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Energy spectrum and polarization of photoneutrons from ^{7}Li

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Fisica. — *Energy spectrum and polarization of photoneutrons from* ^{7}Li. Nota di ANGELO DE MARCO (*), RAFFAELLO GARFAGNINI (*) e GUIDO PIRAGINO (*) presentata (**) dal Socio G. WATAGHIN.

RIASSUNTO. — Sono state misurate la distribuzione energetica e la polarizzazione dei fotoneutroni dalla reazione $\gamma + {}^7$Li ($E\gamma_{max} = 85$ MeV) ad un angolo di 135°, utilizzando come rivelatore una camera a diffusione riempita con elio. I risultati ottenuti, interpretati nell'ambito del modello a particelle indipendenti, escludono per il ^{7}Li lo schema di accoppiamento *j–j* rispetto a quello L–S.

The direct interaction of γ rays on light nuclei, described generally with the single-particle shell model, has been often employed to obtain detailed angular correlation formulae [1] for the neutron photoproduction. The theoretical predictions and the experimental results have been compared in the photodisintegration of ^{9}Be and ^{13}C both [1] for the photoneutron cross section and for the polarization measurements. In this paper we compare the measurements and the theoretical predictions of the energy distribution and the polarization of photoneutrons from ^{7}Li.

The spectrum of photoneutrons from ^{7}Li has been measured previously only by Wataghin et al. [2] at an angle of 90° with respect to a bremsstrahlung γ–ray beam of $E_{\gamma\,max} = 25$ MeV. We have measured the energy distribution and the polarization of photoneutrons from ^{7}Li at $135° \pm 7°$, using the bremsstrahlung γ–ray beam ($E_{\gamma\,max} = 85$ MeV) of the 100 MeV synchrotron of the Turin University.

The experimental apparatus sketched in fig. 1 has been described in detail in a previous paper [3]. The photoneutrons were detected by the scattering on helium gas in the sensitive region of a diffusion cloud chamber, filled at 2.4 absolute atmosphere pressure. The target of natural lithium was a cylinder, 5.4 cm diam. and 11.9 cm long. It was sealed in a thin (1 mm thick) plexiglass container with the front walls in thin mylar. The target axis was parallel to the γ–ray beam direction, and its diameter was greater than that of the beam.

We have analysed about 10.000 photographs and measured 1.300 events of the (n, ^{4}He) elastic scattering reaction. The energy distribution of the photoneutrons was deduced from the recoil spectrum of α particles, corrected for geometric losses and for the energy dependence [4] of the (n, ^{4}He) elastic scattering cross section. The polarization of the photoneutrons was determined by the maximum likelihood method as described in ref. [3]. In order

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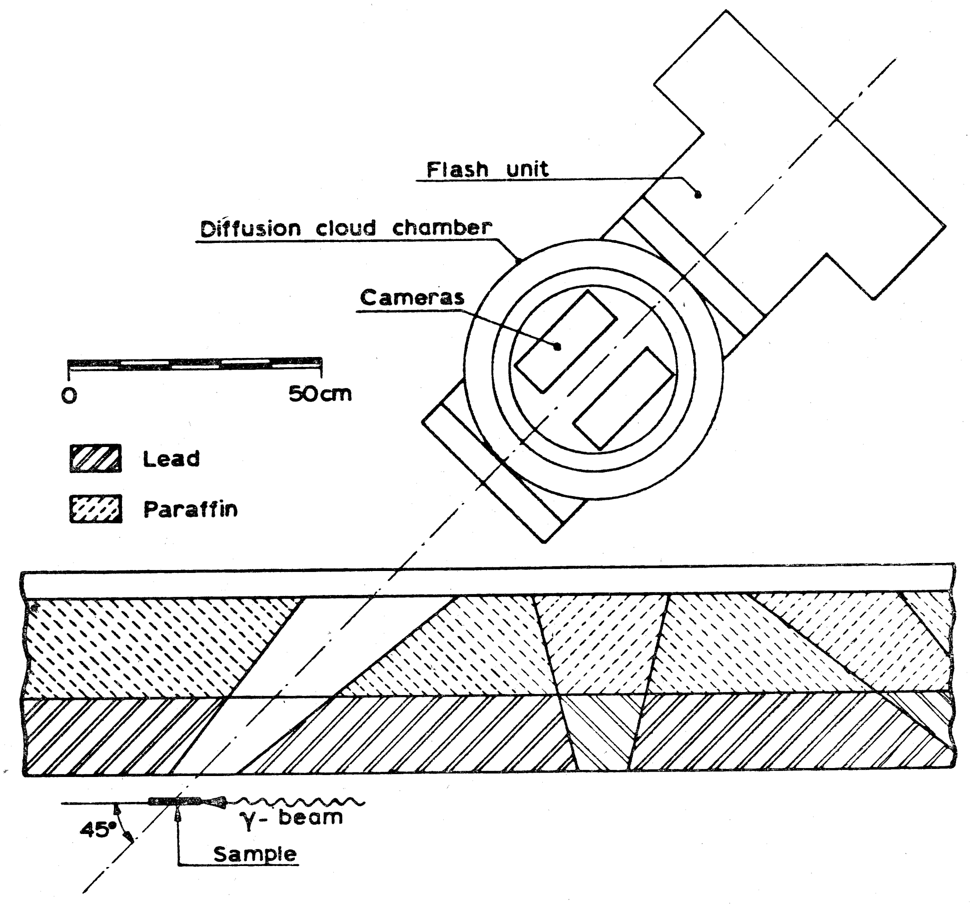

Fig. 1. – Diagram of the experimental arrangement.

to eliminate the asymmetry of our apparatus, we have measured about 1.000 α particles scattered by neutrons from a RaD–Be source. In fig. 2, we report the difference between the values of the polarization of photoneutrons from ^{7}Li and those obtained from the neutron source.

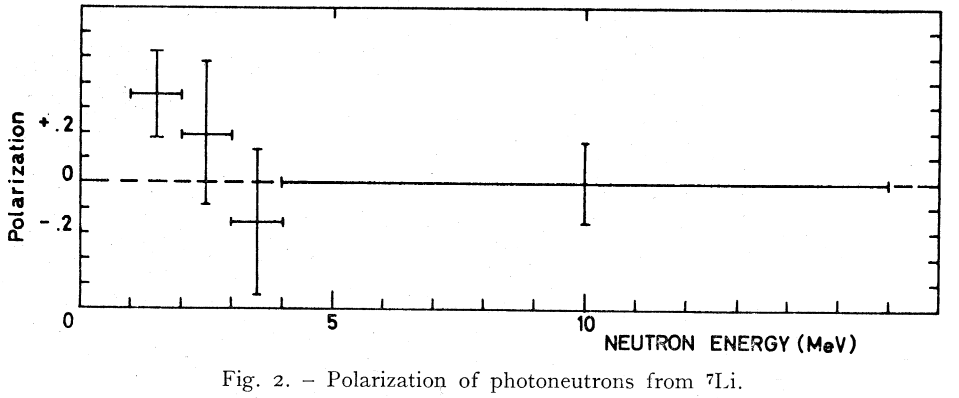

Fig. 2. – Polarization of photoneutrons from ^{7}Li.

Fig. 3 shows the energy distribution of photoneutrons. Our spectrum is in good agreement with the behaviour of the one measured (for neutron energy greater than 3 MeV) by Wataghin et al. [2].

The analysis of our data was performed using the single particle shell model, with the hypothesis that the neutron photoproduction from ^{7}Li proceeds via a direct interaction. The nucleus is considered as an inert core plus a

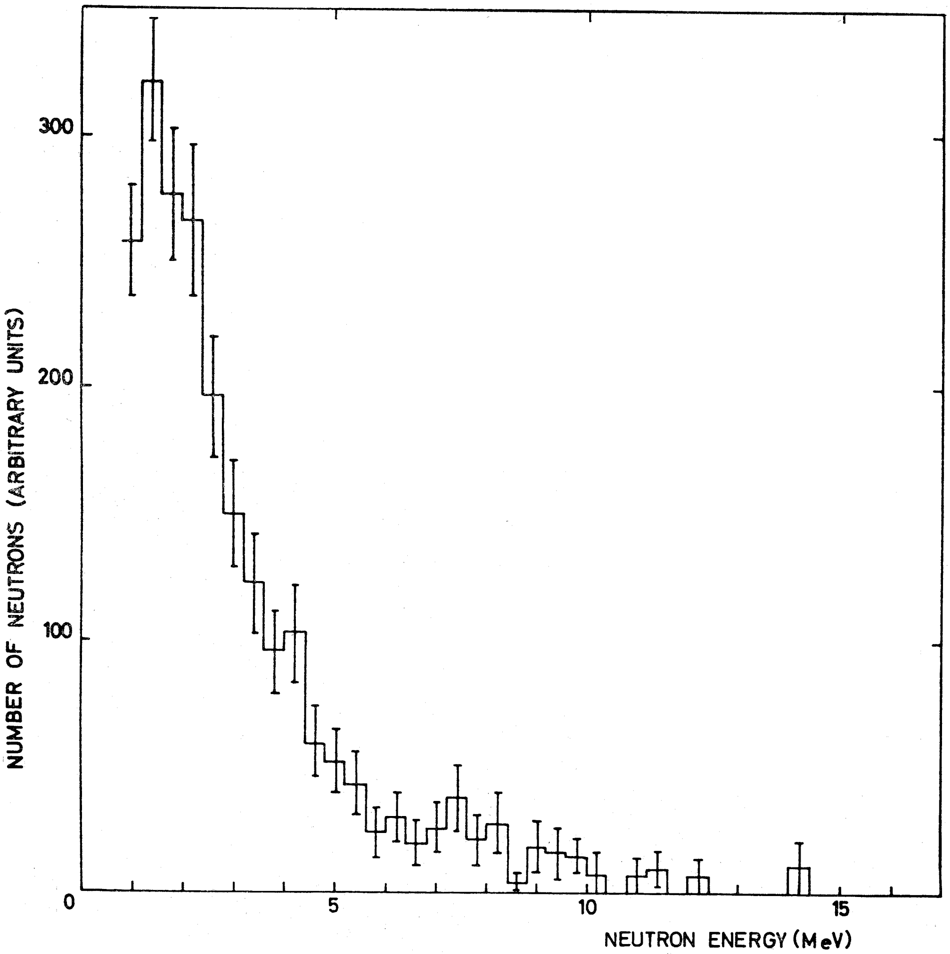

Fig. 3. – Energy distribution of photoneutrons.

certain number of equivalent nucleons which are filling the outermost shell; the electromagnetic interaction has been treated by taking into account only the E1, M1, (E1–M1) dipole terms. The formulae are deduced by Ponzano [1], who assumes that the direct interaction excites into the continuum an outer nucleon leaving the residual nucleons in the same shell as before the interaction. The theoretical results are applied to the first p–shell in the *j–j* coupling scheme disregarding the spin-orbit term in the final-state interaction. For the phase shifts of the elastic scattering (n, ^{6}Li), we have used the values of Table I, which were deduced from the experimental differential cross section of elastic scattering [5] in the neutron energy interval $0.8 \leq E_n \leq 2.2$ MeV. In this energy interval, the calculations are simple because the δ_2 phase shift contribution is negligible with respect to δ_0 and δ_1.

TABLE I.

Phase shift δ_0 *for the reaction* $n(^6\mathrm{Li}, ^6\mathrm{Li})n$ *and the theoretical prediction of photoneutron polarization in the j–j and* L–S *coupling schemes.*

E_0 (MeV)	δ_0 (deg)	$(P)_{c.m.}$ *j–j* coupling	$(P)_{c.m.}$ L–S coupling
0.8	43.5	—0.16	0.05
1.0	48.8	—0.18	0.06
1.2	55.3	—0.19	0.06
1.4	64.5	—0.20	0.07
1.6	71.0	—0.20	0.07
1.8	70.5	—0.19	0.06
2.0	67.8	—0.18	0.06
2.2	63.8	—0.17	0.06

With these assumptions the differential photoneutron cross section and polarization may be written:

$$(1)\qquad \left(\frac{d\sigma}{d\Omega}\right)_{c.m.} = \frac{C}{K_{nf}}\left\{[(I_0^0)^2 + 2(I_2^0)^2] + [-(I_2^0)^2 + 2\, I_0^0\, I_2^0 \cos\delta_0]\, \frac{3\cos\theta - 1}{2}\right\}$$

$$(2)\qquad (P)_{c.m.} = \frac{3\, I_0^0\, I_2^0 \sin\delta_0 \cos\theta \sin\theta}{2[(I_0^0)^2 + 2(I_2^0)^2] + [-(I_2^0)^2 + 2\, I_0^0\, I_2^0 \cos\delta_0](3\cos^2\theta - 1)}$$

where

$$C = \frac{2}{9}\,\frac{K_0\,\mu}{\hbar^2}\, N\, \frac{Z^2}{A^2}\, e^2$$

$\hbar$, e, N, Z and A, have their usual meanings; K_0 and K_{nf} are the wave number of the incident γ-ray and of the outgoing neutron, respectively; μ the reduced mass of the system and θ the c.m. emission angle of the neutron. The radial integrals I_0^0 and I_2^0, which for an harmonic oscillator potential describing the bound state of the $1p$ neutron in the initial nucleus [6], are:

$$I_0^0 = \sqrt{\frac{8}{3\sqrt{\pi}}}\ \frac{1}{b}\int_0^\infty \sin\left(K_{nf}\, r + \delta_0\right) r^2\, e^{-\frac{r^2}{2b^2}}\, dr$$

$$I_2^0 = \sqrt{\frac{4\sqrt{\pi}}{3}}\ \sqrt{K_{nf}}\ \frac{1}{b}\int_0^\infty r^{5/2}\, J_{5/2}\left(K_{nf}\, r\right) e^{-\frac{r^2}{2b^2}}\, dr$$

where

$$b^2 = \frac{\hbar}{\omega m_n},$$

ω is the classical angular frequency and m_n the neutron mass. In Table I we report the photoneutron polarization as deduced in the j–j and in L–S coupling schemes (columns three and four, respectively). The values for the latter coupling scheme were obtained comparing the j–j and L–S correlations for the first p–shell as given by Ponzano [1].

From Table I one can see that the polarization in the neutron energy interval $1 \div 2$ MeV is $-19\,\%$ and $+6\,\%$, respectively in the j–j and L–S coupling schemes, to be compared with the experimental value $(+35 \pm 17)\,\%$. One can conclude therefore that a better agreement between theory and experiment is obtained with L–S coupling. As a matter of fact the L–S coupling explains satisfactorily, at low energy, also the level distribution and the electromagnetic properties [7] of ^{7}Li.

The theoretical polarization values are, however, lower than the experimental one and the neutron energy distribution calculated with formula (1) gives a spectrum (1) harder than that we have found. This indicates that other channels with multiple neutron emission and excited states of ^{6}Li may be important in the process. The latter hypothesis seems to be very unlikely as Wataghin et al. [2] pointed out; on the contrary the former one is in agreement with the results of the cross section measurement for the total neutron photoproduction from lithium given by Fast et al., and Hayward et al. [8]. In the limit of our measurement, we can conclude that the neutrons coming from reaction with multiple neutron emission give an appreciable contribution to the total polarization.

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(1) The spectrum calculated with the j–j coupling scheme has the same behaviour that in the case of L–S.

REFERENCES.

[1] G. PONZANO, «Nuovo Cimento», *31*, 1303 (1964).
[2] A. WATAGHIN, M. SCOTTO and G. PAOLI, «Nuovo Cimento», *40*, 441 (1965).
[3] A. DE MARCO, R. GARFAGNINI and G. PIRAGINO, «Atti Accad. Sci. Torino», *99*, 445 (1964–65).
[4] A. DE MARCO, R. GARFAGNINI and G. PIRAGINO, «Nuovo Cimento», *44*, 172 (1966).
[5] M. D. GOLBERG, V. M. MAY and J. STHEN, BNL 400 sec. Edition, Vol. I (october 1962). R. O. LANE, A. S. LANGSDORF, JR., J. E. MONAHAN and A. J. ELWYN, «Annals of Physics», *12*, 135 (1961).
[6] J. P. ELLIOT and A. M. LANE, «Handbuch der Physik», *39*, 248 (1957).
[7] R. S. WILLEY, «Nucl. Phys.», *40*, 529 (1963). M. BERNHEIM and G. R. BISHOP, «Phys. Letters», *5*, 294 (1963).
[8] R. W. FAST, P. A. FLOURNOY, R. S. TIKLE and W. D. WHITEHEAD, «Phys. Rev.», *118*, 535 (1960). E. HAYWARD and T. STOVALL, «Nucl. Phys», *69*, 241 (1965).