University of Wisconsin-Madison
Engineering Physics Department
Spring 2010 Qualifying Exams

Modern Physics

You must solve 4 out of the 6 problems.
Start each problem on a new page.

SHOW ALL YOUR WORK.
WRITE ONLY ON THE FRONT PAGES OF THE WORKSHEETS, NOT ON THE EXAM PAGES

Grading is based on both the final answer and work done in reaching your answer. All problems receive an equal number of points.

Clearly indicate which problems you want graded. If you do not indicate which problems are to be graded, the first four solutions you provide will be graded.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____

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Problem 1. (10 pts.) The human body contains on the average about 18 wt% carbon and 0.2 wt% potassium. Assuming all decay products escape the body, compute the intrinsic total activity of the average person from the decays of ^{14}C and ^{40}K in decays per second.

Data:

Average person weighs 75 kg.

^{14}C number fraction of natural C = 10^{-12}
Atomic weight of C = 12.0107
Half-life of ^{14}C = 5730 y

^{40}K number fraction of natural K = 0.000117
Atomic weight of K = 39.0980
Half-life of ^{40}K = 1.28×10^{9} y

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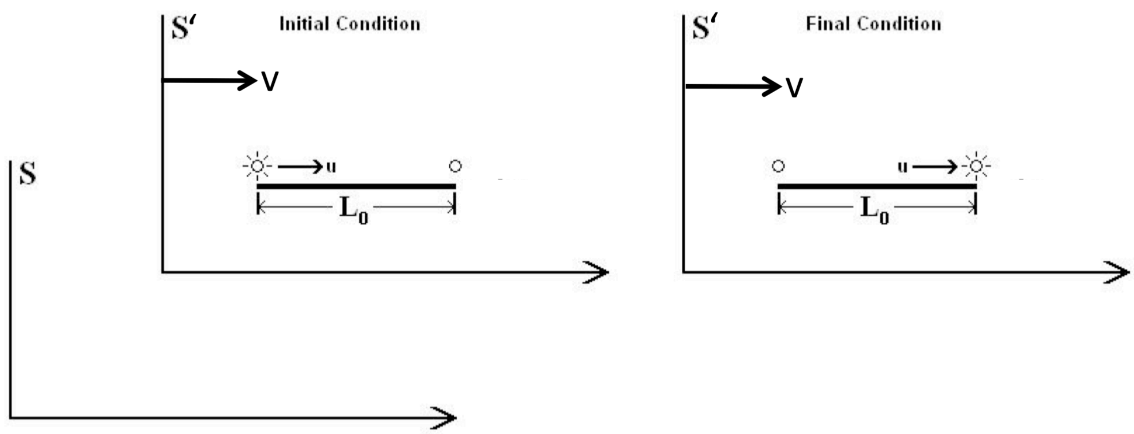
Problem 2. (10 pts.) A rod of proper length L_0 has a small green light at the left end and small red light at the right end. The rod is moving with a velocity v relative to an inertial system S assumed to be at rest. A small projectile is fired at velocity u, relative to the rod, from the position of the green light toward the red light. This causes the green light to flash. When the projectile reaches the red light, the red light flashes. Determine the time interval between these two events (green light flashes and red light flashes) as measured in the inertial frame of reference assumed to be at rest.



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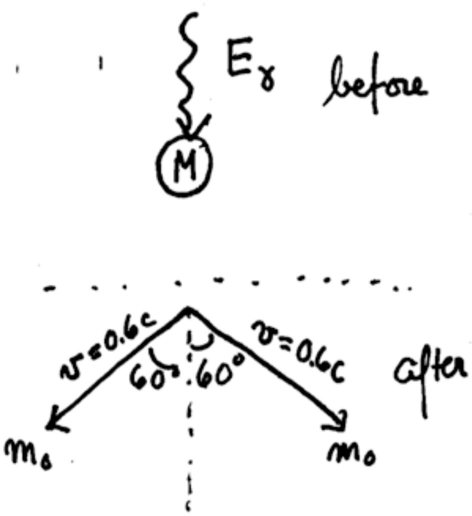
Problem 3. (10 pts.) Cosmic ray photons from space are bombarding your laboratory and smashing massive objects to pieces. For an interaction wherein the gamma is completely absorbed, our detectors indicate that two fragments, each of mass m_0, depart a collision moving at $0.6c$ at 60deg to the photon's original direction of motion.



a) In terms of m_0 and c, what is the energy of the cosmic ray photon?

b) In terms of m_0, what is the mass M of the particle being struck (assumed initially stationary)?

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Problem 4. Consider a particle of mass m trapped in a one-dimensional box (or infinite potential well) of width L. Assume x = 0 at the center of the box.

a) (4 pts) Derive an expression for the wave function for the particle. Be sure your answer is properly normalized and show all details of your calculation.

b) (3 pts) Show that the particle's energy levels are given by $E_n = \frac{n^2\pi^2\hbar^2}{2mL^2}$

c) (3 pts) If the particle is in the first excited state, what is the probability of finding it between x = 0 and x = L/8?

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Problem 5. There are four low-lying levels of $^{13}_{6}C$. The energy and spin-parity of each are:

a) 0 MeV ½- (ground state)
b) 3.09 MeV, ½+
c) 3.68 MeV, $^{3}/_{2}^{-}$
d) 3.85 MeV , $^{5}/_{2}^{+}$

Interpret the four states according to the shell model (shown in figure 5.6 below) to explain the energy and spin-parity of each level.

e) The next states are about 7 MeV and above. Explain how this is consistent with the shell model

(2 points each)

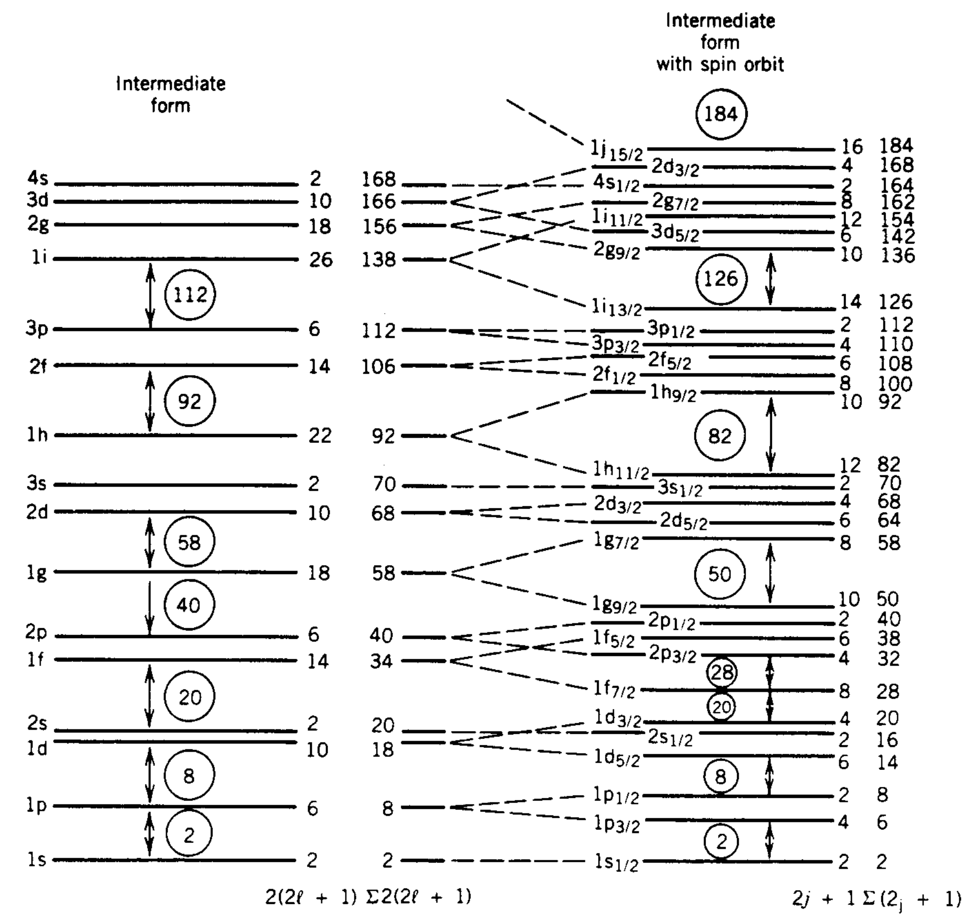

Figure 5.6 At the left are the energy levels calculated with the potential of Figure 5.5. To the right of each level are shown its capacity and the cumulative number of nucleons up to that level. The right side of the figure shows the effect of the spin-orbit interaction, which splits the levels with $\ell > 0$ into two new levels. The shell effect is quite apparent, and the magic numbers are exactly reproduced.

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Problem 6.

In the decay $^{228}Th \rightarrow {}^{224}Ra + \alpha$, the highest energy α particle has an energy 5.423 MeV and the next highest energy is 5.341 MeV. $I\pi$ for the ground state of both nuclei is 0^+. Assume the highest energy decay populates the 224Ra ground state.

a) (4 pts) Compute the Q value for the decay from the measured α energy.

b) (4 pts) Assuming the second α decay populates the first excited state of ^{224}Ra, compute the energy of this excited state.

c) (2 pts) If a gamma decay occurs between the excited state and the ground state with a multipolarity of E2, what I^{π} can we assign to this first excited state?