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MICROSCOPIC OPTICAL POTENTIALS WITHIN WEAK DENSITY DEPENDENT NUCLEON-NUCLEON EFFECTIVE INTERACTIONS

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Abstract: The microscopic optical potentials have been investigated in the framework of the nuclear structure approach based on the energy-density functional approaches. The effective phenomenological nucleon-nucleon interaction SLy5 is consistently used to obtain the Hartree-Fock single-particle states, the collective motion at small amplitudes of the target, and the coupling between the particle and phonons. The role of the weak density-dependent interaction is shown.

Keywords: particle-vibration coupling, microscopic optical potentials, energy-density functional approaches

1 Introduction

With the development of new innovative facilities, as well as for astrophysical purposes, modern nuclear physics is really entering a *renaissance* period with the studies of exotic nuclei. When one has to predict nuclear reactions involving exotic (unstable) targets, the robustness of the nuclear reaction models is crucial and the nuclear reaction inputs have to be trusted. Advancing the theoretical tools for describing nuclear reactions is, therefore, an absolute necessity for studying the structure of the nuclei lying far from the valley of stability.

Microscopic optical potentials (MOPs) are expected to be a reliable tool to link the nuclear reaction models with the underlying structure of exotic nuclei. In literature, two different many-body theory approaches have been used to calculate the MOPs. One is called nuclear matter approaches [1–3] which could produce a satisfactory result at nucleon incident energies greater than or equal to 50 MeV. At energies below 50 MeV, optical potentials are derived from the nuclear structure approach [4–8] to take into account the specific nuclear structure effects, e.g., the low-lying excited states and giant resonances in stable or unstable targets. There was an early nuclear structure calculation for nucleon-nucleus (NN) elastic scattering for heavy-nucleus ^{208}Pb proposed by Bernard *et al.* [6]. The optical potentials are generated from the particle-vibration coupling (PVC), where the complex term arises from the particle-hole (p–h) correlations [6]. They could not, however, fully explain the observed absorption in nuclear scattering below 30 MeV due to the weak absorption (both in the surface and in the interior region) of the imaginary part of the MOPs. Recently, we have successfully improved the calculations carried out within a fully

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self-consistent framework of the particle-vibration coupling approach on top of more realistic Random-Phase-Approximation (RPA) excited states [7]. Angular distributions are in good agreement with the experimental data without ad hoc adjusted parameters. In the latter work, the nuclear reaction observables directly depend on the nuclear structure inputs adopted, especially on the effective NN interaction. Later, the MOPs are applied, for the first time, to systematically study the nucleon-nucleus elastic scattering of a series of double-closed shell targets including ^{16}O, ^{40}Ca, ^{48}Ca, ^{208}Pb [8].

In this paper, we show the effects of choosing the nucleon-nucleon (NN) effective interaction on the imaginary part of the MOPs by comparing our results with the previous work done by Bernard *et al*. The paper is organized as follows. The formalism of the microscopic optical potential and the corresponding absorptive potential are briefly introduced in Sec. 2. In Sec. 3, we analyze the numerical results. The main conclusions of our work are presented in the last section.

2 Theoretical formalism

The optical potentials could be directly generated from effective *NN* interactions [4–8]. We will only sketch here the major points of the formalism and discuss some of its relevant numerical aspects. According to Refs. [6–8], MOP is given as

$$V_{opt} = V_{HF} + \Delta\Sigma(\omega), \tag{1}$$

where

$$\Delta\Sigma(\omega) = \Sigma(\omega) - \tfrac{1}{2}\Sigma^{(2)}(\omega). \tag{2}$$

In Eq. (1), V_{HF} is the real, local, momentum dependent, energy-independent Skyrme Hartree Fock (HF) potential, and ω is the nucleon incident energy. This mean-field potential represents the statistic part of the MOP. The dynamic part, which is the coupling of single particle states to excited states of the target, is described through the non-local, complex and energy dependent potential $\Delta\Sigma(\omega)$. The latter is obtained from the fully self-consistent PVC calculations. The second order potential $\Sigma^{(2)}(\omega)$ is taken into account in order to correct the Pauli principle violated in the underlying RPA states. Hence, our main task here is to calculate $\Delta\Sigma(\omega)$.

We consider the quantity $W(\vec{R},\vec{s}) = \mathrm{Im}\,\Delta\Sigma(\vec{r},\vec{r}';\omega)$, which is responsible for a loss of the incident flux due to the existence of non-elastic channels, where $\vec{R} = \frac{1}{2}(\vec{r}+\vec{r}')$ and $\vec{s} = \vec{r} - \vec{r}'$. The s-dependence and R-dependence of $W(\vec{R},\vec{s})$ represent the non-locality and the shape of the potential, respectively. According to Ref. [5], $W(\vec{R},\vec{s})$ is practically independent of the angle between $\vec{R}$ and $\vec{s}$. Using the partial wave expansion, we have

$$W(\vec{R},\vec{s}) = \sum_{lj} \frac{2j+1}{4\pi} \mathrm{Im}\,\Delta\Sigma^{lj}(r,r';\omega), \tag{3}$$

where $r = R + \frac{1}{2}s, r' = R - \frac{1}{2}s,$ and $\Delta\Sigma^{lj}(r, r'; \omega)$ is given by Eq. (2).

3 Numerical aspects

First, we solve the radial HF equations in the coordinate space on a radial mesh of size 0.1 fm, within a box of 15 fm. The *NN* phenomenological effective interaction SLy5 has been adopted. The residual interaction in this work is fully treated and consistently used in the whole calculations. The continuum is conveniently discretized by imposing box boundary conditions as in Refs. [5, 6]. We, then, use all the hole states and choose the eight lowest unoccupied states to set up the p-h configurations. The energy-weighted sum rules satisfy about 99.5 % for the most collective states such as 3^- and 4^+ states. After calculating the RPA excited states, we need to have a cut-off for all the natural-parity phonons with multipolarity L from 0 to 5 whose energy is lower than 50 MeV, and the fraction of the total isoscalar or isovector strength is larger than 5 % have been selected for the PVC calculations. This cut-off is introduced to avoid the ultraviolet divergences may occur beyond the mean field calculations [9].

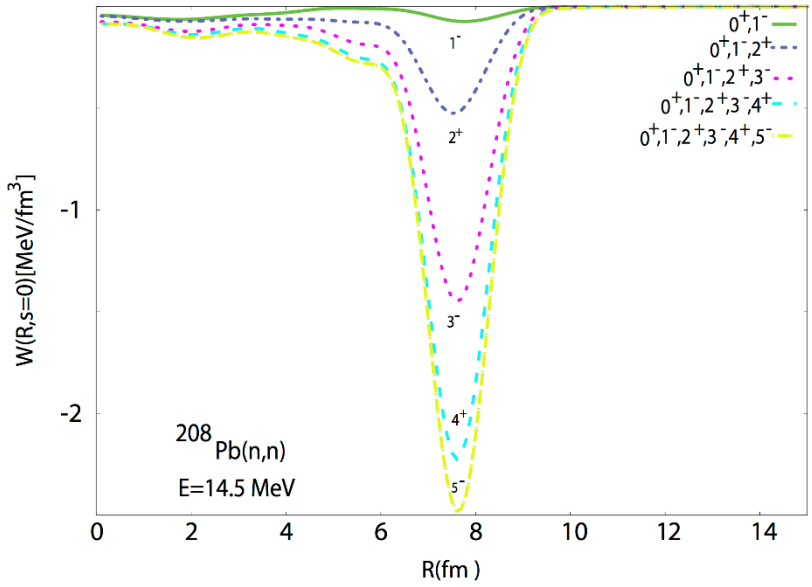

Fig. 1. Contributions of the RPA states to $W(R, s = 0)$ by neutron elastic scattering off ^{208}Pb at E=14.5 MeV.

Fig.1 shows the quantity $W(R, s = 0)$ for neutron elastic scattering ^{208}Pb at the incident energy E = 14.5 MeV. The contribution of each collective state to the imaginary part of the optical potential is analyzed. One can see that the obtained absorption is much stronger than that of Bernard *et al.* at the surface as well as in the interior. It seems that the target becomes "softer" when the weak density dependent on the SLy5 interaction is used (ϱ^α with α = 1/6). Note that the strong density-dependent SIII interaction (ϱ^α with α = 1) has been used in the work of Bernard *et al*. The results show that the main contributions in the interior come from the low-lying 1^- and 3^-

states, while the 5^- states contribute less to the absorption. The results also indicate that at the nuclear surface, the 2^+ and 3^- states dominantly contribute to the imaginary part of the MOPs, followed by 4^+, 5^- and 1^- states.

4 Conclusion

We have studied the absorption part of the microscopic optical potential, which is directly generated from the effective *NN* interaction. The effective interaction SLy5 has been consistently used to generate the HF single-particle states, excited states and the coupling between a particle and excited states. The obtained results are coherent with that of previous work of Bernard *et al* [6]. However, the absorption of the microscopic optical potential at the surface as well as in the interior has been improved.

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