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α-particles optical potential for medium and heavy-mass nuclei around the Coulomb barrier

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Abstract. Recent high-precision measurements of α-particle elastic scattering and (α,x) reaction cross sections has motivated the extension of a previous semi-microscopic analysis for the mass-region 50<A<120 and energies from 13 to 50 MeV to heavy nuclei up to 209Bi. The regional optical model potential for low-energy α-particles which has thus been obtained entirely on the basis of elastic-scattering data analysis, for the nuclei within the above-mentioned mass and energy ranges, is involved within the (α,γ), (α,n) and (α,p) reaction cross sections analysis at incident energies below the Coulomb barrier. The statistical-model parameters used for the cross section calculations were established by analyzing various independent experimental data for the involved nuclei, making possible the focus on the uncertainties of α-particle OMP. An optical potential which describe equally well both the low energy elastic-scattering and induced-reaction data of α-particles has finally been obtained for medium and heavy mass nuclei.

1 Introduction

The still poor knowledge of the α-particle optical model potential (OMP) below the Coulomb barrier is closely related to a couple of main questions which are still open, namely the OMP parameter sets obtained from α-particle elastic scattering at high energies (E_α>80 MeV) which describe neither the lower-energy (<40 MeV) elastic scattering nor complete fusion data, and the statistical α-particle emission that is underestimated by the OMPs that account for elastic scattering on the ground-state nuclei ([1] and Refs. therein). As a consequence we started formerly [1] with the analysis of the α-particle elastic scattering alone, for nuclei in the mass region A ~100 and energies from ~14 to 32 MeV, while an eventual failure to describe reaction data remained to be understood later. At the same time we did not take into account either the available experimental α-induced or the (n,α) reaction cross sections, to avoid additional difficulties because of the remaining parameters needed in statistical model calculations [2]. Within these conditions, the potential of Ref. [1] should not be used for the analysis of more recent reaction cross sections measured at incident energies $E_\alpha \approx$ 8-15 MeV [3–5], i.e. outside the energy range involved for its setting up.

The same semi-microscopic analysis was then extended to A ~50–120 nuclei and energies from ~13 to 50 MeV [6]. The Double Folding Model (DFM) has been involved in order to obtain the real part of the optical potential while the energy-dependent phenomenological imaginary part was obtained including the dispersive correction to the DFM real potential. A concurrent complete phenomenological analysis of the same data basis was also carried out for nuclei within the above-mentioned mass and energy ranges, while an ultimate assessment of (α,γ), (α,n) and (α,p) reaction cross sections proves the suitable description of both the lower energy elastic-scattering and α-particle induced-

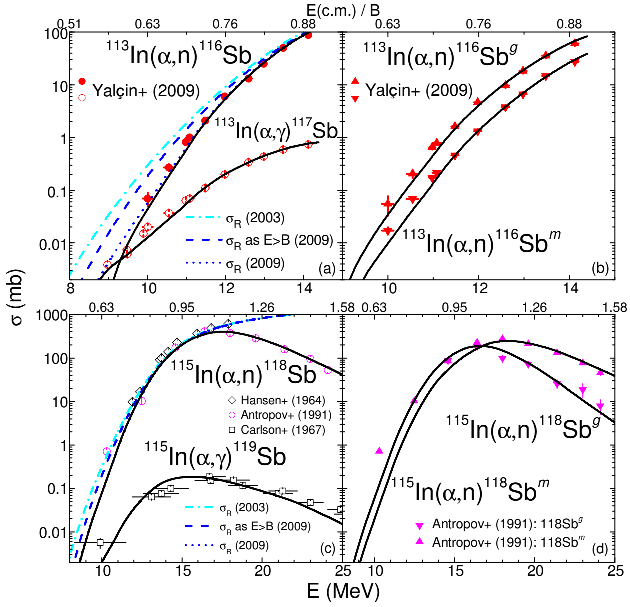

Fig. 1. (Color online) Comparison of (a,c) calculated total α-reaction cross sections using a former OMP [1] (dash-dotted curve), parameters in Ref. [6] obtained above the Coulomb barrier height B, in MeV (E>B), by elastic scattering analysis alone (dashed curve), and the OMP parameters of Ref. [6], as well as of the measured [5,11] and calculated cross sections of (α,γ) and (α,n) reactions on ^{113,115}In nuclei as described in the text, and (b,d) the latter comparison for the ^{113,115}In(α,n) reactions that produce ground ^{116,118}Sb^g and isomeric ^{116,118}Sb^m states.

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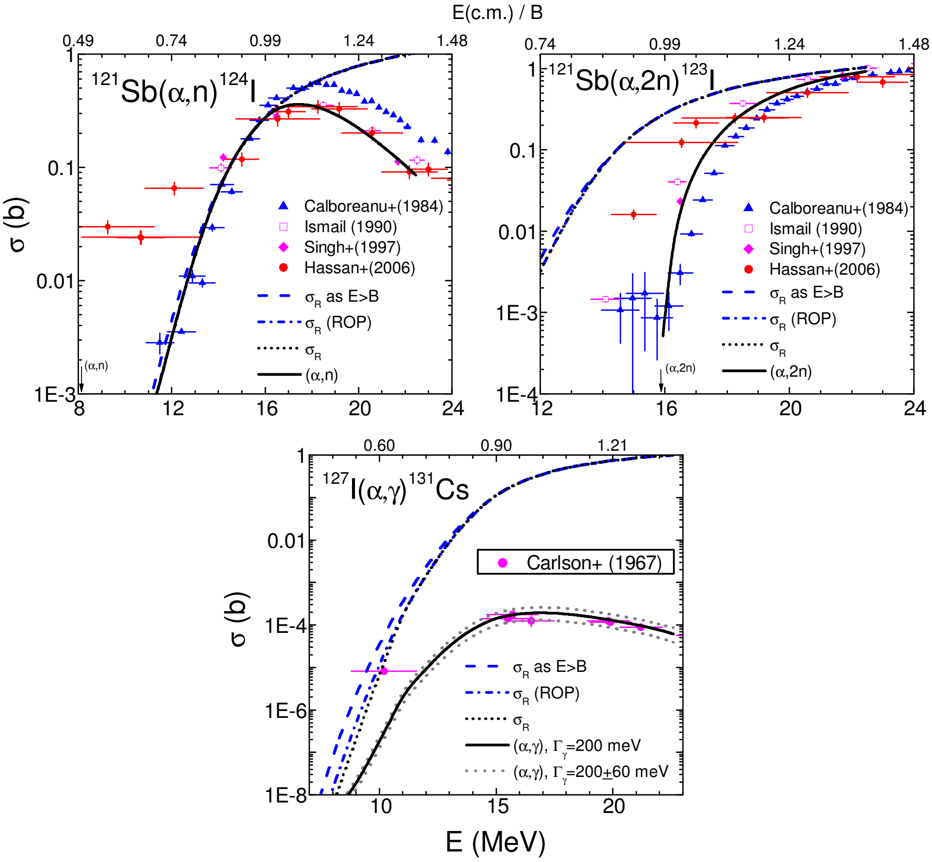

Fig. 2. (Color online) Comparison of calculated total α-reaction cross sections using the parameters [7] obtained above the Coulomb barrier height B by elastic scattering analysis alone (dashed curves), the ROP parameters of Ref. [7] (dotted curves), and the same parameters except the former depth [6] of the imaginary surface potential W_D=4 MeV (dash-dotted curves), with the measured [11] and calculated (solid curves) cross sections of (α,γ) and (α,xn) reactions on ^{121}Sb and ^{127}I target nuclei. The short-dotted curves in the case of the reaction ^{127}I$(\alpha,n)^{131}$Cs reaction correspond to average s-wave radiative widths increased and decreased by 60 meV.

reaction data. A further step has concerned the extension of both the semi-microscopic analysis and phenomenological regional optical potential (ROP) to heavy nuclei A ≥132 nuclei and energies from ~10 to 50 MeV [7], the discussion of the related (α,γ) and (α,n) reaction cross sections having again to prove the suitability of the phenomenological ROP even at the lowest energies.

2 Additional α-particle optical potential test below the Coulomb barrier

The analysis of α-induced reaction cross sections below the Coulomb barrier [6] has shown that the diffuseness a_R of the OMP real part as well as the surface imaginary potential depth W_D, established by the former analysis above B, are responsible for the difficulties encountered in the description of the reaction data at lower energies. Consequently, the modified energy dependence of these two parameters, for $E_{c.m.}/B$ <0.9 (Table 3 of Ref. [6]) have provided an optical potential that describes equally well the low energy α-particle-induced reaction and elastic scattering data. This has been additionally proved [8] to be also the case of recent analysis of the (α,n) reactions on ^{92,94}Mo isotopes and α-capture on ^{112}Sn [3] and ^{117}Sn [4].

Even more recently, Yalçin *et al.* [5] compared newly measured cross sections of (α,γ) and (α,n) reactions on ^{113}In, below the Coulomb barrier B, and statistical model calculations with different optical potentials including also unsuitably the potential of Ref. [1]. Their new data [5] are compared in Fig. 1(a,b) with the results of statistical model calculations using a consistent input parameter set [6,7] and the above-mentioned α-particle optical potential [6]. The corresponding α-particle total reaction cross sections are also compared with the results obtained by using the previous potential [1] involved in Ref. [5], as well as the OMP parameter values of Ref. [6] provided by the only elastic scattering analysis above B. The improvement due to the previous reaction data analysis [6] becomes thus obvious, as well as the failure of the use of former ROP [1] due to the lack of the reaction cross section consideration for its establishment. No adjustment of the statistical model parameters has been made, while an additional description of the neutron-capture data evaluation available for the ^{121}Sb nucleus [9], for the neutron energies up to 3 MeV, has proved the correctness of the adopted γ-ray strength functions. On the other hand, it should be noted

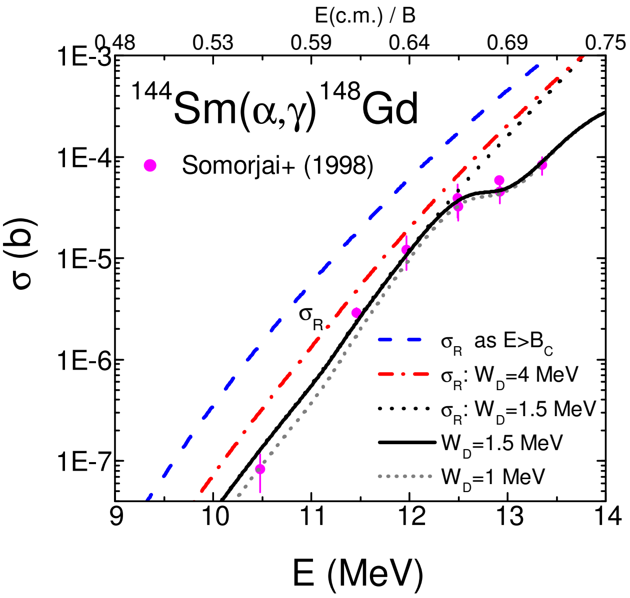

Fig. 3. (Color online) Comparison of calculated total α-reaction cross sections using the parameters [7] obtained above the Coulomb barrier height B by elastic scattering analysis alone (dashed curve), the ROP parameters of Ref. [7] (dotted curve), and the same parameters except the depth of the imaginary surface potential W_D=4 MeV (dash-dotted curve), with the measured [17] and calculated (solid curve) cross sections of the ^{144}Sm$(\alpha,\gamma)^{148}$Gd reaction. The short-dotted curve corresponds to the ROP parameters except the value W_D=1 MeV.

that the low-lying levels and decay scheme of the residual nucleus ^{116}Sb takes into account 21 levels up to the excitation energy of 841 keV [10]. The lower agreement of the calculated and measured cross sections for the ground and isomeric states [Fig. 1(b)] which occurs in the limit of the error bars only for the α-particle energies between 10–11 MeV, corresponds mainly to the population of these discrete levels. Thus, some questions of the level and decay scheme of the ^{116}Sb nucleus could be related to this lower agreement.

The overall good agreement between the measured and calculated cross sections provides a trustworthy confirmation of the recent α-particle OMP [6]. It results especially from the suitable description of the (α,n) reaction cross section within the critical energy range just above the threshold, which was proved in Figs. 4 and 8-9 of Ref. [5] to be a real challenge for the statistical model calculations. The energy dependence of the real-potential diffuseness a_R as well as the surface imaginary potential depth W_D, below the Coulomb barrier, is supported by the conclusion of Yalçin *et al.* [5] according to which a suitable energy dependence of the optical α potential at low energy may improve the reaction data predictions relevant at astrophysical energies. Also this point is supported by an additional similar analysis of the (α,γ) and (α,n) reaction cross sections for the ^{115}In target nucleus, shown in Fig. 1(c,d). The OMP correctness is proved at the higher energies too, in the limit within which the pre-equilibrium emission is known to be not yet important and can be omitted. On the other hand, the usefulness of further measurements to lower energy as in Ref. [5] is obvious.

The ROP extension to A>120 has been validated as well by analysis of other available α-particle induced reaction cross sections for nearby target nuclei. Part of the corresponding results, for the targets ^{121}Sb and ^{127}I, are shown in Figs. 2–3. Concerning the statistical model calculations carried out in this respect, we have taken the advantage of a better knowledge of the neutron OMP and γ-ray strength functions within this atomic mass range [12]. Consequently, we found that the global and local neutron OMPs of Koning and Delaroche [13] describe well the more recent data of the total neutron cross sections for Sn isotopes, but in the limit of ∼15% underestimation for other isotopes. Next, these neutron OMPs were involved within the neutron capture analysis for all stable isotopes of Sn and Te, for the neutron energies up to 3 MeV, at the same time with recently obtained [14] nuclear level density parameters. Actually the systematical analysis of this neutron-capture data basis was carried out in order to adopt a suitable normalization of accurate γ-ray strength functions [12] by means of independent experimental information. Concerning the nuclear level density, the back-shifted Fermi gas (BSFG) formula has been used for the excitation energies below the neutron-separation energy, with the parameters a and Δ obtained by a fit of the recent experimental low-lying discrete levels [10] and s-wave nucleon resonance spacings D_0 [15]. The smooth-curve method was adopted [16] for nuclei without resonance data, leading to a-values of the even-even, odd-odd, and odd-mass nuclei that were next kept fixed during the fit of low-lying discrete levels. The agreement between the calculated and measured data shown in Fig. 2 is of particular interest in the case of (α,n) reaction within the energy range where this reaction cross section is so close to the α-particle total reaction cross section. The usefulness of this comparison is obvious especially when the energy error bars of the experimental data are smaller, this feature appearing to be one of most important for the eventual new (α,x) reaction cross section measurements.

3 The depth of the imaginary surface potential

A particular case has been that of the ^{144}Sm$(\alpha,\gamma)^{148}$Gd reaction cross sections measured by Somorjai et al. [17] (Fig. 3). The related incident energy range, shown in Fig. 4 along the ranges concerned within previous ROP analysis [6], corresponds fully to the constant depth of the imaginary surface potential, being below the energy E_1 limit. It has resulted thus a quite larger sensitivity of the corresponding calculated (α,γ) reaction cross sections to this ROP parameter value, at incident energies where they really coincide with the α-particle total reaction cross sections. Actually, the depth of the imaginary surface potential was formerly [6] established only broadly above the zero value, taking into account the strong change of the number of open reaction channels close to the Coulomb barrier which leads to a strong variation of the imaginary

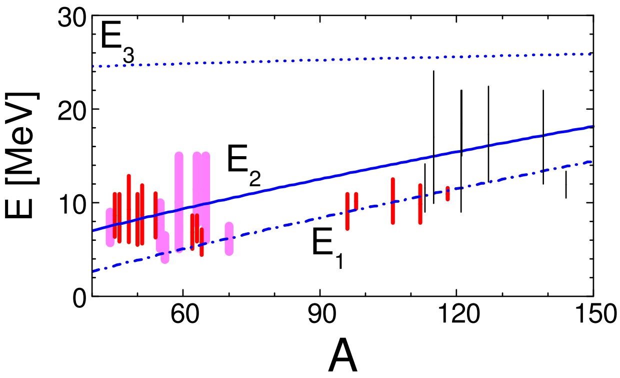

Fig. 4. (Color online) The energies E_1 (dash-dotted curve) below which the imaginary-potential depth W_D is constant, E_2 (solid curve) corresponding to $0.9B_C$, and E_3 (dotted curve), at which the present ROP parameters change their energy dependences, versus the target nuclei atomic-mass number. The mass-dependences corresponding to nuclei with a nuclear asymmetry (N-Z)/A value of 0.14 are shown, while the complete formulas of the energies E_1, E_2, E_3 are given in Table 3 of Ref. [6]. The vertical bars correspond to the energy ranges of the (α, x) reaction data analyzed in Ref. [6] formerly (medium-thick bars) and additionally (thick bars) as well as involved within present work (thin bars).

potentials. Thus a value of W_D=4 MeV was on the whole assumed as a constant value at the lowest α-particle energies. The statistical model analysis results shown in Fig. 3 pointed out however a corresponding overestimation of the measured (α, γ) reaction cross sections. Alternatively, a value W_D=1.5 MeV leads to an overall good agreement between the calculated and experimental data. Moreover, the additional consideration of the measured (α, γ) reaction cross section errors has finally suggested an actual parameter value W_D=(1.5±0.5) MeV. Further (α,x) reaction cross section measurements at similar incident energies will be quite important for the check of this assessment and increase of its precision.

4 Conclusions

Following the extension of a previous semi-microscopic analysis for the mass-region 50<A<120 and energies from 13 to 50 MeV, to heavy nuclei up to 209Bi, a regional optical potential parameter set has been validated by means of (α,γ), (α,n) and (α,p) reaction cross sections analysis at incident energies below the Coulomb barrier. The statistical-model parameters used for the cross section calculations were established by analyzing various independent experimental data for the involved nuclei, making possible the focus on the uncertainties of α-particle OMP. An optical potential which describe equally well both the low energy elastic-scattering and induced-reaction data of α-particles has finally been obtained for medium and heavy mass nuclei.

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References

1. M. Avrigeanu, W. von Oertzen, A.J.M. Plompen, V. Avrigeanu, Nucl. Phys. A **723** (2003) 104; M. Avrigeanu, W. von Oertzen, V. Avrigeanu, Nucl. Phys. A **764** (2006) 246; M. Avrigeanu and V. Avrigeanu, Phys. Rev. C **73** (2006) 038801
2. P. Demetriou, C. Grama, S. Goriely, Nucl. Phys. A **707** (2002) 253
3. W. Rapp, I. Dillmann, F. Käppeler, U. Giesen, H. Klein, T. Rauscher, D. Hentschel, S. Hilpp, Phys. Rev. C **78** (2008) 025804
4. I. Căta-Danil, D. Filipescu, M. Ivaşcu, D. Bucurescu, N. V. Zamfir, T. Glodariu, L. Stroe, G. Căta-Danil, D. G. Ghită, C. Mihai, G. Suliman, T. Sava, Phys. Rev. C **78** (2008) 035803
5. C. Yalçin, R. T. Güray, N. Özkan, S. Kutlu, Gy. Gyürky, J. Farkas, G. G. Kiss, Zs. Fülöp, A. Simon, E. Somorjai, T. Rauscher, Phys. Rev. C **79** (2009) 065801
6. M. Avrigeanu, A. C. Obreja, F. L. Roman, V. Avrigeanu, W. von Oertzen, At. Data Nucl. Data Tables **95** (2009) 501; Report arxiv:0808.0566
7. M. Avrigeanu, W. von Oertzen, A.C. Obreja, F.L. Roman, V. Avrigeanu, in *Proc. 12th Int. Conf. on Nuclear Reaction Mechanisms, 15-19 June 2009, Varenna, Italy*, CERN Proceedings series (in press); http://www.fluka.org/Varenna2009/
8. M. Avrigeanu, V. Avrigeanu, Phys. Rev. C **79** (2009) 027601
9. M. B. Chadwick *et al.*, Nucl. Data Sheets **107** (2006) 2931
10. Evaluated Nuclear Structure Data File (ENSDF), http://www.nndc.bnl.gov/ensdf/index.jsp
11. EXFOR Nuclear Reaction Data, http://www-nds.iaea.or.at/exfor.
12. V. Avrigeanu, F.L. Roman, M. Avrigeanu, in *Proc. 4th NEMEA-4 Workshop on Neutron Measurements, Evaluations and Applications, Prague, Czechia (2007)*, edited by A. Plompen, EC Report EUR 23235EN (EC, Belgium, 2008), p. 143; http://irmm.jrc.ec.europa.eu/html/publications/technical_reports/publications/EUR23235EN_NEMEA4.pdf
13. A.J. Koning, J.P. Delaroche, Nucl. Phys. A **713** (2003) 231
14. V. Avrigeanu, T. Glodariu, A.J.M. Plompen, H. Weigmann, J. Nucl. Sci. Tech. Suppl. **2** (2002) 746; http://tandem.nipne.ro/~vavrig/publications/2002/Tables/
15. IAEA-CRP Reference Input Parameter Library (RIPL-2), http://www-nds.iaea.org/RIPL-2/
16. C.H. Johnson, Phys. Rev. C **16** (1977) 2238
17. E. Somorjai, Zs. Fülöp, A.Z. Kiss, C.E. Rolfs, H.-P. Trautvetter, U. Greife, M. Junker, S. Goriely, M. Arnould, M. Rayet, T. Rauscher, H. Oberhummer, Astron. Astrophys. **333** (1998) 1112