

### Radioactive decay

Sodium ( ${}^{22}_{11}\text{Na}$ ) decays by beta plus decay into neon ( ${}^{22}_{10}\text{Ne}$ ) according to the reaction equation  ${}^{22}_{11}\text{Na} \rightarrow {}^{22}_{10}\text{Ne} + e^+ + \nu_e$ .

- (a) State one property of the neutrino.  
 (b) The following information is available for atomic masses:

$${}^{22}_{11}\text{Na}: 21.994436 \text{ u}$$

$${}^{22}_{10}\text{Ne}: 21.991385 \text{ u}$$

Calculate that the energy released in this reaction is about 1.8 MeV.

- (c) The graph shows the variation with time  $t$  of the number  $N$  of nuclei of  ${}^{22}_{11}\text{Na}$ .



- (i) Deduce that the initial mass of  ${}^{22}_{11}\text{Na}$  was about 20 g.  
 (ii) Determine, in kW, the initial power released by this mass of sodium.  
 (iii) Estimate the mass of sodium remaining after 1 year.

**IB Physics: K.A. Tsokos**

- (iv) The neon isotope produced in the decay of sodium is stable. On the graph, sketch the variation with time of the number of neon nuclei assuming that no neon was present initially.
- (d) The stable nuclide  ${}_{10}^{22}\text{Ne}$  has roughly the same number of protons and neutrons. A much larger stable nuclide such as gold  ${}_{79}^{198}\text{Au}$  has many more neutrons than protons. Explain why.

Answers

(a) Neutral, nearly massless, spin  $\frac{1}{2}$ , very weakly interacting particle.

(b)

$$\begin{aligned}\Delta m &= (21.994436 - 11m_e) - (21.991385 - 10m_e) - m_e \\ &= 21.994436 - 21.991385 - 2m_e \\ &= 0.00195384 \text{ u}\end{aligned}$$

$$\begin{aligned}Q &= \Delta m \times 931.5 = 0.00195384 \times 931.5 \\ &= 1.82 \text{ MeV}\end{aligned}$$

(c)

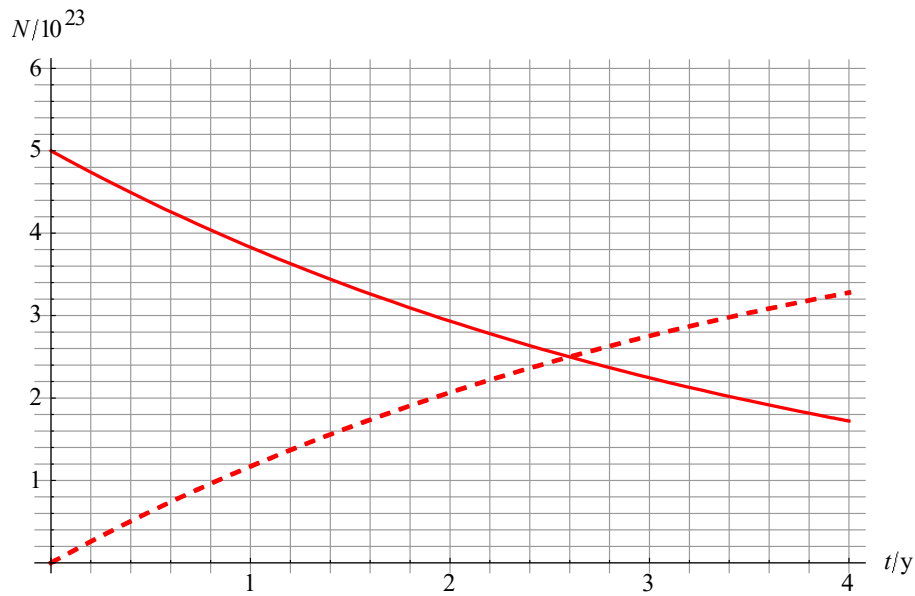
(i) Number of moles is  $\frac{5.0 \times 10^{23}}{6.02 \times 10^{23}} = 0.83$ . Mass is  $0.83 \times 21.994436 = 18.3 \text{ g}$

(ii) Half-life is 2.6 y. Decay constant is  $\lambda = \frac{\ln 2}{2.6} = 0.267 \text{ y}^{-1}$ . Initial activity is

$$\begin{aligned}\lambda N_0 &= \frac{0.267}{365 \times 24 \times 3600} \times 5.0 \times 10^{23} = 4.2 \times 10^{15} \text{ Bq. Power is} \\ 4.2 \times 10^{15} \times 1.8 \times 10^6 \times 1.6 \times 10^{-19} &= 1252 \approx 1.3 \text{ kW.}\end{aligned}$$

(iii) Mass remaining is  $18.3 \times e^{-0.267 \times 1} \approx 14 \text{ g}$ .

(iv) Dashed line as shown below.



(d) As a nucleus gets bigger the protons tend to break it apart through the repulsive electric force that acts on all protons in the nucleus. To eliminate this effect neutrons are needed for 2 reasons. First, by inserting lots of neutrons in between protons the effective distance between protons increases thus decreasing the electric force. Second, the neutrons contribute to binding through the strong nuclear force.