Section 7.5: Nuclear Fusion

Tutorial 1 Practice, page 344

1. (a) Given: m_{He} = 4.002 60 u; m_{C} = 12.000 00 u

Required: mass defect

Analysis:

$\Delta m = 3m_{\text{He}} - m_{\text{C}}$

Solution:

$$\begin{aligned}\Delta m &= 3m_{\text{He}} - m_{\text{C}} \\ &= 3(4.002\ 60\ \text{u}) - 12.000\ 00\ \text{u} \\ \Delta m &= 0.007\ 800\ \text{u}\end{aligned}$$

Statement: The mass defect is 0.007 800 u.

(b) Given: Δm = 0.007 800 u; c^2 = 930 MeV/u

Required: E

Analysis: $E = \Delta mc^2$

Solution:

$$\begin{aligned}E &= \Delta mc^2 \\ &= 0.007\ 800\ \cancel{\text{u}}\left(930\ \frac{\text{MeV}}{\cancel{\text{u}}}\right) \\ &= 7.254\ \text{MeV} \\ E &= 7.25\ \text{MeV}\end{aligned}$$

Statement: The energy released is 7.25 MeV.

(c) Given: E = 7.254 MeV; nucleons = 12

Required: E per nucleon (E_{n})

Analysis:

$$E_{\text{n}} = \frac{E}{n\ \text{nucleons}}$$

Solution:

$$\begin{aligned}E_{\text{n}} &= \frac{E}{n} \\ &= \frac{7.254\ \text{MeV}}{12\ \text{nucleons}} \\ &= 0.6045\ \text{MeV/nucleon} \\ E_{\text{n}} &= 0.60\ \text{MeV/nucleon}\end{aligned}$$

Statement: The energy released is 0.60 MeV/nucleon.

Section 7.5 Questions, page 347

1. In nuclear fission, energy is created by the nuclei of atoms breaking apart. In nuclear fusion, energy is created by the nuclei of two atoms joining together. Both produce large amounts of energy. Nuclear fission usually occurs in elements with large (heavy) nuclei and results in more stable nuclei. Nuclear fusion usually occurs in elements with small (light) nuclei. It also results in more stable nuclei.

2. (a) Nuclear fusion is more difficult to achieve than nuclear fission because a large amount of kinetic energy must be supplied to get the reaction started. This kinetic energy is needed to allow the fusing nuclei to overcome the strong repulsive electrostatic force between them. It is difficult to direct and safely confine this large amount of kinetic energy.

(b) Nuclear fusion is more desirable than nuclear fission for power generation because it produces little pollution and no radioactive waste.

3. (a) Given: $m_{\text{H-1}}$ = 1.007 825 u; $m_{\text{C-13}}$ = 13 003 35 u; $m_{\text{N-14}}$ = 14.003 07 u; c^2 = 930 MeV/u

Required: energy released in third stage (E)

Analysis: $E = \Delta mc^2$

Solution: Find the mass defect in the reaction: ${}^{13}_{6}\text{C} + {}^{1}_{1}\text{H} \rightarrow {}^{14}_{7}\text{N} + \text{energy}$.

$$\begin{aligned}\Delta m &= m_{\text{C-13}} + m_{\text{H-1}} - m_{\text{N-14}} \\ &= 13.003\ 35\ \text{u} + 1.007\ 825\ \text{u} - 14.003\ 07\ \text{u} \\ \Delta m &= 0.008\ 105\ \text{u}\end{aligned}$$

$$\begin{aligned}E &= \Delta mc^2 \\ &= (0.008\ 105\ \cancel{\text{u}})\left(930\ \frac{\text{MeV}}{\cancel{\text{u}}}\right) \\ &= 7.5376\ \text{MeV} \\ E &= 7.54\ \text{MeV}\end{aligned}$$

Statement: The energy released in the third stage of the carbon-nitrogen-oxygen cycle is 7.54 MeV.

(b) Note: After the first printing, the given reaction in this question was updated to show carbon-12 and nitrogen 13. The solution below reflects this change.

Given: E = 1.95 MeV; $m_{\text{H-1}}$ = 1.007 825 u; $m_{\text{C-12}}$ = 12 000 00 u; c^2 = 930 MeV/u

Required: $m_{\text{N-13}}$

Analysis:

$$\begin{aligned}E &= mc^2 \\ m &= \frac{E}{c^2} \\ \Delta m &= m_{\text{C-12}} + m_{\text{H-1}} - m_{\text{N-13}} \\ m_{\text{N-13}} &= m_{\text{C-12}} + m_{\text{H-1}} - \Delta m\end{aligned}$$

Solution:

$$\begin{aligned}m &= \frac{E}{c^2} \\ &= \frac{1.95\ \cancel{\text{MeV}}}{930\ \cancel{\text{MeV}}/\text{u}} \\ m &= 0.002\ 09\ \text{u}\end{aligned}$$

$m_{\text{N-13}} = m_{\text{C-12}} + m_{\text{H-1}} - \Delta m$
$= 12.000\ 00\ \text{u} + 1.007\ 825\ \text{u} - 0.002\ 09\ \text{u}$
$m_{\text{N-13}} = 13.0\ \text{u}$

Statement: The mass of nitrogen-13 is 13.0 u.

4. (a) For Sample Problem 1, fusion reaction:
Given: E = 17.6 MeV; nucleons = 5
Required: energy released per nucleon (E_n)
Analysis:

$$E_n = \frac{E}{n \text{ nucleons}}$$

Solution:

$$E_n = \frac{E}{n \text{ nucleons}} = \frac{17.6 \text{ MeV}}{5 \text{ nucleons}}$$

$$E_n = 3.52 \text{ MeV/nucleon}$$

Statement: The energy released when a deuterium atom fuses with a tritium atom to form helium is 3.52 MeV/nucleon.

For Sample Problem 2, fission reaction:
Given: E = 176.7 MeV; nucleons = 236
Required: energy released per nucleon (E_n)
Analysis:

$$E_n = \frac{E}{n \text{ nucleons}}$$

Solution:

$$E_n = \frac{E}{n \text{ nucleons}} = \frac{176.7 \text{ MeV}}{236 \text{ nucleons}} = 0.748\ 72 \text{ MeV/nucleon}$$

$$E_n = 0.749 \text{ MeV/nucleon}$$

Statement: The energy released when uranium produces tellurium and zirconium is 0.749 MeV/nucleon.

(b) This comparison shows that the fusion reaction releases over four times as much energy for each nucleon as the fission reaction does.

5. This suggests that the fuel for fusion reactors is widely available, especially if fission reactors also continue to operate.

6. (a) ${}^{12}_{6}\text{C} + {}^{1}_{1}\text{H} \rightarrow {}^{13}_{7}\text{N} +$ energy is a fusion reaction. Carbon and hydrogen nuclei fuse to create a nitrogen nucleus.

(b) ${}^{13}_{7}\text{N} \rightarrow {}^{13}_{6}\text{C} + {}^{0}_{+1}\text{e}$ + energy is a beta-positive decay reaction. The product has one fewer protons than the reactant. One proton has changed into one neutron and one positron.

(c) ${}^{13}_{6}\text{C} + {}^{1}_{1}\text{H} \rightarrow {}^{14}_{7}\text{N}$ is a fusion reaction. The product has one more proton than the reactant. A hydrogen atom must have fused with the carbon.
${}^{14}_{7}\text{N} + {}^{1}_{1}\text{H} \rightarrow {}^{15}_{8}\text{O}$ is a fusion reaction. The product has one more proton than the reactant.
${}^{15}_{8}\text{O} \rightarrow {}^{15}_{7}\text{N} + {}^{0}_{+1}\text{e}$ is a beta-positive decay reaction. One proton has changed into one neutron and one positron.
${}^{15}_{7}\text{N} + {}^{1}_{1}\text{H} \rightarrow {}^{12}_{6}\text{C} + {}^{4}_{2}\text{He}$ is a fusion reaction and an alpha decay reaction. The reactant has gained one proton (a hydrogen atom), then lost two protons and two neutrons (a helium atom).

7. Answers may vary. Students' answers should include information about inertial confinement.

8. Answers may vary. Students' answers should describe current advances on the ITER project.