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EXPERIMENTS ON SCATTERING OF FAST NEUTRONS IN TAMPER MATERIALS

Report of Committe consisting of

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The experiments recommended in this report are intended to obtain information about the a) elastic cross section $\sigma_{el}(\theta)$ of neutrons for different energies, as function of the angle θ; in particular the transport average $\int(1 - \cos\theta)\sigma_{el}(\theta)d\Omega$; b) the inelastic scattering, its cross section depending on the incident energy and the energy loss per collision; and c) the capture cross section in dependence of the energy of neutrons.

The materials which should be investigated for possible use as tamper are: Be, C, O as BeO or Al_2O_3, F as C_nF_{2n+2}, Al, Si, Fe, W, Au, Pt, Pb, U.

EXPERIMENTS

1. a). Transmission experiments.

Source: (d-d) neutrons and Li (p,n) neutrons.

Scatterer: Disk of material thin compared to one mean free path.

Detector: Spherical gas chamber. According to preliminary calculations, its response can be made very flat over a large energy interval. It changes less than 25% from 1.5 x bias energy up to 9 x bias energy. This detector registers neutrons of energies above bias. If the bias is chosen close enough to the primary energy it will register only neutrons which have not suffered an energy loss. Since the measurement of the elastically scattered neutrons is an important one, it may be repeated with a spherical chamber coated with

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thick paraffin, in case the high bias in the gas chamber leads to some difficulties. The thick paraffin chamber detects mainly neutrons of the highest energy if suitably biased.

Arrangement: Source and detector in equal distance from disc. Limiting scattering angle θ_ℓ to be 30°, 60°, 90°, 120°.

If the source intensity were spherically symmetrical and mono-energetic, this measurement would give (Christy's theorem):

$$\int_{\theta_\ell}^{\pi} (\sigma_{el} + \sigma'_{in})\, d\Omega + \overline{\sigma_{in}} + \overline{\sigma_c} \, ;$$

where $\overline{\sigma}_{in}$ and $\overline{\sigma}_c$ are the total cross-sections for inelastic scattering and for capture. σ'_{in} is the cross-section for inelastic scattering per solid angle with a final energy high enough to be detected by the detector. It is zero for a bias close to the primary energy or for the thick paraffin detector. Both corrections can be taken into account and give a slightly different expression for what is measured, namely

$$\overline{\sigma_{in}} + \overline{\sigma_c} + \int_0^{\pi} \sigma_{el}\, d\Omega - \int_0^{\theta_\ell} w(\theta)\,\sigma_{el}(\theta)\, d\Omega,$$

where $w(\theta)$ is a weight function which decreases somewhat from unity by going from 0 to θ_ℓ. In order to avoid these corrections it is proposed to have the axis of the arrangement at an angle of 61° with the direction of the deuterons. Most of the asymmetries are averaged out by this arrangement.

1. b). Transmission experiment with 1/v-detector. $\theta_\ell = 90°$ or larger.

Source: (d-d).

Detector: BF_3-chamber or 25-fission.

Purpose: 1) To show that the difference between the results of transmission experiments and back scattering is due to inelastic scattering rather than capture, 2) to give a qualitative measurement of the energy loss in inelastic scattering.

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2. a). Back scattering experiments.

Source: (d-d) or Li (p,n).

Detector: Chamber coated with thick paraffin and made directional, by coating only a limited area of the spherical chamber on the side facing the scatterer, in order to reduce background.

Scatterer: Same as before.

Arrangement: Detector between source and scatterer. It has been shown that, by this experiment, an average value of the back scattering is measured, in which one definite angle θ^* is given a strongly preponderant weight. θ^* is given by $\theta^* = \pi/2 + 2\alpha$, $\tan\alpha = \sqrt{d/D}$, d is distance between scatterer and detector. D is between scatter and source. (The disc must be large enough to make a scattering angle θ^* possible).

The result of this experiment is therefore essentially $\sigma_{el}(\theta^*)$.

It is proposed to perform this for two or three values of θ^*, between 120 and 180. (The present arrangement is: d = 2.55", D = 16", and $\theta^* = 131$. d = 6", D = 16" would give $\theta^* = 153$, d = 1.5", D = 16" gives θ^* 124.) No strong dependence on θ is expected in this region so that the required accuracy is not high.

2. b). Backscattering, thin detector. Same as 2a) but detector with thin paraffin coating on the side facing the scatterer. (probably only (d-d) source.) Gives $\sigma_{el}(\theta^*) + \sigma_{in}'$.

Remarks to 1. and 2.: From 1.a) (high bias, θ = 120) and 2.a) ($\theta^* \sim 120$), one can eliminate σ_{in}, if the latter is assumed to be spherically symmetric. Hence the elastic transport cross-section can be computed. It should be added that the experiments 1.a) are not performed to determine $\sigma_{el}(\theta)$ at every value of θ, but to determine the integral $\int (1 - \cos\theta)\sigma_{el}(\theta)d\Omega$. This integral is some weighted average of the actual transmission coefficients measured in 1.a) and of the backscattering coeffient in 2.a). The accuracy would not be improved if values of $\sigma(\Theta)$ at definite angles were measured, e.g., by scattering on rings.

3. Energy degradation experiment.

Aim: To find out whether neutrons of an energy between 200 and 1,000 KV are still inelastically scattered. The energy E under which inelastic scattering is absent (E is the excitation energy of first level), is also the energy to which fast neutrons are slowed down by inelastic scattering. (Exactly: they are slowed down to a continuum between E and 0.)

Source: Li (p,n) neutrons of energy 200 KV up to maximum possible.

3. a). Scatterer: "thin disk."

Detector: A. 1/V type, e.g., BF_3 or fission chamber.

B. Recoil type, e.g., Gas chamber; the detector should be "thin" for the recoil protons in order to give results comparable with the type A.

Arrangement: Scatterer far from source to insure monochromatic beam; Detector covering most of back face of scatterer.

If no inelastic scattering, Detector A and B will give the same ratio of response with and without scatterer. The presence of inelastic scattering will show up as a larger ratio in Detector A.

3. b). Improved Arrangement: Scatterer a hollow sphere, detector within. Source at distance necessary to insure monochromatic beam. In this case, elastic scattering is balanced out, and the ratio with and without scatterer should be one if there is no inelastic scattering and no capture.

Ratio measured with biased detector B should give amount of inelastic scatterings plus capture. Comparison with ratio measured with Detector A, gives an average of the energy to which the neutrons are slowed down, if there is no, or weak, capture.

If materials are found in Experiment 3. which do not show any inelastic scattering with neutrons of a given energy, the same arrangement as 3. (Particularly the improved arrangement,) gives a measure of the capture cross-section by comparing the intensity in the detector with and without material around.

For elements with energy degradation, this measurement of the capture cannot be performed because the slowed down neutrons cause a different response in the detector.

CAPTURE EXPERIMENTS

4. To test the theoretical prediction that capture of neutrons over 1,000 KV is negligible, gold and perhaps a few other elements which become radioactive should be irradiated with (d-d) neutrons and tested for radioactivity.

There are great difficulties in measuring capture in elements which do not become radioactive. The degradation of energy is one, as mentioned under 3. A fundamental difficulty lies in the fact that only these materials are of interest, whose capture cross-section is small compared to the elastic or inelastic scattering cross-section. If this is so, the absorption in a thin scatterer is very small and hard to measure. The main interest lies in the capture cross-section at the energy of the slowed down neutrons. Therefore, capture in a thick scatterer should be measured, where the neutrons are slowed down before absorption. (see 5.)

In the following paragraph a few methods are discussed which were frequently proposed but which we don't think are worth being carried out. A method frequently proposed is the following: The source is within a hollow sphere of material and this is surrounded by a Mn bath or something equivalent, to slow down and capture all neutrons which penetrate the sphere. The difficulty of this experiment, apart from the small effect mentioned above, lies in the fact that some neutrons leave the Mn bath towards the inside, and are captured in the material. To avoid this, the inside of the bath must be shielded by Cd, which, however, only prevents the thermals from leaving. One also can surround the scatterer + source by the bath in some distance, leaving a large empty spherical space within the bath in which the much smaller unit scatterer + source is placed. The chance that a returning neutren hits the scatterer is then reduced. However, if the scatterer scatters inelastically, the spectrum of the neutrons reaching the bath is different, with and without scatterer. The number of slowed down neutrons absorbed in the Cd-shield, inside of the bath changes and the measurement is spoiled. The Cd shield however is necessary since the thermal neutrons are so much more frequent and so much stronger captured, that the reduction in solid angle would not be enough protection. The difficulty can be avoided by measuring the neutrons by an indium foil. This experiment is not proposed because of the smallness of the effect (see first paragraph), and because of the slight interest in the capture cross section of neutrons higher than the lowest energy reached.

5 a) Capture experiments; thick target: If the material slows down neutrons of all energies available, the following arrangement may give information about capture: Source and detector are included in a big solid sphere of material. The dimensions must be large compared to the diffusion length of the neutrons. The detection intensity is then given by $I = (1/r\ell_\tau)\, e^{-r/L}$ (Apart from small corrections to the diffusion theory), where ℓ_τ is the transport corss section, r is the distance between detector and source, L is the diffusion length: $L = \sqrt{\frac{\ell_\tau \ell_a}{3}}$ where $\ell_a = 1/\sigma_c \cdot \tau$ is the mean free path in respect to capture.

Measurements of I for a few values of r determines ℓ_a. We may assume that the neutrons are slowed down to their final energy after one or two collisions so that σ_c is the capture cross section corresponding to the final energy.

5 b) The final energy reached can be determined by an admixture of B^{10} which shortens the lifetime of all neutrons. The cross section for capture, now will be $(\sigma_c)_{\text{with boron}} = (\sigma_c)_{\text{without boron}} + 1/v\tau$, where v is the velocity of

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the neutrons and τ their lifetime due to the boron, which can be calculated. Thus the same measurement with boron admixture can be used to determine v.

These experiment may perhaps also be performed with natural sources. Any detector which is sensitive for neutrons less than the original energy, can be used.

This experiment supersedes I4, (source and detector in hollow sphere) since it gives data which can be much better interpreted.

RATING:

	Experiment								
Source	1a	1b	2a	2b	3a	3b	4	5a	5b
D - D	A	B	A	B					
Li (p,n)	B		B		A-B	A-B	A	B	C
Natural								B	C

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