University of Wisconsin-Madison
Engineering Physics Department
Fall 2007 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.

A 6.67 eV neutron is radiatively captured 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 2.

A gamma ray with wavelength λ_i scatters from a free electron at rest and emerges with a wavelength λ_f in a new direction at an angle θ measured relative to its initial direction. Derive a formula for the wavelength of the scattered gamma ray expressed as a function of its initial wavelength and the scattering angle θ.

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Problem 3.

An initially pure 10 mC sample of ^{227}Th with a half-life of 18.2 days alpha decays into ^{223}Ra. ^{223}Ra in turn has an alpha decay half-life of 11.7 days.

a) (5 points) At what time is the activity of the ^{223}Ra at a maximum?
b) (5 points) What is the maximum activity of the ^{223}Ra?

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Problem 4.

Consider a particle in a one-dimensional infinite square well of length L that is centered at the origin x=0.

a) (3 points) What are the values of the normalized eigenfunctions of the two lowest energy states ($\psi_1(0)$ and $\psi_2(0)$) evaluated at x=0?
b) (3 points) What are the values of $\langle x \rangle$ for states n=1 and n=2?
c) (4 points) What are the values of $\langle x^2 \rangle$ for the states n=1 and n=2?

Some potentially useful integrals.

$$\int x\sin(x)dx = \sin(x) - x\cos(x)$$

$$\int x\sin^2(x)dx = \frac{x^2}{4} - \frac{x}{4}\sin(2x) - \frac{1}{8}\cos(2x)$$

$$\int x^2\sin^2(x)dx = \frac{x^3}{6} - \frac{x}{4}\cos(2x) - \frac{1}{4}\left(x^2 - \frac{1}{2}\right)\sin(2x)$$

$$\int x\cos(x)dx = \cos(x) + x\sin(x)$$

$$\int x\cos^2(x)dx = \frac{x^2}{4} + \frac{x}{4}\sin(2x) + \frac{1}{8}\cos(2x)$$

$$\int x^2\cos^2(x)dx = \frac{x^3}{6} + \frac{x}{4}\cos(2x) + \frac{1}{4}\left(x^2 - \frac{1}{2}\right)\sin(2x)$$

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Problem 5.

An interstellar spaceship travels from the earth to a distant star system 12 light-years away (as measured in the earth's frame). The trip takes 15 y as measured on the spaceship.

a) (5 points) What is the speed of the spaceship relative to the earth?
b) (5 points) When the ship arrives at the star, it sends a signal to the earth. How long after the ship leaves the earth will it be before the earth receives the signal?

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Problem 6.

Explain each of the following in words, diagrams and formulas.

a) (2 points) Pauli Exclusion Principle
b) (2 points) Fermi's Golden Rule
c) (2 points) Differential scattering cross section
d) (2 points) The physical possibility of a γ transition between a 0- ground state and a 3/2+ first excited state
e) (2 points) The physical possibility of a decay from a 1- to a 0- level.