PHY2005 – Nuclear Physics – Assignment 2

March 2022

Attempt all questions.
The assignment will be marked out of 100.

Q1 $^{212}_{84}Po$ is an isotope of polonium undergoing alpha decay with a half-life ($t_{1/2}$) of 0.3 microseconds. The kinetic energy of the emitted alpha-particle is 8.78 MeV. Assuming the initial nucleus (X) to be at rest, calculate:

(a) The Q-value of such spontaneous nuclear reaction. **[5]**

(b) The kinetic energy of the final nucleus (X'). **[5]**

(c) The number of undecayed nuclei after 100 nanoseconds if 1000 alpha-particles are detected at $t = t_{1/2}$). **[5]**

Clearly show all working for your calculations.

Q2

(a) Derive an expression which would allow to calculate the Q-value for β^+ decay by knowing the atomic masses of the initial and final nuclei involved in such a spontaneous nuclear reaction. **[10]**

[Hint: the electron mass should also appear in such formula for an accurate estimation of Q]

(b) The ^2He nucleus (also known as *diproton*) is an extremely unstable isotope of helium. The diproton is an intermediate nucleus formed in the first step of the proton-proton cycle in the core of the Sun:

$$^1_1H + ^1_1H \rightarrow \, ^2_2He \qquad (1)$$

$$^2_2He \rightarrow \, ^2_1H + e^+ + \nu \qquad (2)$$

Calculate the Q-values for both reactions. Are these reactions spontaneous? What is the overall energy gain for (1) + (2) ? **[15]**

Q3 A nucleus of ^{235}U at rest captures a fast neutron moving with a velocity of $4.4 \cdot 10^6$ m/s to form the compound state $^{236}U^*$.

(a) Calculate the excitation energy of this compound state. **[15]**

(b) State if ^{235}U undergoes nuclear fission and comment on the probability of such nuclear reaction to occur in comparison to the capture of a thermal electron. **[10]**

[$m(^{235}U) = 235.043934$ u; $m(^{236}U) = 236.045563$ u; $m(n) = 1.008665$ u, $E_{act}(^{236}U) = 6.2$ MeV]

Q4 A thermonuclear fusion reactor contains a plasma (fuel) having a temperature of 8 keV and a density of 10^{15} ions/cm^3.

(a) State if the condition to sustain thermonuclear fusion is fulfilled (i.e. power gain higher than radiation losses) in the case of:

(i) DT fusion with a power output of 8 MW/m^3

(ii) DD fusion with a power output of 0.2 MW/m^3. **[15]**

(b) In the case(s) of sustainable thermonuclear fusion, estimate the minimum confinement time needed to achieve a net power gain. **[5]**

[$P_{br}(W/m^3) = 0.5 \cdot 10^{-36} Z^2 n_i n_e (kT)^{1/2}$, where kT is in keV]

[Hint: assume a thermal equilibrium for all plasma particles (ions and electrons) and $n_i = n_e$]

Q5 Using your own words, briefly explain the main differences in the interaction of energetic ions and electrons with matter. **[15]**