

Proton Scattering at Different Ranges of Intermediate Energy

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Abstract

On the basis of the nuclear semi-microscopic approach the differential elastic scattering cross-section for protons by ${}^6\text{Li}$, ${}^{40}\text{Ca}$, ${}^{56}\text{Fe}$, ${}^{90}\text{Zr}$, ${}^{120}\text{Sn}$ at incident energy ranging from 18.8 to 80.2 MeV were calculated. We used microscopic optical potential based on the folding model. The variation of imaginary optical potential with energy for each element at this range has been studied. The study included the volume imaginary potential as well as the surface imaginary potential.

Introduction

The elastic scattering cross-section of protons by different nuclei are always calculated using the optical model. Experimental programs to investigate these processes are already known [1-3]. Many investigations for the optical real potential are made by both the optical and the folding models[4-6]. On the other hand there are not any calculations for the imaginary potentials but a few studies are made on the imaginary potential using the interaction methods [7,8].

In this paper the semi-macroscopic approach is used to calculate the differential elastic scattering cross-section for protons by different nuclei at different incident energy range. This approach releases the fact that the effective two body interaction potential must consist of two parts, the direct and the exchange potential. The energy dependence of the exchange part is an important factor in calculating the scattering cross-section. On the other hand the variation of the real part of the potential are already known.

To recognize how the imaginary potential will vary with energy, we make many calculations of the differential elastic scattering cross-section for protons by different nuclei at different values of energies. For the protons the data are also available in the range of 18.8 to 80.2 MeV. Hence our study in the case of protons included only the variation of the imaginary potential in the range from 18.8 to 80.2 MeV. This study was achieved for protons elastic scattering by ${}^6\text{Li}$, ${}^{40}\text{Ca}$, ${}^{56}\text{Fe}$, ${}^{90}\text{Zr}$, ${}^{120}\text{Sn}$.

Theoretical Formalism

To study the protons scattering, we use the microscopic optical model potential (OMP) V is defined by the standard form [9]

$$V = -(U_r + iW_v) f(r, r_v, a_v) + 4i a_D W_D \frac{d}{dr} f(r, r_D, a_D) \quad (1)$$

where U_r is the real potential calculated in the frame of folding model, W_v and W_D are the imaginary volume and surface potentials. The proton elastic scattering cross-section is calculated in the frame of the optical model, using the folded potential as the real potential. The folding model is used to compute the real part of the optical potential for the interaction of protons by target nuclei using the following equation.

$$U(R) = \int \rho(r) V(|R-r|) dr \quad (2)$$

Where $\rho(r)$ is the density distribution of the target nuclei, $V(R-r)$ is the effective two-body interaction, which has the standard M3Y form [10]:

$$V(r) = [7999.0 \frac{\exp-4r}{4r} - 2134.25 \frac{\exp-2.5r}{2.5r}] + J(E)\delta(r) \quad (3)$$

The first term represents the direct part and the second term represents the exchange part of the interaction potential. The exchange part can be written to good approximation in the form.

$$J(E) = -276(1 - 0.005 \frac{E}{A}) \quad (4)$$

where E is the energy of the incident particle in the center of mass system and A is the mass number of the projectile, which is equal to one in the case of proton particles as a projectiles. The density distribution for the target nuclei are calculated according to Fermiform[11]

$$\rho(r) = \frac{\rho_o}{1 + \exp(r-c)/a} \quad (5)$$

where a and c are known as the Fermi parameters

To study the variation of the imaginary potential with energy included both the volume and surface, the computational procedure is carried out by several stages: The program DF POT [7] has been used to fold the nucleon- nucleon interaction into a nucleon- nucleus potential. The nucleon density functions for the target nuclei have been assumed to take the form given by Eq. (4). The equivalent form factor parameters produced by DEPOT program are introduced to DWUCK4 program. The imaginary part of the optical potential parameters are varied to fit the experimental data. For comparison the calculations, the pure optical potential is assumed in the first case.

This procedure was repeated for the proton scattering by ${}^6\text{Li}$, ${}^{40}\text{Ca}$, ${}^{56}\text{Fe}$, ${}^{90}\text{Zr}$ and ${}^{120}\text{Sn}$ for different values of energies as indicated in figures (1- 5).

In table 1, we listed the optical potential parameters used for calculating the proton elastic scattering by the nuclei ${}^6\text{Li}$, ${}^{40}\text{Ca}$, ${}^{56}\text{Fe}$, ${}^{90}\text{Zr}$ and ${}^{120}\text{Sn}$ at different energy as indicated in that table .

For the real potential the values of r and a are 1.17 fm and 0.53fm respectively, for the imaginary potentials we take $r_V = r_D = 1.32$ fm and $a_V = a_D = 0.53$ fm

Table1: the equivalent optical parameter of proton elastic scattering by different nuclei.

Nucleus	E (MeV)	V (MeV)	W_V (MeV)	W_D (MeV)	Data references
${}^6\text{Li}$	25.9	46.37	2.99	5.32	[12]
	40.1	41.83	6.1	1.77	
	65.0	33.86	11.6	0	
	72.0	31.62	13.4	0	
${}^{40}\text{Ca}$	19.6	50.1	1.61	6.9	[13]
	30.3	46.6	3.9	4.2	
	45.5	41.7	7.31	0.4	
	61.4	36.7	10.8	0	
	80.2	30.7	14.9	0	
${}^{56}\text{Fe}$	24.6	50.6	2.7	6.5	[14]
	30.3	48.7	3.9	5.1	
	40.0	45.6	6.1	2.6	
	49.4	42.6	8.2	0.3	
	65.0	37.6	11.6	0	
${}^{90}\text{Zr}$	18.8	54.2	1.4	8.6	[14]
	30.0	50.6	3.9	5.8	
	40.0	47.4	6.1	3.3	
	61.4	40.6	10.8	0	
	79.8	34.7	14.8	0	
${}^{120}\text{Sn}$	20.4	55.5	1.8	8.7	[14]
	24.6	54.2	2.7	7.6	
	30.3	52.4	3.9	6.2	
	40.0	49.3	6.1	3.8	
	61.4	42.4	10.8	0	

In table 2 we list the parameters of the real potential obtained from the folded potential, in addition to the parameters of the imaginary potential, volume and surface obtained in the frame of folded potential.

Results and Discussions

For any nucleon-nucleus system, the accurate measurements of the elastic scattering provides an essential information for the determination of the nucleon nucleus optical potential, which is further used to generate the distorted waves for the calculations of elastic scattering amplitude in DWBA formalism. The optical potential and the folded potential are successfully used to describe the elastic

scattering of protons by ${}^6\text{Li}$, ${}^{40}\text{Ca}$, ${}^{56}\text{Fe}$, ${}^{90}\text{Zr}$ and ${}^{120}\text{Sn}$ in comparison with the corresponding experimental values as indicated in figures (1-5). In these figures the solid line indicates the data obtained by the folded potential, where as the dashed line shows data obtained by optical potential, and the dotted line refers for the experimental data.

Table 2: the optical parameters of proton elastic scattering on different nuclei on the frame of folded potential.

Nucleus	E (MeV)	V (MeV)	r (fm)	a (MeV)	W_V (MeV)	r_V (MeV)	a_V (fm)	W_D (MeV)	r_D (fm)	a_D (fm)
${}^6\text{Li}$	25.9	25.9	1.15	0.81	0.43	1.46	0.24	5.61	1.02	0.62
	40.1	24.19	1.19	0.62	1.59	1.29	0.42	2.82	1.02	0.62
	65.0	21.98	1.20	0.87	6.09	1.02	0.32	1.86	1.46	0.63
	72.0	25.4	1.19	0.89	7.72	1.02	0.41	2.4	1.35	0.62
${}^{40}\text{Ca}$	19.6	64.32	1.25	0.86	0.17	1.32	0.42	8.90	1.51	0.75
	30.3	61.66	1.15	0.86	0.4	1.24	0.47	10.91	1.2	0.72
	45.5	58.2	1.01	0.96	0.86	1.02	0.41	12.09	1.01	0.62
	61.4	58.2	1.01	0.96	1.26	1.02	0.41	4.8	1.01	0.62
	80.2	50.2	1.01	0.95	1.86	0.98	0.46	4.8	1.01	0.62
${}^{56}\text{Fe}$	24.6	66.66	1.22	0.89	0.54	1.21	0.98	8.06	1.24	0.62
	30.3	63.66	1.22	0.85	0.72	1.22	0.98	6.40	1.15	0.63
	40.0	58.2	1.1	0.83	1.67	1.20	0.88	4.84	1.24	0.62
	49.4	59.2	1.06	0.92	3.2	0.92	0.98	3.72	1.01	0.60
	65.0	50.2	1.01	0.92	6.12	0.92	0.91	3.08	1.01	0.62
${}^{90}\text{Zr}$	18.8	66.1	1.26	0.89	0.02	1.2	0.73	13.2	1.22	0.62
	30.0	63.8	1.26	0.79	0.69	1.2	0.73	8.5	1.12	0.62
	40.0	61.5	1.19	0.77	1.74	1.2	0.73	4.8	1.41	0.62
	61.4	56.9	1.11	0.71	6.2	1.01	0.86	1.69	1.42	0.62
	79.8	55.7	1.02	0.73	8.4	0.98	0.86	1.06	1.36	0.62
${}^{120}\text{Sn}$	20.4	67.66	1.25	0.69	0	0.89	0.73	12.6	1.32	0.63
	24.6	66.5	1.25	0.83	0.06	1.11	0.73	11.3	1.32	0.62
	30.3	69.5	1.26	0.86	0.39	1.2	0.63	7.9	1.12	0.62
	40.0	65	1.3	0.73	1.51	1.2	0.73	5.24	1.26	0.62
	61.4	57.9	1.11	0.86	4.46	0.89	0.86	1.66	1.36	0.63

As for the imaginary potential in table 1, we obtained the imaginary potential parameters volume and surface (W_V and W_D) at different energies of the incident proton for every investigated element, by using optical potential.

From table 1 we can see that the variation of W_V is to increase with increasing the energy of incident proton in the range (indicated in the table from 20 – 80 MeV). While W_D decreases, but it must be noted that W_D is very small or zero in the of energy greater than 40 MeV.

Table 2 gives the values of potential parameters obtained by folded potential. We can see from the data obtained for the variation of W_V and W_D that W_V also increase with increasing the energy of incident proton.

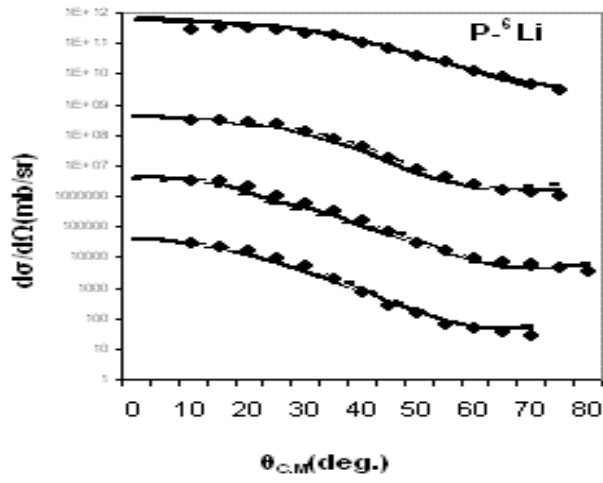


Figure: 1

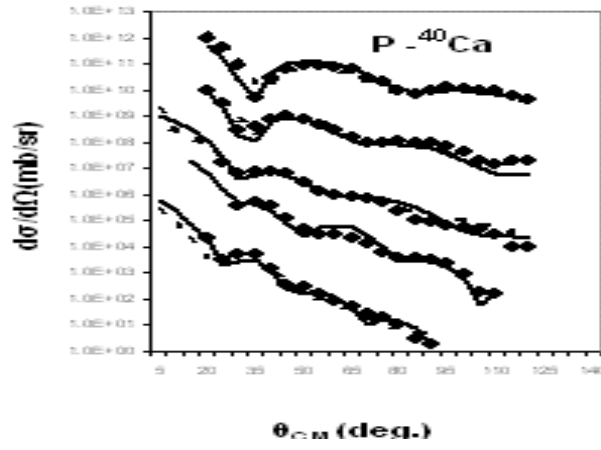


Figure: 2

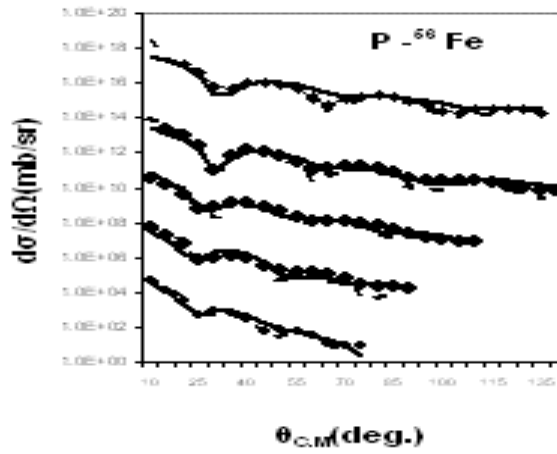


Figure: 3

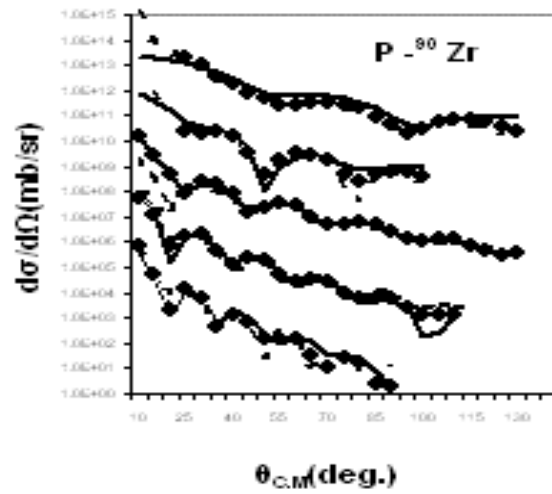


Figure : 4

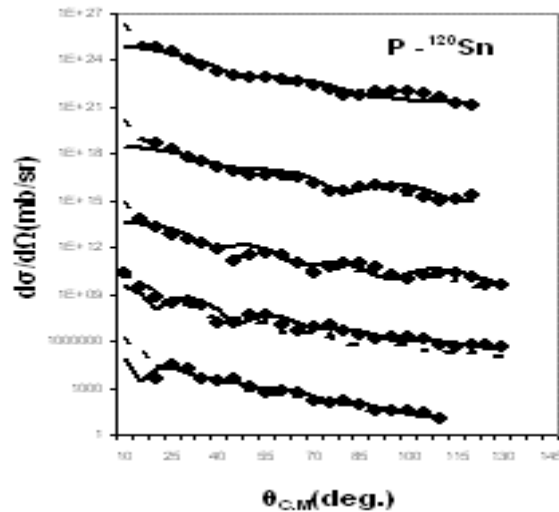


Figure : 5

But in the range from 0 to 15 MeV their values are very small, this is possibly due to the great value of the real potential obtained by the folded potential. The variation of W_D is to decrease with increasing the energy of incident proton, i. e. having the same behavior as that obtained in table 1 but with a different rate.

References

- [1] B. Morillon and P. Romain Phys. Rev. C 70: 14601 (2004).
- [2] H.F. Arellano, H.V. Von Geramb, and Luruper Chausser Phys. Rev. C 66:

- 24602 (2002).
- [3] A.A.Ogloblin, Yu. A.Glukhov, W.H. Trzaska, A.S.Demyanva and G.R.Satchler, *Phys. Rev. C* 62: 44601 (2000).
 - [4] H.Feshbach, A.Kerman, S.Koonin, *Ann. Phys.* 125: 429 (1980).
 - [5] T.Tamara, *Rev Mod. Phys.*, 37: 679 (1965).
 - [6] P.D.Kunz, L.D.Rickertsen, and G.W.Hoffman, *Phys. Rev. C*9: 1659 (1974).
 - [7] W.Tornow, and Z.P.Chen, *Phys. Rev. C*, 42: 693 (1990).
 - [8] G.Pollarolo, L.S.Ferreira, etal, *Phys. Rev. C*, 59: no 3 1534 (1999).
 - [9] C.M. Perey and F.G. Perey, *Atom. Data and Nucl. Data tables* 13, 293(1974); 17: 1 (1976).
 - [10] E.Gadioli, and P.E.Hodgson, *Rev. Prog. Phys.*, 49:951 (1986).
 - [11] H.Deveries and C.W.De Jager. *Nucl. Data Tables*, 36: 495 (1987).
 - [12] C.Samanta, *J. Phys.* 57 : 519 (2001).
 - [13] W.Tornow and Z>P.Chen, *Phys.Rev. C*42 : 693 (1990).
 - [14] E.Bauge, J.P.Delarche, and M.Girod, *Phys.Rev. C*58 : 1119 (1998).