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Target Mass Dependence of σ, A_y and A_{yy} in Deuteron Elastic Scattering at 56 MeV

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We have measured the differential cross section, vector and tensor analyzing powers for the elastic scattering of 56 MeV deuterons on several targets from ^{12}C to ^{208}Pb. The experiments were carried out at RCNP, Osaka University. Here a target mass dependence of σ, A_y and A_{yy} is discussed in relation to the nuclear rainbow scattering[1]. At forward angles, σ, A_y and A_{yy} show diffractive angular distributions for all target nuclei studied. The experimentally observed characteristic features at backward scattering angles are summarized as follows.

1) For ^{12}C, ^{16}O, ^{40}Ca, ^{52}Cr and ^{58}Ni nuclei, σ falls off almost exponentially, and both A_y and A_{yy} rise to large positive values close to unity.

2) For ^{144}Sm and ^{208}Pb nuclei, σ, A_y and A_{yy} show oscillatory patterns in the whole angular region measured.

3) For ^{90}Zr and ^{118}Sn nuclei, σ, A_y and A_{yy} show intermediate behaviors between those observed in the cases 1) and 2).

Fig. 1 shows σ and A_y for ^{40}Ca, ^{118}Sn and ^{208}Pb as examples for the three cases described above.

The features of 1) are similar to those observed for deuteron elastic scattering on ^{58}Ni at 80 MeV. The behaviors of σ, A_y and A_{yy} at 80 MeV have been interpreted as due to the nuclear rainbow scattering in a semiclassical description of the scattering involving only the real central and spin-orbit potentials[2]. Using the partial cross section σ_m , A_y and A_{yy} are expressed as

$$A_y = \frac{\sigma_1 - \sigma_{-1}}{\sigma_1 + \sigma_0 + \sigma_{-1}}, \qquad A_{yy} = \frac{\sigma_1 + \sigma_{-1} - 2\sigma_0}{\sigma_1 + \sigma_0 + \sigma_{-1}}, \tag{1}$$

where m is the projection of the deuteron spin along the normal to the scattering plane. Due to the spin-orbit potential, the real potential depth and the classically defined maximum deflection angle Θ_{max} depends on m. In the angular region beyond Θ_{max}, all three cross sections σ_1, σ_0 and σ_{-1} fall off exponentially, and σ_1 is roughly an order of magnitude greater than σ_0 and σ_{-1}. The dominance of the m = 1 cross section throughout the fall-off region gives both A_y and A_{yy} large positive values close to unity according to eq. (1) [ref. 2)].

In order to estimate the critical energy, E_{crit}, for the occurrence of the nuclear rainbow scattering, the effective potential

$$S(r) = V_N(r) + V_C(r) + \frac{\hbar^2}{2\mu}\frac{\ell(\ell+1)}{r^2} \tag{2}$$

was calculated for each nucleus and the results for ^{40}Ca, ^{118}Sn and ^{208}Pb are shown in fig. 1. Here $V_N(r)$ and $V_C(r)$ are the nuclear and Coulomb parts of the real central potential, respectively. The potential parameters used were the best fit ones to the experimental data. E_{crit} is the value of S at the point where dS/dr = 0 in the S curve for which the 'pocket' just disappears as ℓ is increased[3]. It is seen from fig. 1 that the value of E_{crit} depends upon the nuclear size. In the present case E_{crit} is about 30, 50 and 75 MeV for ^{40}Ca, ^{118}Sn and ^{208}Pb, respectively. When $E > E_{crit}$, the deflection function $\Theta(\ell)$ has a negative extremum (nuclear rainbow angle). If the maximum value of $|\Theta(\ell)|$ is smaller than 180°, we observe the nuclear rainbow scattering. For energies $E < E_{crit}$, there is an ℓ value such that $E = S$ and $dS/dr = 0$ can be satisfied simultaneously at a radius $r = r_0$. In this case there is neither radial velocity nor acceleration at $r = r_0$ so that the particle continues 'orbiting' or 'spiralling' at that radius. At E_d = 56 MeV, $E > E_{crit}$ for nuclei lighter than ^{58}Ni, $E < E_{crit}$ for ^{144}Sm and ^{208}Pb and $E \sim E_{crit}$ for ^{90}Zr and ^{118}Sn.

Thus the features 1), 2) and 3) described above have close connection with the value of E_{crit} for each nucleus. For lighter nuclei than ^{58}Ni, the condition $E > E_{crit}$ is realized at E_d = 56 MeV and the behaviors of σ, A_y and A_{yy} at backward angles manifest the features of nuclear rainbow scattering. For nuclei heavier than ^{144}Sm, E is smaller than E_{crit} and the rainbow scattering does not occur. For ^{90}Zr and ^{118}Sn, present incident energy is near (or just surmounts) the value of E_{crit} and no clear features of rainbow scattering can be observed.

References

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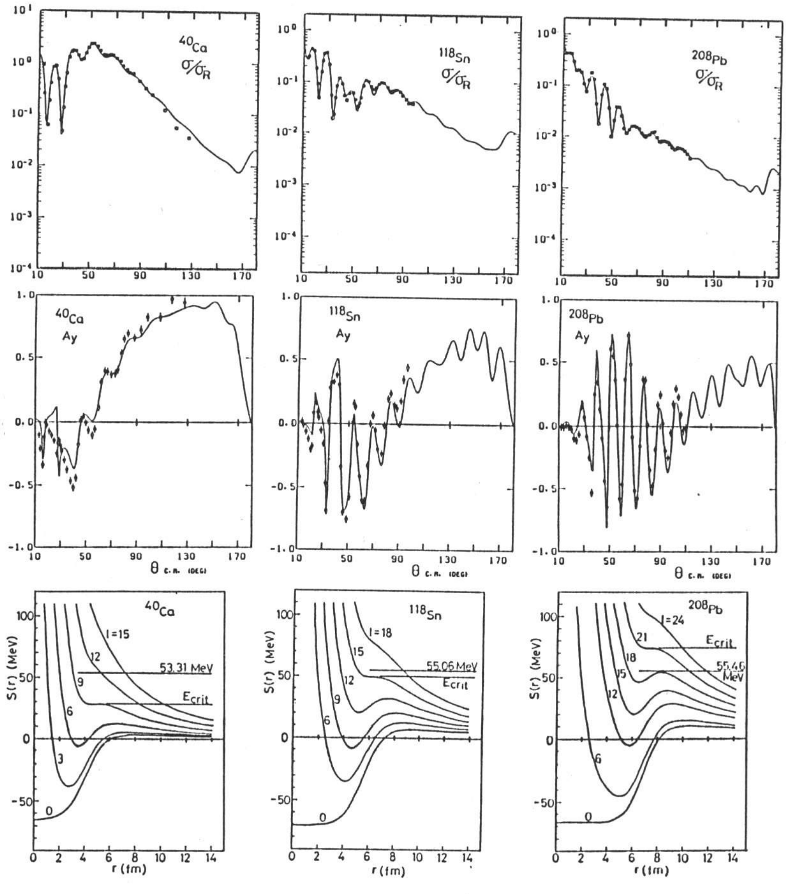

Fig. 1. Differential cross section (Rutherford ratio), vector analyzing power A_y and the effective potential S(r) for 56 MeV deuteron elastic scattering on ^{40}Ca, ^{118}Sn and ^{208}Pb. The curves in σ/σ_R and A_y show best fit results of optical model calculations. S(r) is calculated for various values of ℓ. The critical energy for the occurrence of nuclear rainbow scattering is shown.