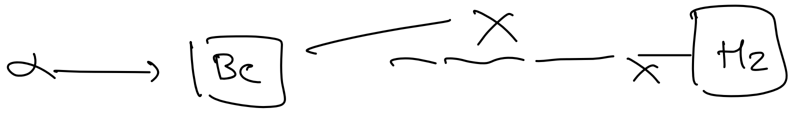
Scoperta del neutrone

Chadwick 1932

$$\alpha + {}^9_4Be \rightarrow {}^{12}_6C + X$$

α: decadimento del Polonio
$K_\alpha \simeq 5$ MeV



X: – neutra elettricamente
– radiazione molto penetrante

1) $X = \gamma$

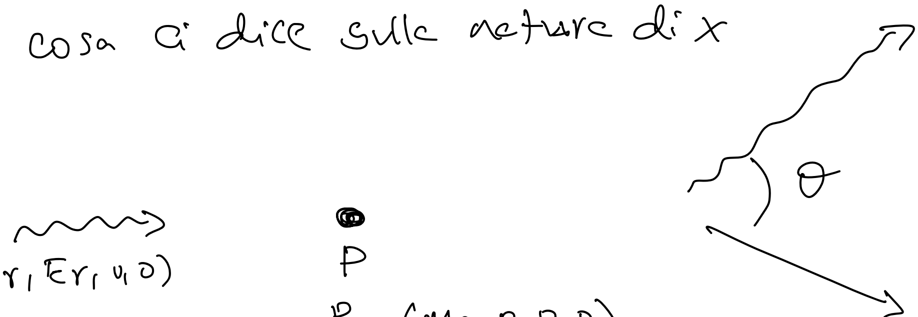
2) $X =$ nuova particella neutra

studiare un processo alla Compton $\quad X + p \rightarrow p + X$

Dato sperimentale: $K_p = 5$ MeV

$\Rightarrow$ cosa ci dice sulla natura di X

Ipotesi: γ



$\underline{P}_1 = (E_\gamma, E_\gamma, 0, 0)$ $\qquad$ p $\quad \underline{P}_2 = (m_p, 0, 0, 0)$

$\gamma \quad \underline{P}_3 = (E_\gamma', \vec{E}_\gamma')$ $\qquad \theta$

$\underline{P}_4 = (E_p, \vec{P}_p)$

$E_p = m_p + K_p$

$$K_p = E_p - m_p = (\gamma - 1) m_p$$

$$\Rightarrow \gamma = \frac{K_p}{m_p} + 1 = 1 + \frac{5\text{ MeV}}{1000\text{ MeV}} = 1 + 5\times 10^{-3}$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} \simeq 1 + \frac{1}{2}\beta^2 \Rightarrow \beta^2 = 2\times 5\times 10^{-3} = 10^{-2}$$

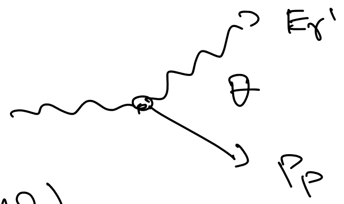
$$\Rightarrow \beta = 0.1 \quad \text{del protone}$$

$$s = (\underline{P}_1 + \underline{P}_2)^2 = (\underline{P}_{in})^2 = \underbrace{|\underline{P}_1|^2}_{m_\gamma^2 = 0} + \underbrace{|\underline{P}_2|^2}_{m_p^2} + 2\,\underline{P}_1 \cdot \underline{P}_2 = m_p^2 + 2 m_p E_\gamma$$

$$\underline{P}_{fin} = \underline{P}_3 + \underline{P}_4 \qquad |\underline{P}_{fin}|^2 = \underline{P}_3^{\,2} + \underline{P}_4^{\,2} + 2\,\underline{P}_3 \cdot \underline{P}_4 =$$

$$= 0 + m_p^2 + 2\left(E_\gamma' E_p - \vec{P}_\gamma' \cdot \vec{P}_p\right)$$

$$|P_{fin}|^2 = m_p^2 + 2\left(E_\gamma' E_p - E_\gamma' P_p \cos\theta\right)$$



$$S_{in} = S_{fin.} \Rightarrow \cancel{2} m_p E_\gamma = \cancel{2}\left(E_\gamma' E_p - E_\gamma' P_p \cos\theta\right)$$

$$E_\gamma' = E_\gamma \frac{m_p}{E_p - P_p \cos\theta} = E_\gamma \frac{m_p}{E_p} \frac{1}{1 - \frac{P_p}{E_p}\cos\theta}.$$

$$E_p^2 = m_p^2 + P_p^2 \qquad \frac{m_p}{E_p}, \frac{P_p}{E_p} < 1$$

Sperimentalmente si misura $K_p = 5$ MeV

$$E_p = m_p + K_p \qquad \beta \ll 1. \Rightarrow K_p = \frac{P_p^2}{2m_p} \Rightarrow P_p = \sqrt{2m_p K_p}.$$

$$P_p = \sqrt{2 \times 1000\ \text{MeV} \times 5\ \text{MeV}} = \sqrt{10^4\ \text{MeV}^2} = 100\ \text{MeV}$$

$P_p = 100$ MeV

$\theta = \pi \Rightarrow \cos\theta = -1.$

$$E_\gamma' = E_\gamma \frac{m_p}{E_p + P_p} = E_\gamma \frac{m_p}{m_p + K_p + P_p} = E_\gamma \frac{1000\ \text{MeV}}{(1000+5+100)\ \text{MeV}}$$

$\cos\theta = -1$

$$E_\gamma' = E_\gamma \frac{1}{1 + 105/1000} \simeq E_\gamma\left(1 - \frac{105}{1000}\right) = 0.9\, E_\gamma.$$

Conservazione dell'energia: $E_f = E_i$

$$E_i = E_\gamma + m_p$$

$$E_f = E_\gamma' + E_p = E_\gamma' + m_p + K_p$$

$$E_f = E_i \Rightarrow \quad E_\gamma + \cancel{m_p} = E_\gamma' + \cancel{m_p} + K_p.$$

$$\begin{cases} E_\gamma - E_\gamma' = K_p \\ E_\gamma' = 0.9\, E_\gamma \end{cases} \Rightarrow E_\gamma(1 - 0.9) = K_p$$

$$\Rightarrow E_\gamma = \frac{K_p}{0.1} = 10\, K_p = 50\ \text{MeV}$$

$E_\gamma = 50$ MeV $\gg$ energie dei fotoni emessi dai nuclei.

Radiazione γ

E raggi $\gamma \sim$ MeV

$$\alpha + {}^{9}_{4}Be \rightarrow {}^{12}_{6}C + \gamma$$

$E_\gamma = 50$ MeV

che è troppo.

non compatibile con reazioni termonucleari.

energie $\sim$ MeV

Ipotesi 2

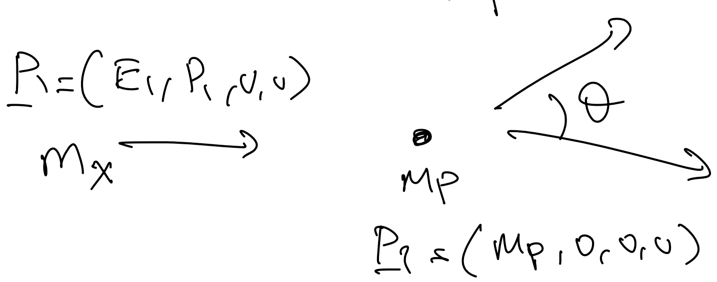
$X = n$ particelle massive senza carica elettrica

Fermione

con massa simile al protone.

Chadwick.

$$\frac{m_n - m_p}{m_p} \lesssim 10\%$$



Esercizio di Cinematica

oggi:

$m_p = 938.3$ MeV

$m_n = 939.6$ MeV

$$\frac{m_n - m_p}{m_p} \simeq \frac{1 \text{ MeV}}{938} \simeq 1‰$$

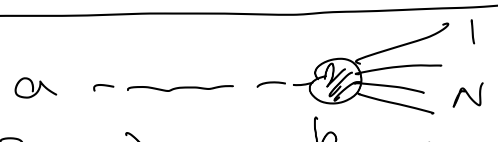
$$\alpha + {}^{9}_{4}Be \rightarrow {}^{12}_{6}C + n$$

urto anelastico

$$\alpha + {}^{A}_{Z}N \rightarrow {}^{A}_{Z}N + \alpha$$

urto elastico

Energia di soglia negli urti anelastici



particelle nello stato finale

$\underline{P_a} = (E_a, P_a, 0, 0)$ $\quad \underline{P_2} = (m_b, 0, 0, 0)$

$E_a = m_a + K_a$

$$S_{in} = (\underline{P_a} + \underline{P_b})^2 = m_a^2 + m_b^2 + 2 E_a m_b = m_a^2 + m_b^2 + 2(m_a + K_a) m_b$$

$$= \underbrace{m_a^2 + m_b^2 + 2 m_a m_b}_{(m_a + m_b)^2} + 2 m_b K_a.$$

$$\Rightarrow \quad K_a = \frac{S - (m_a + m_b)^2}{2 m_b}$$

Stato finale $\quad \underline{P_{fin}} = \Sigma_i \underline{P_f^i}$

$$S_{fin} = (\underline{P_{fin}})^2 = (\Sigma_i \underline{P_f^i})^2$$

S inv. di Lorentz $\Rightarrow$ nel riferimento del centro di massa

Def. centro di massa: $\quad \Sigma_i \vec{P}_f^{*i} = 0$

$$S = \Sigma_i \underline{P_f^{*i}} = (\Sigma_i E_f^{*i})^2 = \left(\Sigma_i (m_i + K_f^{*i})\right)^2$$

$$K_a = \frac{\left(\Sigma_i (m_i + K_f^{*i})\right)^2 - (m_a + m_b)^2}{2 m_b}$$

K_f^{*i} : en. cinetica della i-esima particella finale nel centro di massa

$K_f^{*i} \geq 0$

$$K_a \geq \frac{(\Sigma_i m_i)^2 - (m_a + m_b)^2}{2 m_b}$$ = Energia Cinetica di soglia per urto anelastico

urti elastici

$a + b \rightarrow a + b.$

$$(\Sigma_i m_i)^2 = (m_a + m_b)^2$$

$K_a \geq 0$ $\quad$ nessuna soglia. urto elastico sempre possibile