Interaction of Heavy Charged Particles with Matter
Interaction of Heavy Charged Particles with Matter

- Primary interaction with atomic electrons
  - Ionization
  - Excitation
Interaction of Heavy Charged Particles with Matter

- \( \frac{m_e}{M} \ll 1 \)
  - Very little deflection
  - Small energy loss/interaction
  \[ \Delta E_{\text{max}} = E(4m_e/M) \]
  - Concept of range
Heavy Charged Particles

Bethe-Bloch Equation (non-relativistic)

\[
\frac{dE}{dx} = \left( \frac{e^2}{4\pi \varepsilon_0} \right) \left( \frac{4\pi z^2 N_0 \rho Z}{m_e v^2 A} \right) \ln \left( \frac{2m_e v^2}{I} \right)
\]

\[
\frac{dE}{dx} = C_1 \left( \frac{z^2 Z}{v^2} \right) \ln \left( C_2 v^2 \right)
\]
Heavy Charged Particles

Bethe-Bloch Equation Key Points

dE/dx depends on:

- \( v \), the velocity of the particle
- \( Z \), the atomic number of the absorber
- \( z^2 \), the particle’s charge squared
Protons and Alphas in Aluminum

At what energies do protons and alphas have the same velocity?

\[ K_p = \frac{1}{2} m_p v^2 \quad \text{and} \quad K_\alpha = \frac{1}{2} m_\alpha v^2 \]

\[ \frac{K_p}{m_p} = \frac{K_\alpha}{m_\alpha} \quad \text{or} \quad K_\alpha = \frac{m_\alpha}{m_p} K_p = 4K_p \]

At the same velocities protons and alphas have the same dE/dx except for the \(z^2\) term.

Thus, at the same velocity: \((dE/dx)_\alpha = 4(dE/dx)_p\)
Example:
Protons and alphas in Al
Find the dE/dx for 6-MeV alphas from the proton dE/dx

6-MeV alphas have the same velocity as \((\frac{6}{4}) = 1.5\)-MeV p

From graph: \(\frac{dE}{dx}(K_p = 1.5 \text{ MeV}) = 130 \text{ MeV cm}^2/\text{g}\)

\(\frac{dE}{dx}(K_\alpha = 6 \text{ MeV}) = 4(130 \text{ MeV cm}^2/\text{g}) = 510 \text{ MeV cm}^2/\text{g}\)
Low-Energy Behavior

Pickup and loss of electrons

Bragg peak

Protons and Alphas in Aluminum

protons

alphas

\[ \frac{dE}{dx} \text{ (MeV cm}^2\text{/g)} \]

\[ K \text{ (MeV)} \]

0 2 4 6 8 10
Proton Effective Charge vs Energy

Nuclear Reaction Analysis, Marion and Young (Wiley, 1968)
Equilibrium Charge States for Hydrogen

Nuclear Reaction Analysis, Marion and Young (Wiley, 1968)
Equilibrium Charge States for Oxygen

Nuclear Reaction Analysis, Marion and Young (Wiley, 1968)