ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione Siciliana
Gruppo di Catania

INFN/BE-71/1
28 Gennaio 1971

S. Notarrigo, F. Porto, A. Rubbino, S. Sambataro and A. Strazzeri: ANGULAR DISTRIBUTIONS OF THE ^{26}Mg(^{3}He, α)^{25}Mg REACTION AT 10 MeV ANALYZED BY MEANS OF A DIFFRACTIONAL MODEL. -

209

Reparto Tipografico
dei Laboratori Nazionali di Frascati

Istituto Nazionale di Fisica Nucleare
Sezione Siciliana - Gruppo di Catania

INFN/BE-71/1
28 Gennaio 1971

S. Notarrigo, F. Porto, A. Rubbino, S. Sambataro and A. Strazzeri:

ANGULAR DISTRIBUTIONS OF THE $^{26}Mg(^{3}He,\alpha)^{25}Mg$ REACTION AT 10 MeV ANALYSED BY MEANS OF A DIFFRACTIONAL MODEL.

SUMMARY -

The angular distribution of the α particles from the $^{26}Mg(^{3}He, \alpha_0)^{25}Mg$ reaction have been measured at an incident energy of 9.8 MeV. The data are compared with a diffractional formula together with other data from the literature.

RIASSUNTO -

E' stata misurata la distribuzione angolare delle particelle α emesse nella reazione $^{26}Mg(^{3}He, \alpha_0)^{25}Mg$ ad energia delle particelle incidenti di 9.8 MeV.

I risultati assieme a quelli di altri autori vengono confrontati con una formula di tipo diffrazionale.

1. - INTRODUCTION -

D.W.B.A. calculations are universally employed to analyse direct reactions. However, in case of strong absorbtion, the experimental angular distributions suggest the analysis by means of diffractional models$^{(1,4)}$. These models have had a good success; yet the parameters used in fitting the data have hitherto only a phenomenological meaning, and do not show any definite correlation with the physical quantities characterizing the nuclear interaction.

A particular diffractional model was used in the analysis of the ^{26}Mg(^{3}He, α)^{25}Mg reaction at 5 MeV$^{(4)}$; the good agreement found between the experimental data and this model led us to extend its application at higher energies. For this reason we measured the angular distribution of ^{26}Mg(^{3}He, α_0)^{25}Mg reaction at 9.8 MeV.

2. - EXPERIMENTAL ARRANGEMENT AND RESULTS -

The helium-3 particles were supplied by the 5.5 MeV Van de Graaff accelerator of the Institut für Kernphysik at Frankfurt/M. The magnesium 26 target was 0.4 mg/cm^2 thick and was deposited on a Nickel-foil, 0.45 mg/cm^2 thick. The target was at 45° to the beam direction. The details of the experimental set up have already been given in a previous paper(5). The angular distribution of the α particles leading to the ground state of the residual nucleus in the ^{26}Mg(^{3}He, α_0)^{25}Mg reaction at 9.8 MeV is shown in fig. 1. In this figure the data are compared with recent data at 10.2 MeV appeared in the mean while in the literature$^{(6)}$. They are normalized at the point at 50°. At backward angles the two curves do not agree. We cannot say if this discrepancy is due to experimental systematic errors or to statistical fluctuations in the cross section as evidenced at 5 MeV$^{(5)}$. In fact our target had a thickness corresponding to about 200 KeV while Nurzynski's$^{(6)}$ target was about 50 KeV.

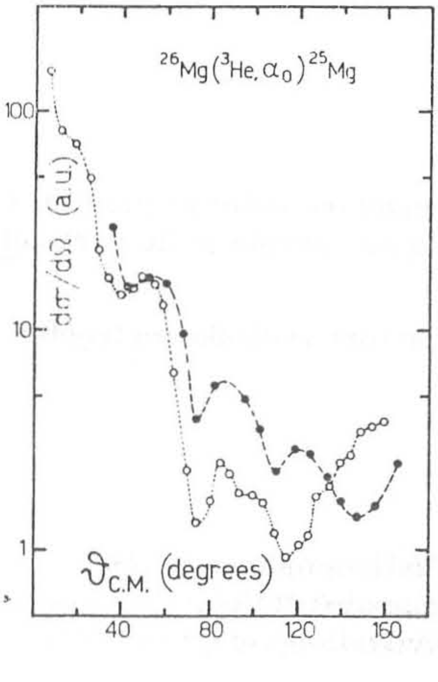

FIG. 1 - Angular distribution for the ^{26}Mg(^{3}He, α)^{25}Mg reaction leading to the ground state of ^{25}Mg. Black points are our results; circles are the results of ref.(6).

3. - HAUSER-FESHBACH CALCULATIONS -

Since we expect some statistical contribution also at 10 MeV, however less pronounced as compared to the 5 MeV data, we calculated the angular distributions of the α -particle for the $^{26}\text{Mg}(^{3}\text{He},\alpha)^{25}\text{Mg}$ reaction by means of the formula(7)

$$\frac{d\sigma_{\alpha\alpha'}}{d\omega} = \sum_{J}(-)^{s-s'}\,\overline{Z}(\ell J \ell J, sL)\overline{Z}(\ell' J \ell' J, s'L)\ \mathrm{x}$$

$$(1) \qquad \mathrm{x}\ P_L(\cos\theta)\,\frac{T_\ell\, T_{\ell'}}{g(J)}\ \frac{\chi^2}{4}\ \frac{1}{(2I_\alpha+1)(2i_\alpha+1)}$$

with

$$g(J) = \sum_{\nu}\sum_{\ell\nu}\sum_{s\nu}\sum_{I\nu}\int_{0}^{E_{max}} T_{\ell\nu}(E_\nu)\,\rho(E^{*}_{\nu}, I_\nu)\,dE_\nu$$

where ν indicates the channels in which the compound nucleus states decay, T_ℓ are the transmission coefficients and $\rho(E^{*}_{\nu}, I_\nu)$ is the level density in (ν, I)-channel at energy E^{*}. For the level density we used the expression due to Lang and Le Couteur(8); this expression depends chiefly on the following parameters: the radius of the residual nucleus $R \simeq r_0 A^{1/3}$ fm, the pairing-energy Δ and the a-parameter related to the spacing of the single nucleon states near the top of the Fermi distribution(9). For these parameters we used the following values: for a(10).

$a(^{28}\text{Si}) = 4.8\ \text{MeV}^{-1}$; $a(^{28}\text{Al}) = 5.6\ \text{MeV}^{-1}$;

$a(^{25}\text{Mg}) = 4.5\ \text{MeV}^{-1}$

for Δ(11)

$\Delta(^{28}\text{Si}) = -4.3$ MeV; $\Delta(^{25}\text{Mg}) = -2.1$ MeV.

and $r_0 = 1.4$ fm.

The above parameters were fixed at 5 MeV(5).

The transmission coefficients were calculated with an optical model potential which fitted the elastic scattering(6, 12).

The parameters for ^{3}He and α particles are reported in table I. The angular distributions calculated by formula (1) are shown in fig. 2 together with the Nurzynski's experimental results.

TABLE I

Particle	Potential Form	V_i (MeV)	W_j (MeV)	r_o (fm)	a (fm)	r'_o (fm)	a' (fm)
^{3}He	S.W.	151.8	14.6	1.08	0.80	1.78	0.60
α	S.W.	220	17	1.41	0.60	1.41	0.60

4. - COMPARISON WITH A DIFFRACTIONAL FORMULA -

Under the hypothesis of strong absorption, which is valid for the (^{3}He, α) reactions, it seems that the dependence of the transition amplitude from the detailed shape of the effective interaction is not easily observable$^{(1-4, 13, 14)}$.

Thus the stripping radial integrals $I(\ell)$ appearing in the DWBA differential cross-section show a considerable localization in ℓ-space$^{(14, 15)}$.

This fact suggest the following phenomenological parametrization of these integrals$^{(1, 4)}$:

$$I(\ell) \propto \frac{d}{d\ell}\left[\left(1 - \exp\frac{\pi(\ell_o - \ell)}{\beta}\right)\right]^{-1} \exp(2i\sigma_\ell) \tag{2}$$

With such an assumption in a previous paper a diffractional formula was obtained by the methods of complex angular momenta$^{(16)}$.

The results of the comparison between the prediction of this formula and our experimental data are shown in fig. 3. In fig. 4 the same comparison has been made with the Nurzynsky's data after subtraction of the statistical contribution.

As in the previous paper$^{(4)}$ the points in the angular distributions corresponding to angles $\theta \leq 25^o$ and $\theta \geq 140^o$ were neglected because the model breaks down at these extreme angles. We choose, as free parameters in the fitting procedure the same one's as in ref. (4), the normalization constant h which in some way is related to the spectroscopic factor, the parameter ℓ_o which corresponds to the angular mo-

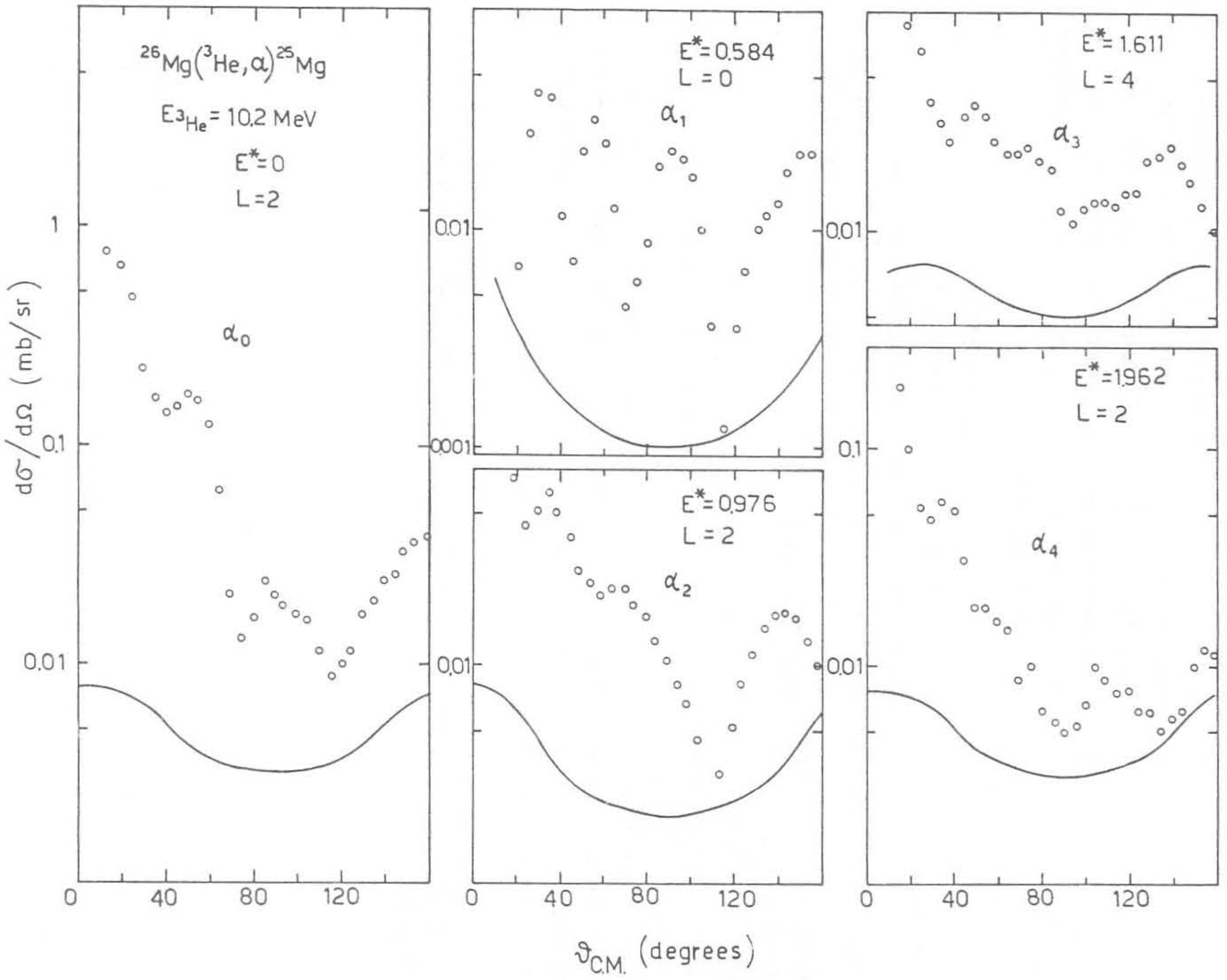

FIG. 2 - Angular distributions for the $^{26}Mg(^3He, \alpha)^{25}Mg$ reaction leading to the ground state and the first four excited levels in ^{25}Mg. The data are those of J. Nurzynski, taken from ref. 6. The solid lines are the angular distributions calculated as described in Sect. 3.

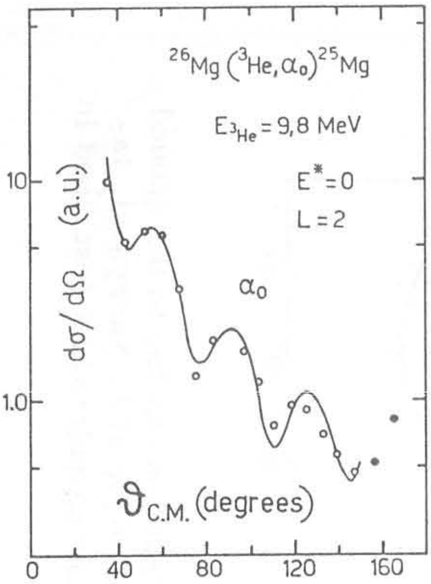

FIG. 3 - Angular distribution (in arbitrary units) for the $^{26}Mg(^3He,\alpha)^{25}Mg$ reaction at 9.8 MeV, leading to the ground state of ^{25}Mg. The solid line is the best-fitted curve of the diffractional model (see text) with the parameter values given in table II.

mentum where one has the maximum strenght of the stripping integral according to the parametrization (2), the parameter β which gives a measure of the degree of localization in ℓ-space, the parameter σ_i which represents the immaginary part of the σ_ℓ phase: finally the parameters σ'_r and σ'_i which represent the real and immaginary part respectively of the variation with ℓ of the phase σ_ℓ around ℓ_0 (see ref. (4)).

The parameters obtained from the best-fits are given in the table II and III togheter with the corresponding σ_i, σ'_r and σ'_i calculated with the following approximate formula of the Coulomb phase shift, valid for $|\ell| \gg 1$$^{(17)}$:

$$\sigma_\ell \approx n \log(1+\ell)$$

where n is the Coulomb parameter.

Since it is expect that the statistical contribution is percentually higher at backward angles we also fitted the Nurzynski's data only up to θ = 120°.

The results of the comparison are shown in fig. 5 and the parameters obtained from the best-fits are reported in table IV.

TABLE II

h	l_0	β	σ_i	σ'_r	σ'_i	r_0 (fm)	d (fm)
960	4.88	0.77	-0.41 (0.31)	-0.33 (0.31)	-2.92 (-0.041)	1.24	0.17

From the tables II, III and IV it can be seen that the σ_i parameters are generally smaller than the corresponding Coulomb phase shifts: this could be expected because the empirical parameter σ_i takes into account nuclear contributions which tend to reduce it (being of opposite sign).

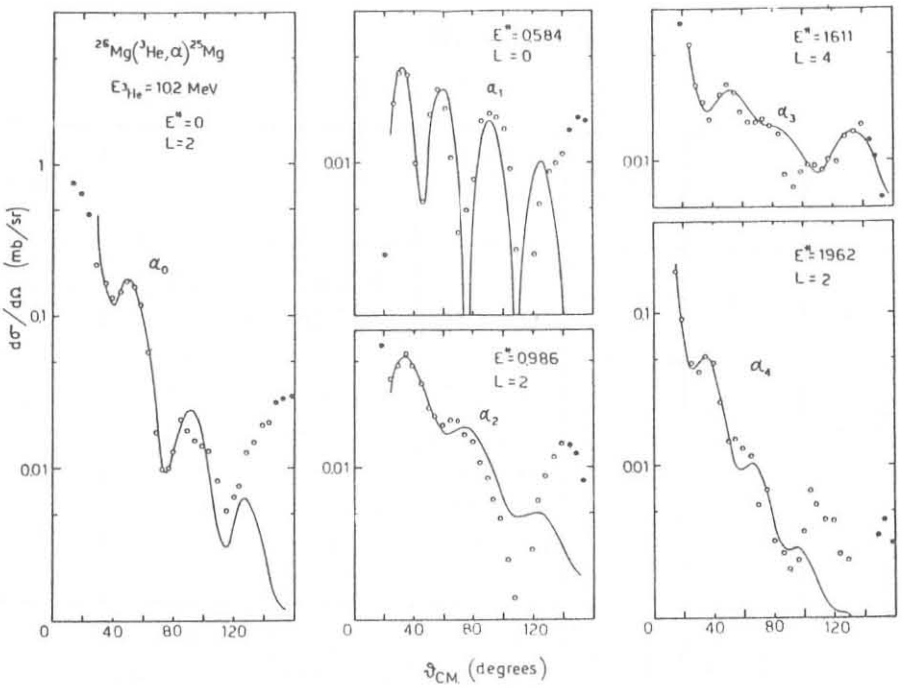

FIG. 4 - Angular distributions for the ^{26}Mg(^{3}He,α)^{25}Mg reaction leading to the ground state and the first four excited levels in ^{25}Mg. The data are those of J. Nurzynski, taken from ref. 6. The solid lines are the best-fitted curves of the diffractional model (see text) with the parameter values given in table III.

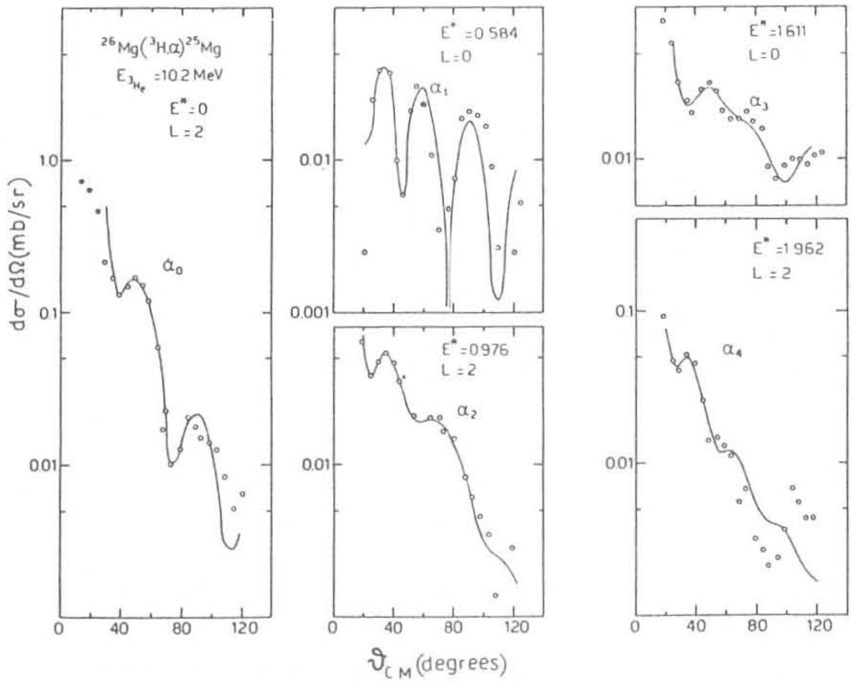

FIG. 5 - As in Fig. 4. Best-fits have been performed up to $\theta = 120^{\circ}$; the parameter values are given in table IV.

TABLE III

groups	h	ℓ_o	β	σ_i	σ'_r	σ'_i	r_o (fm)	d (fm)
α_o	1134	4.95	2.72	0.545 (0.793)	0.360 (0.256)	-0.078 (-0.256)	1.23	0.59
α_1	142.5	4.89	1.32	0.277 (0.416)	0.305 (0.300)	0.051 (-0.067)	1.23	0.29
α_2	61.11	3.38	1.49	0.535 (0.635)	0.063 (0.382)	0.074 (-0.130)	1.01	0.31
α_3	11.58	3.25	0.69	0.629 (0.307)	0.624 (0.431)	0.0005 (-0.070)	1.00	0.15
α_4	3.09	5.41	1.27	-0.270 (0.374)	1.380 (0.284)	-0.2000 (-0.056)	1.34	0.29

TABLE IV

groups	h	ℓ_o	β	σ_i	σ'_r	σ'_i	r_o (fm)	d (fm)
α_o	1272	4.70	2.09	0.495 (0.645)	0.356 (0.285)	-0.276 (0.285)	1.19	0.45
α_1	165	4.94	1.39	0.290 (0.427)	0.309 (0.296)	0.046 (-0.069)	1.24	0.30
α_2	194	3.70	2.06	0.720 (0.765)	0.210 (0.333)	0.099 (-0.146)	1.06	0.45
α_3	18.05	3.63	0.83	-0.037 (0.339)	0.570 (0.394)	-0.059 (-0.071)	1.06	0.18
α_4	3.66	5.76	1.17	-0.280 (0.330)	1.080 (0.271)	-0.320 (-0.047)	1.40	0.26

In the same tables the r_o values, connected to the interaction radius R, and the surface-width d of the interaction region are reported as derived according to the semiclassical picture$^{(4, 18)}$:

$$\ell_o(\ell_o+1) = KR(KR - 2n)$$

$$(2\ell_o+1)/\beta = 2\pi Kd(KR - n)$$

where

$$R = \frac{r_o}{2}\left(A_T^{1/3} + A_R^{1/3} + A_{^3He}^{1/3} + A_\alpha^{1/3}\right)$$

and

$$n = \frac{1}{2}\,\frac{e^2}{h^2}\left[\frac{m_{^3He} Z_T Z_{^3He}}{K_{^3He}} + \frac{m_\alpha Z_R Z_\alpha}{K_\alpha}\right]$$

Finally in fig. 6 the r_o-values at 10 MeV are shown (see table IV) versus r_o-values at 5 MeV (see ref. (4)); the "errors" represent the corresponding d-values for the five α-groups.

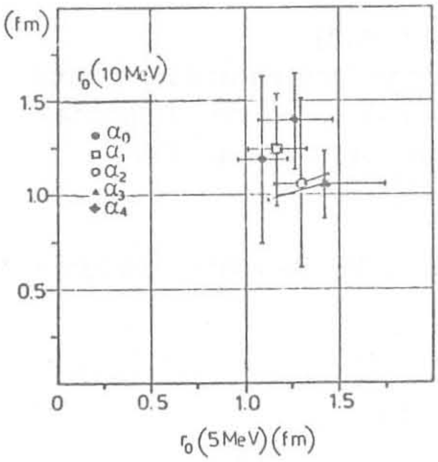

FIG. 6 - (r_o-values) ± (d-values) at 10 MeV (see table IV) versus (r_o-values) ± (d-values) at 5 MeV (see ref. 4).

The values of r_o at different energies are not very different.

In conclusion, the present analysis seems to show that our diffractional model describes adeguately the angular distribution also at energies around 10 MeV, in spite of its simplicity and of the relatively small set of parameters.

More experimental and theoretical work seems worthwhile in order to understand why that is so, because it is not clear, at the moment, whether such an agreement, has some deep significance or it is due to the compensating effect of the parameters.

This accomplishement would be extremely valuable in order to extract, later on, in a very simple manner, as compared to D.W.B.A. calculations, relevant spectroscopic informations from the experimental data.

We would like to thank Prof. R. Potenza for useful discussions and comments. Thanks are also due to the staff of the CENCO electronic computer where the calculations have been carried out.

Finally we thanks Prof. E. Shopper and the staff of the accelerator of the Frankfurt/M University for their kind hospitality and for their assistance during the experiment.

REFERENCE -

(1) W.E. Frahn and R.H. Venter, Nuclear Phys. 59, 654 (1964).
(2) W.E. Frahn, Nuclear Phys., 75, 577 (1966).
(3) W.E. Frahn and M.A. Sharaf, Nuclear Phys., A 133, 593 (1969).
(4) S. Notarrigo, A. Rubbino, S. Sambataro and S. Zubke, Nuovo Cimento, 64 B, 7 (1969).
(5) A. Rubbino, Nuovo Cimento, 54 B, 37 (1969).
(6) J. Nurzynski, Nuclear Phys., A 141, 257 (1970).
(7) M.A. Preston, Physics of the Nucleus (Addison-Wesley, 1962).
(8) K.J. Le Couteur and D.W. Lang, Nuclear Phys. 13, 32 (1959).
(9) T. Ericson, Advanc. Phys., 9, 425 (1960).
(10) E. Erba, U. Facchini and E. Saetta-Menichella, Nuovo Cimento 22, 1237 (1961).
(11) A.G.W. Cameron, Can. J. Phys., 36, 1040 (1958).
(12) G.S. Mani, M.A. Melkanoff and I. Iori, Proton Pentrabilities Using an Optical Model Potential, Rapport CEA n. 2379; Neutron Penetrabilities Using an Optical Model Potential, Rapport CEA n. 2380.
(13) A. Agodi, Suppl. Nuovo Cimento 3, 483 (1965).
(14) N. Austern, Ann. Phys., 15, 299 (1961).
(15) R. Stock, R. Bock, P. David, H.H. Duhm and T. Tamura, Nuclear Phys., A 104, 136 (1967).
(16) E.V. Inopin, Sov. Phys.-JETP, 21, 1090 (1965).
(17) T. Ericson, Preludes in Theoretical Physics, ed. by A. de-Shalit, H. Feshbach and L. Van Hove (Amsterdam, 1965).
(18) R.H. Venter and W.E. Frahn, Ann. Phys., 27, 401 (1964).