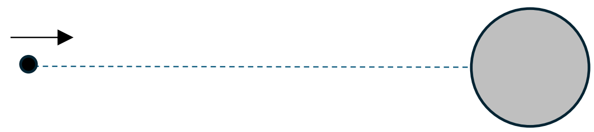
Problem of the week

Nuclear Physics (HL only)

(a) Explain why all nuclei have the same density.

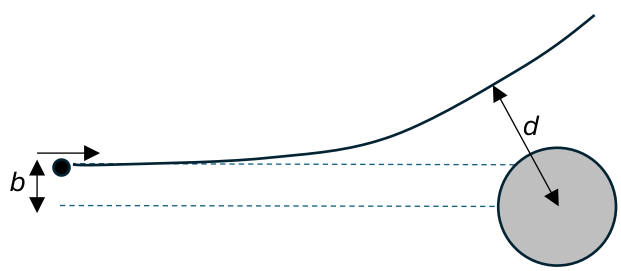
(b) An alpha particle has kinetic energy 4.8 MeV when far from a nucleus of proton number 28. The alpha particle is directed head-on towards the nucleus.



(i) Determine the distance of closest approach.

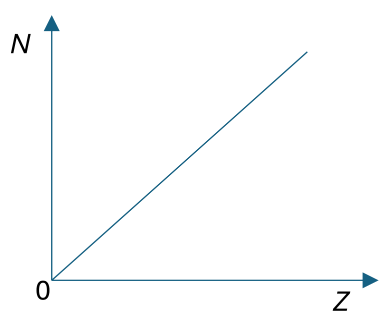
(ii) Outline how nuclear radii are determined.

(c) Another alpha particle is directed towards the nucleus as shown.



Explain how it may be deduced that $d > b$.

(d) The graph shows the line $N = Z$ in a plot of neutron number N versus proton number Z.



Draw a curve on this graph to indicate the position of stable nuclei.

(e) Nickel-60 is stable but nickel-72 is unstable.

(i) Suggest the likely reason for this observation.

(ii) Nickel-72 decays into copper (Cu). Suggest the type of this decay.

(iii) After a time of 6.0 s, the ratio $\frac{\text{number of Ni} - 72 \text{ nuclei that have not yet decayed}}{\text{number of Ni} - 72 \text{ nuclei that have decayed}}$ is $\frac{1}{11}$.

Calculate the half-life of Ni-72.

(f)

(i) State the evidence for nuclear energy levels.

(ii) Suggest why alpha decay is often accompanied by the emission of a gamma ray photon.

Answers

(a) A nucleus of nucleon number A has mass that is approximately equal to A expressed in u's.

The radius of the nucleus is $R = R_0 A^{\frac{1}{3}}$ and so the density is

$\rho = \frac{\text{mass}}{\text{volume}} = \frac{Au}{\frac{4\pi}{3}\left(R_0 A^{\frac{1}{3}}\right)^3} = \frac{3u}{4\pi R_0^3}$ which is independent of A.

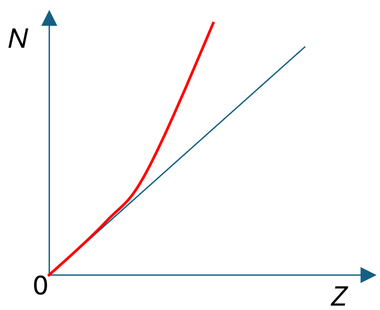
(b)

(i) $E = \frac{k2e \times 28e}{d} \Rightarrow d = \frac{k56e^2}{E} = \frac{8.99 \times 10^9 \times 56 \times (1.6 \times 10^{-19})^2}{4.8 \times 10^6 \times 1.6 \times 10^{-19}} = 1.7 \times 10^{-14}\text{ m}$.

(ii) The energy of the alpha particles is increased until the distance of closest approach becomes about equal to the nuclear radius. This happens when deviations from Rutherford scattering start being observed.

(c) By conservation of angular momentum: $mub = mvd$ where u is the initial speed and v the speed at the point of closet approach. Some of the kinetic energy has been transferred to electrical potential energy and so $v < u$. Hence $d > b$.

(d)



(e)

(i) It has too many neutrons.

(ii) The number of neutrons has to be reduced so beta minus decay.

(iii) $\frac{\text{number of Ni} - 72 \text{ nuclei that have not yet decayed}}{\text{number of Ni} - 72 \text{ nuclei that have decayed}} = \frac{N_0 e^{-\lambda t}}{N_0 - N_0 e^{-\lambda t}} = \frac{e^{-\lambda t}}{1 - e^{-\lambda t}}$. Hence

$\frac{e^{-\lambda t}}{1 - e^{-\lambda t}} = \frac{1}{11} \Rightarrow e^{-\lambda t} = \frac{1}{12}$. Thus, $-\lambda t = \ln\left(\frac{1}{12}\right) \Rightarrow \lambda = \frac{\ln 12}{6.0} = 0.41415\text{ s}^{-1}$.

Finally, $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = 1.67\text{ s}$.

(f)

(i) The discrete energies of alpha particles and gamma rays in alpha and gamma decay.

(ii) The decaying parent nucleus ends up in an excited nuclear energy state of the daughter nucleus. A gamma ray photon will be emitted when the daughter nucleus makes a transition to a lower nuclear energy level.