# Kinematics for fusion products energies characterized to D-T fusion reaction

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## Abstract

Theoretical consideration of the possible kinematics for neutron / alpha particles emission phenomena's are necessary in understanding the physical behavior concern the thermonuclear fusion reaction. Our study concentrate on the calculation of the fusion products energies for the D-T fusion reaction ,since these materials represent the essential fuels in almost fusion power devises like Tokomak, dense plasma focus,….etc. it seen that there exist a good agreement between our calculations and the standard theoretical and experiment. And for this case, one can depend our model for the calculations of these physical parameters.

**Key words :** DT reaction, fusion products, neutron emission, alpha particles kinematics, bombarding angles.

## حركية طاقات نواتج الاندماج المميزة للتفاعل الاندماجي D-T

## الخلاصة

الاستدراك النظري لميكانيكية انبعاث نواتج التفاعل النووي الاندماجي الحراري ضروريا لفهم السلوك الفيزيائي للتفاعلات النووية الحرارية الاندماجية . تركزت الدراسة الحالية على حساب طاقة النيوترونات وجسيمات ألفا المنبعثة من التفاعل النووي الاندماجي نوع D-T وذلك كون هذه المواد تعد الوقود الرئيسي لمعظم أجهزة إنتاج الطاقة الفائقة

والصغيرة مثل أجهزة التوكاماك وأجهزة بؤرة البلازما الكثيفة . لوحظ التوافق مابين النتائج المحسوبة وفقا للنموذج المستخدم مع نظيرتها القياسية (النظرية والعملية)مما يعكس إمكانية اعتماد هذا النموذج لغرض حساب معاملات فيزيائية أخرى .

**كلمات مفتاحيه:** التفاعلD-T, نواتج الاندماج ,انبعاث النيوترونات ,ميكانيكية انبعاث جسيمات ألفا ,زوايا التصادم.

## INTRODUCTION

Fusion energy is a potential source for power production in the mid- to late-21st Century. The fusion reaction occurs within plasma composed of light nuclei. A commercial fusion power facility would likely use either magnetic or inertial means to confine the plasma and facilitate the fusion process. The fusion confinement method influences the radiation types and fuel materials that must be controlled by the health physicist.[1]

Nuclear fusion is the process by which the stars exist. Our own sun is a prime example of natural nuclear fusion. Artificially induced nuclear fusion usually involves the fusion of deuterium and tritium nuclei. These are simply isotopes of hydrogen and are available in everyday water supplies. The reason for the use of deuterium and tritium rather than hydrogen is that it is easier to fuse nuclei which are neutron rich; as the charge density is reduced by the presence of the additional neutron. That is to say that the density of the isotopes is so great that the attractive force due to gravity overcomes the coulomb repulsion between the isotopes. Thermonuclear fusion is the term applied to the process of combining two nuclei together. This process is useful because it is a method of releasing usable energy in an environmentally friendly way. The energy released in this process has the potential to fulfill mankind's ever growing requirements [2, 3].

The most important interactions that are subject to hydrogen isotopes are the following reactions.[4]

$$^{2}_{1}H + ^{2}_{1}H \rightarrow \ ^{3}_{1}H(1.011MeV) + ^{1}_{1}H(3.022MeV)$$

$$^{2}_{1}H + ^{2}_{1}H \rightarrow \ ^{3}_{2}He(0.820MeV) + ^{1}_{0}n(2.499MeV)$$

$$^{3}_{1}H + ^{2}_{1}H \rightarrow \; ^{4}_{2}He(3.561MeV) + ^{1}_{0}n(14.09MeV)$$

$$^{2}_{1}H + ^{3}_{2}He \rightarrow \; ^{4}_{2}He(3.6MeV) + ^{1}_{1}H(14.7MeV)$$

The D-T reaction has the highest reaction cross-section, so it is preferable on the rest of the interactions. And it is the easiest because the extra neutrons on the nuclei of the deuterium and tritium increase their size and thus the probability of a fusion reaction. They also each have the smallest possible positive charge (since hydrogen has only one proton), making it relatively easy to have the two nuclei overcome their repulsion and fuse together.[5]

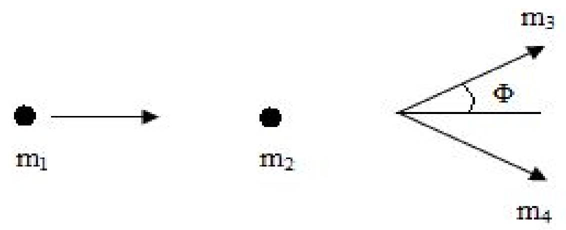
**D-T Reaction**

This reaction is the most energetic of the reactions capable to produce monoenergetic neutrons. It is especially useful with low energy deuteron accelerators, since, from cross sections considerations, it would be expected that at 150 keV incident deuteron energy, the output to be about 300 times greater than that from the D-D reaction. The very high Q-value of the reaction, 17.586 MeV, makes possible also the production of neutron with energies up to 30 MeV.[6]

The thermonuclear fusion process involves neutrons in almost all reactions, and therefore the neutrons play a key role. The most important in a fusion reactor is to carry the energy out from the burning fuel to the outside of the plasma vessel. The neutrons carry 4/5 of the fusion energy of the D-T fusion reactions and they can also be used to extract information about the reactants if properly measured.[7]

**Kinematics**

To understudy the physical for any nuclear reaction. Consider the following two-body reaction, in the following figure. Initially nucleon (1)of mass ($m_1$) is incident on nucleon( 2) of mass ($m_2$) which is at rest in the lab system; after the interaction only nucleons( 3) of mass ($m_3$) and( 4) of mass ($m_4$) emerge.




The general expression for the energy of nucleon (3) in the lab system can be written in the form.[8]

$$E_{l}(m_3,\Phi) = \left(\frac{m_1}{m_1+m_2}\right)^2 \frac{m_3}{m_1} E_o \cos 2\Phi \frac{m_4}{m_3+m_4}\left(\frac{m_2}{m_1+m_2} E_0 + Q\right)$$

$$\pm 2\left(\frac{2\cos\Phi}{m_1+m_2}\right)\sqrt{\left(\left(\frac{m_4}{m_3+m_4}\right)/\, m_1 m_3\right) E_o \left(\frac{m_2}{m_1+m_2} E_0 + Q\right)} \times \sqrt{1 - \frac{m_1 m_3}{m_1+m_2} \frac{E_o \sin^2\Phi}{m_4\left(\frac{m_2}{m_1+m_2} E_o + Q\right)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where $E_o$ is the energy of nucleon 1 in the lab system, Φ is the lab angle made by the velocity vector of nucleon 3 with the beam direction, the mi's are the respective nucleon masses, and the Q of the reaction is defined customarily as Q = $m_3 + m_4 - m_1 - m_2$.

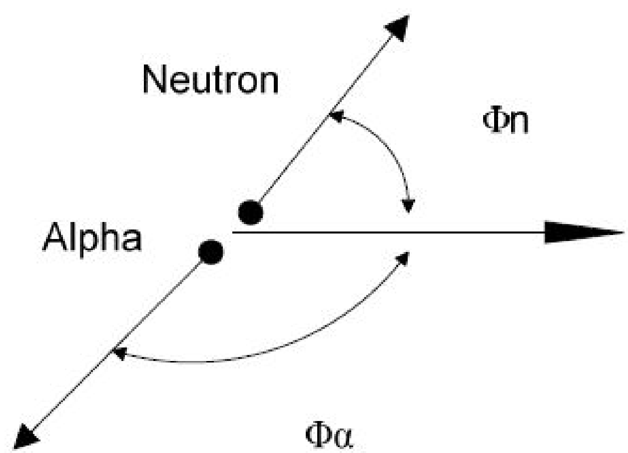
For the case of the reaction D+T $\rightarrow {}^1_0n + {}^4_2He$, equation (1) yields for the neutron energy.[9]

$$E_n(E_o,\Phi_n) = 0.08E_o \cos 2\Phi_n + 0.8(0.6E_o + 17.6) + 0.8\cos\Phi_n \sqrt{0.4E_o(0.6E_o + 17.6)} \times \sqrt{1 - \frac{E_o \sin^2\Phi_n}{10(0.6E_o + 17.6)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where Q = 17.6 MeV of D-T reaction. And equation (1) yields for the alpha particle energy.

$$E_\alpha(E_o,\Phi_\alpha) = 0.32E_o\cos 2\Phi_\alpha + 0.2(0.6E_o+17.6) + 0.8\cos\Phi_\alpha\sqrt{0.025E_o(0.6E_c+17.6)} * \sqrt{1-\frac{8E_o\sin^2\Phi_\alpha}{5(0.6E_o+17.6)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

In the Lab frame of reference, the relation between neutron and associated α-particle from a given D-T encounter are to be found. Equation (4), relates$\Phi_\alpha$, the angle made by the the α-particle with beam direction, to$\Phi_n$, that made by the neutron and the beam direction, and this relation is described as in picturly as follow.[8]




$$\tan\Phi_\alpha = \frac{0.5\sin 2\Phi_n + \sin\Phi_n\sqrt{\frac{1}{\gamma^2}-\sin^2\Phi_n}}{-\sin^2\Phi_n+\cos\Phi_n\sqrt{\frac{1}{\gamma^2}-\sin^2\Phi_n}-\frac{m_\alpha}{m_n}} \quad \ldots\ldots\ldots\ldots\ldots \quad 4$$

Here,

$$\frac{1}{\gamma^2} = \frac{V_n}{V_{c.m.}} = \frac{m_\alpha}{m_n}\frac{(m_1+m_2)}{m_1}\left(\frac{m_2}{m_1+m_2}+\frac{Q}{E_o}\right)$$

Where, $m_1$= mass of incident particle, $m_2$= mass of target particle, $m_n$= mass of neutron, $m_\alpha$= mass of alpha, $E_o$= incident energy.

## Calculation and Discussion

Result describes the variation of neutron energies produce by the D-T fusion reaction are completely tabulated in table (1), and picturly in fig.(1). It is observed there exist an agreement between our calculated neutron energies with the standard theoretical value ($E_n$=14.1 MeV), specially at angles approach ($90^o$),and this case can be explained as there is no scattering from the beams or bombarding beams energy, but we are clearly observed a shift at others bombarding angles. Result involved the alpha particles energies produce by D-T fusion reaction are tabulated in table (2), and picturly describe in fig.(2),previously explained we observed that we calculate value about ($E_\alpha = 3.5\ MeV$) ,at bamberding angle ($90^o$) which gives a logical explanation that there is no scatterning or losses in the fusion reactant nuclear . the relation between the angle made by the neutron and associated alpha particles with incident deuteron beam line, are tabulated in table (3) and described picturly in fig.(3). Finally we concluded that it is useful to depend our physical kinematics for describing others important, parameter deal with D-T fusion reaction

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**Table 1: Neutron Energy Vs Lab Angle for Deuteron Bombarding Energy $E_o$.**

| Φn (lab)° | E0=0.1MeV En MeV | E0=0.2MeV En MeV | E0=0.3MeV En MeV | E0=0.4MeV En MeV | E0=0.5MeV En MeV |
|---|---|---|---|---|---|
| 0 | 14.80838 | 15.1445 | 15.41655 | 15.6556 | 15.87367 |
| 10 | 14.79768 | 15.12905 | 15.39732 | 15.63309 | 15.8482 |
| 20 | 14.76594 | 15.08326 | 15.34035 | 15.56643 | 15.77279 |
| 30 | 14.71426 | 15.00878 | 15.24778 | 15.45819 | 15.65042 |
| 40 | 14.6444 | 14.90827 | 15.12302 | 15.31246 | 15.48582 |
| 50 | 14.55874 | 14.78528 | 14.97059 | 15.13466 | 15.28523 |
| 60 | 14.46012 | 14.64405 | 14.7959 | 14.93123 | 15.05604 |
| 70 | 14.35178 | 14.48936 | 14.60498 | 14.7093 | 14.80643 |
| 80 | 14.23721 | 14.32627 | 14.4042 | 14.47638 | 14.5449 |
| 90 | 14.12 | 14.16 | 14.2 | 14.24 | 14.28 |
| 100 | 14.00376 | 13.99565 | 13.9987 | 14.00748 | 14.01992 |
| 110 | 13.89196 | 13.83813 | 13.80625 | 13.78567 | 13.77229 |
| 120 | 13.78788 | 13.69195 | 13.6281 | 13.58077 | 13.54396 |
| 130 | 13.69448 | 13.56117 | 13.46908 | 13.39822 | 13.34088 |
| 140 | 13.61438 | 13.44929 | 13.33332 | 13.24265 | 13.16808 |
| 150 | 13.54974 | 13.35922 | 13.22422 | 13.11781 | 13.02958 |
| 160 | 13.50232 | 13.29325 | 13.14442 | 13.02659 | 12.92849 |
| 170 | 13.47336 | 13.25302 | 13.09579 | 12.97105 | 12.86698 |
| 180 | 13.46362 | 13.2395 | 13.07945 | 12.9524 | 12.84633 |

**Table 2: Alpha Energy Vs Lab Angle for Deuteron Bombarding Energy $E_o$.**

| Φa (lab)° | E0=0.1MeV $E_\alpha$ MeV | E0=0.2MeV $E_\alpha$ MeV | E0=0.3MeV $E_\alpha$ MeV | E0=0.4MeV $E_\alpha$ MeV | E0=0.5MeV $E_\alpha$ MeV |
|---|---|---|---|---|---|
| 0 | 3.90019 | 4.084252 | 4.236274 | 4.371799 | 4.496836 |
| 10 | 3.894585 | 4.076012 | 4.22588 | 4.359497 | 4.482781 |
| 20 | 3.877944 | 4.051553 | 4.195032 | 4.322991 | 4.441079 |
| 30 | 3.85078 | 4.011639 | 4.144707 | 4.263454 | 4.373087 |
| 40 | 3.81393 | 3.957517 | 4.076496 | 4.182786 | 4.280997 |
| 50 | 3.768525 | 3.890862 | 3.992527 | 4.083527 | 4.167733 |
| 60 | 3.715952 | 3.813723 | 3.895397 | 3.968761 | 4.036829 |
| 70 | 3.657813 | 3.728452 | 3.788071 | 3.841998 | 3.892296 |
| 80 | 3.595871 | 3.637633 | 3.673796 | 3.707067 | 3.738493 |
| 90 | 3.532 | 3.544 | 3.556 | 3.568 | 3.58 |
| 100 | 3.468129 | 3.450367 | 3.438204 | 3.428933 | 3.421507 |
| 110 | 3.406187 | 3.359548 | 3.323929 | 3.294002 | 3.267704 |
| 120 | 3.348048 | 3.274277 | 3.216603 | 3.167239 | 3.123171 |
| 130 | 3.295475 | 3.197138 | 3.119473 | 3.052473 | 2.992267 |
| 140 | 3.25007 | 3.130483 | 3.035504 | 2.953214 | 2.879003 |
| 150 | 3.21322 | 3.076361 | 2.967293 | 2.872546 | 2.786913 |
| 160 | 3.186056 | 3.036447 | 2.916968 | 2.813009 | 2.718921 |
| 170 | 3.169415 | 3.011988 | 2.88612 | 2.776503 | 2.677219 |
| 180 | 3.16381 | 3.003748 | 2.875726 | 2.764201 | 2.663164 |

**Table 3: Angle between Alpha Particle and Incident Beam for Deuteron Bombarding Energy $E_o$.**

| $\phi_n(Lab)^o$ | E=0.1MeV $\phi_\alpha(Lab)^o$ | E=0.2MeV $\phi_\alpha(Lab)^o$ | E=0.3MeV $\phi_\alpha(Lab)^o$ | E=0.4MeV $\phi_\alpha(Lab)^o$ | E=0.5MeV $\phi_\alpha(Lab)^o$ |
|---|---|---|---|---|---|
| 0 | 180 | 180 | 180 | 180 | 180 |
| 10 | 168.69 | 168.07 | 167.61 | 167.11 | 166.68 |
| 20 | 157.44 | 156.24 | 154.97 | 154.37 | 153.56 |
| 30 | 146.29 | 144.57 | 143.17 | 141.94 | 140.81 |
| 40 | 135.28 | 133.14 | 131.41 | 129.9 | 128.54 |
| 50 | 124.45 | 121.98 | 120.02 | 118.32 | 116.8 |
| 60 | 113.82 | 111.13 | 109.03 | 107.23 | 105.63 |
| 70 | 103.41 | 100.6 | 98.43 | 96.61 | 94.99 |
| 80 | 93.2 | 90.38 | 88.23 | 86.43 | 84.86 |
| 90 | 83.21 | 80.46 | 78.38 | 76.67 | 75.18 |
| 100 | 73.42 | 70.81 | 68.87 | 67.27 | 65.89 |
| 110 | 63.82 | 61.41 | 59.97 | 58.19 | 56.95 |
| 120 | 54.38 | 52.23 | 50.66 | 49.38 | 48.29 |
| 130 | 45.09 | 43.23 | 41.89 | 40.81 | 39.89 |
| 140 | 35.92 | 34.4 | 33.31 | 32.43 | 31.68 |
| 150 | 26.85 | 25.69 | 24.86 | 24.19 | 23.63 |
| 160 | 17.87 | 17.08 | 16.52 | 16.07 | 15.52 |
| 170 | 8.92 | 8.53 | 8.21 | 8.02 | 7.83 |
| 180 | 0 | 0 | 0 | 0 | 0 |

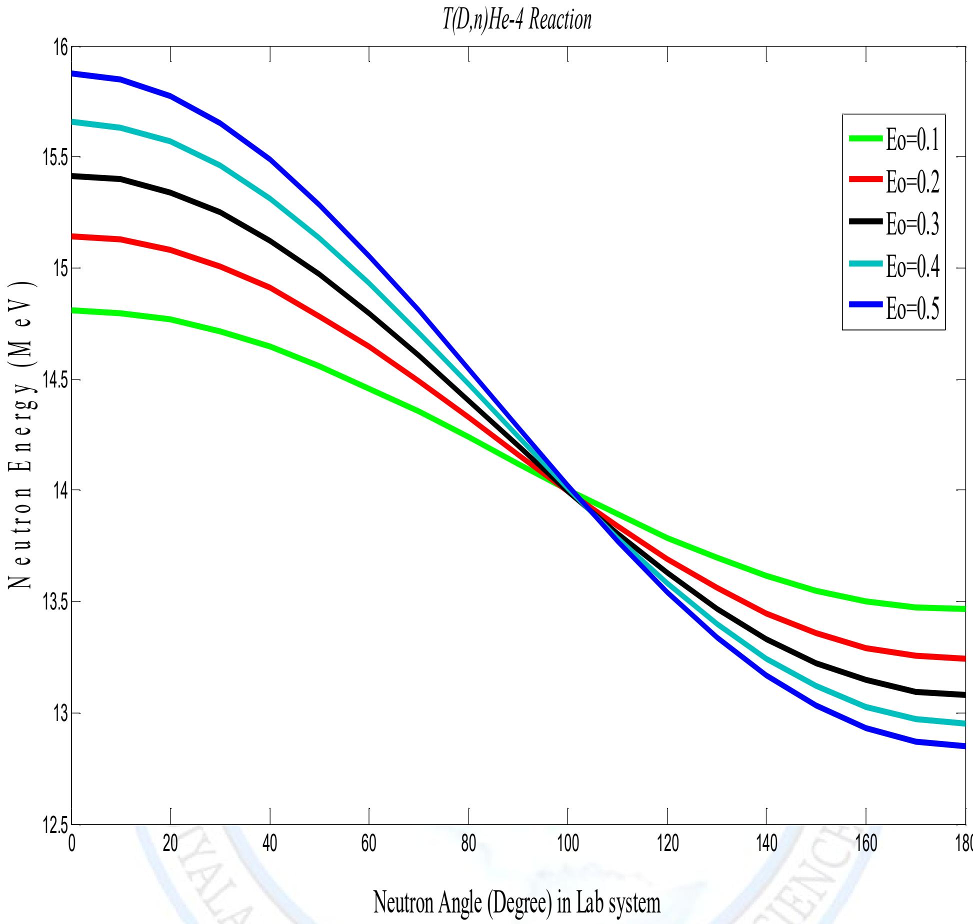


**Fig.1: Neutron energy from the reaction T (D, n) He as a function of observation angle in the lab system. Eo is the energy in MeV of the incident deuteron.**

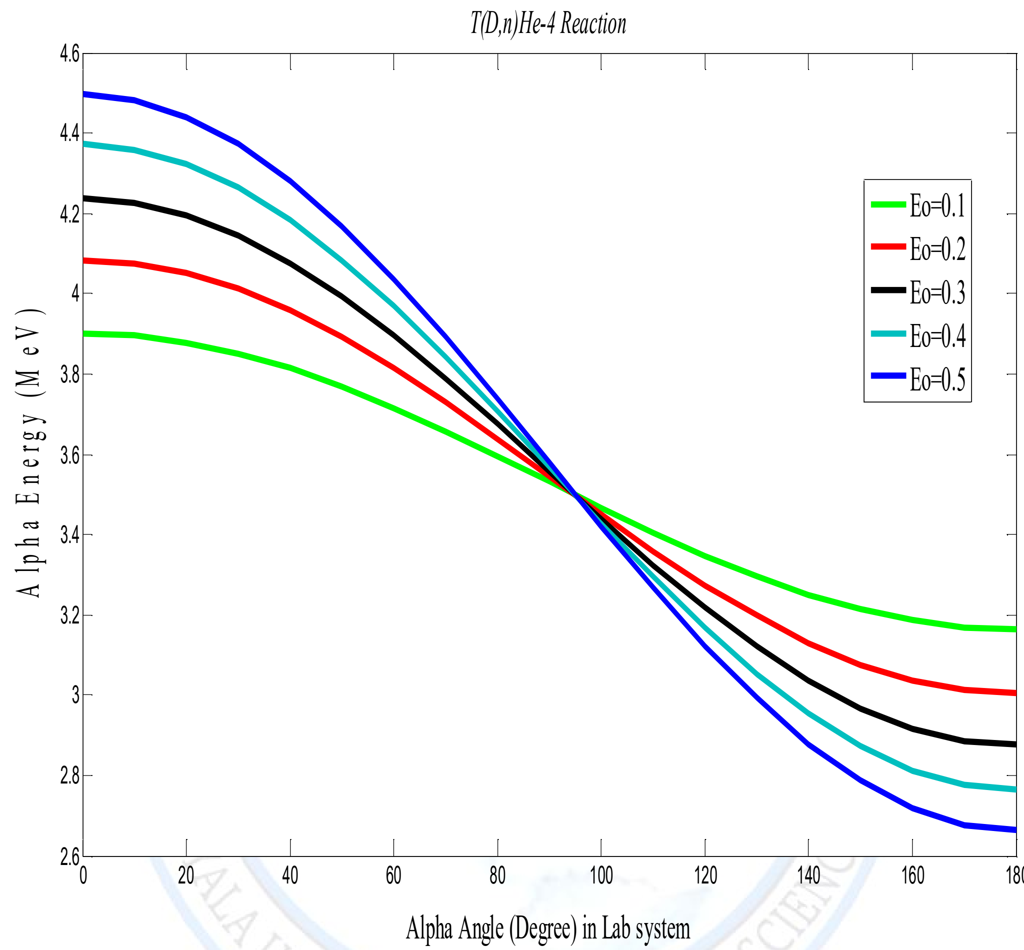


**Fig.2: Alpha energy from the reaction T (D, n) He as a function of observation angle in the lab system. $E_o$ is the energy in MeV of the incident deuteron.**

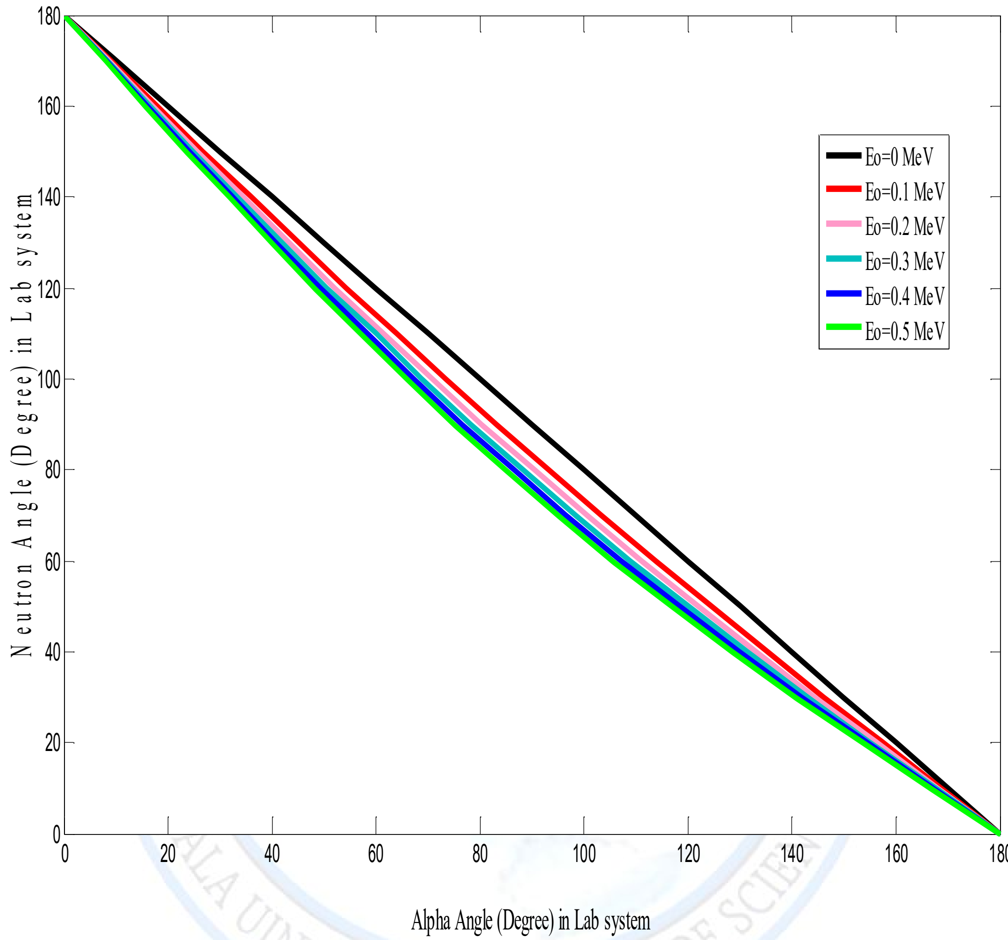


**Fig.3: Relation between the angles made by the neutron and associated alpha particle with incident deuteron beam line. $E_o$ is the energy in MeV of the incident deuteron.**