Answers to Coursebook questions – Chapter 6.2

1 The equation is $C=\frac{k}{(d+d_0)^2}$, i.e. $d+d_0=\sqrt{\frac{k}{C}}$. So a graph of d versus $\frac{1}{\sqrt{C}}$ would give a straight line with slope $\sqrt{k}$ and intercept $-d_0$.

2 From $I=I_0e^{-\mu x}$ we deduce that $\ln I=\ln I_0-\mu x$, so a graph of $\ln I$ versus x gives a straight line with slope $-\mu$.

3 The elapsed time of 18 minutes corresponds to 6 half-lives. Every half-life that goes by reduces the mass by a factor of 2 and so $32\to16\to8\to4\to2\to1\to0.5$. We are left with 0.5 mg of the radioactive isotope.

4 The activity drops by a factor of 2 every half-life and so since $120\to60\to30\to15$ three half-lives went by. This is 24 h and so one half-life is 8 h.

5 Two alpha particles, ${}^{4}_{2}\text{He}$.

6 Protons contribute to splitting the nucleus since they are electrically charged and so repel. We cannot have too many protons in a nucleus compared to the number of neutrons.

7 They have opposite electric charges and so experience magnetic forces in opposite directions.

From $r=\frac{mv}{qB}$,

$$\frac{r_\alpha}{r_e}=\frac{\frac{m_\alpha v}{2eB}}{\frac{m_e v}{eB}}=\frac{m_\alpha}{2m_e}\approx\frac{4u}{2\times5.49\times10^{-4}u}=3640.$$

8 ${}^{3}_{1}\text{H}\to{}^{0}_{-1}\text{e}+\overline{\nu}+{}^{3}_{2}\text{He}$, producing an antineutrino and an isotope of helium.

9 ${}^{14}_{7}\text{N}\to{}^{0}_{-1}\text{e}+\overline{\nu}+{}^{14}_{6}\text{C}$.

10 ${}^{210}_{83}\text{Bi}\to{}^{0}_{-1}\text{e}+\gamma+{}^{210}_{84}\text{Po}$

11 ${}^{239}_{94}\text{Pu}\to{}^{4}_{2}\alpha+{}^{235}_{92}\text{U}$

12 ${}^{A}_{Z}\text{X}\to2\,{}^{0}_{-1}\text{e}+{}^{4}_{2}\alpha+{}^{A-4}_{Z}\text{X}$

13 ${}^{22}_{11}\text{Na}\to{}^{0}_{+1}\text{e}+\nu+{}^{22}_{10}\text{Ne}$

14 One way is to let the emissions go through a region of magnetic field at right angles to the direction of motion of the particles emitted.

a Alpha particles would deflect according to the rule for the magnetic force on a positive charge.

b Beta particles would deflect according to the rule for the magnetic force on a negative charge, i.e. opposite to the alpha particles.

c The gamma arrays would be undeflected.

15 The number of ions is $6000 \times 30 = 1.8 \times 10^5$ and so the number of ion pairs is 9.0×10^4. The energy required is $9.0 \times 10^4 \times 32 = 2.88 \times 10^6 \text{ eV} = 2.88 \text{ MeV}$. This is the energy of the alpha particle.

16 This question is completely off-syllabus, where you are asked to go and research the answer a bit. You will find that the issue of stability of a nucleus has to do with the dependence of binding energy (see **chapter 6.3** in *Physics for the IB Diploma*) on mass, proton and neutron number. You will discover that the empirical formula giving this energy favours nuclei with $A = 2Z$ in the sense that the binding energy becomes more positive (and hence the nucleus more stable) in this case. The condition $A = 2Z$ implies $Z = N$, i.e. equal numbers of protons and neutrons. This indicates that binding is strong when the neutrons can all be paired with the protons. Further, the formula shows that there is a small preference for even–even nuclei over those that are odd–odd.

17 As the nucleus gets heavier, more protons and neutrons must be added to the nucleus. The neutrons contribute to nuclear binding through the nuclear force but the protons contribute to repulsion through the electrical force in addition to binding through the nuclear force that they also participate in. However, the electrical force has infinite range and all the protons in the nucleus repel each other, whereas only the very near neighbours attract through the nuclear force. To make up for this imbalance it is necessary to have more neutrons, i.e. particles that contribute to only binding.

18 Nuclei with a large neutron to proton ratio are likely to decay by beta minus decay that reduces the number of neutrons in the nucleus. Conversely, those that have too small a neutron to proton ratio decay by beta plus decay that increases the number of neutrons. Those that decay by beta minus decay are found above the line of stability in the Segre plot and those that decay by beta plus decay are found below the line.