University of Wisconsin-Madison
Engineering Physics Department
Spring 2013 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. An electron of mass m is subject to a constant force F.
(a) (5 pts) What is its velocity as a function of time if the electron is initially at rest? Assume the electron reaches a relativistic speed.
(b) (5 pts) Show that for short times the speed is in agreement with the classical nonrelativistic values.

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Problem 2. A gas comprised of particles with mass at thermodynamic equilibrium with temperature T has a velocity distribution given by the Maxwell velocity distribution:

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

where k is the Boltzmann constant.

(a) (5 pts) From this, derive an expression for the mean speed of the particles.
(b) (5 pts) Consider the gas contained in a box with a small hole of area A on one side of the box. Calculate the net flux of particles out of the hole and express it in terms of the mean speed derived in (a).

Useful integrals:

$$I(n) = \int_0^\infty e^{-\alpha x^2} x^n \, dx \quad \text{where } n \geq 0.$$

$$I(0) = \frac{1}{2}\sqrt{\pi}\alpha^{-1/2} \qquad I(1) = \frac{1}{2}\alpha^{-1} \qquad I(2) = \frac{1}{4}\sqrt{\pi}\alpha^{-3/2} \qquad I(3) = \frac{1}{2}\alpha^{-2}$$

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Problem 3. Consider the inelastic scattering of an energetic neutron with kinetic energy E with a stationary nuclide target of mass A where $A > 1$ in the laboratory reference frame. Assume the nuclide is excited to an energy level ε_1.

a) (7.5 pts) Derive, using conservation of mass, energy and momentum laws, the final energy of the neutron, E', after the scattering event in terms of the scattering angle ϑ relative to the incoming direction of the incident neutron. (Assume $m_n = 1$ and $m_A = A$).

b) (2.5 pts) Determine the angle at which the neutron loses the maximum amount of energy. What is the final energy of the neutron at this angle?

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Problem 4. It is desired to study the low-lying excited states of ${}^{35}_{17}\mathrm{Cl}\left({}^{+}\tfrac{3}{2}\right)$ through the reaction ${}^{32}_{16}\mathrm{S}(\alpha,p)\,{}^{35}_{17}\mathrm{Cl}$. The low-lying states are $1.219\left({}^{+}\tfrac{1}{2}\right)$, $1.763\left({}^{+}\tfrac{5}{2}\right)$, $2.646\left({}^{+}\tfrac{7}{2}\right)$, $2.694\left({}^{+}\tfrac{3}{2}\right)$, and $3.003\left({}^{+}\tfrac{5}{2}\right)$ MeV above the ground state.

(a) (7 pts) If the incident α particle has 4.90 MeV of kinetic energy, which of the excited states can be reached?

(b) (3 pts) These states decay by gamma emission, indicate the primary type and multipole of the emitted radiation associated with transitions to the ground state (G.S.). (Note, the level parity and spin are provided in the parenthesis following the level energy).

Mass	Mass
M(${}^{1}_{1}$H) = 1.007825 amu	M(${}^{4}_{2}$He) = 4.002603 amu
M(${}^{35}_{17}$Cl) = 34.968853 amu	M(${}^{32}_{16}$S) = 31.972071 amu

1 amu = 931.5 MeV

$$T_{th} = (-Q)\left(\frac{m_Y + m_b}{m_Y + m_b - m_a}\right)$$

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Problem 5.
A particle of energy E is confined within the following potential well

$$V(x) = \begin{cases} +\infty & x \le 0 \\ 0 & 0 < x < a \\ +V_0 & x \ge a \end{cases} .$$

Derive an implicit equation for the energy E of the particle.

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Problem 6. A radioactive isotope used in a medical procedure is produced by irradiating a sample in a nuclear reactor. The reaction scheme for this irradiation is

$$ {}^{A}_{Z}X_{N} + n \rightarrow {}^{A+1}_{Z}X^{*}_{N+1} \rightarrow {}^{A}_{Z-1}X_{N+1} + p + \gamma . $$

There is no place to store the radioactive material once it has been produced and it requires 90 minutes to deliver the material from the reactor facility to the room where the medical procedure will take place.

a) (8 pts) If the procedure requires 15 mCi of material delivered at 2:30 PM, when should the reactor staff start irradiating the sample?

b) (2 pts) How many atoms of radioactive material are produced during irradiation?

Sample mass	= 1 gram
Atomic weight	= 5 grams/mole
Reaction cross section	= 10 barns
Product half-life	= 2.5 hours
Beam intensity	= 1.5 x 10^{9} neutrons/cm^{2} –s

1 Ci = 3.7 x 10^{10} dis/sec, 1 barn = 10^{-24} cm^{2}, N_{Av}= 6.023 x 10^{23} atoms/mole