22.02 – Introduction to Applied Nuclear Physics

Problem set # 3

Issued on Sunday March 4st, 2012. Due on Monday March 12, 2018

Problem 1: Proton tunneling

A proton of energy 15 MeV is incident on a square barrier of height $V_H = 30$ MeV and width $L = 10$ fm. Calculate the tunneling probability for the proton to penetrate the barrier in two ways:

a) First, make a simple estimate using only the approximate tunneling probability, $P_{\text{tun}} \simeq 4\exp(-2\kappa L)$.

b) Second, use the exact formula

$$T^{-1} = 1 + \frac{1}{4}\frac{V_H^2}{E(V_H - E)}\sinh^2(\kappa L), \qquad E < V_H$$

and compare with the previous result.

c) What is the condition for the approximate formula to be valid? Is it satisf ed here?
Show that in the limit when $\kappa L \gg 1$ the exact formula for $E = V_H/2$ reduces to the approximate formula.

d) Discuss in qualitative terms how the tunneling probability varies if $E \neq V_H/2$ (but still $E < V_H$).

Problem 2: Neutron Scattering

a) Consider a beam of neutrons scattering from an inf nite barrier with $V_H = 2E$ and compute the position x where the neutron f ux in region II is $1/4$ of the incident beam f ux.
[Assume the neutrons are coming from the left and $V = 0$ for $x < 0$ (Region I) and $V = V_H$ for $x > 0$ (region II)]

b) Compute the distance x found above for a beam of neutrons with rest mass $m_p c^2 = 939\ MeV$ and kinetic energy $E = 10\ MeV$.

Problem 3: Alternative decay modes

Consider the isotope Ra-224, which is an alpha-emitters with half-life $t_{1/2} = 3.66$days.
Is the decay ^{224}Ra$\rightarrow$^{210}Pb+^{14}C a competitive decay mode to alpha decay?

a) Answer this question by considering only the energy involved in the nuclear reactions.

b) Now answer the same question by estimating and comparing the half-lives

c) What is the experimentally reported branching ratio? (i.e. the relative probability of alpha and ^{14}C decay?) You can f nd this information on http://www.nndc.bnl.gov/chart/.

Problem 4: Q-values for alpha-decay

From the known atomic masses, f nd the Q-value and the kinetic energies and velocities of the decay products for the following alpha decays:

a) ^{211}Po $\rightarrow$ ^{A}X + α.

b) ^{210}Po$\rightarrow$ ^{A}X + α.

Problem 5: Atomic mass of unstable nuclides

The mass of some nuclides is diff cult to measure if their half-lives are too short. Studying their alpha decay allows to calculate the masses.

Consider Attinium-213. It decays into the stable Bi-209 with a half-life of $t_{1/2} = 125$ns. The kinetic energy of the emitted alpha particles is 9080keV. Calculate the atomic mass of At-213.

22.02 Introduction to Applied Nuclear Physics
Spring 2012