University of Wisconsin-Madison
Engineering Physics Department
Fall 2010 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 isotope ^{233}Pa ($t_{1/2}$ =27.0 days) can be produced following neutron capture by ^{232}Th. The resulting ^{233}Th decays to ^{233}Pa with a half-life of 22.3 minutes. A fresh one gram sample of ^{232}Th is placed in a reactor and ^{233}Th is produced at a rate of $2.0 \times 10^{11}\ s^{-1}$.

a) (4pts) At the end of a one hour irradiation period, what are the resulting activities of ^{233}Th and ^{233}Pa?

b) (4pts) Irradiation of the sample is stopped after one hour. What are the activities of ^{233}Th and ^{233}Pa after a 24-hour storage period?

c) (2pts) The ^{233}Pa decay results in ^{233}U, which is radioactive with a half-life of 1.6×10^{5} years. After the sample has been stored for 2 years, what is the ^{233}U activity? (you do not need to setup and solve a differential equation for this).

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Problem 2. A deuterium target is bombarded with a beam of photons in order to produce neutrons by the $^{2}\text{H}(\gamma,n)\,^{1}\text{H}$ reaction. The rest mass energies (in MeV) of the reactants and products are $m(\text{H})c^2 = 938.7890$, $m(\text{n})c^2 = 939.5714$, and $m(\text{D})c^2 = 1876.1360$.

Compute the energy of the neutrons emitted at an angle of 45 degrees when the incoming gamma photon has an energy of 2.75 MeV.

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Problem 3.

a).(4pts) Sketch the Zeeman Effect using an energy level diagram that shows the expected splitting of a $2p$ and $1s$ state in the presence of an external magnetic field. **<u>Ignore spin.</u>**

b). (3pts) What are the selection rules for transitions governing the l and m_l quantum numbers?

c). (3pts) Indicate the energies of all allowed transitions from each of the m_l states of the $2p$ level to the $1s$ level.

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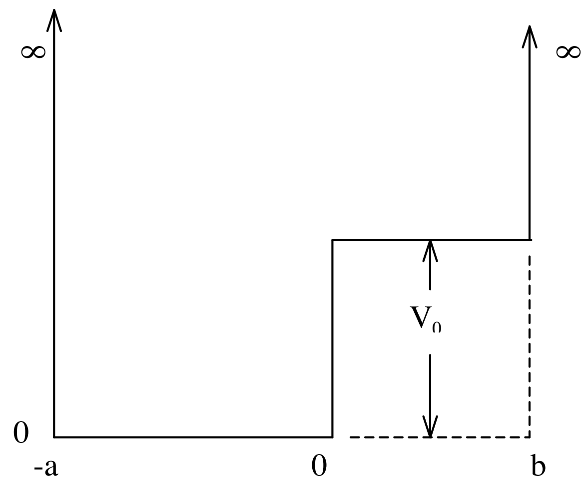
Problem 4. A particle of mass *m* moves in a 1-dimensional potential well described by

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

The well is shown on the right.



a). (2pts) What are the boundary and interface conditions for this problem?
b). (4pts) Derive an expression from which one can determine the allowable energy levels of the particles in this well for $E>V_0$.
c). (2pts) What is the probability density in the region $0<x<b$?
d). (2pts) How would the wave solution in the region $0<x<b$ change if the particle has an energy less than the potential height V_0? (just words, no calculations)

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Problem 5.
Consider the emittance of light or electromagnetic wave in a vacuum where the source is moving towards a receiver with a velocity v.

Derive the relativistic Doppler Effect equation for this case.

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Problem 6. ${}^{20}_{11}\mathrm{Na}({}^{+}2)$ decays to an excited state of ${}^{20}_{10}\mathrm{Ne}$ through the emission of positrons of maximum kinetic energy 5.55 MeV. The excited state of ${}^{20}_{10}\mathrm{Ne}$ decays by α emission to the ground state of ${}^{16}_{8}\mathrm{O}$.

(a). (2pt) Sketch the energy level diagram (scheme) for this series of decays.

(b). (6pt) Compute the energy of the emitted α.

(c). (2pt) What is the degree of forbiddenness if the positrons decay to the ${}^{+}2$ excited state of ${}^{20}_{10}\mathrm{Ne}$?

Mass	Mass
$M({}^{4}_{2}\mathrm{He}) = 4.002603$ amu	$M({}^{20}_{11}\mathrm{Na}) = 20.007344$ amu
$M({}^{20}_{10}\mathrm{Ne}) = 19.992436$ amu	$M({}^{16}_{8}\mathrm{O}) = 15.994915$ amu