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A PROPOSED METHOD OF MEASURING NEUTRON ENERGIES BY THE (n,α) REACTION IN Li^6 USING NUCLEAR EMULSIONS

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A Proposed Method of Measuring Neutron Energies by The (n,α) Reaction in Li^6 Using Nuclear Emulsions

Introduction

One of the difficult problems faced in neutron physics is to obtain good measurements of the energy of fast neutrons, especially if the geometry is such that neutron collimation cannot be obtained.

It has been suggested[1] that one might make use of nuclear emulsions loaded with lithium to measure the energies of fast neutrons. This paper is an analysis of the problems involved and a study of the feasibility of this method, together with suggestions as to how the difficulties may be overcome. To use this reaction, of course, it will be necessary to measure the excitation function of Li^6 to higher energies. The maximum energy for which it has been measured to date is about 0.8 Mev.

The Nuclear Reaction

The reaction under consideration is the following:

$$_3Li^6 + {}_0n' \longrightarrow {}_2He^4 + {}_1H^3 + Q.$$

This reaction is exothermic and Q = 4.64 Mev. If the reaction is with thermal neutrons, the conservation of momentum and energy require that the particles will be emitted in opposite directions, the alpha particle having an energy of 1.99 Mev

[1] C. F. Powell and G. P. S. Occhialini, Nuclear Physics in Photographs.

and the triton an energy of 2.65 Mev. Since there are no known excited states in the products of disintegration, all of the energy will go into the kinetic energy of the nuclei.

Suppose an incident neutron enters the nucleus of a Li^6 atom. Fig. 1 shows vector diagrams of the momentum of the incident neutron and of the disintegration products. Let P_n be the momentum of the neutron, P_α the momentum of the alpha particle, and P_T the momentum of the triton.

From the law of cosines and the conservation of momentum, we have

$$P_n^2 = P_\alpha^2 + P_T^2 - 2P_\alpha P_T \cos \phi$$

Since $\phi = \pi - \theta$,

$$P_n^2 = P_\alpha^2 + P_T^2 + 2P_\alpha P_T \cos \theta \qquad (1)$$

The Q of the reaction will be the difference between the kinetic energy of the disintegration products and of the incident neutron:

$$Q = \frac{1}{2m_\alpha} P_\alpha^2 + \frac{1}{2m_T} P_T^2 - \frac{1}{2m_n} P_n^2 , \qquad (2)$$

where m_α, m_T and m_n, are the masses of the alpha particle, the triton, and the neutron respectively. From equations (1) and (2),

$$Q = E_\alpha + E_T - \frac{m_\alpha}{m_n} E_\alpha - \frac{m_T}{m_n} E_T - \frac{P_\alpha P_T}{m_n} \cos \theta$$

$$= E_\alpha \left(1 - \frac{m_\alpha}{m_n}\right) + E_T \left(1 - \frac{m_T}{m_n}\right) - \frac{1}{m_n} P_\alpha P_T \cos \theta$$

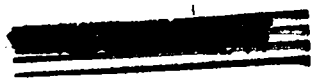
Solving for $\cos\theta$ we have

$$\cos\theta = \frac{E_\alpha \left(1 - \frac{m_\alpha}{m_n}\right) + E_T \left(1 - \frac{m_T}{m_n}\right) - Q}{\frac{P_\alpha \quad P_T}{m_n}} \qquad (3)$$

Since $P_\alpha = \sqrt{2m_\alpha E_\alpha}$ and $P_T = \sqrt{2m_T E_T}$, this equation essentially involves three quantities which can vary for a given neutron energy, θ, E_α, and E_T. The measurement of any two of these quantities uniquely determines the third, and therefore the neutron energy (Eq. 2). If one could obtain a good measurement of all three quantities a good check would result.

Fig. 2 gives a plot of the angle as a function of the neutron energy if in the disintegration the excess energy supplied by the neutron is equally divided between the alpha particle and triton. A more detailed study of the angle as it depends upon how the energy of the neutron is taken up by the two particles of disintegration is given by the following table for a neutron energy of 0.3 Mev.

The angle approaches 180° if either the alpha particle or the triton is emitted in the direction from which the neutron came and approaches a minimum of 169°7' if the energy of the neutron is equally divided between the alpha particle and triton. If the point at which the two tracks originated can be accurately determined, the reactions for which $\theta = 180°$

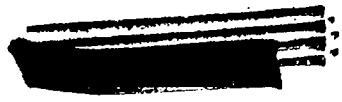


may give very useful data in the determination of neutron energies in the low energy region ($\sim$ 0.3 Mev).

Energy of α particle	Energy of triton	θ
1.67	3.27	180°
1.99	2.95	169° 25'
2.14	2.80	169° 7'
2.29	2.65	170° 24'
2.39	2.55	172° 19'
2.49	2.45	173° 13'
$\sim$ 2.68	$\sim$ 2.26	180°

Quantities to be measured and inherent difficulties in the method

If the incident neutron producing the disintegration is perpendicular to the plane of the emulsion, it would not be possible to obtain sufficient accuracy in the measurement of the angle to determine the neutron energy. However, if the tracks lie approximately in the plane of the emulsion, the angle can be measured with fair precision; the measurement of the angle, together with the measurement of the range of the alpha particle should in this case be sufficient to determine the neutron energy. The angle could not be measured with good precision in a number of cases also because of the scattering of the particles of disintegration. However, for every reaction observed, the length of the triton track should also be measured;



after many tracks have been measured, it should be possible to determine the range energy relationship for the triton tracks from the tracks for which the angle can be measured with sufficient precision.[2]

In exploring the feasibility of this method, it would be well to do the following:

(1) Expose the lithium loaded plates to thermal neutrons; work out the best developing technique to obtain clear discrimination between the alpha and triton tracks. When this technique is established, measure the lengths of an appreciable number of alpha and triton tracks (if it turns out that one can determine clearly the point where the two particles originated), and determine the variation in length due to straggling, etc.

(2) Expose lithium loaded plates to monoenergetic neutrons produced either by an accelerator or by a photoneutron source[3] (e.g., Na^{24} - γ - Be producing 1.0 Mev neutrons). Make a careful study of the tracks--measuring lengths and angles when feasible. Determine the probability of misinterpreting the neutron energy associated with observed disintegrations. This should be done for three or four neutron energies. One

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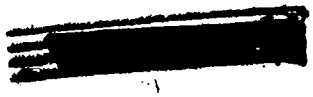
[2] R. E. Schreiber has suggested that the range-energy curves should be deducible with good precision for proton and deuteron range energy curves. For the same charge and velocity, $-\left(\frac{dE}{dx}\right)_T = -\left(\frac{dE}{dx}\right)_{\text{proton}}$.

[3] This may not be feasible because of the high gamma-ray background.

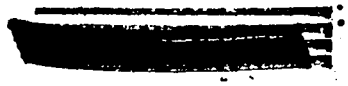


energy should be 0.2 or 0.3 Mev, to determine how far down the energy scale one can go.

If the two problems above are solved in a satisfactory way, one should be ready to study neutron sources emitting neutrons over a wide range of energies. The neutron spectrum from a source which has been previously studied should be measured first, to determine how the method compares with others.

One of the chief difficulties inherent in this method is the high background of proton tracks which one obtains from n-p scattering. The lithium loaded emulsions produced by Eastman Kodak and Ilford Limited contain about ten times as many hydrogen atoms as lithium atoms. The capture cross section of normal lithium for the n-p reaction in Li^6, at 0.8 Mev, the highest neutron energy for which the cross section has been yet measured, is about 0.03 barns. The cross section for n-p scattering at this energy is about 5 barns. This means that there would be about 1700 proton tracks for every track from the Li^6 disintegration. This ratio is so large that it would appear that the method is entirely unfeasible in lithium loaded emulsions currently produced. In the lower energy region, of course, the proton tracks would be very short and could probably be tolerated. For neutrons of several Mev energy the proton tracks would probably make the plates entirely unusable.

There are two possible solutions to the above problem, both of which may have to be feasible in order for the method



to work:

(1) Normal lithium contains only about 7.5% Li^6. If the plates could be loaded with lithium enriched by a factor of ten in the Li^6 isotope, the ratio of proton tracks to alpha-triton tracks could be reduced to about 170. Lithium thus enriched in the Li^6 isotope can be obtained, and either Eastman Kodak or Ilford Limited would be happy to put it into nuclear emulsions.

(2) If ten times as much lithium could be loaded into the emulsions as is currently done, the ratio of tracks could also be reduced to about 170 to 1. Eastman Kodak reports that they can load emulsions so that there are 1.3 atoms of hydrogen to every atom of lithium.

Since it appears that both of these problems can be solved the solutions can be combined, and the ratio of tracks reduced to about 17 to 1. There should be no inherent difficulty in discriminating between the two types of tracks produced in such a lithium loaded emulsion.

Another possible solution to increasing the ratio of lithium to hydrogen atoms is to reduce the number of hydrogen atoms. Photographic plates containing practically no hydrogen have been produced. Inquiries are being made concerning the properties of these plates, so that the feasibility of their use can be determined.

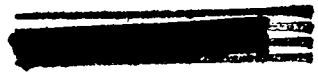
Another difficulty is the small cross section of the (n, α) reaction in lithium. This limits the method to rather

high neutron fluxes. However, it can be readily shown that the method is applicable to neutron sources that are currently produced. Suppose, for example, that a neutron source with a yield of 10^6 neuts/sec is to be studied. If this is a source with small volume (about one cubic centimeter), small photographic plates could be put close to it so that the neutron flux through the plate is of the order of 10^5 neutrons per cm^2 per sec. Lithium loaded emulsions 50 microns thick produced currently have about 1.3×10^{19} lithium atoms per cm^2. If one assumes a cross section of 0.02 barns, a twenty-four hour exposure would give about 2000 tracks per cm^2, or with a microscope with a field of view of 1.3×10^{-4} cm^2, there would be about 0.3 tracks per field of view. If lithium enriched in the Li^6 isotope is put into the emulsion and if more lithium atoms are put in this number will be further increased.

Inherent Advantages of the Method

If the method should prove to be feasible it has the following inherent advantages in neutron spectra measurements:

(1) In the proton recoil method, the neutrons must either be collimated or else an integral curve is obtained which must be differentiated properly if the neutron energies are to be determined. In the method proposed in this paper, the neutron energy associated with an observed disintegration is uniquely determined without a knowledge of the direction of the incident neutron. In fact, it should be possible to determine



the direction of the neutron as well as its energy if a study of this is desired.

(2) If one desires to measure the neutron energy distribution inside a medium, a photographic plate does not occupy much space as compared with a proton recoil counter. It would therefore produce a smaller perturbation of the quantities to be measured. A proton recoil counter also requires collimated neutrons if the results are to be readily interpreted.

(3) A more complete picture of the neutron spectrum should be obtained as compared with that obtained by the method of activating foils, such as various threshold detectors.

Acknowledgment

Acknowledgement is made to L. Rosen of the Los Alamos Scientific Laboratory, to B. D. McDaniel of Cornell University, and to C. Critchfieldof the U. of Minn. for profitable suggestions and discussions concerning the feasibility of this method.

The experimental features of the method are being investigated by W. Stratton, a graduate student from the University of Minnesota.

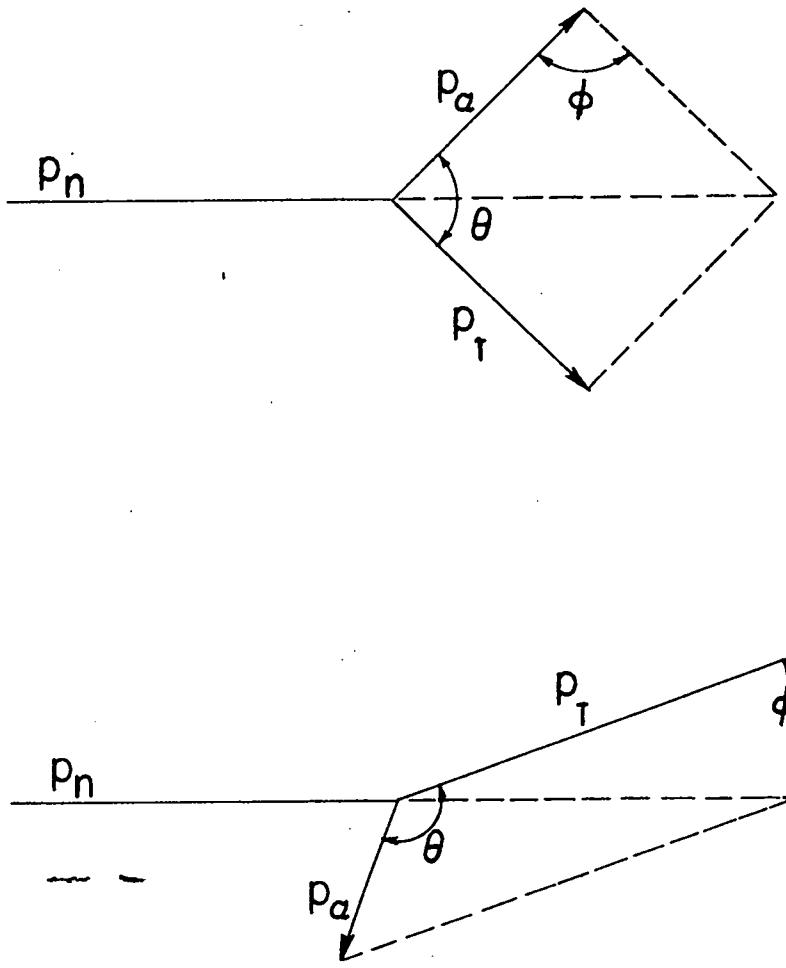


FIG 1

VECTOR DIAGRAMS SHOWING CONSERVATION OF LINEAR MOMENTUM IN THE (n, α) REACTION IN Li^6

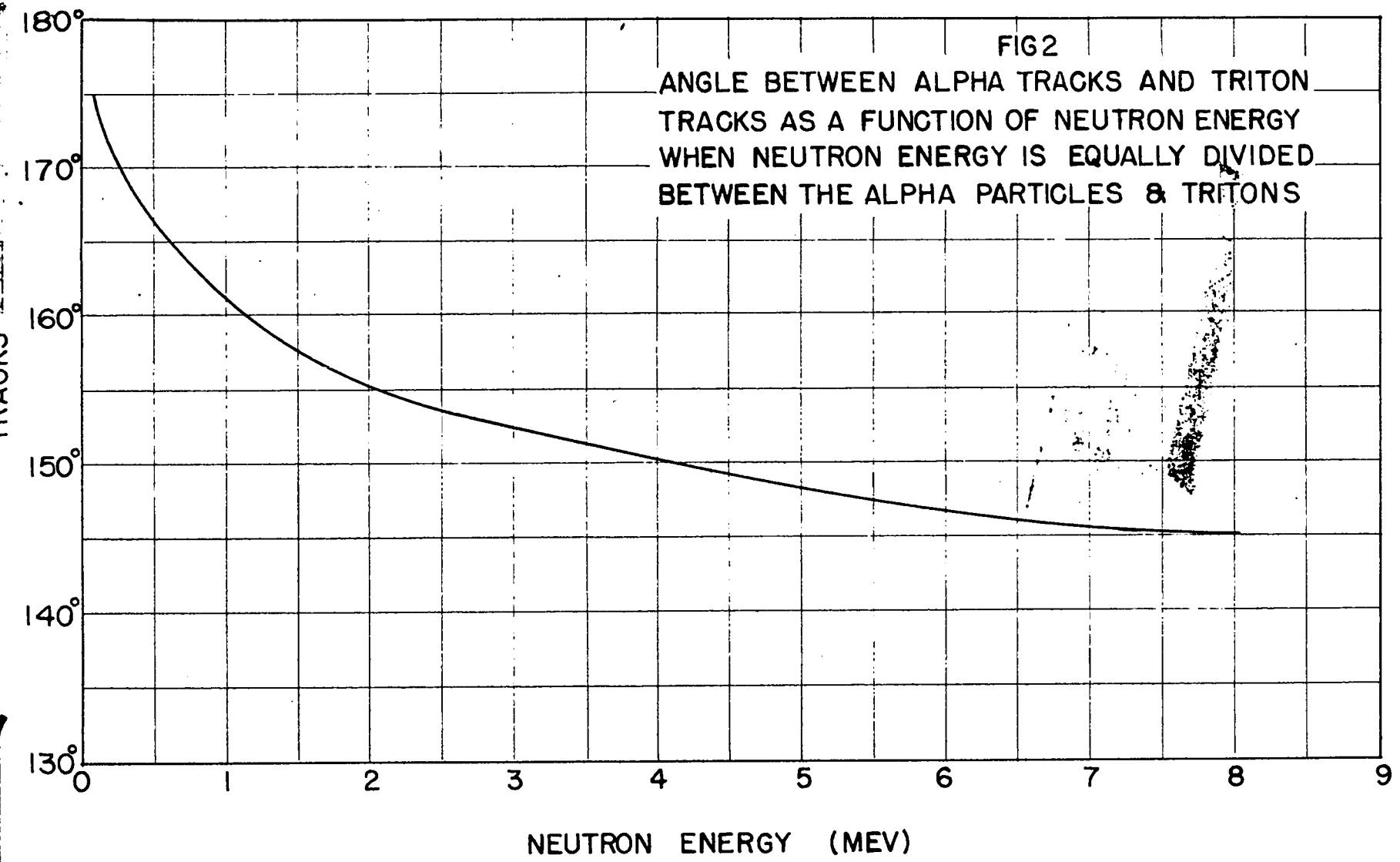


FIG 2
ANGLE BETWEEN ALPHA TRACKS AND TRITON TRACKS AS A FUNCTION OF NEUTRON ENERGY WHEN NEUTRON ENERGY IS EQUALLY DIVIDED BETWEEN THE ALPHA PARTICLES & TRITONS

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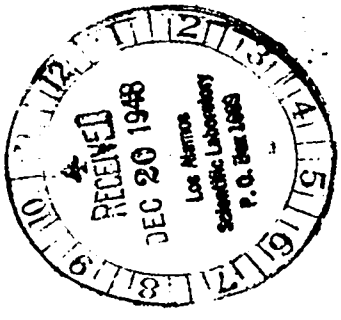

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