Introduction

Early investigations regarding neutron induced reactions were limited by the lack of mono-energetic neutron sources. With the availability of tritium, the high energy 14 MeV mono energetic neutrons from the $^3H(d,n)^4He$ reaction, and also the large cross-section for this reaction obtained with low deuteron energy, made it a very strong source of mono-energetic neutrons. These neutrons being fast and uncharged their penetrability is high even for large values of angular momenta, and for this reason a nuclear level possessing a large spin might be excited by these neutrons, which might not be the case in reactions using slower charged particles of low angular momenta.

Neutrons experience no potential barrier difficulty in penetrating even very heavy and highly charged atomic nuclei, and as such the neutron induced reactions have played a significant role towards the understanding of the mechanism of nuclear reactions. A study of $(n,\alpha)$ interactions can throw considerable light on energy level densities, because of the improbability of the presence of direct interaction processes in these reactions, as well as on problems of nuclear structure.

Many possible interactions of neutrons with matter may be expressed quantitatively in terms of the cross-sections for the various interactions, which can be visualized as the cross-sectional area presented by the nucleus to the incident neutrons. Neutron cross-section measurement is of fundamental importance in neutron
physics and it can be said that practically all the neutron researches deal with the measurement of neutron cross sections. The experimental values of total cross-section show individual variation from element to element but are in reasonable agreement with the simple picture of cross-section as a nuclear area. Although there are many cross-section measurement techniques but all of them are governed by the same principles. The particular technique used for cross-section measurement may vary greatly with neutron energy and with the material under investigation, but the equations used to calculate cross-sections from the experimental data remain the same. Total cross-section can be measured by transmission with great accuracy, because only the ratio of counting rates with and without the sample is significant, and the knowledge of the absolute efficiency of the detector is not needed. It is much more difficult to measure the partial cross-section for scattering or absorption. The scattering cross section may be measured from the flux of the scattered neutrons. The absorption cross sections which are extremely small can be obtained from the measurement of the diffusion length of slow neutrons in a pile and by other methods which may suit the purpose.

When a beam of neutrons passes through a material the number of neutrons removed from the beam is proportional to the total cross section $\sigma$, whether the individual process concerned is neutron scattering, absorption or both. In a thickness of the material $dx$ containing $N$ nuclei/cm$^3$, the fractional neutron flux removed from the beam, $d(\nu \sigma)/\nu$, will be

$$d(\nu \sigma)/\nu = -N \sigma d\chi$$
Integration of this gives
\[ \eta \nu = (\eta \nu)_0 e^{-N \delta_T x} \]
where \((\eta \nu)_0\) is the neutron flux incident on the material and \(\eta \nu\) the flux after traversal of the distance \(x\). The ratio of flux at a point \(x\) to the initial flux is called the transmission \(T\) for the thickness \(x\) and is given by
\[ T = e^{-N \delta_T x} \]
\[ \delta_T = \frac{I_n (\frac{1}{T})}{N} \]
The neutron flux per unit solid angle \((\omega)\) measured at a certain angle relative to the incident flux gives the differential scattering cross section \(d \sigma_s/da\)
\[ d \sigma_s/da = \frac{\eta \nu N \omega}{(\eta \nu)_0^2} \Delta \omega \]
in the laboratory system when \(\Delta \omega\) is the solid angle subtended at the sample by the detector. The activation cross sections \(\sigma_{\text{act}}\) are most commonly determined by the radioactivity of the product nucleus, usually, by the results of \((\gamma, \nu)\) reactions, and in a few cases which are specially marked, by \((\gamma, P)\) and \((\gamma, \omega)\) reactions. In some cases \((\gamma, P)\) and \((\gamma, \omega)\) reactions have been measured in cloud chambers and counters, while other activation cross-sections have been estimated from the changes in the isotopic abundance after long pile irradiations. The activation cross-sections refer to particular isotopes and are therefore the isotopic cross-section, whereas reaction cross-sections refer to all the cases in which neutron is not re-emitted, and can be measured by various techniques. Absorptions cross-sections \(\sigma_{\text{abs}}\) are measured by observing the reaction itself in which the neutron is absorbed. The principal method in this case
being the pile oscillator one which measures the effect on the re-activity of a pile caused by the absorption of neutrons. In several instances e.g. B.U. & Au isotopes absorption cross-section has been obtained from the total cross-section by subtracting the scattering cross-section, or by extrapolation from subthermal energies where the scattering is negligible.

The fundamental equation for neutron activation is

\[ \frac{dN}{dT} = \eta \nu \sigma_{\text{act}} N_T \]

where \(N_T\) represents the total number of atoms in the neutron flux \(\nu\) and \(N'\) the number of activated atoms.

The so-called total cross section \(\sigma_t\) such as would apply to the attenuation of a collimated beam of incident particles is

\[ \sigma_t = \sigma_{\text{el}} + \sigma_{\text{sc}} \]

when \(\sigma_{\text{sc}}\) includes the elastic resonance scattering.

Nuclear emulsions have lately proved to be a useful tool for recording the nuclear events particularly in the measurement of angular and energy distribution of reaction products and reaction cross-section measurements. The advantage lies in its small size, sensitivity of record, and a clear discrimination from the background of scattered neutrons, deuterons and \(\alpha\) rays.

The use of nuclear emulsions neutron flux measurement
was reported by Rosen (R_1) (1953) who measured the neutron flux by studying the proton recoil tracks in nuclear emulsions. He used the emulsion as a radiator and a detector of protons; and also as a detector only, having in this case and external radiator. Whereson and Reins (W_1) (1950) studied neutron flux by scanning the alpha tracks in Li loaded plates by the \( \text{Li}^6(\gamma,\alpha)\text{Be} \) reaction. Energy and angular distribution of neutrons for various elements using nuclear emulsions as detectors only, was measured by Graves and Rosen for about 11 elements (G_1) (1953). In this method the plates were exposed to neutrons from a 14 Mev neutron source, isolated so far as possible from all scattering materials, and to the same source surrounded by a thin spherical shell of the material under investigation. 14 Mev (\( \gamma,\alpha \)) interaction results in a case of Al were reported by Allan (A_1) (1958), using almost the same experimental arrangement, excepting that instead of surrounding the source with the target he surrounded the plate by a thin shell of the element.

Kumabe (K_1,K_2) (1957,58) reported cross section measurements of certain elements taking the element in the form of a thin foil, and sandwiching it between two plates and then exposing this assembly to the incident neutron beam at 45°.

The author carried forward the method suggested by Rosen (R_1) (1953) for neutron flux determinations, and what by
Nereson and Reins (1950) for similar measurements for low energy neutrons, and has as far as he is aware, for the first time used a simple method for studying ($\gamma$,L) reactions in which the element to be studied is loaded in the emulsion in the form of a suitable salt. The nuclear emulsion serves as a radiation and a detector of alpha particles. These studies have been made with the help of Ilford C2 (200 micron) (1" x 3") plates and the details are furnished in chapter I of this dissertation.

Some work has been reported in the field of cosmic ray measurements making use of Boron and Lithium loaded plates by Gibson and Livesey (1947) and the method is more or less in the same line as the one used here for a detailed study of alpha particles from 14 Mev neutron induced ($\gamma$,L) interactions.

This is however limited in its applicability because many elements cannot be conveniently loaded in emulsions because of their adverse effects on the emulsions; and in those cases it may be necessary to have the sample in the form of a thin foil or a thin spherical shell.

In the subsequent chapters an attempt has been made to present a review of ($\gamma$,L) study by the emulsion technique. The methods suggested by various workers have been compared with this method. In addition to that a detailed study of the processing technique for different types and thickness of emulsions has been
presented, in view of the vital role which the processing plays in the distinguishing of various nuclear events, and also in getting the desired grain densities and track structures. Emphasis has been laid on this particular aspect of the problem which forms an important part of this dissertation and is discussed in chapter III.
References:


(K1) Kumabe I and others; Phys. Rev. 106 (1957) 155.


(K6) Kaul O.N.; See manuscript attached to Chapter V.


(R1) Rosen L; Nucleonics 11 No. 7 (1953) 32; 11 No. 7 (1953).