reach the surface of the earth (sea level). (4)

   (b) In actual fact, experiment shows most of the muons reach the surface of the earth. Explain how this occurs considering the viewpoint of an observer on earth. (5)

   (c) Show that a hypothetical observer travelling with the muon would agree with the earth bound observer. (5)

   (Hint : You will need to use time dilation in the one case, and length contraction in the other, but you must justify your choice, as well as perform the calculation.)

   [14]

2. (a) Sketch the relativistic and the classical expressions for kinetic energy on the same graph and label the graph as completely as you can. (5)

   (b) Show that the classical expression is recovered from the relativistic one at low velocities. (5)

   (c) In an atomic bomb, a uranium nucleus is induced to fission by neutron capture, leading to two fission fragments of roughly equal mass as well as a few neutrons.

   $$n + {}^{235}\mathrm{U} \longrightarrow {}^{A_1}\mathrm{F}_1 + {}^{A_2}\mathrm{F}_2 + 3n$$

   i. Which side of the equation would be lighter, considering this is an exothermic reaction. Explain your answer. (4)

   ii. The mass difference is about 21% of the mass of a nucleon. Calculate the energy release per fission and express the answer in MeV. (6)

   [20]

3. Use the Uncertainty Principle to show that if an electron were confined inside a nucleus of diameter 2×10^{-15}m, it would have to be moving relativistically, whereas a nucleon confined to move in the same nucleus would be moving non- relativistically

   [10]

4. A linear quantum dot can be modelled as a electron in a box. It can be formed by deposting contacts on a slab of GaAs and then applying a bias voltage in such a way as to create a linear confining potential.

   (a) Suppose the observed ground-state electron energy is 0.03 eV. How big is the quantum dot ? (6)

   (b) Find the expectation value $\langle x \rangle$ for the position of the electron. (6)

   (Reminder : $P(x)dx = |\psi(x)|^2 dx$ and $\langle x \rangle = \int xP(x)dx$).

   (c) Show that the ground state energy of a particle in a rectangular linear potential well with infinitely high sides is compatible with Heizenberg's Uncertainty Principal. (4)

[16]

Note : Using $\hbar c = 197$ MeV.fm with 1 fm $= 10^{-15}$m can speed things up.

Total Marks [60]