CHAPTER 16

The nucleus and nuclear reactions

Answers to revision questions

1. Nucleons are sub-atomic particles that make up the nucleus; they include protons and neutrons.

2. (a) See Chapter 16.

(b) The paraffin wax provided the source of protons. The neutrons, which were unable to be detected directly, collided and knocked out protons from the paraffin wax; the protons could then be detected since they carried charge.

(c) The two laws used were the law of conservation of momentum and the law of conservation of energy. They were important as Chadwick used them to calculate backwards, based on the measurements taken from the knocked out protons, to determine the mass of the neutrons. This allowed Chadwick to demonstrate the existence of the neutrons without directly observing them.

3. See Chapter 16.

4. See Chapter 16.

5. (a) and (b)

(i) Beta (minus): ${}^{40}_{19}K \rightarrow {}^{40}_{20}Ca + {}^{0}_{-1}e + \bar{\nu}$

(ii) Alpha: ${}^{232}_{90}Th \rightarrow {}^{228}_{88}Ra + {}^{4}_{2}He$

(iii) Alpha: ${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$

(iv) Beta (minus): ${}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e + \bar{\nu}$

6. ${}^{59m}_{26}Fe \rightarrow {}^{59}_{26}Fe + \gamma$

7. Neutrino was postulated to account for the wide range of energy difference of the ejected electrons during beta decays. The discovery of neutrino was a direct consequence of the law of conservation of energy.

8. (a) ${}^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{31}_{15}P$

(b) ${}^{31}_{15}P \rightarrow {}^{30}_{15}P + {}^{0}_{1}n$

9. ${}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$

10. (a) The following equations describe this scenario:

$${}^{7}_{3}Li + {}^{1}_{0}n \rightarrow {}^{8}_{3}Li$$

$${}^{8}_{3}Li \rightarrow {}^{8}_{4}Be + {}^{0}_{-1}e + \bar{\nu}$$

$${}^{8}_{4}Be \rightarrow {}^{4}_{2}He + {}^{4}_{2}He$$

Therefore, the original nucleus is ${}^{7}_{3}Li$ and the two intermediate products are ${}^{8}_{3}Li$ and ${}^{8}_{4}Be$.

(b) There will be neutrinos emitted as there is a beta decay involved in this scenario, as shown in the second equation.

11. (a) Strong nuclear force is the force that is responsible for holding the nucleons together inside the nucleus.

(b) (i) Acts equally between proton–proton, proton–neutron and neutron–neutron.

(ii) It is a very powerful force; however, it only acts over a very short distance. For detail, see Chapter 16.

(c) To counter the repulsive forces between the positively charged protons inside the nucleus.

12. Control rods absorb the extra neutrons produced by the fission reaction in order to control and adjust the rate of the fission reaction.

13. See Chapter 16.

14 (a) Two neutrons.

(b) ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{55}Cs + {}^{93}_{37}Rb + 2({}^{1}_{0}n)$

15. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{139}_{54}Xe + {}^{95}_{38}Sr + 2({}^{1}_{0}n)$

16. For descriptions and equations, see Chapter 16. Fermi's main contributions could be summarised as the following:

- experimenting with transmutation reactions with slow neutrons
- production of the first transuranic element, neptunium and other transuranic elements
- describing chain nuclear fission reactions
- construction of the first ever controlled nuclear reactor pile in the basement of the University of Chicago
- involvement in the Manhattan Project.

17. (a) Lithium-7, mass = 7.016003 u

$$\text{Mass defect} = \left(\frac{1.675\times10^{-27}}{1.661\times10^{-27}}\right)\times 4 + \left(\frac{1.673\times10^{-27}}{1.661\times10^{-27}}\right)\times 3 + \left(\frac{9.109\times10^{-31}}{1.661\times10^{-27}}\right)\times 3 - 7.016003$$

$$= 0.0410305 \text{ u}$$

$$E_{binding} = 0.0410305 \times 1.661\times10^{-27}\times(3\times10^{8})^{2} \quad (E = mc^{2})$$

$$= 6.13\times10^{-12}\text{J}$$

$$= 0.0410305 \times \frac{1.661\times10^{-27}\times(3\times10^{8})^{2}}{1.602\times10^{-19}\times10^{6}}$$

$$= 38.28 \text{ MeV}$$

Lithium has four neutrons and three protons, therefore altogether seven nucleons. Hence:

$$E_{binding\ per\ nucleon} = \frac{38.28}{7} = 5.47 \text{ MeV/nucleon}$$

(b) Zinc-64, mass = 63.92915 u

$$\text{Mass defect} = \left(\frac{1.675\times10^{-27}}{1.661\times10^{-27}}\right)\times 34 + \left(\frac{1.673\times10^{-27}}{1.661\times10^{-27}}\right)\times 30 + \left(\frac{9.109\times10^{-31}}{1.661\times10^{-27}}\right)\times 30 - 63.92915$$

$$= 0.5906134 \text{ u}$$

$$E_{binding} = 0.5906134 \times 1.661\times10^{-27}\times(3\times10^{8})^{2}$$

$$= 8.83\times10^{-11}\text{J}$$

$$= 0.5906134 \times \frac{1.661 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.602 \times 10^{-19} \times 10^{6}}$$

$= 551.13$ MeV

Zinc has 34 neutrons and 30 protons, therefore altogether 64 nucleons. Hence:

$$E_{binding\ per\ nucleon} = \frac{551.13}{64} = 8.61 \text{ MeV/nucleon}$$

(c) Radon-219, mass = 219.00948 u

$$\text{Mass defect} = \left(\frac{1.675 \times 10^{-27}}{1.661 \times 10^{-27}}\right) \times 133 + \left(\frac{1.673 \times 10^{-27}}{1.661 \times 10^{-27}}\right) \times 86 + \left(\frac{9.109 \times 10^{-31}}{1.661 \times 10^{-27}}\right) \times 86 - 219.00948$$

$= 1.7800067$ u

$$E_{binding} = 1.7800067 \times 1.661 \times 10^{-27} \times (3 \times 10^{8})^{2}$$

$= 2.66 \times 10^{-10}$ J

$$= 1.7800067 \times \frac{1.661 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.602 \times 10^{-19} \times 10^{6}}$$

$= 1661.00$ MeV

Radon has 133 neutrons and 86 protons, therefore altogether 219 nucleons. Hence:

$$E_{binding\ per\ nucleon} = \frac{1661.00}{219} = 7.58 \text{ MeV/nucleon}$$

18. $^{235}_{92}U \rightarrow {}^{231}_{90}Th + {}^{4}_{2}He + energy$

The energy liberated is directly related to the loss in mass when the reactants go to form the products. Hence:

The mass loss in u = mass of reactants in u – mass of products in u

= mass of $^{235}_{92}U$ – mass of $^{231}_{90}Th$ and $^{4}_{2}He$

$= 235.04392 - (231.03630 + 4.00260)$

$= 0.00502$ u

Therefore, the energy liberated can be calculated as:

$$E = 0.00502 \times \frac{1.661 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.602 \times 10^{-19} \times 10^{6}}$$

$= 4.68$ MeV

19. $^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{14}_{7}N$

The energy liberated is directly related to the loss in mass when the reactants go to form the products. Hence:

The mass loss in u = mass of reactants in u – mass of products in u

= mass of $^{12}_{6}C$ and $^{1}_{1}H$ – mass of $^{14}_{7}N$

$= 12.000000 + 1.007225 - 13.005738$

$= 0.001487$ u

Therefore, the energy liberated can be calculated as:

$$E = 0.001487 \times \frac{1.661 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.602 \times 10^{-19} \times 10^{6}}$$

$= 1.39$ MeV

To convert MeV to J: $1.39 \times 10^{6} \times 1.602 \times 10^{-19} = 2.22 \times 10^{-13}$ J