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Calculation of the Reaction Cross-Section for Proton-Nucleus Using Recently Optical Potential

M. M. OSMAN
Department of Physics, Faculty of Science,
Cairo University, Giza - EGYPT

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Abstract

The eikonal approximation is used to calculate the reaction cross-section for proton scattering from different nuclei. The imaginary proton - nucleus optical potential is derived from relativistic mean field theory approach. We found a fair agreement with experimental data.

1. Introduction

Recently, successful attempts [1,2] have been made to apply the Dirac-Bruckner -Hartree-Fock (DBHF) approach [3] to nuclear matter problem[5]. Common to all DBHF result is that a repulsive relativistic many-body effect is obtained, which is strongly density dependent such that empirical nuclear matter properties can be explained starting from a realistic nucleon-nucleon interaction.

In spite of the success of DBHF approach to calculate nuclear matter properties, it is much more elaborate when applied to finite nuclei. For this reason, an alternative approach in which the DBHF results for nuclear matter are parameterized in terms of an effective Lagrangian which reproduce the binding energy, scaler and vector self-energy term as the original DBHF calculations. This approach has been used by Machledit et al to derive the proton-nucleus optical model potential. In the present paper, we apply this relativistic approach to calculate several proton-nucleus reaction cross-sections and compare our results with the experimental data. This enable us to show to what extent the method of Ref.[4] is successful in reproducing the proton-nucleus optical potential.

In the next section we briefly describe the method and in section III we compare our results for the reaction cross-section with experiment.

2. Theory

The nucleon self energy in a finite nucleus is obtained by means of the local density approximation, in which the spatial dependence of the microscopic optical potential is directly related to the density of the target nucleus. For a self-consistent description of the nucleon-nucleus scattering, the target density should also be determined from the effective Lagrangian [4],

$$L = \bar{\Psi}[i\gamma_\mu \partial^\mu - m - g_\sigma(\rho)\Phi_\sigma - g_w(\rho)\gamma_\mu \Psi_w^\mu]\Psi + \frac{1}{2}(\partial^\mu \Phi_\sigma)^2 - \frac{1}{2}m_\sigma^2 \Phi_\sigma^2 - \frac{1}{4}(\partial_\mu \Phi_w^v - \partial_v \Phi_w^\mu)^2 + \frac{1}{2}m_w^2 \Phi_w^{\mu^2}, \quad (1)$$

The Dirac equation for the single-particle motion of the projectile nucleon in the mean field of the target nucleus can be written as

$$[\alpha.K + \beta(m + U_S) + U_V + V_C]\Psi = E_\Psi \quad (2)$$

with

$$U_S = \frac{\sum_S - m\sum_V}{1 + \sum_V}, U_V = \frac{\sum_O + E\sum_V}{1 + \sum_V}, \quad (3)$$

where E is the energy o the projectile in the center of mass (c.m) system of the projectile and nucleus, which is related to the incident energy T_{lab} by

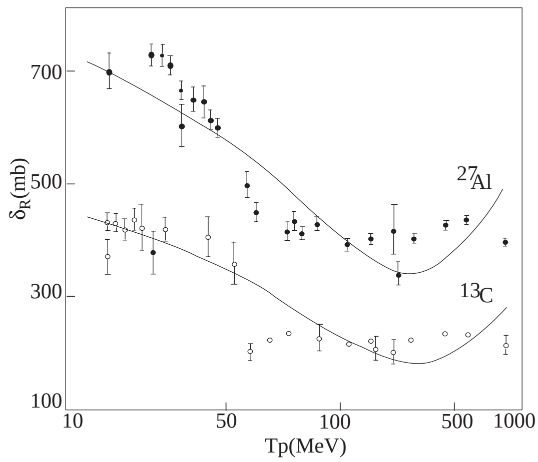

Figure 1. Calculated reaction cross - section σ_R, together with experimental data [6], for the reaction of proton with ^{13}C and ^{27}Al.

$$E = \frac{m^2 + m_T(m + T_{lab})}{[(m + M_T)^2 + 2m_T T_{lab}]^{1/2}} \tag{4}$$

with m and m_T being the mass of the projectile and target, respectively. V_C is the coulomb field and is treated as in Ref.[5].

In terms of the scaler potential U_S and the vector potential U_V, the momentum of a nucleon propagating through a uniform nuclear medium can be determined from

$$E = [(m + U_S)^2 + K^2]^{1/2} + U_V \tag{5}$$

and can be written as

$$\frac{K^2}{2m} + V + iW = E - m + \frac{(E - m)^2}{2m}. \tag{6}$$

Here, V is the real part and W is imaginary part of the optical potential. They are given by[4]

$$V = U_{SR} + U_{VR} + \frac{(E - m)}{m} U_{VR} + \frac{1}{2m}(U_{SR}^2 + U_{VI}^2 - U_{SI}^2 - U_{VR}^2) \tag{7}$$

$$W = U_{SI} + U_{VI} + \frac{(E - m)}{m} U_{VI} + \frac{1}{m}(U_{SR}U_{SI} - U_{VR}U_{VI}), \tag{8}$$

where the real and imaginary part of the scaler and vector potential are given by $U_S = U_{SR} + iU_{SI}$ and $U_V = U_{VR} + iU_{VI}$,

To calculate the reaction cross-section for nucleon-nucleus system, we used the eikonal approximation

$$\sigma_R = 2\pi \int bdb(1 - exp[-4\delta_1(b)]) \tag{9}$$

where δ_1(b) is the imaginary part of the nuclear elastic phase shift within the eikonal approximation,

$$\delta_1(b) = -\frac{1}{4}\frac{2\mu}{\hbar^2 K} \int dZ' W(\sqrt{b^2 + Z'^2}). \tag{10}$$

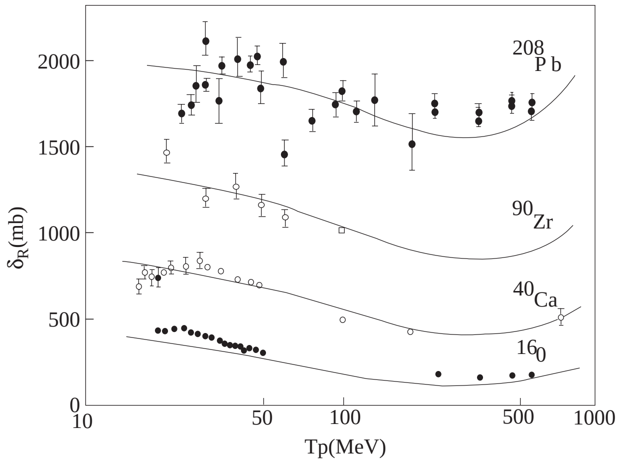

Figure 2. Same as Fig.(1) but for ^{16}O, ^{40}Ca, ^{90}Zr and ^{208}Pb, with experimental data are taken from Ref.[7].

3. Results and Discussion

The scaler potentials (U_{SR} and U_{SI}) and the vector potentials (U_{VR} and U_{VI}) can be calculated for protons scattered from nuclei from ref.(4). Using equations (9) and (10), we calculated the reaction cross - section σ_R for 20-800 MeV proton scattering from ^{12}C, ^{16}O, ^{27}Al, ^{40}Ca, ^{90}Zr, and ^{208}pb. Figure(1) shows the calculated σ_R together with the experimental data [6], for the reaction of proton with ^{12}C, and ^{27}Al. In figure (2), the calculated σ_R and the experimental data [7], for the reaction of proton with ^{16}O, ^{27}Al, ^{40}Ca, ^{90}Zr and ^{208}pb, are shown. From the figures, we can say that the calculated reaction cross-section σ_R for proton - nucleus systems using relativistic mean field theory approach is in fair agreement with the experimental results. This shows that this parameter free model can be used to describe the proton - nucleus scattering processes over a wide range of incident proton energy.

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