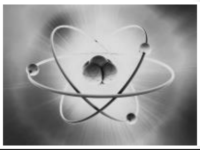


Series of Exercises - 03

Chapter 03 and 04: Nuclear Reactions and Nuclear Energy

Useful data: $1uc^2 = 931.5[MeV]$; $m_p = 1.0078u$; $m_n = 1.0087u$; $m_\alpha = 4.00260u$

Exercise 01:

A neutron passing through a body of matter and not absorbed in a nuclear reaction undergoes frequent elastic collisions in which some of its kinetic energy is given up to nuclei in its path. Very soon the neutron reaches thermal equilibrium. At room temperature such a thermal neutron has an average energy around $0.04eV$ and a most probable energy of $k_BT = 0.025\,eV$; the latter value is usually quoted as the energy of thermal neutrons.

The cross section of ^{113}Cd (12% *of natural* Cd) for capturing thermal neutrons is $2 \times 10^4[b]$, the mean atomic mass of natural cadmium is $112u$, and its density is $8.64[g.cm^{-3}]$.

(a) What fraction of an incident beam of thermal neutrons is absorbed by a cadmium sheet of $0.1\ mm$ thick?

(b) What thickness of cadmium is needed to absorb 99% of an incident beam of thermal neutrons?

(c) Find the mean free path of thermal neutrons in this case.

Exercise 02:

Natural gold consists entirely of the isotope $^{197}_{79}Au$ whose cross section for thermal neutron capture is $99\ [b]$. When $^{197}_{79}Au$ absorbs a neutron, the product is $^{198}_{79}Au$ which is beta-radioactive with a half-life of $2.69\ days$. How long should a 10.0-mg gold foil be exposed to a flux of $2 \times 10^{16}\left[\frac{n}{m^2.s}\right]$ in order for the sample to have an activity of $200\ \mu Ci$?

Assume that the irradiation period is much shorter than the half-life of $^{198}_{79}Au$ so the decays that occur during the irradiation can be neglected.

Exercise 03:

Determine the unknown particle X in the following reactions:

(a) $^{18}_{8}O(d,p)X$, (b) $X(p,\alpha)^{87}_{39}Y$, (c) $^{122}_{52}Te(X,d)^{124}_{53}I$

Exercise 04:

Determine the compound nucleus and some of the possible reaction products when $\alpha - particles$ are incident on $^{19}_{9}F$.

Exercise 05:

An incident neutron beam is bombarding hypothetical scattering target of a density $n = 10.6[g/cm^3]$ made from an isotope of number mass $A = 200$ with a total scattering cross-section $\sigma_S = 1.1[b]$.

If only $10^{-3}\%$ of the incoming neutrons are scattered, find the thickness of the target.

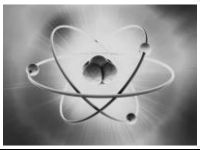
Exercise 06:

As observed in the laboratory system, a $6MeV$ proton is incident on a stationary $^{12}_{6}C$ target. Find the velocity of the center-of-mass system. Take the mass of the proton to be 1u.

Exercise 07:

Find the minimum kinetic energy in the laboratory system needed by an alpha particle to cause the reaction $^{14}N(\alpha,p)^{17}O$.

The masses of ^{14}N, ^{4}He, ^{1}H, and ^{17}O are respectively $14.00307, 4.00260, 1.00783,$ and $16.99913\ u$.



Exercise 08:

When ${}^{6}_{3}Li$ is bombarded with $4MeV$ deuterons, one reaction that is observed is the formation of two $\alpha - particles$, each of $13.2MeV$ of energy. Find the Q-value of this reaction.

Exercise 09:

Calculate the Q-values for the reactions:

(a) ${}^{16}_{8}O(\gamma,p){}^{15}_{7}N$, (b) ${}^{150}_{62}Sm(p,\alpha){}^{147}_{61}Pm$

$M(8,16) = 15.994915; M(7,15) = 15.000108$

$M(62,150) = 149.917276; M(61,147) = 146.915108$

Exercise 10:

Using the following data, find the Q-value for the reaction ${}^{192}_{76}Os(d,t){}^{191}_{76}Os$.

$\boldsymbol{\Delta M(76,192) = -0.038550u, \Delta M(76,191) = -0.039030u}$

$\boldsymbol{\Delta M(1,2) = +0.014102u, \Delta M(1,3) = +0.016050u}$

Exercise 11:

Determine the total final kinetic energy in the photofission of ${}^{235}_{92}U$ by a 6 MeV $\gamma - ray$ into ${}^{90}_{36}Kr$ and ${}^{142}_{56}Ba$, and three neutrons.

Exercise 12:

About 185 MeV of usable energy is released in the neutron-induced fission of ${}^{235}_{92}U$. If the ${}^{235}_{92}U$ in a reactor is continuously generating 100MW of power, how long it will take for 1kg of the uranium to be used up?

Exercise 13:

One of the induced-fission channels of the ${}^{235}_{92}U$ is the following:

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow [{}^{236}_{92}U]^* \rightarrow {}^{143}_{56}Ba + {}^{90}_{36}Kr + 3{}^{1}_{0}n$$

1. Calculate the energy released from this fission reaction.
2. Estimate the Coulomb energy of repulsion for both fission products (${}^{143}_{56}Ba$, ${}^{90}_{36}Kr$) just after they are formed. (we can assume two touching spherical nuclei)

Exercise 14:

Given: $k_B = 8.6173303 \times 10^{-5}[eV/K]$ (The Boltzmann constant), find the energy of a thermal neutron at room temperature $T = 300K$. The thermal energy of a particle is given by: $E_{th} = k_B T$.

Exercise 15:

On the average, neutrons lose half their energy per collision with quasi-free protons. How many collisions, on the average, are required to reduce 2 MeV neutron to a thermal energy of 0.04 eV?

Exercise 16:

1. Estimate the temperature required to produce fusion in a deuterium plasma (a neutral mixture of negatively charged electrons and positively charged deuterium nuclei), assuming a Coulomb repulsion to overcome with an inter-distance of $2fm$ between two nuclei just before fusioning.
2. What will be the energy released if two deuterium nuclei fuse into an $\alpha - particle$.

Exercise 17:

If we know that D-T fusion reaction produce an energy given by $Q = 17.6MeV$, calculate the rate at which deuterium and tritium are consumed to produce an output power of 1MW.

Exercise 18:

1. Calculate the total energy released in the following carbon (Bethe) cycle:

$$p + {}^{12}_{6}\mathrm{C} \rightarrow {}^{13}_{7}\mathrm{N}$$
$${}^{13}_{7}\mathrm{N} \rightarrow {}^{13}_{6}\mathrm{C} + e^+ + \nu$$
$$p + {}^{13}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N}$$
$$p + {}^{14}_{7}\mathrm{N} \rightarrow {}^{15}_{8}\mathrm{O}$$
$${}^{15}_{8}\mathrm{O} \rightarrow {}^{15}_{7}\mathrm{N} + e^+\nu$$
$$p + {}^{15}_{7}\mathrm{N} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He}$$

2. Determine the released energy per 1kg of Hydrogen consumed in that cycle.

3. If we know that is estimated that the carbon cycle in the sun releases about $4 \times 10^{26}W$ of power, determine the rate at which hydrogen is consumed.