University of Wisconsin-Madison
Engineering Physics Department
Spring 2015 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. Suppose the vacuum vessel of a fusion device is made of pure ${}^{56}_{26}Fe$ and the vessel is exposed to a high-energy neutron flux of $\phi_0 = 1.0 \times 10^{12}$ neutrons/cm^2-s. The following high-energy reaction occurs as the neutrons interact with the iron: ${}^{56}_{26}Fe(n,p)\,{}^{A}_{Z}Mn$. The manganese in turn decays by β^- emission with a half-life of $t_{1/2} = 2.6$ hours.

(a). (1 pts) Determine the specific resultant product nuclides (isotopes) from the (n,p) and β^- decay reactions.

(b). (2 pts) Determine the rate equations for the nuclides involved.

(c). (5 pts) Solve for the time-dependence of the iron and manganese isotopes.

(d). (2 pts) Find the limit of the nuclide concentrations as $t \to \infty$.

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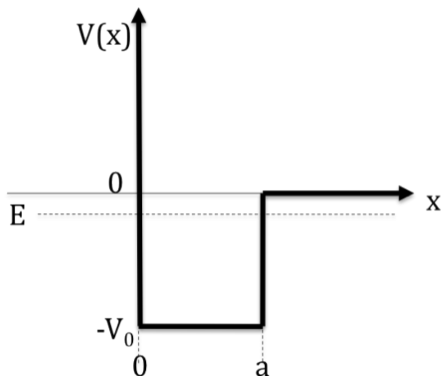
Problem 2. A particle with total energy E is bound in the one-dimensional potential well:



$$V(x) = \begin{cases} +\infty & x < 0 \\ -V_0 & \text{for: } 0 < x \le a \\ 0 & x > a \end{cases}$$

(a). (7 pts) Derive a relationship for the allowed values of the energy E.
(b). (3 pts) What is the minimum potential well depth V_0 required to have a bound state?

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Problem 3. A photon of energy E_γ Compton scatters, and the scattered photon induces pair production.
(a). (7 pts) For the case of $E_\gamma = 10\, m_e c^2$ and using the basic momentum and energy conservation equations, determine the photon scattering angle θ for the case where the scattered photon's energy is equal to the threshold energy to induce pair production.
(b). (3 pts) What is the scattering angle θ for the limiting case of $E_\gamma >> m_e c^2$?

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Problem 4.
(a). (2 pts) Write down the Semi-empirical Mass Formula for nuclei.

(b). (4 pts) Qualitatively describe the physical meaning of each term in the formula for the binding energy per nucleon.

(c). (4 pts) Give a simple physical argument for the functional dependence of each of the terms on A (mass number) and Z (charge).

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Problem 5. A gas comprised of particles with mass *m* at thermodynamic equilibrium with temperature *T* has a velocity distribution given by the Maxwell velocity distribution:

$$f(\vec{v})d^3\vec{v} = n\left(\frac{m}{2\pi kT}\right)^{3/2} e^{-mv^2/2kT} d^3\vec{v}$$

where *k* is the Boltzmann constant.

(a). (6 pts) Derive an expression for the energy distribution of the particles.
(b). (4 pts) Calculate the average energy of the particles.

Useful integrals:

$$I(n) = \int_0^\infty e^{-\alpha x}\, x^n\, dx = \frac{\Gamma(n+1)}{a^{n+1}} \quad \text{where } n \geq 0.$$

$$\Gamma(\tfrac{1}{2}) = \sqrt{\pi} \qquad \Gamma(n+1) = n\Gamma(n)$$

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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 (lab frame) of 2.45 MeV. From this, determine at which alpha energy (lab frame) the reaction $^{11}B(\alpha,n)^{14}N$ (Q = 0.15 MeV) may be expected to have a resonance. (Hint: consider the compound nucleus formed in each case.)

Mass [amu] (where1 amu = 931.502 MeV/c^2)	Mass [amu]
$M({}^{1}_{1}H) = 1.007825$	$M({}^{1}_{0}n) = 1.008665$
$M({}^{2}_{1}H) = 2.014102$	$M({}^{4}_{2}He) = 4.002603$
$M({}^{13}_{6}C) = 13.003355$	$M({}^{14}_{6}C) = 14.003242$
$M({}^{11}_{5}B) = 11.009305$	$M({}^{14}_{7}N) = 14.003074$
$M({}^{15}_{7}N) = 15.000109$	---