This month's discussion

Rutherford Scattering

Scattering of α particles from atomic nucleus (of infinite mass) is, historically, called Rutherford scattering.

In general, if a light particle (l_p) interacts with a heavy particle (h_p) (at a distance r) according to the force law

$$F \propto \frac{1}{r^2}$$

then the scattering (in the domain of classical mechanics) of the incident light particle (projectile) by the heavy particle (target) is Rutherford scattering.

The least distance by which a non interacting α would have passed by the nucleus is called the impact parameter (b). The angle of deviation of the path of the interacting α particle, on scattering from the nucleus, is called the scattering angle (θ). (See Fig.1). It is assumed that the nucleus is a point nucleus and has infinite mass.

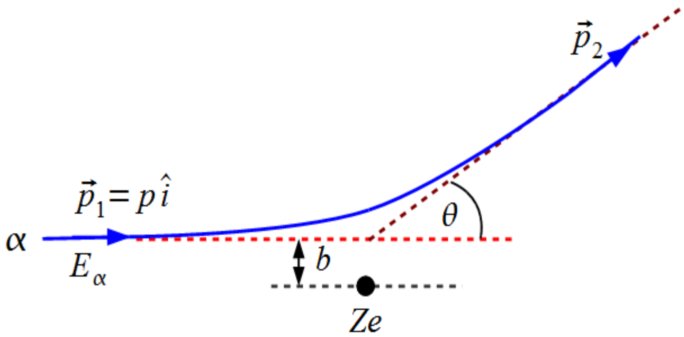

Fig.1

Known parameters are

$$\textit{charge on } \alpha \textit{ particle} = 2\,e$$

$$\textit{charge on nucleus} = Z\,e$$

energy of incident α *particle* = E_α

thickness of target foil = t

number of nuclei per unit volume of target foil = n

total number of incident α *particles* = $N_{0\alpha}$

Measured parameters are

scattering angle = θ

distance of the α *detector from the target foil* = r

total number of α *particles scattered between angle* θ *and* $\theta+d\theta$ *and received in a unit area of the detector* = $N(\theta)$.

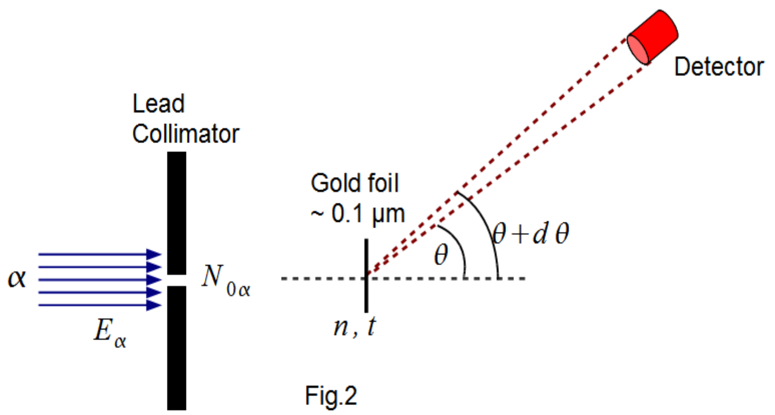

Fig.2

In classical mechanics, using conservation of total energy and angular momentum; and inverse square force law, $F=k/r^2$ where $k=2Ze^2/(4\pi\epsilon_0)$ for α -nucleus scattering, the following relations are derivable.

(1) Relation between impact parameter and the scattering angle:

$$b=\frac{k}{2E_\alpha}\cot(\frac{\theta}{2})$$

(2) Fraction of incident α particles scattered at an angle θ or more -

$$f = n t \pi b^2$$

(3) Number of α particles scattered between angle θ and $\theta + d\theta$ and received in a unit area of the detector placed at a distance *r* from the target foil -

$$N(\theta) = \frac{N_{0\alpha} n t k^2}{16 r^2 E_\alpha^2} \frac{1}{\sin^4(\theta/2)}$$

or $$N(\theta) = \frac{N_{0\alpha} n t k^2}{16 r^2 E_\alpha^2} \operatorname{cosec}^4(\theta/2) \quad .$$

Use the above information to answer the following:

1. Assume that some laboratory is able to produce a uniform beam of anti-alpha particles. If we consider the anti-alpha nucleus scattering, how will the above relations (1) to (3) change?

2. In Rutherford scattering what is the assumption regarding the size and mass of the nucleus?

3. Plot $N(\theta)$ versus θ on a (i) linear scale, (ii) semilog scale.

4. Guess, what would happen if a thick foil of gold is used as a target instead of a thin foil? (Think about the role of *nt* in the relation (2) and (3)).

5. What possible problem(s) one would face if instead of a gold foil, one uses a thin mica sheet as a target.

6. Why electrons surrounding the nucleus do not play any significant role in the Rutherford scattering?

7. What is so special about gold foil, why can't one use cheaper material like (i) aluminum, (ii) copper or (ii) lead?

8. Now a days, some labs have facilities to provide a beam of (a) protons, (b) electrons , (c) positrons (d) neutrons (e) neutrinos and (f) anti-neutrinos. Guess possible advantages / disadvantages of using these beams for studying Rutherford scattering.

9. A beam of 7.7 MeV α particles is incident on a gold foil of thickness $3\times10^{-7}m$ .The density of gold ${}_{79}\mathrm{Au}^{197}$ is $1.93\times10^{4}\mathrm{kg/m}^{3}$. What percentage of the beam will be scattered by an angle $\theta\geq45^{o}$?

(Ans. 0.007 percent)

9. (a) An alpha particle of energy 2 MeV, (b) a proton of energy 2 MeV, is incident on a gold foil. What is the distance of closest approach for a head-on-collision with a gold nucleus ${}_{79}\mathrm{Au}^{197}$?

(Ans. (a) 57 fm. (b) 114 fm)

10. A 5 Mev α particle is incident on a copper (Z = 29) foil, and is found to scatter at an angle of 60^{o} . What is the impact parameter?

(Ans. 14.4 fm)

11. Show that in the α -scattering experiment, the number of alpha particles scattered between 60^{o} and 90^{o} is twice the number scattered at an angle $\theta\geq90^{o}$.

(Submit your answers and questions before the end of the month.) - Next month's topic – Hofstadter's experiments to estimate charge and nuclear density distributions for nuclei.