3.14 Physical meaning and theoretical description of anomalous absorption of light ion partial waves by nuclear optical potential

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ABSTRACT

An interesting phenomenon relating to the nuclear optical potential was discovered [1] [2],[3]which is called the anomalous absorption of partial waves by the nuclear optical potential. It is found, by extensive numerical calculations, that, for a special combinations of the total angular momentum (j) *,angular momentum* (l) *,energy* (E) *and the target nuclei* (A)*, the elastic S-matrix elements corresponding to nucleon elastic scattering become zero. This phenomenon is universal for light ion elastic scattering on composite nuclei[3]. It is very interesting that this phenomenon occurs for the realistic nuclear optical potential and it exhibits striking systematic in various parameter planes. For example, all nuclei which absorb a partial waves of a definite node lie along a straight in the plane* $(R_C, A^{\frac{1}{3}})$ *,where* R_C *is the closest approach and* A *is mass number of the target nucleus. Theoretical description of this systematic has been actually very difficult, though attempts have been made by the Kyushu group in Japan. In this contribution, we explain mathematically the most striking systematic of this phenomenon and its physical meaning..*

Explanation of the systematic

Partial wave $u_l(k,r)$ of angular momentum l and incident wave number k satisfies the Schrödinger equation

$$\frac{d^2u_l}{dr^2}+\left[k^2-\frac{l(l+1)}{r^2}-\frac{2\mu}{\hbar^2}\{V(r)+iW(r)\}\right]u_l(k,r)=0 \qquad (1)$$

where $V(r)$ is the total real part and $W(r)$ is the total imaginary part of the optical potential. Starting from this equation , one obtains [3]

$$k=\frac{2\mu}{\hbar^2}\int_0^\infty |W(r)||u_l(k,r)|^2\,dr \qquad (2)$$

As a matter of fact, this equation must give all information of the anomalous absorption since the absence of the imaginary part $W(r)$ of the optical potential results in unitary S-matrix element. This equation can be used to explain two important properties of the phenomenon., namely,(1) Absorptive wave number k is related to the potential parameters(2)Striking systematic in the N-

Z plane. In case neutrons, (2) can be written as

$$k = \frac{2\mu}{\hbar^2 a_I}\left[W_v \int_0^\infty \log[1+e^{-(r-a_I A^{\frac{1}{3}})/a_I}]\frac{d|u_l|^2}{dr}dr + 4W_S \int_0^\infty \log[1+e^{-(r-a_I A^{\frac{1}{3}})/a_I}]\frac{d^2|u_l|^2}{dr^2}dr \right] \quad (3)$$

where $W_S = 13.0 - 0.25E_{lab} - 12.0(N-Z)/(N+Z)$, $a_I = 0.58$, and N, Z are the neutron and the proton numbers of the target nucleus Real potential has the term $V = 56.3 - 0.32E_{lab} - 24.0(N-Z)/(N+Z)$.This equation clearly shows that the absorptive wave number k is related to potential parameters $a_I, A^{\frac{1}{3}}, W_v, W_S$ of the imaginary part of the optical potential and the parameters of the real potential since k depends on $|u_l|$.To understand the systematic in the $N-Z$ plane (See the figure) for fixed angular momentum in case of .neutron, one has to assume that the slow change of V and W. For example $W_S = 13.0 - 0.25E_{lab} - 12.0(1 - \frac{2Z}{N+Z})$ changes slowly if Z is consent and $N+Z$ is sufficiently large, as shown in the figure.

In order to explain the most striking systematic, the straight lines in the $(R_C, A^{\frac{1}{3}})$ plane, we have derived the equation

$$\frac{1}{|u_l|^2}\frac{d}{dr}|u_l|^2 = -\frac{g'(r)}{2g(r)} + \frac{W_h(r)}{g(r)|u_l|^2}\int_0^r W_h(r)|u_l|^2 dr \quad (4)$$

for large r,where $g(r) = \left[k^2 - \frac{2\mu}{\hbar^2}V(r) - \frac{l(l+1)}{r^2}\right]$, $W_h(r) = -\frac{2\mu}{\hbar^2}W(r)$.If $W(r)$ decays much more rapidly than $V(r)$ in case of a partial wave under consideration $\frac{1}{|u_l|^2}\frac{d}{dr}|u_l|^2 = -\frac{g'(r)}{2g(r)}$ and by integrating this equation with respect to r, we obtain

$$|u_l(k,r)|^2 (g(r))^{\frac{1}{2}} = C \quad (5)$$

where C is a constant, and the equation (5) is valid for large values of r. From this equation we have obtained linear relation [4]

$$\frac{[l(l+1)]^{\frac{1}{2}}}{k} = 1.17A^{\frac{1}{3}} + C_1 \quad (6)$$

for the most striking systematic, where C_1 is a constant. This relation has found to be well satisfied in the cases we have tested numerically. (6) shows that the wave number k absorbed by the nuclear optical potential is inversely proportional to the size parameter $A^{\frac{1}{3}}$ of the target nucleus.

Physical meaning; A zero of s-matrix element for positive k means the absence of the out going wave in case of elastic scattering. We have shown[5],using WKB approximation, in case of ^{4}He scattering, that this due to the destructive interference of the internal wave and the barrier wave and necessary and sufficient condition for this is given by $S_{31} = (2n+1)\frac{\pi}{2}$, where S_{31} the phase integral associated with inner most and the outermost turning points. We have found that this condition is well satisfied in case of deuteron, and also in case of nucleon scattering the same condition is satisfied approximately.

References

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Figure caption

In the figure, numbers indicate the angular momentum of the partial wave absorbed by the nucleus of mass number A, neutron number N, proton number Z. It is shown that the same partial wave is absorbed in the clusters with the same proton number with increasing neutron number.