

# Calculation of Maximum Energy Loss of Neutron upon Collision With Material

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## Abstract :

The aim of this research is determination the fractional loss of neutron energy when it collides with different material with different mass numbers i.e (He, C, Al, Mn, Cd, Au and  $\text{Eu}_2\text{O}_3$ ) when colliding at different collision angles ( $10^\circ$ – $180^\circ$ ), in addition to the maximum fractional energy loss of neutron upon collision of neutron. The ratio ( $\sin^2 \theta / \sin^2 \theta_0$ ) was also calculated showing that the ratio is equals unity collision angle of  $100^\circ$  and increases with the increase in collision angle until it reaches its maximum value.

**Keyword :** Energy loss, Fractional loss, Collision angles,

## 1. Introduction

Protection from neutrons is an important issue because of several factors effecting the magnitude of loss of the neutron energy upon collision with the atoms of the targeted material<sup>[1]</sup> including : the nature of targeted material (mass number , and density), The nature of collision according to the nucleus of target material as in the case when the targeted atom is stationary when the neutron approaches or both are in motion relative to the center of mass. Besides, the magnitude of neutron energy loss depends on the angle of collision. The attenuation of neutrons emitted from two sources Ra- $\alpha$ -Be and Ra- $\alpha$ -B were studied by<sup>[2]</sup> in some materials including Bi, Pb, Fe through its inelastic scattering through different angles. The method is based on the average counts of detector when spherical materials used in scattering neutrons exist or not. A decrease in the detector count was observed when material were put around the source.<sup>[3]</sup> studied the reaction of neutrons with nitrogen using neutrons from the reaction  $^7\text{Li}(p,n)^7\text{Be}$  when the reaction  $^{14}\text{N}(n,p)^{14}\text{C}$   $^{14}\text{N}(n, \alpha)^{11}\text{B}$  with several energies were conducted. It was observed that the threshold reaction (n , p) takes place at the

## 2. Theory

Since the neutron charge less, Thus it is cannot lost energy by ionization. However, they can lose energy by elastic and inelastic collision with atoms of moderating material. For determination the amount of energy lost by the neutron, we had to study the collision process. The process of collision between two bodies at the axes in

energies of 499, 640, 993, 1415 keV. while the reaction, (n,  $\alpha$ ) takes place at the energies 1415, 1800 keV. The attenuation of neutrons having energy of 14.8 MeV was studied by<sup>[4]</sup> in the material of lead, steel, aluminum, and paraffin in order to detect the primary neutrons. Energies higher than 1 eV were detected by<sup>[5]</sup> using the resonant detector technique using gamma reactions (n ,  $\gamma$ ) for some chips including  $^{113}\text{In}$ ,  $^{139}\text{La}$ ,  $^{238}\text{U}$ ,  $\text{Au}^{197}$ . calculating<sup>[6]</sup> the energy of neutrons emitted from PuBe by putting a source inside a hemisphere with a radius of 23 cm in which its first radius 3.5cm is filled with light water and its second radius 19.5cm filled with heavy water  $\text{D}_2\text{O}$ . The energy of neutron was calculated to be 0.34 Mev and it was found that the energy 47.8% of neutrons have energy less or equal 0.4eV. Energy of neutrons rebounding at various angles in various material including Xe, Ar, Ne were calculated by<sup>[7]</sup>. The current study aims at determining the amount of fractional loss of neutron energy when it collides besides the ratio ( $\sin^2 \theta / \sin^2 \theta_0$ ) for various material.

with the target nuclear is positioned before collision and the incident neutron is approaching. These axis called the L-axes (laboratory axes). While the axis in which both the center of mass of the neutron and target nuclear positioned and both nuclear and neutron approach the centre of mass, are in this case called the mass body center axis or C- axes. (see fig 1)<sup>[8]</sup>.

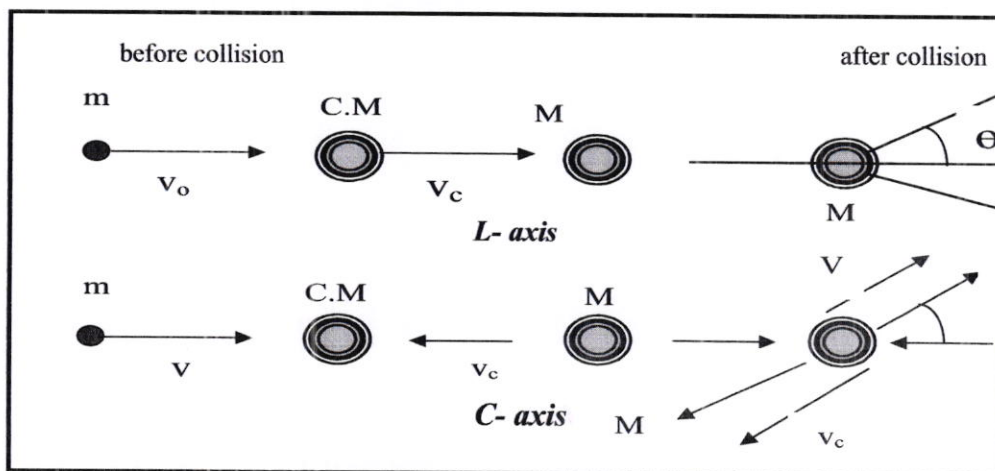


Figure 1 : types of axes at the time of collision between two particles.

When a neutron with a mass of  $m$  approaches the stationary nuclear of target  $M$  at a velocity  $V_0$ , the momentum of the neutron is shown by the following eq.<sup>[9]</sup>:  $P = m v_0 \dots (1)$

While the velocity of center of mass is given by the equation  $v_c = v_0 \frac{m}{M + m} \dots (2)$

In the L- axes and after collision the neutron moves at a velocity  $v$  at an angle  $\theta$  relative to its original direction of movement and the nuclear moves at a velocity of  $v'$  at an angle with the original direction of neutron. while the description of movement in the C- axes the neutron moving to the right at a velocity of:

$$V = v_c - v_0 = v_0 \frac{M}{M + m} \dots (3)$$

The nucleus moves to the left at a velocity of  $V_c$  and the total momentum at the C- axis is calculated by<sup>[10]</sup>:

$$P = m\left(\frac{Mv_0}{M + m}\right) - M\left(\frac{mv_0}{M + m}\right) = 0 \dots (4)$$

That means that the total momentum before collision is zero and the reason is that momentum is a vector and the direction of movement of the nuclear is opposite to the

direction of the neutron movement. The neutron makes an angle ( $\phi$ ) with its original direction after collision. while the total momentum is conserved, the momentum must equal to zero after collision and the nucleus moves at an angle of ( $\pi - \phi$ ) relative to the incident neutron. The moment equal to zero in the C- axes made the calculations simpler than those for L- axes. The observer of these axes sees changes only in the direction of neutron and nuclear as a result of collision. Each of the bodies move departing at opposite directions but the dynamic energy remains conserved in elastic collision and the velocity of both bodies remain the same before and after collision. That means that the velocities do not change in magnitude at collision but only the directions. In the case of L- axes, in which the nuclear is considered stationary before collision, the velocities change but the directions do not. The velocity of scattered neutron  $v$  at an angle  $\theta$  equals the vector sum of the velocity of the neutron and the velocity of center of mass in the C-axes. Figure 2 shows the relations between these velocities<sup>[11][12]</sup>.

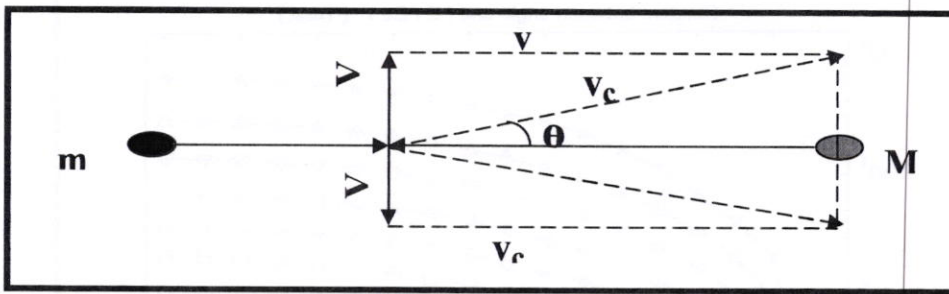


Fig 2: the relationship between various velocities.

### 3. Calculations

#### 3.1 Calculation of fractional loss of energy

The relationship between velocities is given by the relation<sup>[13]</sup>

$$v^2 = v_c^2 + V^2 + 2Vv_c \cos \theta$$

..... (5)

Also

$$\frac{v}{V} = \frac{\sin \phi}{\sin \theta} \dots (6)$$

Assuming the mass number of nucleus is  $A$  and it is 1 for the neutron, the equation can be expressed as follows:

$$\frac{m}{M} = \frac{1}{A} \dots (7)$$

Substituting in 2, 3 we have  $V = v_0 \frac{A}{1 + A}$

$$\dots (8) \quad \& \quad v_c = v_0 \frac{1}{1 + A} \dots (9)$$

If  $E_0$  was the energy of the neutron before collision and  $E$  is its energy after collision we can form a relation between them using the equations (5), (8), (9) in the following form:

$$\frac{E}{E_0} = \frac{0.5mV^2}{0.5mv_0^2} = \frac{V^2}{v_0^2} = \frac{1 + A^2 + 2ACos \theta}{(1 + A)^2} \dots (10)$$

The fractional loss of energy is given by the following relationship<sup>[14][15]</sup>:

$$\left(\frac{E}{E_0}\right) = \left(\frac{A - 1}{A + 1}\right)^2 \cos \phi \dots (11)$$

For all scattering angles between  $0 < \phi < \pi$

we can express  $(A - 1) / (A + 1)$  in the formula above by  $\alpha$  and we can write the eq. (10) in terms of  $\alpha$ .

$$\frac{E}{E_0} = \frac{1 + \alpha}{2} + \frac{1 - \alpha}{2} \cos \phi \dots (12)$$

#### 3.2 Determining the relationship between the scattering angles of $\phi$ and $\theta$ .

we can find a relation between the scattering angle  $\phi$  in the C- axes and the scattering angle  $\theta$  in the L- axes by

the combination of formula (6) with both (7 & 8)<sup>[15]</sup>

$$\frac{\sin^2 \theta}{\sin^2 \phi} = \frac{V^2}{v^2} = \frac{v_0^2}{v^2} \left(\frac{A}{1 + A}\right)^2 = \frac{E_0}{E} \left(\frac{A}{1 + A}\right)^2 \dots (13)$$

using equation 10 we had:

$$\frac{\sin^2 \theta}{\sin^2 \phi} = \frac{A^2}{1 + A^2 + 2ACos \phi} \dots (14)$$

#### 3-3 Calculating The Average $\cos \theta$ .

In order to determine the average  $\cos \theta$  we substitute and arrange the eq. 14 to determine:

$$\sin^2 \theta = \frac{A^2 \sin^2 \phi}{1 + A^2 + 2A \cos \phi} \quad \dots\dots (15)$$

but <sup>[16] [15]</sup>

$$\cos^2 \theta = 1 - \sin^2 \theta$$

..... (16)

Substituting in 16 we have

$$= 1 - \frac{A^2 \sin^2 \phi}{1 + A^2 + 2A \cos \phi}$$

..... (17)

$$= \frac{1 + A \cos \phi}{(1 + A^2 + 2A \cos \phi)^2} \quad \dots\dots (18)$$

Which means

$$\cos \theta = \frac{1 + A \cos \phi}{(1 + A^2 + 2A \cos \phi)^2} \quad \dots\dots (19)$$

We integrate 19 for all values off scattering angles  $\phi$  in the C- axes. the integration depend on the probability of scattering of neutrons at the angles laying between

( $\phi$  and  $\phi + d\phi$ ). Integrating the 3 dimensional angle element  $2\pi \sin \phi d\phi$  we have <sup>[13] [15]</sup>

$$\overline{\cos \theta} = \frac{1}{4\pi} \int_0^\pi (\cos \theta) 2\pi \sin \phi d\phi$$

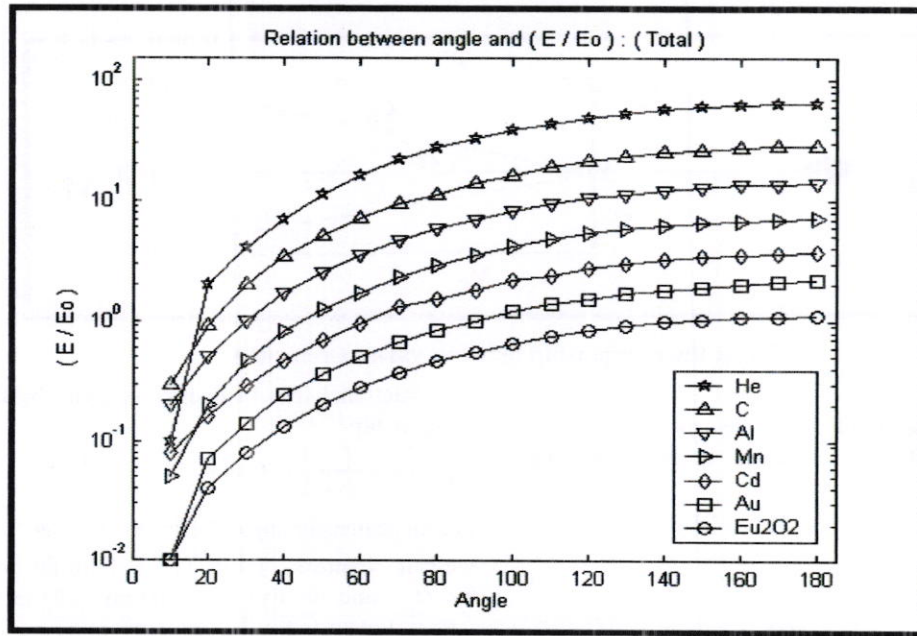
$$= \frac{1}{2} \int \frac{1 + A \cos \phi}{(1 + A^2 + 2A \cos \phi)^2} \sin \phi d\phi$$

after making  $x = \cos \phi$

$$\cos \theta = \frac{1}{2} \int_{-1}^{+1} \frac{1 + Ax}{(1 + A^2 + 2Ax)^2} dx = \frac{2}{3A} \dots$$

(20)

#### 4. Results and Discussion



**Fig 3 : fractional loss of neutron energy as a function of scattering angle for the used material.**

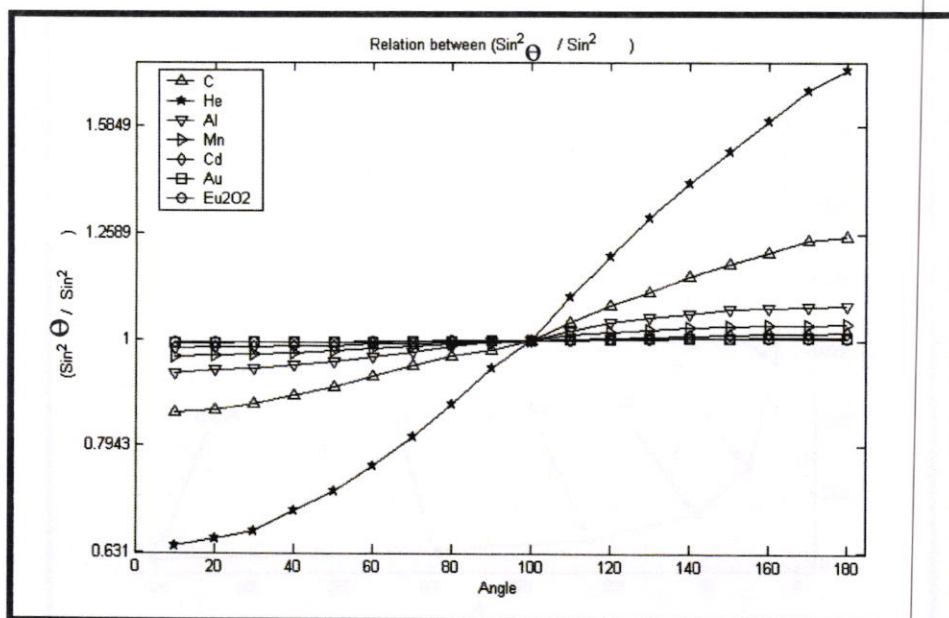


Fig 4 : the ratio of both scattering angles as a function of change in collision angle for the material used.

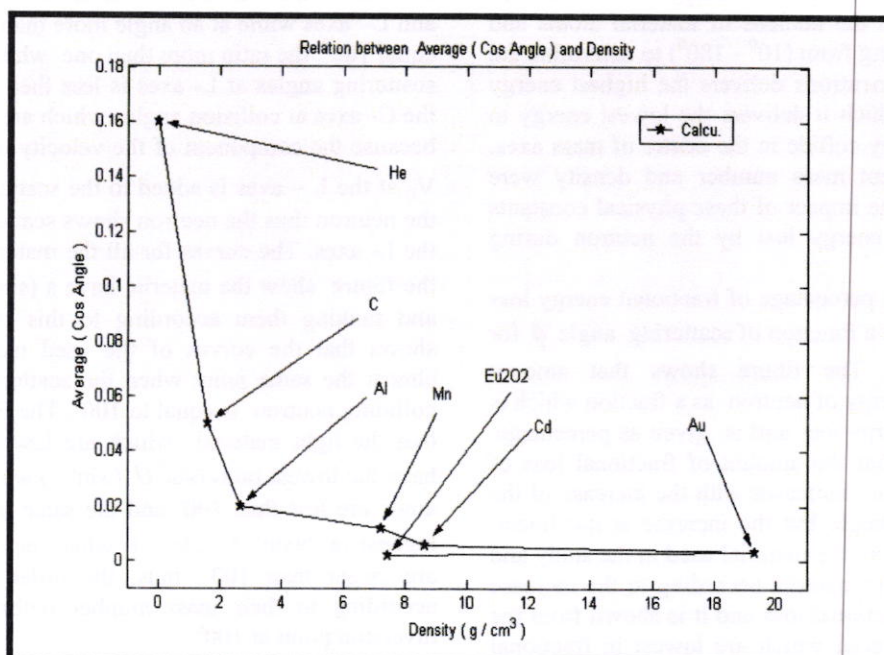
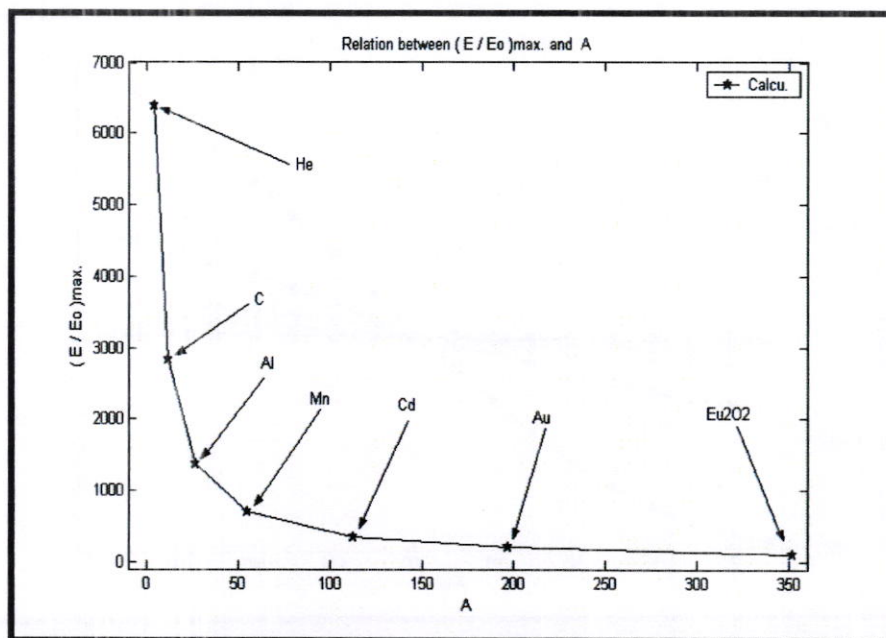


Fig 5 : the average of cosine of scattering angle as a function of density of used material.



**Fig 6 : the maximum fractional loss of energy as a function of mass number of the used material.**

The fractional loss of neutron energy was calculated when colliding with the nucleus of material atoms and various angles ranging from ( $10^0 - 180^0$ ) to determine the angle in which the neutrons delivers the highest energy and the angle in which it delivers the lowest energy to the atoms when they collide in the center of mass axes. Materials of different mass number and density were used to determine the impact of these physical constants on the amount of energy lost by the neutron during collision.

**Figure 3:** shows the percentage of fractional energy loss of neutron ( $E/E_0$ ) as a function of scattering angle  $\phi$  for different materials. The figure shows that amount fractional loss of energy of neutron as a fraction which is called fractional energy loss and is given as percentage. The figure shows that the amount of fractional loss of energy by the neutron increases with the increase of the value of scattering angle but the increase is not linear. The figure includes all the material used in the study and show the order of the material according to the increase in the amount of fractional loss and it is shown from the figure that the material which are lowest in fractional loss are  $\text{Eu}_2\text{O}_2$  which is the heaviest material (larger in mass number) followed by Au, Cd, Mn, Al, C and the highest of the material losing energy is He which is the lightest of the material used.

In figure 3 the amount of fractional energy lost when colliding in the C- axes which means a collision angle  $\phi$  while the angle of scattering in the L- axes is  $\theta$ . We used eq. (14) to determine the relationship between the two scattering angles.

In figure 4 The Relationship between the ratio of scattering angles ( $\sin^2 \theta / \sin^2 \phi$ ) which is the sine of the scattering angle in the L- axes / sine of the scattering angle in the C- axes as a function of change in the scattering angle of the neutron when colliding with the nuclei of the atoms. The figure shows that the ratio ( $\sin^2 \theta / \sin^2 \phi$ ) is less than unity for the scattering angles between ( $0^0 - 90^0$ ) and equal to one at an angle of  $100^0$

that means that the angle of scattering equal in both C - and L- axes while at an angle more than  $100^0$  and less or equal  $180^0$  the ratio more than one which means that the scattering angles at L- axes is less then the scattering in the C- axes at collision angles which are lower than  $100^0$  because the component of the velocity of center of mass  $V_c$  at the L - axes is added to the scattering velocity for the neutron thus the neutron shows scattering in favor for the L- axes. The curves for all the material are shown in the figure show the material have a ( $\sin^2 \theta / \sin^2 \phi$ ) less and ranking them according to this ratio. The figure shows that the curves of the used material cross in almost the same point when the scattering angle of the colliding neutron is equal to  $100^0$ . The figure also shows that the light material which are low in mass number have the lowest ratio ( $\sin^2 \theta / \sin^2 \phi$ ) when the scattering angle are less than  $100^0$  and the same material have the highest ratio ( $\sin^2 \theta / \sin^2 \phi$ ) when the scattering angles are larger than  $100^0$ . thus, the order of the material according to their mass number before and after the inversion point at  $100^0$ .

**Figure 5 :** The average of cosine the angle of scattering on the L- axis was calculated using the formula 20. The average was drawn as a function of densities of material used in the study. From the figure it is shown that the relation is almost exponential between the density of the material and the average of cosine the angle of scattering. In other words, whenever the density is lower the average of cosine the angle of scattering increases, except for an irregular point at the density of  $\text{Eu}_2\text{O}_2$  because this material is an oxide and not a pure element.

**Figure six :** It was found from the figure 3 that the maximum fractional loss of the neutron energy takes place at an angle of  $180^0$  that means that the neutron gives the maximum amount of energy to the nuclei of the atoms when colliding with them. The maximum fractional loss of energy was drawn as a function of change in mass number for the used material. The figure shows that the relationship is exponential. Whenever the

mass number decreased, the amount of maximum energy loss increases, thus, light material like water and graphite are used to attenuate the neutrons in nuclear reactors.

## 5. Conclusions

The highest average of cosine of scattering angle in the laboratory axes take place at the lowest density of the material used and the results show that the scattering angle in the laboratory axes is less than the scattering

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angle at the axes of center of mass for collision angles less than  $100^\circ$  and it was found that the ratio  $(\sin^2 \theta / \sin^2)$  is the lowest for the light material before the point of inversion and the ratio  $(\sin^2 \theta / \sin^2)$  is highest for the same material after the point of inversion. The material that cause highest loss in neutron energy are those with the lowest mass number.

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## حساب أعظم خسارة في طاقة النيوترون عند تصادمه مع المواد

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### الملخص

يهدف البحث إلى حساب أعظم خسارة كسرية في طاقة النيوترون عند تصادمه مع مواد مختلفة بالعدد الكتلي منها He, C, Al, Mn, Cd, Au,  $\text{Eu}_2\text{O}_2$  ، فضلاً عن حساب الخسارة الكسرية في طاقة النيوترون عند تصادمه مع هذه المواد وبزاويا تصادمية مختلفة  $10^\circ$ - $180^\circ$  درجة وتم أيضاً حساب النسبة  $(\sin^2 \theta / \sin^2)$  ، إذ ظهر من النتائج أن هذه النسبة تكون مساوية للواحد عند زاوية تصادم  $100^\circ$  درجة وتزداد بزيادة زاوية التصادم إلى أن تصل إلى أكبر قيمة لها .