University of Wisconsin-Madison
Engineering Physics Department
Spring 2011 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. ______

Student No.________________

Engineering Physics Department
Spring 2011 Qualifying Exams

Problem 1. A sample containing atoms of nuclide N_1 ($^{A}_{Z}X_N$) is placed in a neutron beam with a flux ϕ. The radionuclide N_2 ($^{A'}_{Z'}X_{N'}$) is produced from the (n,p) neutron reaction with a cross section σ_{p1}. Radionuclide N_2 is a beta emitter (β^-) while in the neutron beam, nuclide N_2 can be transmuted through the (n,alpha) reaction with a cross section $\sigma_{\alpha 2}$. The initial concentration of N_1 at $t = 0$ is N_0 and that of N_2 at $t = 0$ is zero.

(a) (1.5pts) What are atomic number *A*', neutron number *N*' and proton number *Z*' for radionuclide N_2 in terms of the *A*, *Z* and *N* of the original nuclide?

(b) (1.5pts) The decay of radionuclide N_2 leads to nuclide N_3 ($^{A''}_{Z''}X_{N''}$). What are *A*'', *N*'', and *Z*'' for this nuclide in terms of the *A*, *Z* and *N* of the original nuclide?

(c) (3pts) Write out the rate equations for radionuclides N_1 and N_2.

(d) (4pts) Assuming that the (n,alpha) reaction rate for N_2 is quite small and can be neglected as a first approximation, develop a general expression for the time-dependent concentrations of the radionuclides N_1 and N_2.

Student No.________________

Engineering Physics Department
Spring 2011 Qualifying Exams

Problem 2. K+ mesons (positive kaons) decay into other particles, particularly pions. Their proper mean lifetime (i.e. the average time they exist before decaying) is $\tau_0 = 1.24 \times 10^{-8}$ sec and their rest energy is 494 MeV. Suppose a beam of kaons is created in an accelerator laboratory with velocity $\mathbf{v} = 0.9c$

a) (2pts) What is the energy of the kaons in the laboratory?
b) (2pts) What will the kaon's mean lifetime be in the laboratory? Is it longer or shorter than τ_0?
c) (2pts) How far will the kaon travel (on the average) in the laboratory's frame of reference?
d) (2pts) Suppose the kaon beam is directed at another kaon beam with the same speed but moving in the opposite direction, so that a head on collision occurs as determined in the laboratory. What is the speed of the second kaon beam as determined in a frame of reference moving along with the first kaon beam?

e) (2pts) What is the total energy of a colliding pair of kaons, one from each beam, as measured in the laboratory?

Student No.________________

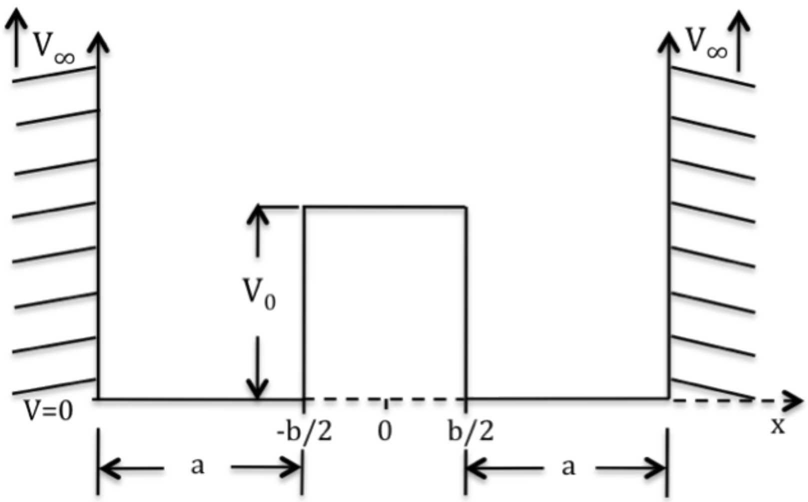
Engineering Physics Department
Spring 2011 Qualifying Exams

Problem 3. Write down the Semi-empirical Mass Formula for nuclei, and qualitatively describe the origin of each term in the formula for the binding energy per nucleon. Give a simple physical argument for the functional dependence of each of the terms on A (mass number) and Z (charge).

Student No.________________

Engineering Physics Department
Spring 2011 Qualifying Exams

Problem 4. A particle of mass *m* is subject to the potential distribution shown in the figure below. Consider the case when the energy of the particle is less than V_0.



(a) (2pts) Draw qualitatively the wavefunctions of the first two energy eigenvalues for the potential in the figure.

(b) (1pt) In the limit when $V_0 \to \infty$, is the ground state eigenvalue larger or smaller than in part (a)?

(c) (2pts) What are the general solutions to the wavefunctions in the various regions?

(d) (5pts) Determine the relations (expressions) required to find the lowest-energy and the next lowest-energy solution.

Student No.________________

Engineering Physics Department
Spring 2011 Qualifying Exams

Problem 5. (a) (8pts) Determine the neutron energy needed to produce neutron-induced fission of the following nuclei (neglect recoil): (i) ${}^{241}_{95}\mathrm{Am}$ and (ii) ${}^{242}_{95}\mathrm{Am}$.

Mass [amu] where 1 amu = 931.502 MeV/c^2	E_a [MeV] (for the A+1 nucleus) where E_a = activation energy
$M({}^{241}_{95}\mathrm{Am}) = 241.056824$	6.5
$M({}^{242}_{95}\mathrm{Am}) = 242.059542$	6.2
$M({}^{1}_{0}\mathrm{n}) = 1.008665$	---
$M({}^{243}_{95}\mathrm{Am}) = 243.061375$	---

(b) (2pts) Briefly explain the physical origin of the difference in fissile potential of ${}^{241}_{95}\mathrm{Am}$ and ${}^{242}_{95}\mathrm{Am}$.

Student No.________________

Engineering Physics Department
Spring 2011 Qualifying Exams

Problem 6. A proton is incident on ${}^{7}_{3}\mathrm{Li}$ which undergoes a (p,n) reaction.
(a) (2pts) Compute the *Q*-value of the reaction.
(b) (8pts) Develop an expression for the threshold energy for the reaction using the basic momentum and energy conservation laws (recall, at threshold, the product particles have equal speed and move in the same direction as the incoming particle).

Mass [amu] (where1 amu = 931.502 MeV/c^2)	Mass [amu]
$M({}^{1}_{1}\mathrm{H}) = 1.007825$	$M({}^{1}_{0}\mathrm{n}) = 1.008665$
$M({}^{7}_{3}\mathrm{Li}) = 7.016003$	$M({}^{7}_{2}\mathrm{He}) = 7.02803$
$M({}^{7}_{4}\mathrm{Be}) = 7.016928$	$M({}^{8}_{4}\mathrm{Be}) = 8.005305$