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Exploring the potential of the São Paulo Potential

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Abstract. Recent development of an imaginary potential based on the São Paulo potential is briefly presented. Further developments of the model in order to describe weakly bound systems (*e.g.* ^{7}Li +^{120}Sn) are discussed and compared to experimental data. New preliminary data on the ^{18}O+^{110}Pd transitional system are also presented and apparent similarities to the weakly bound case are commented.

1 Introduction

The predictive power of nuclear models for nuclear reactions is rather limited in many cases. Part of the limitations come from the need for specific parameter adjustments to the experimental data, which can only be performed after the data have been taken. The present work describes the development of models based on the São Paulo Potential (SPP) [1–3] in an attempt to partly overcome these difficulties. The SPP is theoretically founded on the Pauli non-locality, which arises from quantum exchange effects. It has been experimentally tested in a wide variety of mass and energy regions (up to 200 MeV/nucleon) in combination with different theoretical approaches. It does not contain any adjustable parameter and, combined with coupled channel (CC) calculations, provides a powerful tool for predicting cross sections for quite different systems and energies around the Coulomb barrier [4]. Recently, a new generation of SPP/CC calculations has been developed [5] with the aim of describing reactions at energies for which dissipative processes, such as deep inelastic collisions (DIC), are important. This has been done with the introduction of an imaginary potential with the same shape of the SPP, and the predictions have been confirmed in diverse systems. This will be briefly described in Sec. 2. In Sec. 3 further developments will be described to deal with light weakly bound participant systems (e.g ^{6,7}Li+^{120}Sn) [6, 7] where the effect of the coupling to the continuum becomes important, and in Sec. 4 a similar situation in transitional systems where, apparently, the coupling to an energy region of high level density comes about. Some new data on such systems (viz. ^{18}O+^{110}Pd) [8] will be presented and compared to the theoretical predictions.

2 The SPP based imaginary potential

The São Paulo bare potential (SPP), in the local equivalent version, is given by:

$$V_{LE}^{SP}(R,E) = V_F(R)e^{-\frac{4v^2(R)}{c^2}} \quad (1)$$

where $V_F(R)$ is the double folding [9] potential, and the term $e^{-\frac{4v^2(R)}{c^2}}$ is the local velocity ($v(R)$) dependent correction arising from Pauli non-locality (PNL).

As mentioned in the introduction, the SPP used in a CC calculation with the relevant couplings provides a good description of elastic and quasi-elastic processes near the barrier. The compound nucleus (CN) formation can be appropriately taken into account by an internal absorption (IA) potential consisting of a Woods-Saxon shape with large depth and small diffuseness parameter (a = 0.2 fm). When dissipative processes such as deep inelastic collisions (DIC) are important (at higher energies or very large masses), the number of channels becomes very large and a different approach is necessary. In this case a very good description can be done by introducing an imaginary potential which is proportional to the SPP. The constant of proportionality can be estimated considering a relatively simple energy region (where Pauli blocking and Pauli non-locality are unimportant) around 200 MeV/nucleon, where both the real and imaginary potential are approximately equal and proportional to the double folding potential:

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$$V(R) \approx W(R) \approx 0.6V_F(R) \quad (2)$$

For energies below 100 MeV/nucleon, however, the folding potential has to be replaced by the SPP. This is discussed in detail in [5]. The resulting nuclear potential is presented in the following equation:

$$U_1(R) = (1 + 0.6i)V_{LE}^{SP}(R) \quad (3)$$

With this potential a varied number of systems can be described very well (in CC calculations), such as: p+^{40}Ca, n+^{27}Al, ^{16}O+^{27}Al, ^{16}O+^{60}Ni, ^{58}Ni+^{124}Sn [5], without the readjustment of any parameter. For weakly bound cases, however, a modification of the real potential is necessary. This is the subject of the next section.

3 The weakly bound case ^{7}Li

Sakuragy, Yahiro, and Kamimura [10] have shown, with the method of coupled discretized continuum channels (CDCC), that the dynamic polarization potential due to the ^{6}Li breakup is strongly repulsive, and effectively reduces the intensity of the real double-folding potential (in a single-channel calculation) by a factor of 0.5-0.6. It is interesting to note that in this case, according to our view, such a reduction results in a situation similar to that encountered at the 200 MeV/nucleon region, *i.e.* both real and imaginary potentials approximately equal (see also [6,7]). We propose, therefore, to test if the following nuclear potential would be appropriate also for the weakly bound cases:

$$U_2(R) = (0.6 + 0.6i)V_{LE}^{SP}(R) \quad (4)$$

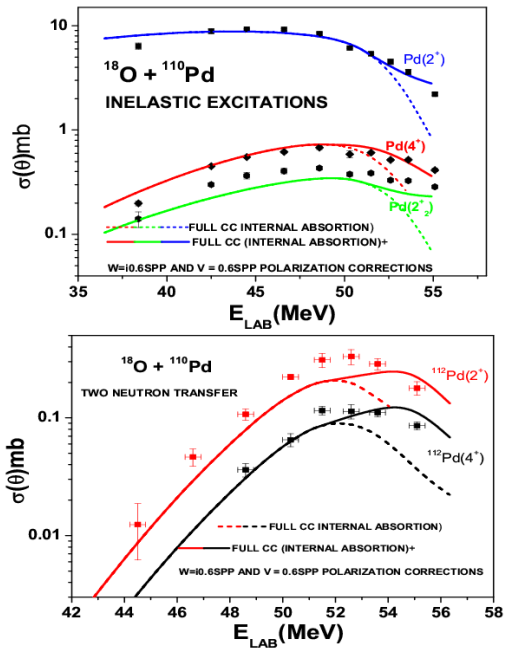
It has to be noticed, however, that the above procedure could not be applied to a collision with a very high-Z target, where the long-range Coulomb-breakup plays an important role. The inclusion of the Coulomb break-up in the calculations is under development.

A good description of the ^{7}Li + ^{120}Sn reaction experimental quasi-elastic angular distributions is obtained at a beam energy of 19.5 MeV (slightly below the barrier) with the potential U_1 (eq. 3), while at 20.5 (the barrier) and 25 MeV, a consistent description is obtained with the potential U_2 (eq. 4), considering the usual densities obtained from a Dirac Hartree-Fock calculation systematics [3]. This is described in more detail in [6,7]. There is a characteristic enhancement of the cross section at large angles (see also [11]).

4 The transitional case ^{110}Pd

The ^{18}O+^{110}Pd system was studied in [12]. In that experiment, besides particle singles spectra, measurements were performed with an annular particle detector in coincidence with two gamma-ray detectors. The excitation functions extracted for the inelastic and transfer to excited states are well described, below and near the barrier, with a coupled channels calculation employing the potential of eq. 1.

Fig. 1. Excitation functions of ^{18}O+^{110}Pd system (top: inelastic; bottom: 2n transfer to excited states)



At somewhat higher energies, however, the experimental cross sections are relatively enhanced and a better agreement with the data is again accomplished by the use of the potential U_2 as in the ^{7}Li case (see fig. 1). This suggests that again a dynamic polarization potential which decreases the effective real potential is in operation. This could be due to an increased level density, at somewhat high excitation energies, of the transitional nucleus of ^{110}Pd.

In order to study this system in more detail, a new experiment was performed with the Saci-Perere [13] gamma ray spectrometer of the University of São Paulo. This spectrometer was configured with a set of collimators in order to limit the angular range of the particle detectors [8], which allowed for the measurement of gamma-particle angular distributions. Figure 2 presents sample spectra at a beam energy of 54 MeV obtained in this experiment. Figure 3 presents preliminary results of the measurements at two different energies. The theoretical calculations with the potential U_2 have not been performed yet, but it can be seen that the standard CC calculation (with potential U_1) indeed tends to underestimate the cross sections as the scattering angle is increased. However, detailed calculations of the gamma-particle angular correlation, considering the nuclear potential, have still to be performed for a more precise comparison. So far, the Coulomb excitation angular correlation has been used as a rough approximation, since the energies studied are not far above the barrier. Figure 3 presents the results obtained from one of the 4 gamma detectors (at 110° to the beam direction). Simi-

Fig. 2. Sample spectra of the ^{18}O+^{110}Pd experiment obtained with the Saci-Perere spectrometer. The target was composed of a 0.84 mg/cm^2 thickness ^{110}Pd with a 1.49 mg/cm^2 thickness gold backing. Top-left: Typical plastic scintillator $\Delta E - E$ bi-parametric spectrum at $\theta_{lab} = 60°$; Bottom: Gamma spectrum at $\theta_{lab} = 110°$ in coincidence with the beam-like particles cut on the previous bi-parametric spectrum. Top-right: beam-like particles ΔE-projection spectra (such heavy particles stop on the 0.1mm thick ΔE plastic layer) gated on the $2^+ \rightarrow 0^+$ transition (374 keV) of ^{110}Pd, and on the $\frac{5}{2}^+ \rightarrow \frac{3}{2}^+$ transition (279 keV) of ^{197}Au, as indicated in the figure (the Compton and random coincidences related background has been subtracted).

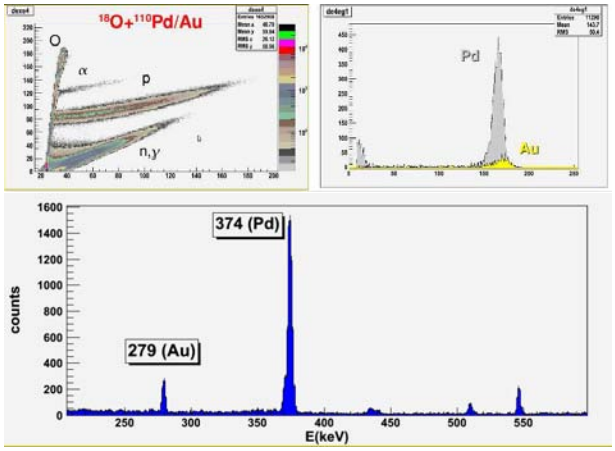
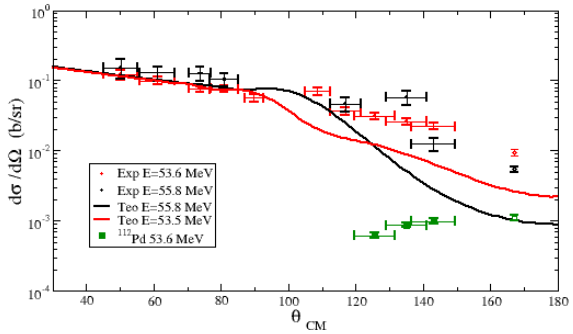


Fig. 3. Angular distributions of the inelastic excitation of the 2^+ states of ^{110,112}Pd (^{18}O +^{110}Pd reaction) at two different energies (the 3 data points at $\theta_{CM} = 167°$ are from the previous measurement [12]).



lar results are obtained from any one of the other 3 gamma detectors, indicating consistency of the approximation.

5 Conclusions

The description of various low-energy nuclear reactions can be successfully accomplished with a coupled channels calculation using an optical model with both real and imaginary parts taken as proportional to the SPP. The procedure is free of parameter adjustments and therefore should have considerable predictive power. For weakly bound and transitional nuclei it appears that a reduction of the real potential (SPP) by a factor of 0.6 is necessary for consistency with the experimental results. Further studies, both experimental and theoretical are under way in order to define the degree of generality and reliability of this approach.

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