University of Wisconsin-Madison
Engineering Physics Department
Fall 2009 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.

The radioactive decay of ^{232}Th with $t_{1/2} = 1.41 \times 10^{10}$ y leads eventually to stable ^{208}Pb. A rock is determined to contain 3.65 g of ^{232}Th and 0.75 g of ^{208}Pb. What is the age of the rock, as deduced from the Th/Pb ratio? [Ignore all intermediate decays in the decay chain and assume there is no Pb at t=0].

Data:
Pb atomic weight=207.977 amu;
Th atomic weight=232.038 amu.

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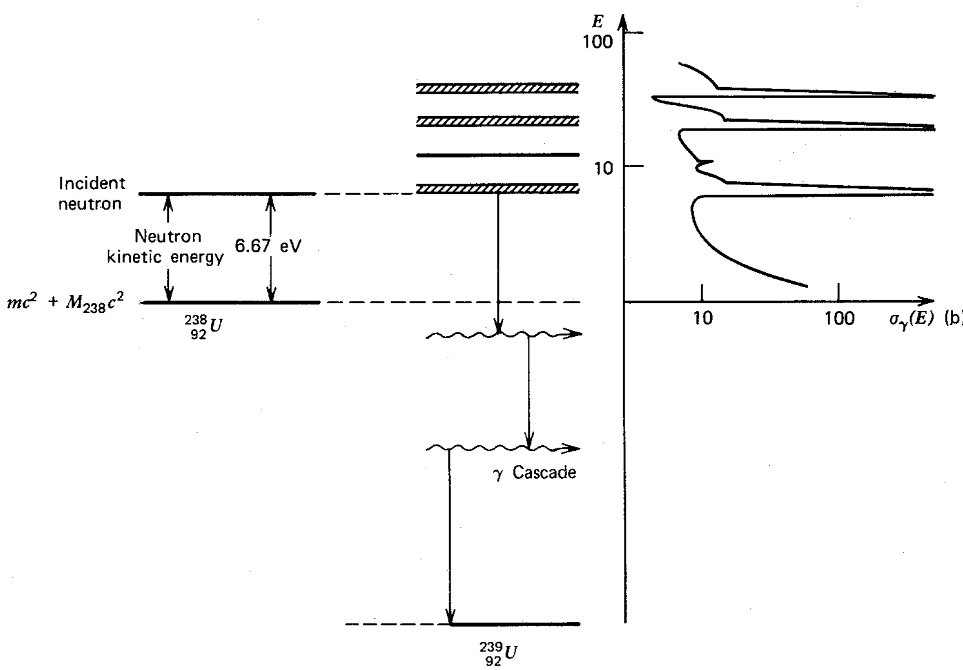
Problem 2.

The figure below shows radiative capture of a neutron by a ^{238}U nucleus. Given the data below, determine the total energy of the emitted gamma rays.



Neutron rest mass = 1.6749544 x 10^{-27} kilograms = 939.5731 MeV/c^2
^{238}U rest mass = 238.0508 amu = 221,744 MeV/c^2
^{239}U rest mass = 239.0543 amu = 222,679 MeV/c^2
1 amu = 1.6605655 x 10^{-27} kilograms = 931.502 MeV/c^2
k = 1.6021892 x 10^{-13} Joule / MeV
c = 2.99792458 x 10^8 m/s

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Problem 3.

A particle of mass m moves in a 1-dimensional square well potential

$$V(x) = \begin{cases} 0 & |x| > a \\ -V_0 & -a < x < a \end{cases}$$

a) [7 points] A plane wave with momentum $\hbar k$ hits the potential well from the left. For certain values of k the wave is perfectly transmitted by the potential. That is, the reflection coefficient vanishes and the transmission coefficient is equal to unity. What are the values of $E = \hbar^2 k^2 / 2m$ for which this occurs?

b) [3 points] The cross section for scattering low energy electrons off xenon atoms exhibits a dip at electron energy of around 0.7 eV. Suppose the xenon atom can be modeled as a 1-D square well potential. Given that the size of the xenon atom is around 0.1 nanometer, what is the minimum depth of the potential V_0?

Useful facts: $\hbar c \approx 2 \times 10^{-5}$ eV $\cdot$ cm and $m_e c^2 \approx 511$ keV

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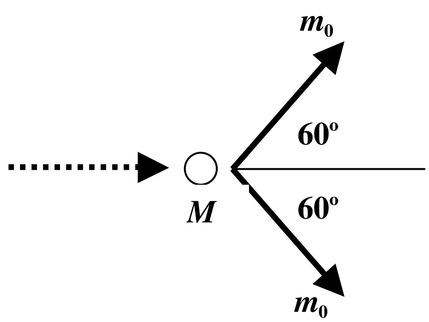
Problem 4.

Cosmic ray photons bombard particles of rest mass M. Your detectors indicate that two fragments, each of mass m_0, depart such a collision moving at speed $0.6c$ at 60^o to the photon's original direction of motion.



a) [5 points] In terms of m_0 and c, what is the energy of the cosmic ray photon?

b) [5 points] In terms of m_0, what is the mass M of the particle being struck?

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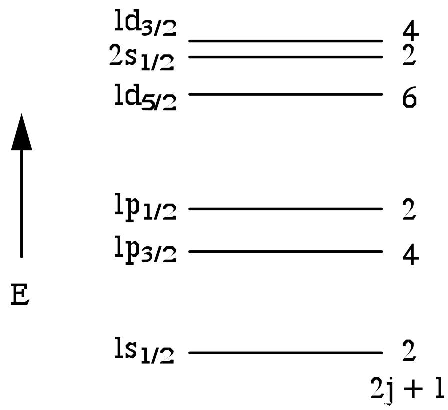
Problem 5.

a) [4 points] Using the nuclear shell model (shown below), give the total angular momentum and parity of the ground states of ^{15}O, ^{16}O, and ^{17}O. (note: $Z_{OX} = 8$)



b) [4 points] Assume a neutron (spin = 1/2) with orbital angular momentum $l = 1$ is absorbed by each of the nuclei in (a). What are the possible values of the total angular momentum I* for each of the resulting compound nuclei?

c) [2 points] What is the parity of the compound nucleus for each case?

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Problem 6.

The reaction $^{13}C(d,p)^{14}C$ (Q = 5.95 MeV) has a resonance at a deuteron energy of 2.45 MeV in the lab frame of reference. Considering the compound nuclei formed, determine at which alpha particle (lab) energy the reaction $^{11}B(\alpha,n)^{14}N$ (Q = 0.15 MeV) may be expected to have a resonance.

Some useful Atomic masses:

$m\left({}^{1}_{1}H\right) = 1.007825$ amu

$m\left({}^{2}_{1}H\right) = 2.014102$ amu

$m\left({}^{4}_{2}He\right) = 4.002603$ amu

$m\left({}^{11}_{5}B\right) = 11.009305$ amu

$m\left({}^{13}_{6}C\right) = 13.003355$ amu

$m\left({}^{14}_{6}C\right) = 14.003242$ amu

$m\left({}^{14}_{7}N\right) = 14.003074$ amu

$m\left({}^{15}_{7}N\right) = 15.000109$ amu

Neutron mass:

$m\left(n\right) = 1.008665$ amu

Mass unit:

1 amu = 931.502 MeV/c^2