1.3 What fraction of the original mass in d-t fusion is actually converted into energy? Compare this to the case of nuclear fission, Eq.(1.3).

Solution)

핵분열 반응: $n+{}^{235}U \rightarrow \nu n+\sum P_i$ E=200 MeV

핵융합 반응: $d+t \rightarrow \alpha + n$ E=17.6 MeV

Origin mass에 대한 Fraction.

- ${}^{235}U$ Fission

$$\frac{\mathrm{E}}{[(\text{mass of } {}^{235}U)+(\text{mass of n})]\times[\text{converting factor from mass to E}]}$$
$$=\frac{200}{(235+1)\times 931.49}\left[\frac{\mathrm{MeV}}{\mathrm{u}\times(\mathrm{MeV/u})}\right]$$
$$=0.091$$

- d-t Fusion

$$\frac{\mathrm{E}}{[(\text{mass of d})+(\text{mass of t})]\times[\text{converting factor from mass to E}]}$$
$$=\frac{17.6}{(2+3)\times 931.49}\left[\frac{\mathrm{MeV}}{\mathrm{u}\times(\mathrm{MeV/u})}\right]$$
$$=0.378$$

따라서, 핵융합 반응이 핵분열 반응에 비해 네 배 더 크다.

1.8 The first artificial nuclear transmutation without the use of radioactive substances was successfully carried out in the Rutherford Laboratory by Cockcroft and Walton when they bombarded Lithium (at rest) with 100 keV proton canal rays (protons accelerated by a voltage of 100 kV and passing through a hole in the cathode). By scintillations in a Zincblende-screen, the appearance of α-particles with a kinetic energy of 8.6 MeV was determined.

(a) Formulate the law of energy conservation valid for the above experiment referring to the nuclear reaction

$$^{7}_{3}Li + ^{1}_{1}H \rightarrow 2\,^{4}_{2}He$$

and find therefrom the reaction energy, Q_{p7Li}, via the involved rest masses ($m_p, m_\alpha = 6.64455\times10^{-27}$ kg, $m_{7Li} = 11.64743\times10^{-27}$ kg).

Solution)

- 반응 전 후의 질량 변화

$$\begin{aligned} Q_{ab} &= -[(m_d + m_e) - (m_a + m_b)]c^2 \\ &= -[2m_\alpha - (m_{Li} + m_p)]c^2 \\ &= -[2\times6.64455\times10^{-27} - (11.64743\times10^{-27} + 6.64455\times10^{-27})]c^2 \\ &= 1.73\times10^4 \text{ keV} \end{aligned}$$

- 입자의 운동에너지의 변화

$$2E_{ke}\left(He\right) - 100 \text{ keV} = 17.2 \text{ MeV} = \Delta\left(KE\right)$$

$\Delta\left(KE\right) = 0$ 이므로 에너지는 보존 된다.

3.5 Calculate the ratio of bremsstrahlung power to fusion power for a d-t plasma with $N_i = N_e = 10^{20}$ m^{-3} at 2 keV and 20 keV.

Solution)

Fusion power

$$P_f = n_d n_t < \sigma v >_{dt} Q_{dt} = \frac{n_i^2}{4} < \sigma v >_{dt} Q_{dt}$$

$$\begin{aligned} P_{br} &= A_{br} n_i n_e \sqrt{kT} \\ &= 4.8 \times 10^{-37} n_i n_e \sqrt{kT} \quad \left(\text{J/sec m}^3,\ kT \text{ in keV}\right) \\ &= 3.0 \times 10^{-24} n_i n_e \sqrt{kT} \quad \left(\text{MeV/sec m}^3,\ kT \text{ in keV}\right) \end{aligned}$$

$$n_i = n_e$$

$$\frac{P_{br}}{P_f} = \frac{4 \times 3.0 \times 10^{-24} \sqrt{kT}}{17.6 < \sigma v >_{dt}} = 6.8 \times 10^{-25} \frac{\sqrt{kT}}{< \sigma v >_{dt}} \quad \left(kT \ \text{ in } \ \text{keV}\right)$$

$$\therefore \left.\frac{P_{br}}{P_f}\right|_{at\ 2\ \text{keV}} = 3.4$$

$$\left.\frac{P_{br}}{P_f}\right|_{at\ 20\ \text{keV}} = 0.008$$