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NOTE

Energy Dependence of the Optical Potential for Proton Scattering from Si

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The Si-Ge polarimeter has been developed for polarized proton scattering in the energy region between 45 MeV and 65 MeV at RCNP, Osaka. The details will be published elsewhere.[1] In the course of developing the polarimeter, the differential cross sections and analyzing powers for proton scattering from Si were measured in the above-mentioned energy region.[2] The experimental results are summarized in Fig. 1. Differential cross sections were corrected by the detector efficiency due to the nuclear reaction in the Ge itself.[3]

A conventional optical model analysis has been performed. Starting with the parameter values given by Bechetti and Greenlees,[4] Raynal's automatic search code MAGALI[5] was used to search for those values of the parameters which provide the best fits to the experimental data. The optical potential used was as follows;

$$\begin{aligned} U(r) = & V_{Coul}(r) - V_R f(r;\ r_R,\ a_R) - iW_V f(r;\ r_{WV},\ a_{WV}) \\ & + 4a_{WS} W_S i \frac{d}{dr} f(r;\ r_{WS},\ a_{WS}) \\ & + V_{LS}\left(\frac{h}{m_\pi c}\right)^2 \left(\frac{1}{r}\frac{d}{dr} f(r;\ r_{LS},\ a_{LS})\right)(\sigma \cdot L) \end{aligned}$$

where

$$f(r;\ r_0,\ a_0) = (1 + exp((r - r_0 A^{1/3})/a_0))^{-1}$$

$$V_{Coul}(r) = \begin{cases} \dfrac{Ze^2}{2r_C A^{1/3}}\left(3 - \dfrac{r^2}{r_C^2 A^{2/3}}\right) & r \leq r_C A^{1/3} \\ \dfrac{Ze^2}{r} & r \geq r_C A^{1/3} \end{cases}$$

At first, the experimental differential cross sections and analyzing powers were fitted individually at each energy by varying all parameters except for r_C. The individual best fit parameters (we call them 'individual best fit parameter set'.) are shown in Table I. At each energy we have obtained a excellent fit to the data. Values of the chi-square

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Table I. Individual Best Fit Parameter Set. N_C Denotes the Renormarization Factor of Differential Cross Sections.
$r_C=1.25$, $r_R=1.17$

E_p(MeV)	V_R	a_R	W_V	r_{WV}	a_{WV}	W_S	r_{WS}	a_{WS}	V_{LS}	r_{LS}	a_{LS}	N_C	χ^2/F
45	40.72	0.709	8.19	0.972	0.658	4.45	1.345	0.490	6.39	1.038	0.559	1.059	0.78
50	38.94	0.705	8.71	1.005	0.637	3.92	1.361	0.485	6.17	1.021	0.565	1.055	0.51
55	37.40	0.714	9.09	1.028	0.645	3.54	1.369	0.479	6.04	1.013	0.575	1.052	0.67
60	35.80	0.724	9.48	1.021	0.659	3.29	1.373	0.493	5.88	1.014	0.594	1.046	0.95
65	34.40	0.714	10.65	1.014	0.649	3.16	1.363	0.506	5.95	1.000	0.604	1.092	0.83

per degrees of freedom (χ^2/F) are distributed in the range of 0.5-1.0. Throughout the fitting process, radial parameter of the real central potential r_R was fixed at the value $r_R=1.17$, which was given by Bechetti and Greenlees, to avoid a so-called VR^n type ambiguity. After we obtained the individual best fit parameter set, we searched other all parameters except for r_R by fixing the radial parameter r_R at several points between 1.15 and 1.20. Even in this case, we can fit all our data within $(\chi^2/F)=1.0$ and decided that 1.17 is the optimum value of the radial parameter r_R. At the next stage, we tried to determine a optical potential parameter set which had simple energy dependence and were able to reproduce our experimental data. As seen in Table I, every

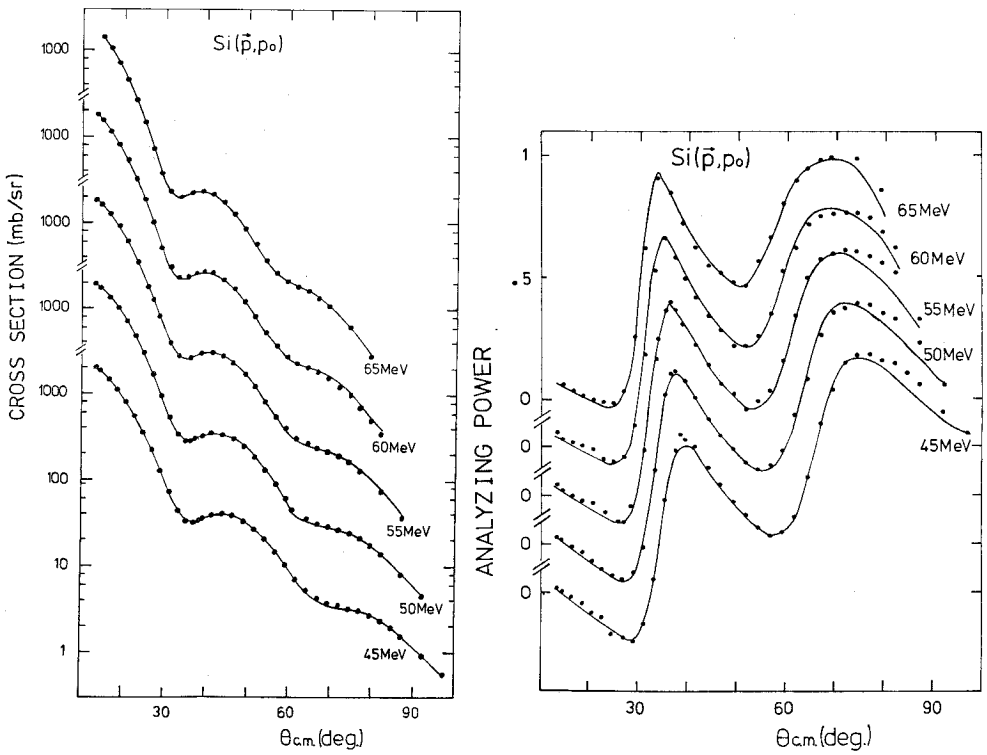

Fig. 1. Measured differential cross sections and analyzing powers. Solid curves represent the calculations using our linear energy dependent parameter set.

geometrical parameter is almost constant independently of incident energies. Therefore, we determined each geometrical parameter and well depth parameter of spin-orbit term common to all five energies. Then, we assumed linear energy dependence for the well depth parameters of real central, volume imaginary and surface imaginary potentials and searched for these parameters. Finally we have obtained the following results. (we call them 'linear energy dependent parameter set'.)

$$
\begin{array}{lll}
r_C = 1.25 & & \\
V_R = 52.8 - 0.28\,E_p & r_R = 1.17 & a_R = 0.71 \\
W_V = 2.3 + 0.12\,E_p & r_{WV} = 1.06 & a_{WV} = 0.64 \\
W_S = 4.4 - 0.02\,E_p & r_{WS} = 1.38 & a_{WS} = 0.48 \\
V_{LS} = 6.1 & r_{LS} = 1.01 & a_{LS} = 0.59
\end{array}
$$

Even in this case, good fits have been obtained and values of the chi-square per degrees of freedom (χ^2/F) are less than 1.7. (see Fig. 1.)

In Fig. 2 we compared the volume integrals of our real central and imaginary potentials with those of the potentials which were determined by fitting the data of much lower energy region ($20\ \mathrm{MeV} < E_p < 40\ \mathrm{MeV}$). In view of a so called VR^n type ambiguity, volume integral is a more significant measure than a individual parameter in case of the comparision of potential. The volume integrals are calculated as follows

$$
\begin{aligned}
J_R/A &= \frac{1}{A}\int V_R f(r;\ r_R,\ a_R)\,dr = \frac{4}{3}V_R r_R^3\left(1+\left(\frac{\pi a_R}{r_R A^{1/3}}\right)^2\right) \\
J_{WV}/A &= \frac{1}{A}\int W_V f(r;\ r_{WV},\ a_{WV})\,dr = \frac{4}{3}W_V r_{WV}^3\left(1+\left(\frac{\pi a_{WV}}{r_{WV} A^{1/3}}\right)^2\right) \\
J_{WS}/A &= \frac{1}{A}\int W_S q(r;\ r_{WS},\ a_{WS})\,dr = 16\pi W_S r_{WS}^2 A^{-1/3}\left(1+\frac{1}{3}\left(\frac{\pi a_{WS}}{r_{WS} A^{1/3}}\right)^2\right) \\
J_W/A &= \frac{1}{A}(J_{WV}+J_{WS})
\end{aligned}
$$

Although our energy dependence were determined in energy region between 45 MeV and 65 MeV, similar energy dependence seems to be applicable in the much lower energy region as shown in Fig. 2. Using the data between 15 MeV and 40 MeV, Resmini et al. obtained a linear energy dependent optical potential.[6] The volume integrals of our linear energy dependent parameter set agree approximately with those of theirs. (see Fig. 2)

Finally we compared our phenomenological optical potential with microscopic optical model calculations by Jeukenne, Legeune and Mahaux.[7] Starting from the Brueckner-Hartree-Fock approximation and Reid's hard core nucleon-nucleon interaction, they calculated and parametrized the energy- and the density-dependence of the isoscalar, isovector, and Coulomb components of the complex optical model potential in infinite nuclear matter. Then they constructed the optical model potential in a finite nucleus making use of a local density approximation. According to their theoretical calculations, their micrscopic optical potentials of the real central and imaginary parts for proton scattering from ^{28}Si are given as follows respectively;

$$V(\rho(r),\ E-V_C(r)) + iW(\rho(r),\ E-V_C(r))$$

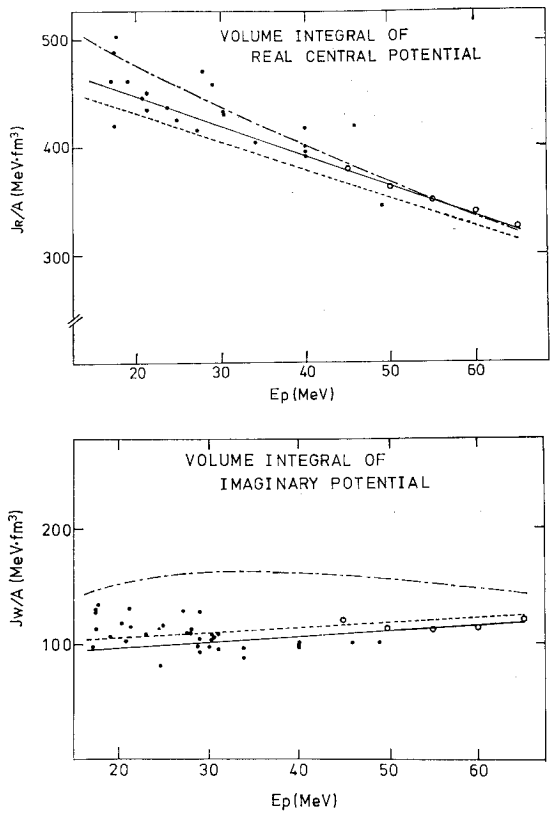

Fig. 2. Volume integrals of real central and imaginary potentials. Open circles denote the values which are calculated by using our individual best fit parameter set. The dots are the values calculated from the parameters which are determined by fitting the data of much lower energy regon. Solid lines represent the results of our linear energy dependent parameter set. The dashed lines represent those of Lesmini et al.. The dashed and dotted lines are those of microscopic calculation.

$$V(\rho, E) = \sum_{i,j=1}^{3} a_{ij}\rho^i E^{j-1} \qquad \text{for real part}$$

$$W(\rho, E) = (1+D/(E-\varepsilon_F)^{-2})^{-1} \sum_{i,j=1}^{4} d_{ij}\rho^i E^{j-1} \qquad \text{for imaginary part}$$

where

$$\rho(r) = \frac{\rho_0(\kappa)}{1+exp((r-c_\rho)/a_\rho)}$$

$$\varepsilon_F(\rho) = \rho(-510.8+3222\,\rho-6250\,\rho^2)$$

where (a_{ij}), (d_{ij}), $\rho_0^{(\kappa)}$, C_ρ, D, and a_ρ are constant values and $V_C(r)$ is a Coulomb potential. As shown in Fig. 2, the volume integrals of our linear energy dependent parameter set agree well with their calculations in respect to real central part. But the shape of their real central potential has a little deeper well depth and smaller radius than ours. The volume integrals of our imaginary part are twenty or thirty percents larger than

those of ours. This disagreement may be attributed to the difference of the shape between our imaginary potentials and their ones. And further to mention, there is a few left to discuss that volume integral is a good measure to compare two potentials which have different potential shapes each other.

In the last two paragraphs, we compared our phenomenological potentials with those of much lower energy region and with microscopic potentials. As discussed in these two paragraphs, we may say that the energy dependence of our parameters are reasonable.

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