LETTERS TO THE EDITOR

Neutron Flux and Spectrum Measurement

It is also demonstrated in an appendix to the above paper that

$$F^{ap\,LM}_{bq\,lm}(\mathrm{I}) = \pm F^{-a-p\,L-M}_{-b-q\,l-m}(\mathrm{I}) \qquad \ldots\ldots (6)$$

only one of the signs holding for a given process.

Now, if the Hamiltonian is invariant under reflection of coordinate axes and time reversal, it can be shown (e.g. Coester 1951) that

$$S^{bqlm}_{apLM}(\mathrm{II}) = \pm S^{-a-p\,L-M}_{-b-q\,l-m}(\mathrm{I}) = \pm S^{apLM}_{bqlm}(\mathrm{I})$$

by (5) and (6), the relevant sign being determined by the process under consideration.

It therefore follows at once from (3) and (4) and the fact that $L+l$ is always even or always odd for a given process, that the equality (2) is true provided the Hamiltonian possesses the invariance properties listed.

I am indebted to Professor Pryce for informing me that the foregoing theorem is an example of a more general relation which can be shown to hold between inverse physical processes

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19th March 1952.

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Neutron Flux and Spectrum Measurement

The measurement of a neutron spectrum by observing the recoil protons produced in a hydrogenous medium is usually subject to two difficulties If the energy spectrum of all the protons produced in an ion chamber containing hydrogen is to be measured, the dimensions of the chamber must be large compared to the range of a recoil proton. For protons of more than a few hundred kilovolts energy this requires either a very high pressure filling or a very large chamber If, alternatively, the proton recoils from a thin hydrogen-containing film are observed, then, although the chamber dimensions may be reduced to one proton range, the number of recoils from a thin film is inconveniently small.

An attempt to overcome the first difficulty is described here, in which a scintillating anthracene crystal is used instead of an ion chamber. A crystal of quite small size ($\sim$5 mm side) will fulfil the condition as to proton range, and, provided the relation between light output and proton energy is known, it should be possible to determine the energy spectrum of proton recoils in such a crystal. Scintillations from the recoiling carbon atoms are negligibly small since not only is their energy lower, but also the light output per MeV dissipated in the crystal is much less. The relation between light output and proton energy has been calculated by Birks (1951) in terms of the energy–range relation for protons, and is given as

$$\frac{dS}{dE} = \frac{A}{1+B\,dE/dx}, \qquad \ldots\ldots (1)$$

where S represents light output, A and B are constants, and dE/dx is the rate of energy loss of a proton in anthracene.

Anthracene was chosen for this work because of its high luminous efficiency, which is important since the statistical spread in the number of electrons released at the photocathode must be kept as low as possible to give the best energy resolution. Unfortunately, the use of an organic scintillator gives the counter a disproportionately high sensitivity to γ-radiation, and its use is limited to measurements in the absence of γ-radiation, or where the γ-radiation effect may be subtracted by means of a 'background' run.

A counter consisting of a clear piece of anthracene, weighing 0·433 g, cemented to the window of an E.M.I. photomultiplier type VX 5045 was exposed to 2·54 MeV neutrons

emitted from the D–D reaction at 90° to the beam, and a pulse height distribution was taken with a 30-channel pulse analyser (fig 1). Using eqn. (1), this distribution was transformed to the energy spectrum of the recoil protons to give fig 2. On the same figure is plotted the neutron spectrum $N(E)$ derived from

$$N(E) \propto \frac{E}{\sigma(E)} \frac{d}{dE}\{N'(E)\}. \qquad (2)$$

$N'(E)$ is the distribution of proton energies, and $\gamma(E)$ is the n–p scattering cross section.

To test the counter further it was used for an absolute measurement of the flux from the D–D source, under conditions for which this flux was known. To this end the counter

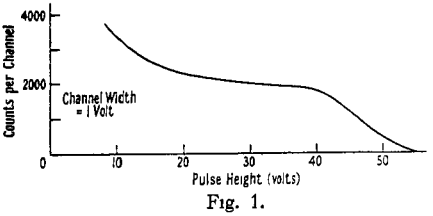

Fig. 1.

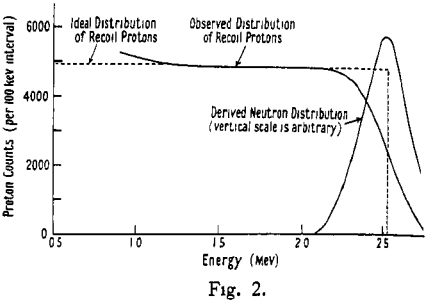

Fig. 2.

and an Ilford type C2 nuclear plate were simultaneously exposed at equal distances from the source, and the number of pulses above 27·5 volts amplitude was counted. From this, and from eqn. (1), the total number of proton recoils was calculated, and so the number of neutrons falling on the crystal. This figure was compared with that obtained from examination of the plate, and the results are: crystal $8{\cdot}7(\pm 0{\cdot}2)\times 10^7$ neutrons/cm^2, plate $8{\cdot}0(\pm 0{\cdot}5)\times 10^7$ neutrons/cm^2.

Atomic Energy Research Establishment, Harwell, Berks. M. J. Poole.

7th March 1952.

Birks, J. B., 1951, *Proc. Phys. Soc.* A, **64**, 10.

The Range–Energy Relation for Protons in Aluminium

No experimental determinations of the stopping power of aluminium for protons in the energy range from 5 to 10 Mev appear to have been reported. To fill this gap, Ilford C2 nuclear emulsions have been used to measure the energy loss of initially 10 Mev protons in traversing a thickness of aluminium which reduces their energy to about 3 Mev.

The source of protons was the extracted beam of the Birmingham 60 in. cyclotron, operated with no ion-source arc to give a suitably low intensity. The plates were tilted slightly from the horizontal so that the protons entered the emulsion at a small glancing angle. Part of the beam struck the plate after passing through a sheet of aluminium mounted just before the plate with its plane vertical; part of the beam passed below the aluminium and struck the plate directly. The difference in height of the two beams is only about a millimetre, and is in the vertical direction in which the beam energy is known not to vary greatly.

The table shows the results of six determinations, including measurements made with four different plates and three different absorbers. 20 to 30 tracks were measured at each range, the mean range being thus determined within 2μ. In this table, U refers to the unstopped beam, S to the beam which has traversed the aluminium absorber. Columns 4 and 5 are obtained by converting ranges in the emulsion into proton energies by means of the range–energy relation for C2 emulsions given by Rotblat (1951), and then converting these energies into ranges in aluminium by means of the range–energy relation calculated by Smith