650 reacoes nucleares

S/C.Lattes

SYS NO: 1358705

Instituto de Física
Universidade de São Paulo

Proton halo effect in the 16O(d,n1)17F* reaction near the threshold.

R. Lichtenthäler, M.P.M. Assunção, V. Guimarães, A. Lépine-Szily, G.F. Lima

Instituto de Física, Universidade de São Paulo, CP 66.318 05315-970, São Paulo, SP, Brasil

Publicação IF – 1568/2003

Proton halo effect in the $^{16}O(d,n1)^{17}F^*$ reaction near the threshold.

R. Lichtenthäler, M.P.M. Assunção, V. Guimarães, A. Lépine-Szily, G.F. Lima
Departamento de Física Nuclear
Instituto de Física da Universidade de São Paulo
CP 66318, 05315-970 São Paulo SP, Brasil

May 22, 2003

Abstract

Angular distributions of the proton stripping reactions $^{16}O(d,n0)^{17}F_{gs}$ and $^{16}O(d,n1)^{17}F^*$ leading to the first excited state of ^{17}F at incident deuteron energies $E_d = 2.29 - 3.19$MeV have been analysed using the DWBA formalism. A conspicuous evidence of the proton halo in the outgoing channel of the transfer reaction $^{16}O(d,n1)^{17}F^*$ was observed. In order to obtain realistic spectroscopic factors from the $(d,n1)$ reaction it was necessary to introduce a long-range absorptive component in the optical potential of the outgoing channel $n +^{17} F^*$. This effect is not observed in the $^{16}O(d,n0)F_{gs}$ reaction data.

One of the most exotic features observed in unstable nuclei is the neutron halo, first reported by Tanihata *et al* [1] in ^{11}Li and $^{6,8}He$ nuclei. This phenomenon can be understood as the spreading of the wave function of the valence neutrons to distances far from the core and is explained by the association of two factors: small separation energies and low angular momentum of the bound neutrons. The experimental signatures of the neutron halo are an abnormally large reaction cross section and the presence of a narrow component in the transverse momentum distribution of the core ^9Li observed from the fragmentation of ^{11}Li [2]. In proton rich nuclei, the proton halo is expected to be less prominent due to the Coulomb barrier which reduces the tail of the wave function of the bound proton. Nuclei such as ^8B and the first excited state of $^{17}F(0.495MeV; 2s_{1/2})$ are candidates for a proton halo, the latter having a proton bound only by $E_b = 0.1$ MeV in an s-state. Some evidence of the halo characteristic effect of these two nuclei have been reported [3, 4, 5, 6]. An interesting signature of the proton halo of the first excited state of $^{17}F^*$ is the strong increase in the astrophysical S-factor for the proton capture reaction $^{16}O(p,\gamma)^{17}F^*$ to this state observed at low energies [6]. This enhancement is an effect of the long range tail of the wave function of the valence proton in the $^{17}F(0.495; 2s_{1/2})$. Halo phenomena in nuclei is of great interest in astrophysical issues since its presence can considerably enhance the neutron and proton capture cross sections, having consequences for the energy production in stars and in the nucleosynthesis of elements.

In this paper we present a new dynamical effect of the proton halo in the first excited state of $^{17}F^*$, observed as a long-range absorptive component in the optical potential for the outgoing channel of the transfer reaction $^{16}O(d,n1)^{17}F^*$. We present the results of a DWBA analysis of the proton transfer angular distributions $^{16}O(d,n0)^{17}F_{gs}$ and $^{16}O(d,n1)^{17}F^*$ at energies near to the reaction thresholds for these reactions 1.627MeV and 2.127MeV respectively. The inclusion of a long-range absorptive component in the "normal" neutron-$^{17}F^*$ optical potential is necessary to reproduce the spectroscopic factor of the vertex $<^{17} F^*|^{16}O>$ which is known to be close to 1. This "anomalous" component of the absorptive potential is not manifested in the $^{16}O(d,n0)^{17}F_{gs}$ reaction data.

The experimental data were measured at São Paulo Van de Graaff accelerator in the 1960's by O. Sala[7], O. Dietzsch at al.[8]. Several complete angular distributions of the elastic scattering $^{16}O(d,d)$ and transfer reactions $^{16}O(d,n)$ and $^{16}O(d,p)$ were obtained in the energy range from $E_d = 2.29$MeV up to $E_d = 3.27$MeV in steps of $50 - 70$keV. The energy resolution due to the beam and target thickness was about 12 keV. The cross sections show fluctuations as a function of the energy which have been smoothed out by performing an energy averaging of the angular distributions. The energy averaging was performed in an energy interval of about 140 keV by interpolating the excitation functions at fixed angles using second degree splines. This procedure is important in order to smooth the narrow fluctuations which have been observed in the excitation functions.

As a first step for the DWBA analysis, the optical potential parameters for the entrance channel $d +^{16} O$ were determined by fitting the elastic scattering angular distributions at 4 energies. The energies of the elastic scattering angular distributions were choosen in order to cover the entire energy interval of the measurements. We used the search version of the computer code SFRESCO [9] and started the search procedure from two different sets of initial parameters [8, 10]. In table 1, a and b are the final potentials obtained from the search. In figure 1b the elastic scattering fits corresponding to potentials a (dashed) and b (solid) for two representative energies are shown. Potential b is a variation of the Satchler potential [10] with some parameters slightly changed in order to improve the fit to the low energy $^{16}O(d,d)$ data. Although excellent fits of the elastic scattering angular distributions could be obtained at each energy by small variations in the potential parameters, we decided for simplicity to use a fixed set of parameters (potential a and b) for all four energies. Very similar fits for the transfer angular distributions and similar spectroscopic factors have been obtained with the potentials (a and b) for the entrance channel. Thus, in the subsequent discussion of the DWBA analysis, we will present only the result using potential b.

The deuteron form factors used in the analysis of the $^{16}O(d,n0)$ and $^{16}O(d,n1)$ reactions were calculated using the Reid soft core potential with contributions of $l=0$ and $l=2$ to the deuteron wave function. As for the form factor of the $p+^{16}O$ bound state, a real volume Wood-Saxon potential was considered with standard geometrical parameters $r_o = 1.25 fm$ and $a = 0.65 fm$;the depth of the single particle potential was adjusted to reproduce the binding energies and number of nodes of the bound-state wave function. A spin-orbit term with depth of $6.0 MeV$ and the same geometry was also included.

Very little information is available for the neutron-^{17}F optical potential at these low energies. The instability of ^{17}F means that there are no experimental elastic scattering data. Thus, for the $n+^{17}F$ outgoing channel we used an optical potential (called potential c in table 1) which was obtained from ref. [11, 12]. Using this potential in the outgoing channel, very good fits of the $^{16}O(d,n0)^{17}F_{gs}$ reaction have been obtained.

The compound nucleus contribution to the transfer cross section was estimated by Hauser- Feschbach calculations [8]. An isotropic angular distribution of a few millibarns has been obtained by the Hauser-Feshbach estimate for the transfer reactions. For the $(d,n0)$ reaction the compound nucleus contribution is about $10-30\%$ at forward angles. For the $(d,n1)$ reaction which has a forward peaked cross section of some hundreds of millibarns the compound contribution is negligible. The spectroscopic factors C^2S, which normalize the DWBA calculations to the experimental data were obtained by including the calculated compound contributions.

We obtained a normalization factor $C^2S = 0.85(8)$ for the $(d,n0)$ reaction. We consider the spectroscopic amplitude $< d|n >= 1.0$. This result agrees very well with previous measurements [6, 13, 14, 15] of the spectroscopic amplitude $<^{17}F_{gs}|^{16}O>$. In figure 1c the fits for two energies of the $(d,n0)$ reaction are presented.

In contrast to the $(d,n0)$ results, the analysis of the reaction $^{16}O(d,n1)^{17}F^*$ using potential c in the outgoing channel provided normalization factors of $C^2S \approx 0.7$, which is in disagreement with the values $C^2S \approx 1.0$ obtained from previous measurements. The DWBA cross sections for the $(d,n1)$ reaction were about a factor 1.3 above the experimental data in the forward angle region as shown by the dotted lines in the upper part of figure 1a. Also the form of the angular distribution was also not so well reproduced with potential c. The observed overestimate of the transfer cross section can not be accounted by reasonable variations in the parameters of the single particle potential for the $p+^{16}O \rightarrow ^{17}F^*$ bound state. The increase in the radius parameter, from the standard $r_o = 1.25$ fm to some higher values, which could be expected as a halo effect in the bound state, would result in an increase in the transfer cross section in contradiction to the experimental data. This motivated us to try modifications in the outgoing channel optical potential.

Using the search version of the FRESCO program we fixed the expected normalization factor $C^2S = 1$ for the $(d, n1)$ reaction and performed an automatic search in the parameters of a component added to the optical potential c of table 1. This additional component was choosen to have real and imaginary parts (6 parameters) and two different shapes: Wood-Saxon and the derivative of a Wood-Saxon. This component would act as a correction to the "normal" potential c and was left free to allow a different geometry. The search was performed for $(d, n1)$ angular distributions at 4 energies independently. The resulting correction had always the same characteristic for the 4 energies and two shapes: a long-range pure imaginary (absorptive) potential with a large radius. The real part of the correction was always negligible and in most cases null. In table 1 we call potential d a typical parameter set obtained for the correction term using a Wood-Saxon shape. In the upper part of figure 1a we present the fits obtained (solid line) at the four energies analysed using the correction term d of table 1 added to the "normal" potential c. In order to display the effect of the correction term, the solid and dashed calculations presented in figure 1a have the same normalization factor. Some ambiguity in the fits for the $(d, n1)$ reaction was observed using different parameters of the correction term. We found that a lower diffuseness implies a larger radius and a larger depth of the imaginary component. Also very good fits have been obtained using a derivative of the Wood-Saxon shape with large radius and diffuseness. In all cases, the common feature was the large radial extension of the imaginary potential indicating a halo-like effect.

The same search procedure was applied to the $(d, n0)$ reaction data and a null correction was found indicating that this anomalous long range potential, necessary to fit the $(d, n1)$ data, is not present in the $n+^{17}F_{gs}$ channel. In fact, the inclusion of the correction term d in the $(d, n0)$ analysis changes the shape of the angular distributions in complete disagreement with the experimental data. This is evidence that the proton halo is much less prominent in $^{17}F_{gs}$, as we would expect due to the higher binding energy $E_b = 0.6$ MeV and higher angular momentum $1d_{5/2}$ of the bound proton in the ground state compared to the $E_b = 0.1$ MeV; $2s_{1/2}$ first excited state of ^{17}F.

It is interesting to observe how the transfer process $^{16}O(d, n1)^{17}F$ is sensitive to a region in r-space where the mainly long range absorptive potential is present. This is shown in the upper part of figure 2 where we present the χ^2 for the $(d, n1)$ reaction calculated at $E_d = 3.051$MeV as a function of R_{cut}, which is the lower cutoff of the radial transfer integrals. This calculation shows that the transfer is sensitive mainly to a radial region beyond 6 fm where the long range absorptive halo is present (lower part of figure 2).

We also analysed the data from [15, 16, 17] of $^{16}O(d, n1)$ reactions at energies $E_d = 8$ MeV and $E_d = 12.0$ MeV. For the higher energy data we used the optical potential of Satchler in the deuteron channel and potential c in the outgoing neutron channel in the DWBA calculation. The spectroscopic factor obtained from this analysis for the $(d, n1)$ reaction was $C^2S \approx 1.0$, indicating that this anomalous effect is not present at higher energies. It is worthwhile to mention that, at the incident deuteron energies of the present paper, the corresponding kinetic energies in the outgoing channel $n +^{17} F^*$ are between 300 keV and 700 keV, in the range of astrophysical energies. It seems that at these low energies the transfer process is very peripheral and particularly sensitive to the halo properties.

In summary, we observed an "anomalous" decrease in the magnitude of the experimental $^{16}O(d,n)^{17}F^*$ cross section at forward angles which we attribute to the proton halo of the first excited $1/2^+$ state of $^{17}F^*$. The effect of the halo is observed in the DWBA analysis since a long range imaginary component was necessary to be added to optical potential in the outgoing channel $n +^{17} F^*$ in order to explain the data. This component was not necessary in the $^{16}O(d,n0)^{17}F_{gs}$ analysis, where no halo is expected. The effect of this long range absorptive potential is basically to decrease the calculated $(d,n1)$ cross section at forward angles, resulting in more realistic spectroscopic factors for the $<^{17} F^*|^{16}O>$ amplitude. One would expect an increase in the transfer cross section involving halo nuclei, however this was not what we observed probably due to the competition with other reaction channels. The long range absorptive correction to the outgoing potential in the $(d,n1)$ reaction can be understood as a dynamical effect of the $^{17}F^*$ proton halo, probably related to the opening of more reaction channels in the $n +^{17} F^*$ scattering. Neutron capture and/or $^{17}F^*$ breakup could be some reaction channel candidates. The observed effect can be directly related to an anomalous enhancement of the $n +^{17} F \rightarrow^{18} F$ capture cross section at astrophysical energies. The sensitivity that the transfer reaction $^{16}O(d,n)^{17}F$ at very low energies shows to certain spacial regions in r-space seems to play an important role in the present observations.

1 acknowledgements

This work was supported by FAPESP, Projeto Temático no. 2001/06676-9.

References

[1] I. Tanihata *et al.*
Phys. Lett. **160B**, 380(1985),Nucl. Phys. **A552**, 275c(1991)

[2] T. Kobayashi, O. Yamakawa, K. Omata, K. Sigimoto, T. Shimoda, N. Takahashi, I. Tanihata
Phys. Rev. Lett. **60**, 2599(1988)

[3] M.H. Smedberg *et al.*
Phys. Lett. **B452**, 1-7(1999)

[4] V. Guimarães, J.J. Kolata *et al.*
Phys. Rev. Lett. bf 84, 1862(2000)

[5] M.M. Obuti *et al.*
Nucl. Phys. **A609**, 74(1996)

[6] R. Morlock, R. Kunz, A. Mayer, M. Jaeger, A. Müller, J.W. Hammer,
Phys. Rev. Lett. **79**, 3837(1997)

[7] O. Sala
Catedra thesis - University of São Paulo - 1962

[8] O. Dietzsch, R.A. Douglas, E. Farrelly Pessoa, V. Gomes Porto, E.W. Hamburger, T. Polga and O. Sala.
Nucl. Phys. **A114**, 330(1968)

[9] I.J. Thompson
Computer Physics Reports **7** (1988),167-212

[10] G.R. Satchler
Nucl.Phys. **85**, 273(1966)

[11] F.D. Becchetti and G.W. Greenlees
Phys. Rev. **182**, 1190(1969)

[12] L. Rosen, *Proceedings of the 2nd International Symposium on Polarization Phenomena of Nucleons* (Birkhaüser Verlag, Basel, 1966),p253

[13] C. Rolfs
Nucl. Phys. **A217**, 29(1973)

[14] C.J. Oliver *et al.*
Nucl. Phys. **A127**, 567(1969)

[15] S.J. Thornton
Nucl. Phys. **A137**, 531(1969)

potential	particle	V_r	r	a	V_i	r_i	a_i	V_{s-o}	r_{s-o}	a_{s-o}	Ref.
a	$d+^{16}O$	75.0	1.4	0.7	7.155*	1.4*	0.7*	6.0	1.4	0.7	[8]
b	$d+^{16}O$	110.0	1.012	0.876	9.3*	1.837*	0.356*	6.0	1.4	0.7	[10]
c	$n+^{17}F$	49.0	1.25	0.65	5.75*	1.25*	0.70*	6.0	1.25	0.65	[8]
d	$n+^{17}F^*$	0.0	1.25	0.65	7.97	2.27	0.8	0.0	1.25	0.65	[8]

Table 1: Optical Model potential parameters Parameters with $*$ correspond to surface derivative of Wood-Saxon shape: $\frac{4Ve^{\frac{r-R}{a}}}{1+e^{\frac{r-R}{a}}}$. The spin-orbit term has the shape above multiplied by: $\frac{1}{2ra_{s-o}}$. All other parameters correspond to Wood-Saxon shape.

[16] F.G. Forest, Ph.D. thesis, University of Wisconsin, 1967.
Available at University Microfilms, Ann Arbor, Michigan

[17] R. Lewis, A.C. Hayes
Phys. Rev. **C59**, 1211(1999)

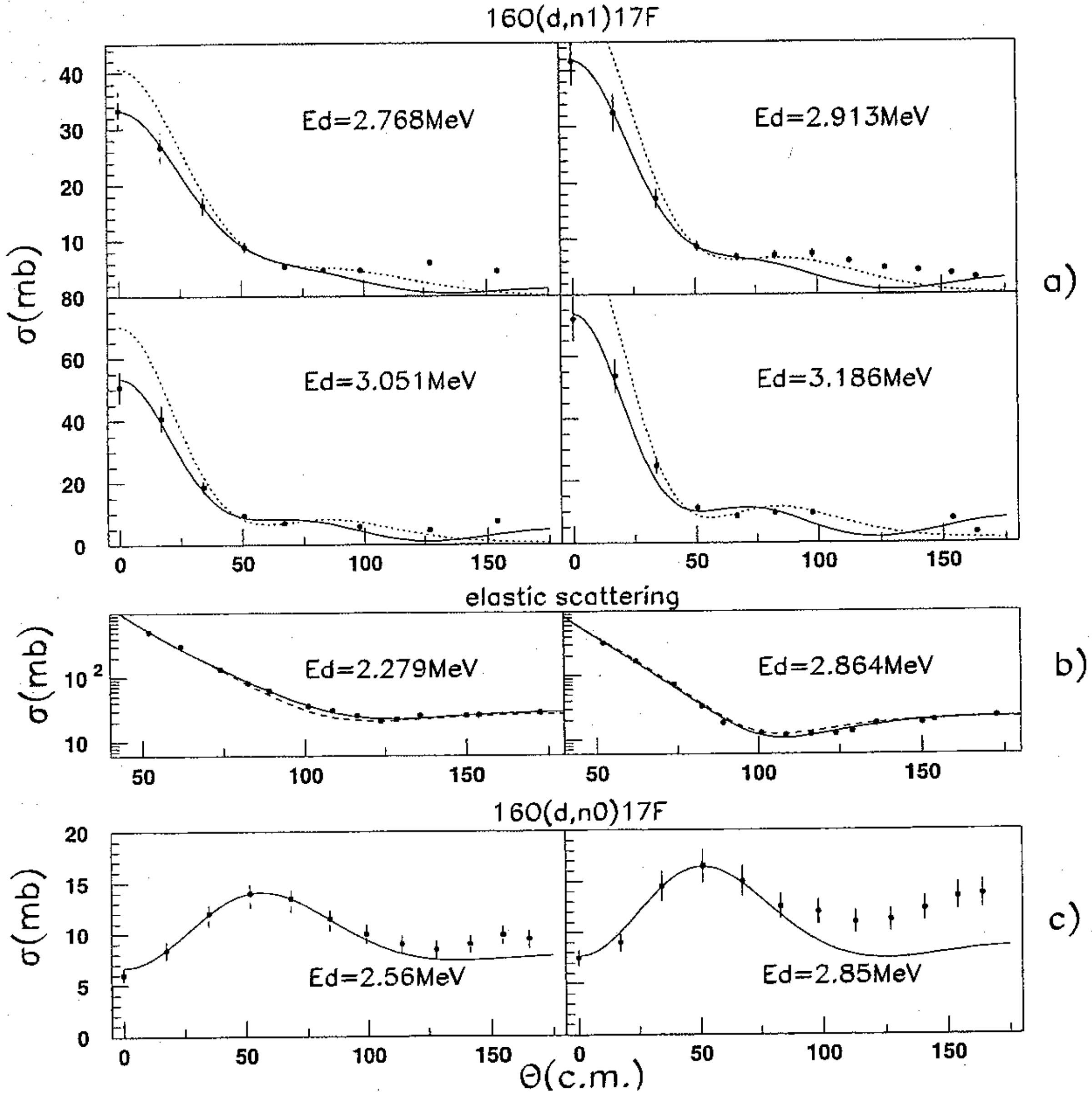

Fig.1: a) DWBA calculation for the $^{16}O(d,n)^{17}F^{*}$ with (solid) and without potential d(dotted), b) elastic scattering angular distributions using potential b (solid) and a (dashed), c) $^{16}O(d,n)^{17}F_{gs}$ DWBA calculations with potential c.

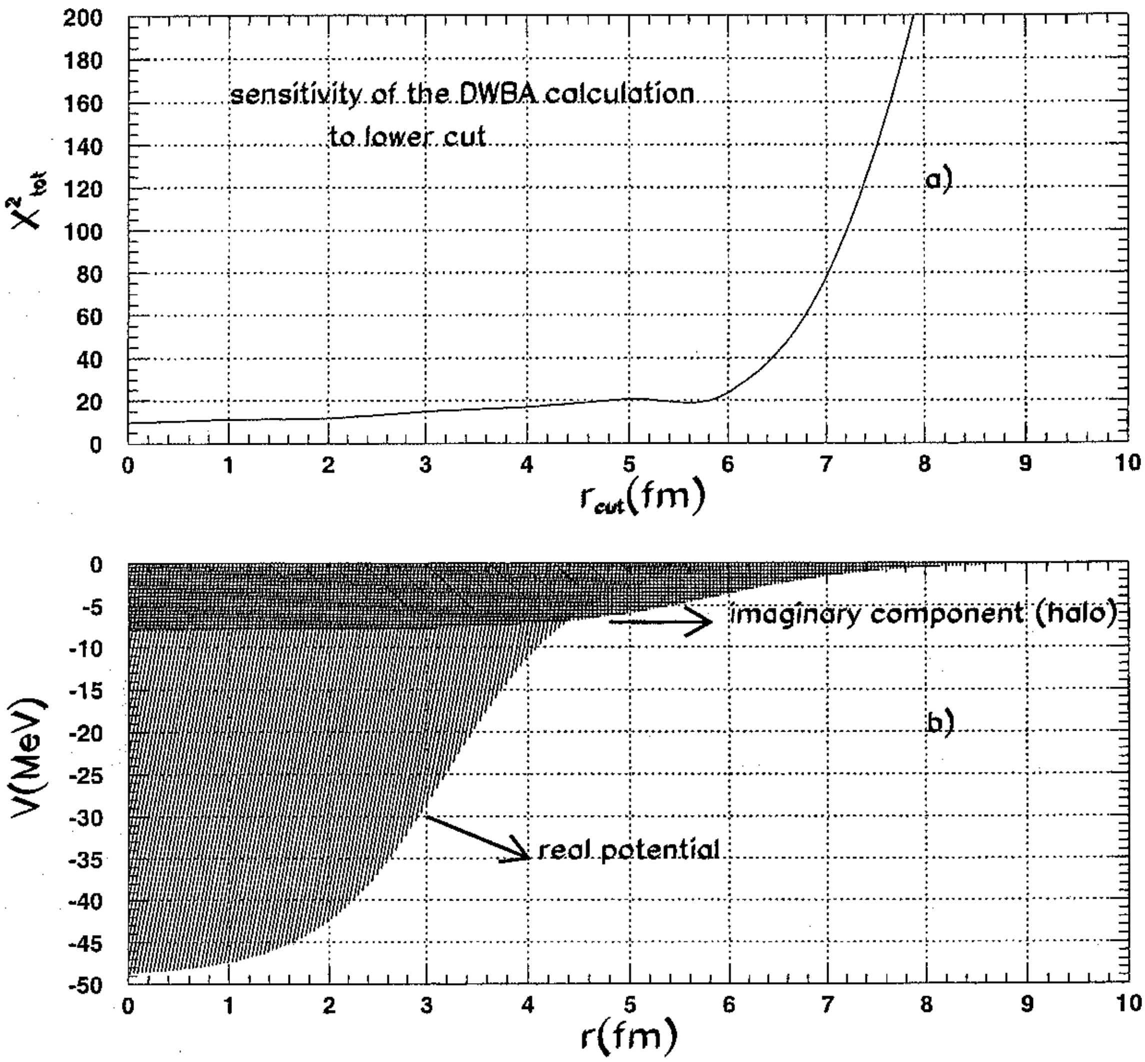

Fig.2: a) χ^2_{tot} for the DWBA calculation for the $(d, n1)$ reaction at 3.051MeV as a function of the lower cut R_{cut} in the radial integral. b)real part of optical potential c and the imaginary "anomalous" component d (hatched).

Subject: PREPRINT
From: Rosemary Cruz <rosemary.cruz@dfn.if.usp.br>
Date: Thu, 22 May 2003 13:26:36 -0300
To: "virginia@sbi.if.usp.br

nome=ROSEMARY C. CRUZ
funcao=FNC
Titulo do Preprint=Proton halo effect in the 16 O(d,n1)17 F* reaction near the threshold
Autores=Lichtenthäler, R.; Assunção, M.P.M.; Guimarães, V. et.al.
Departamento=FÍSICA NUCLEAR
Telefone / ramal=6942
Telefone / ramal=2424410
Data =22/05/2003
e-mail=RCRUZ@IF.USP.BR
Observações=Preprint para o prof. Rubens.
Segue via correio interno.