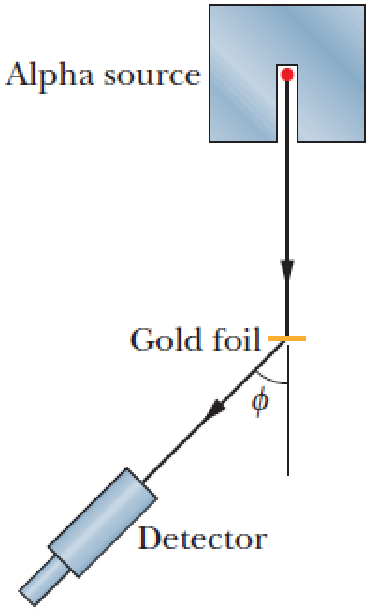
Nucleus and Nuclear properties

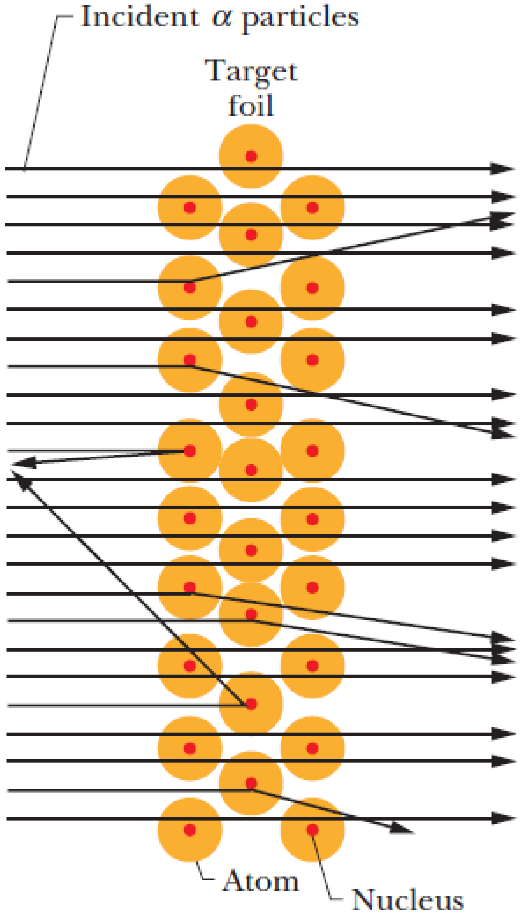
LECTURE 28

Applied Physics PH-122

Discovering the Nucleus

An arrangement (top view) used in Rutherford's laboratory in 1911–1913 to study the scattering of α particles by thin metal foils. The detector can be rotated to various values of the scattering angle ϕ. The alpha source was radon gas, a decay product of radium. With this simple "tabletop" apparatus, the atomic nucleus was discovered.





Discovering the Nucleus

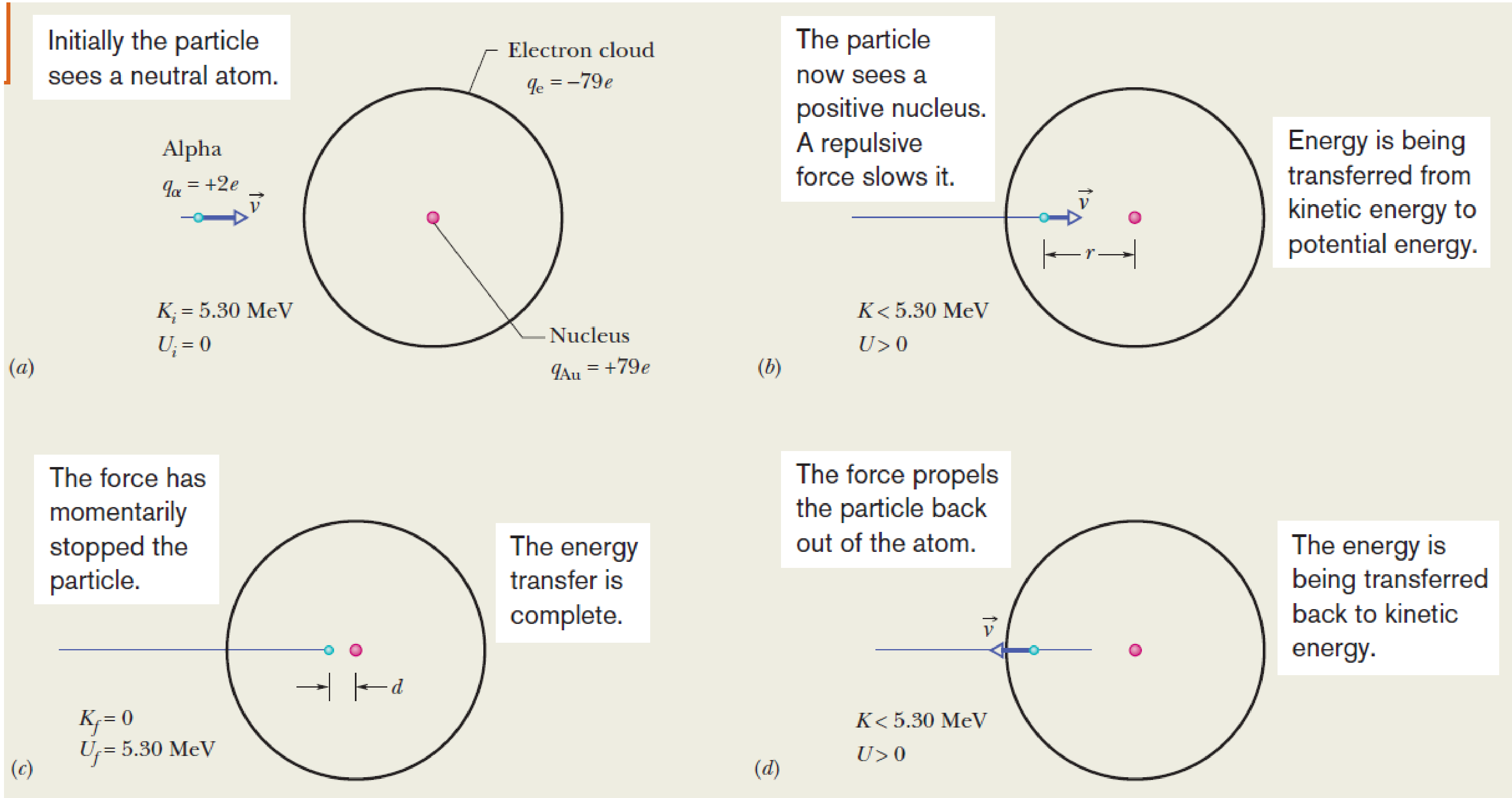


Figure 42-4 An alpha particle (*a*) approaches and (*b*) then enters a gold atom, headed toward the nucleus. The alpha particle (*c*) comes to a stop at the point of closest approach and (*d*) is propelled back out of the atom.

Properties of Nucleus

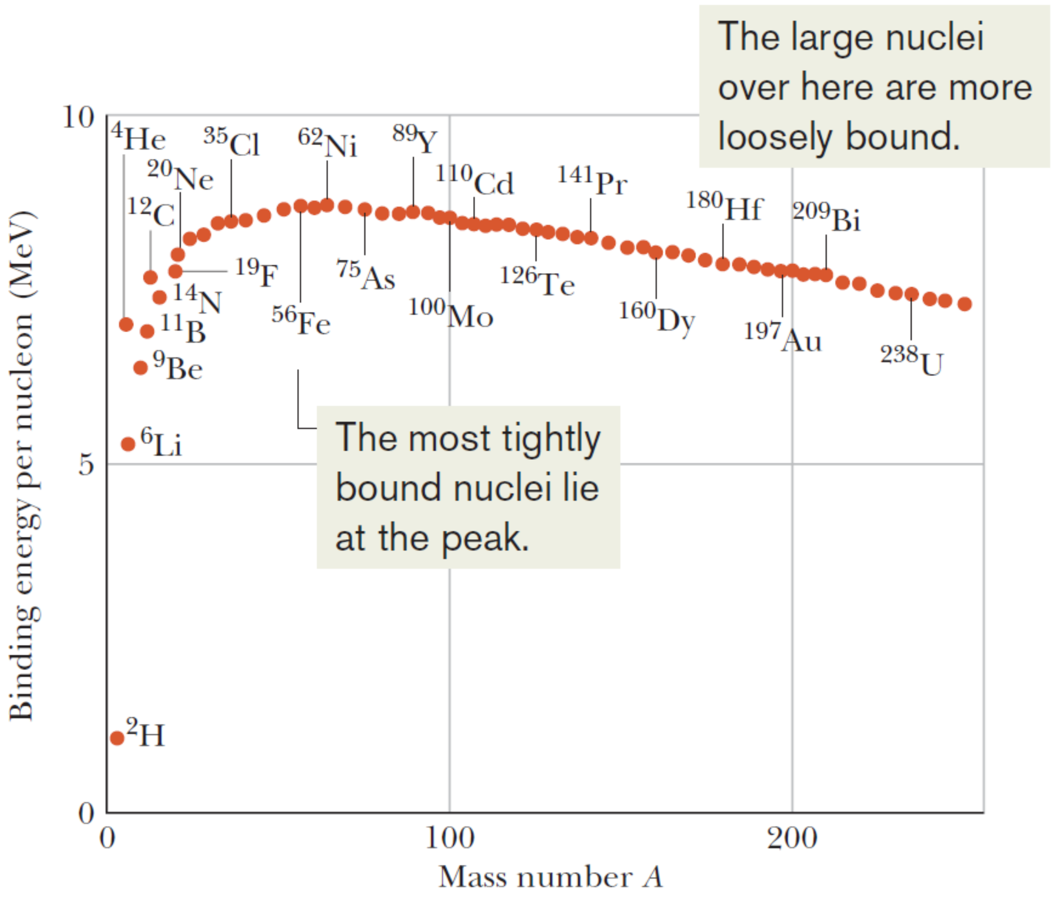
- Z=charge number/atomic number, A=mass number, N=number of neutrons.
- Mean radius of nuclei is given by $r = r_0 A^{1/3}$ where $r_0 \approx 1.2\ \mathrm{fm}$
- Binding energy binds the nucleons together in the nucleus. It is given by:

$$\Delta E_{\mathrm{be}} = \Sigma(mc^2) - Mc^2$$

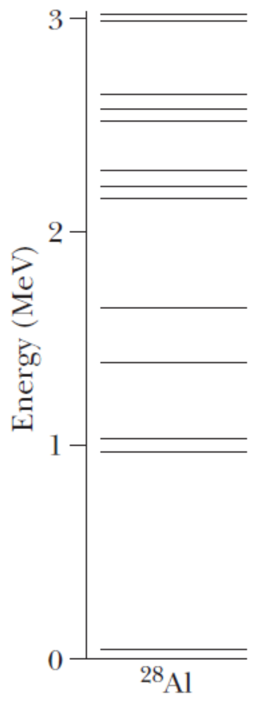
- Binding energy per nucleon is the ratio between the binding energy and number of nucleons (A) of a nucleus. It is given by:

$$\Delta E_{\mathrm{ben}} = \frac{\Delta E_{\mathrm{be}}}{A}$$

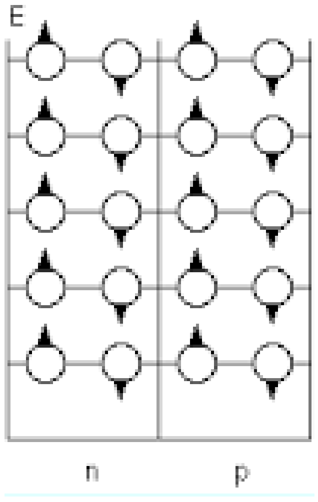
Properties of Nucleus

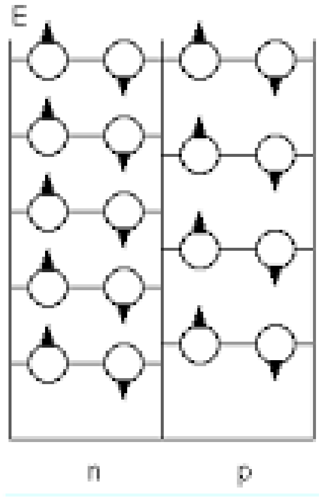


Properties of Nucleus



Nucleons are also paired as spin-up and spin-down, similar to electrons.





Strong nuclear force is responsible for binding the nucleus together. It is a strong attractive force that is strong enough to overcome the repulsive force between protons and to bind nucleons together into extremely small volume of nucleus.

Problem

- Find the binding energy for Sn^{120}. (Z=50)

- For Sn^{120} there are 50 protons and 70 neutrons.
- The binding energy is of a nucleus but usually the binding energy calculations are based on mass of atom rather than nuclear mass as mass of atom is much easier to measure.

$$\Delta E_{\mathrm{be}} = \Sigma(mc^2) - Mc^2$$
$$= \left[50(m_{\mathrm{H}}c^2) + 70(m_{\mathrm{n}}c^2)\right] - M_{\mathrm{Sn}}c^2$$

Problem

$$
\begin{aligned}
&= 50(1.007\,825\ \text{u})c^2 + 70(1.008\,665\ \text{u})c^2 \\
&\quad - (119.902\,197\ \text{u})c^2 \\
&= (1.095\,603\ \text{u})c^2 \\
&= (1.095\,603\ \text{u})(931.494\,013\ \text{MeV/u}) \\
&= 1020.5\ \text{MeV},
\end{aligned}
$$

$$
\Delta E_{\text{ben}} = \frac{\Delta E_{\text{be}}}{A} = \frac{1020.5\ \text{MeV}}{120}
$$

$$
= 8.50\ \text{MeV/nucleon}.
$$

Problem

- Find the average nuclear density.

- If 'm' represents the mass of each nucleon in a nucleus then the mass of nucleus can be given by 'Am'.
- Assuming that the nucleus is spherical. The volume is given by:

$$\rho = \frac{Am}{\frac{4}{3}\pi r^3};$$

- But $r = r_0 A^{1/3}$

Problem

- So that,

$$\rho = \frac{\cancel{A} m}{\frac{4}{3}\pi r_0^3 \cancel{A}} = \frac{m}{\frac{4}{3}\pi r_0^3}.$$

$$\rho = \frac{\underline{1.67 \times 10^{-27}}\,\mathrm{kg}}{\frac{4}{3}\pi(\underline{1.2 \times 10^{-15}\ \mathrm{m}})^3} \approx \underline{2 \times 10^{17}}\ \mathrm{kg/m^3}.$$