Coulomb Scattering

- Elastic or inelastic.
- Elastic ▶ Rutherford scattering.
- At any distance: \[ \frac{1}{2} m v_o^2 = \frac{1}{2} m v^2 + \frac{1}{4 \pi \varepsilon_o} \frac{z Z e^2}{r} \]

\[ V = 0 \]
\[ T_a = \frac{1}{2} m v_o^2 \]
\[ l = m v_o b \]

\[ V = \frac{1}{4 \pi \varepsilon_o} \frac{z Z e^2}{d} \]
\[ T_a = 0 \]

No dependence on \( \phi \)

Accelerator Physics, JU, First Semester, 2010-2011 (Saed Dababneh).
Coulomb Scattering

• Closest approach “d”.
• \( E_\alpha = E_{\text{Coulomb}} \) \( \Rightarrow d = \frac{2kZe^2}{E_\alpha} \)
• What about the recoil nucleus?

**HW 9** Show that

\[
d = \frac{2kZe^2m_N}{E_\alpha (m_N - m_\alpha)}
\]

where \( m_N \): mass of the nucleus
\( m_\alpha \): mass of alpha

What are the values of \( d \) for 10, 20, 30 and 40 MeV \( \alpha \) on Au?

How does this explain …?
Coulomb Scattering
Coulomb Scattering

\[ b \uparrow \theta \]
\[ < b \uparrow > \theta \]
\[ db \uparrow d\theta \]

\[ f = (nx)\pi b^2 \]
\[ df = (nx)2\pi bdb \]

\( n \equiv \text{target nuclei / cm}^3 \)
\( x \equiv \text{target thickness (thin)}. \)
\( nx \equiv \text{target nuclei / cm}^2 \)

**HW 10**

Show that

\[ b = \frac{d}{2}\cot \frac{\theta}{2} \]

and hence

\[ \frac{d\sigma(\theta)}{d\Omega} = \left( \frac{zZe^2}{4\pi\varepsilon_o} \right)^2 \left( \frac{1}{4T_a} \right)^2 \frac{1}{\sin^4 \frac{\theta}{2}} \]

Rutherford cross section
Coulomb Scattering

study Fig. 11.10 (a,b,c,d) in Krane

See also Fig. 11.11 in Krane.

HW 11
Show that the fraction of incident alpha particles scattered at backward angles from a 2 µm gold foil is $7.48 \times 10^{-5}$. 

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Coulomb Scattering

- RBS – Channeling.
- Ion implantation.
- Occupational or substitutional impurities.
Coulomb Scattering

• Elastic ► Rutherford scattering.
• Inelastic ► Coulomb excitation.

See the corresponding alpha spectrum of Fig. 11.12 in Krane.
Coulomb Scattering

Figure 11.12 Continued.
Principles of Spectrometry

Interaction of heavy charged particles

- **Electronic** or nuclear (Rutherford, nuclear reactions, …) or radiative (Bremsstrahlung).

\[ \text{Rutherford} \quad \frac{d\sigma(\theta)}{d\Omega} = \left( \frac{zZe^2}{4\pi\varepsilon_0} \right)^2 \left( \frac{1}{4T_a} \right)^2 \frac{1}{\sin^4 \frac{\theta}{2}} \]

- Energy loss
- Excitation
- Ionization → ion-pair, suppress recombination in detectors.

**SRIM**

http://www.srim.org

- Depletion layer.
- Delta rays and secondary electrons.
- Electron suppression for charge integration in accelerators.
- Faraday Cup.
- Tracks.

Detectors mainly designed to make use of electronic interactions.
**Principles of Spectrometry**

**Stopping power**

Bethe-Bloch formula

\[- \frac{dE}{dx} = \frac{4\pi e^4 z^2}{m_0 v^2} \frac{NZ}{I} \ln\left(\frac{2m_0 v^2}{c^2}\right) - \ln\left(1 - \frac{v^2}{c^2}\right) - \frac{v^2}{c^2} \]

\(~1/E~

Minimum ionizing particles (mip).

~1/E
Units

You will encounter this when you run SRIM

eV / Å
keV / μm
MeV / mm
keV / (μg/cm²)
MeV / (mg/cm²)
keV / (mg/cm²)
eV / (1x10^{15} atoms/cm²)
• Energy loss is a **stochastic** process, thus **energy straggling**.

**Principles of Spectrometry**

**What about fission fragments?????**

**Electron pick-up.** ~1/E

**Stopping Experiment/Theory Helium Stopping (eV·cm²/10¹⁶)**

**Ion = Helium (2)**
**Target = Tantalum (73)**

STOP 2003
STOP 1999

Plotted are Ion Names
\( \langle E \rangle = 729 \)
\( V_\phi = 1.122 \)

Data Set=11 (45pts)
Mean Error= 8.3 a/o

**Ion = Helium (2)**
**Target = Tantalum (73)**

STOP 2003

Data Set=11 (45pts)
Mean Error= 8.3 a/o

**Distance of penetration**

**Parallel beam**

**Bragg curve**
Hadrontherapy

- Only Low Energy package
- Low Energy and Precompound hadronic model
- Markus chamber data

Normalized Dose [a.u.]

Depth [mm]