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POLARIZATION OF ELASTICALLY SCATTERED NEUTRONS WITH ^{4}He AND ^{12}C

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ABSTRACT

Study of the contribution of the interference between the direct resonance and potential scattering matrices on the angular vector polarization of elastically scattered neutrons with spinless nuclei has been performed. Theoretical calculations depending on this additional effective term have been carried out and compared with some experimental data of n-^{4}He and n-^{12}C elastic scattering. A reasonably good agreement between the theoretical and experimental results is found in the trends and magnitudes of polarization.

INTRODUCTION

As a matter of course, while the problem of the differential cross section gives a quantitative idea about the proceeding of the nuclear reaction, the reaction polarization gives a general important knowledge about the scattering of the nuclear reactions. In essence the angular distribution is the expectation value in the scattering wave of the spin tensor of rank zero. The vector polarization in similar manner is simply the expectation values of the tensor moment of rank one. The most established formula for the angular distribution for unpolarized beam in terms of the scattering matrix was developed by Blatt and Biedenharn[1].

The general theory is then specialized for the case of nuclear reactions and scattering associated with one isolated resonance level of the compound nucleus. The forgoing treatment has fully concerned lonely to the case of elastic scattering i.e the background reactions together with their interference with the resonance reaction both for neutral and for charged particles were considered. In the treatment of Blatt and Biedenharn[1], the incident particles as well as the target nucleus were considered to be unpolarized, i.e. their spins are randomly oriented in space but as there is a strong spin orbit coupling there arise the polarized reactions. Accordingly, Simon and Welton[2] performed expressions for the polarization resulting from nuclear reactions in terms of the reaction matrix and the Racah coefficients[3]. After that, Simon[4] made a comprehensive calculations to comprise the spin tensor moments yielding from a nuclear reaction at resonance initiated by an arbitrary polarized beam. They assumed that the non-resonance scattering contribution can be neglected. The aim of the present work is to deduce an expression for the resonance-potential scattering interference and study its contribution on the vector polarization of the elastically scattered neutrons with some spinless nuclei at resonance. The analyzing power of the elastic n-^{4}He scattering has been measured by Klages et al[5] in the energy range from 15 to 50 MeV and by Broste et al[6] in the energy range 11.0 to 30.3 MeV. The polarization of elastically scattered neutrons from ^{12}C at neutron energies 1.89 and 1.983 MeV have measured by Aspelund et al[7]. Similar measurements have been performed by Lane et al[8] at neutron energies $0.1 \leq E_n \leq 2.0$ MeV and by Kelsey[9] in the energy range 4.38 to 8.64 MeV. The second goal of this work is to perform a theoretical calculation depending on the here deduced resonance-potential interference expression and comparing it with available experimental measurements[5-9].

THEORY

One starts from the general formula for the polarization of neutron in the neighbourhood of single energy level[10], taking into account the potential contribution. The potential may be represented, in a phenomological manner, in terms of the phase shifts not of a hard sphere as long as they are independent of the total angular momentum and the channel spin representation.

The reaction **R** for the transition $\alpha s l$ to $\alpha' s' l'$ can be written as a sum of the resonance and potential matrices $\mathbf{R}_r$ and $\mathbf{R}_p$; thus:

$$< S'l'J\,|R|\,S\,l\,J > = < S'l'J\,|R_r|\,S\,l\,J > + R_p\,(l)$$

As pointed out by Goldfarb and Rook[11], the resonance and the potential-matrices take the form

$$R_r(l) = < S'l'J\,|R|\,S\,l\,J >$$

$$= e^{i(\phi_l + \phi_l')} \times < S'l'J\,|K|\,S\,l\,J >$$

and

$$R_p(l) = (e^{2i\phi_l} - 1) \times < S'l'J|\mathrm{I}|SlJ >$$

where $< S'l'J\,|\mathbf{K}|\,S\,l\,J >$ and $< S'l'J\,|\mathbf{I}|\,S\,l\,J >$ are defined from the Breight-Wigner formula as:

$$< S'l'J|K|S\,l\,J > = i.\frac{g_{\alpha\,Sl}\,g_{\alpha' S' l'}}{[\,(E - E_o)^2 + (\frac{1}{2}\Gamma)^2\,]^{1/2}}\,.\,e^{i\beta}.\delta_{JJ_c}$$

and

$$< S'l'J \,|I|\, S\,l\,J > = \delta_{s's}\,\delta_{l'l}$$

with

$$\tan\beta \;= (E - E_o)/1/2\,\Gamma$$

By a direct substitution of these reaction matrices in Simon's general formula of polarization[4] and introducing the well known Huby correction of time reversal[12] and the correction due to normalization[2], one thus get a more general formula **dP** dΩ for the elastic scattering of a neutron:

$$\frac{dP}{d\Omega} = n\sqrt{6}\, i < T_1' > = n\lambda_\alpha^2 \frac{1}{(2I+1)}$$

$$.\Sigma\{\Sigma g_\alpha\, S_1 l_1 \cdot g_\alpha\, S_1' l_1' \cdot g_\alpha\, S_2 l_2 \cdot g_\alpha\, S_2' l_2' \cdot (2J_c+1)^2$$

$$.\frac{\sin(\phi_{l_2} + \phi_{l_2'} - \phi_{l_1} - \phi_{l_1'})}{[(E-E_o)^2 + (\tfrac{1}{2}\Gamma)^2]} .(-1)^{I-\frac{1}{2}-S+l_1'+J_c-S_1'}$$

$$.[(2l_1+1)(2l_2+1)(2l_1'+1)(2l_2'+1)(2S_1'+1)(2S_2'+1)]^{\frac{1}{2}}$$

$$.(l_1 l_2 OO|LO).(l_1' l_2' OO|LO).W(\tfrac{1}{2}S_1'\,\tfrac{1}{2}S_2', I1)$$

$$.W(l_1 J_c l_2 J_c.SL).X(J_c l_1' S_1'; J_c l_2' S_2'; LL1)$$

$$-\,4\Sigma(-1)^{I-\frac{1}{2}-S-l_1'+J_c-S_1'} . \frac{g_\alpha\, Sl_1 \cdot g_\alpha\, S_1' l_1'}{[(E-E_o)^2 + (\tfrac{1}{2}\Gamma)^2]^{\frac{1}{2}}} .\mathrm{Sin}\,\phi_{l_2}$$

$$COS(\phi_{l_2} - \phi_{l_1'} - \phi_{l_1} - \beta)(2J_c+1)(2J_c+1)(2l_2+1)$$

$$.[(2l_1+1)(2l_1'+1)(2S_1'+1)(2S+1)]^{\frac{1}{2}}(l_1 l_2 OO|LO)$$

$$.(l_1' l_2' OO|LO).\quad W(\tfrac{1}{2}S_1'\,\tfrac{1}{2}S.I1)\;\; W(l_1 J_c l_2 J_2.SL)$$

$$.X(J_c l_1' S_1', J_2 l_2 S, LL1)\}\overline{P}_L^{1}(\cos\theta),$$

where the first sum is over $l_1,l'_1,l_2,l'_2,S_1,S_2,S'_1,S_2$,S and L and the second sum is over J_2 with parity states included.

The first term represents the resonance polarization, while the second term represents the interference between the resonance and the potential contributions. The vector polarization **p** is related to the differential polarization d **P** / d Ω

$$p = 3\frac{dP}{d\Omega} / \frac{d\sigma}{d\Omega}$$

For the differential cross section d σ / d Ω, the Blatt and Biedenharn[1] formula can be applied.

RESULTS AND CONCLUSION

Table I shows the selected experimental data from references (5-9). By applying the different selection rules governing the scattering processes and by choosing the best values for the partial widths of the corresponding levels, the vector polarization **p** can be deduced.

Table I

Nuclei	E_n (MeV)	E_x (MeV)	J^π	$\Gamma_{cm.}$ (MeV)	Γ_n (MeV)
^4He	17.0[5] 17.7[6]	16.76±0.13[13]	$3/2^+$	0.10±0.05	0.08
^{12}C	1.88[8] 1.983[7]	6.864[14]	$5/2^+$	0.006	0.004
^{12}C	4.38[9]	8.87[14]	$1/2^-$	0.210±0.015	0.210

From the theoretical calculations, it is clear that the resonance-potential term has the predominant contribution. At the same time and according to the selection rules, the Racah, Clebch-Gordan and the **X**-coefficients in the resonance-resonance term for such spinless (^{4}He and ^{12}C) nuclei vanishes. The theoretically predicted values for the polarization and the experimental results are displayed together in figures 1,2 and 3. Whereas, figure 1 and 2 show a partial agreement between the theoretical and experimental results where most values are somewhat underestimated by the theory, figure 3 reproduces a fairly good agreement between them.

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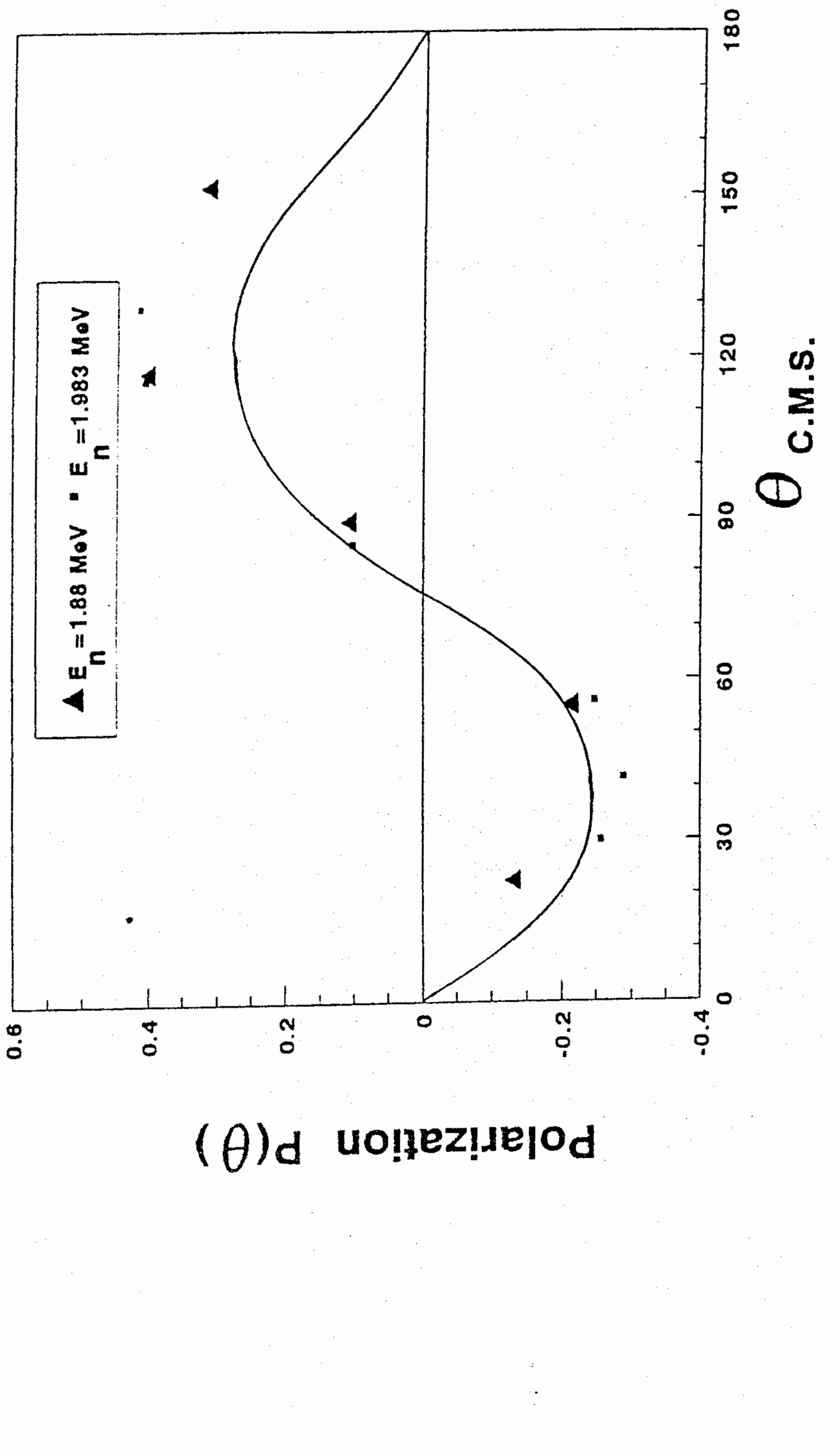

Fig. 1: Polarization of elastically scattered neutrons from Carbon at E_n=1.88 and 1.983 MeV. Solid line,theoretical analysis.

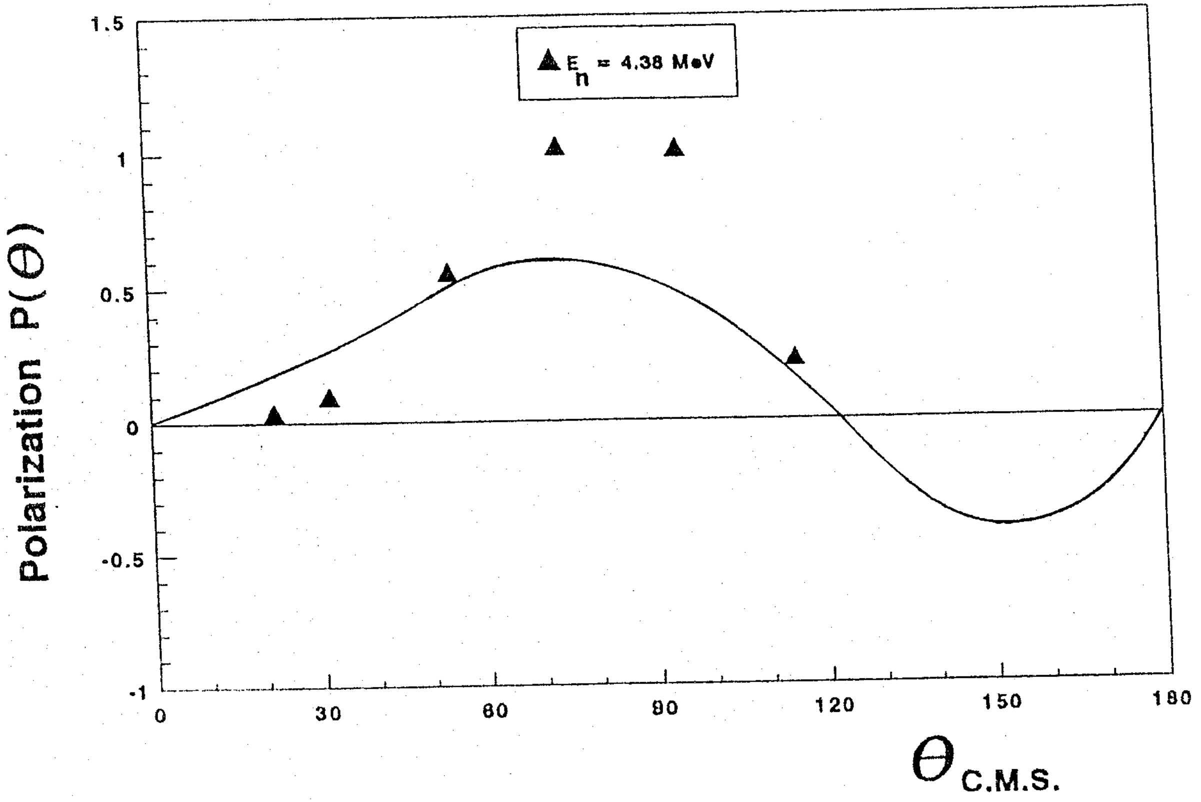

Fig. 2: Polarization of elastically scattered neutrons from carbon at E_n =4.38 MeV .Solid line,theoretical analysis.

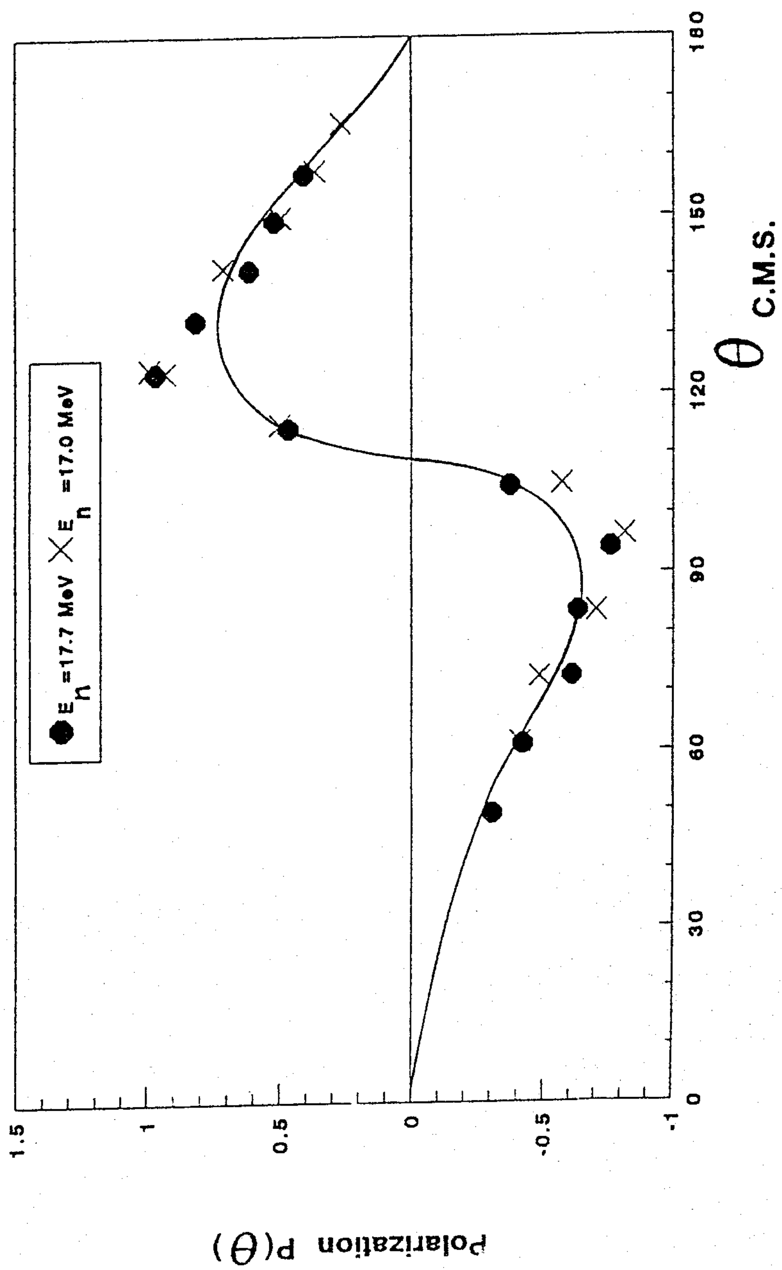

Fig. 3-Polarization of elastically scattered neutrons with Helium at E_n=17.7 and 17 MeV.Solid line,theoretical analysis.

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الإستقطاب الناشىء عن التشتت المرن للنيوترونات
مع هى^{٤} و ك ^{١٢}

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تم دراسة تأثير التداخل المباشر بين مصفوفات التشتت الرنينى وتشتت خيد على متجه الإستقطاب فى حالة التشتت الرنينى للنيوترونات مع أنوية ذات لف زاوى منعدم . وقد أجريت حسابات نظرية تعتمد على تأثير هذا الحد الإضافى لمقارنتها ببعض النتائج العملية لتشتت نيوترونات مع هى^{٤} و ك ^{١٢} . لوحظ توافق جيد بين كل من حسابات النظرية والنتائج العملية لقيمة الإستقطاب .