REMARKS ON ABSORPTIVE POTENTIALS AND HEAVY ION ELASTIC SCATTERING*

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Abstract

The nature of the gross structure in the optical model analysis of heavy ion elastic scattering is investigated. Further, the success of the double-resonance effect [11] in reproducing intermediate structure is studied.

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The elastic scattering excitation functions for all heavy ion systems studied to date display prominent gross structures above the Coulomb barrier. These gross structures are broad (several MeV) and appear to have simple dependence on the sizes of the target and projectile ions and their relative energy [1]. For this reason the macroscopic optical model has provided fairly satisfactory fits to this gross structure over large ranges of energy and angle with a complex, local potential which has only modest energy or angular momentum dependence [1,2]. It is the purpose of this letter to clarify the nature of these gross structures within the optical model.

Fig. 1 illustrates several of the effects which enter into elastic scattering from a real potential. The dashed curve on the left gives the excitation function for scattering from the real part of the potential given in table 1. On the right are displayed several of the partial wave scattering functions, S_ℓ , in the complex plane where the scattering amplitude is given by

$$f(\theta, E) = f_{\text{coulomb}}(\theta, E) + \sum_{\ell} (2\ell + 1) (S_\ell(E) - 1) P_\ell(\cos \theta).$$

The spike at 21.2 MeV is caused by the single-particle resonance in the $\ell=16$ partial wave potential as can be seen by the rapid counter-clockwise crossing of S_{16} through -1. On the other hand the broad structure at 23 MeV is caused by an $\ell=0$ antiresonance or "echo" described by McVoy et al. [3]. The minima at 19.5 and 25 MeV are caused by minima in $S_{10}-1$ and $S_{12}-1$, respectively, which affect the coherent sum in $f(\theta, E)$.

The situation for a complex potential, however, is much different and this is also illustrated in fig. 1, the full curves being produced by the potential in table 1 with the imaginary part included. Both the sharp single-particle resonance and the broader antiresonance vanish for even

very slight absorption and, for the W given, is lost even to a Regge Pole analysis [5]. This is, of course, the smoothing effect of the optical model [6]. The gross structure near 23 MeV is not related to these definite angular momentum effects at all but is an interference of the partial waves between $\ell=10$ and $\ell=14$. We emphasize that the different roles played by real and complex potentials seen here is not limited to this particular example but appears to be generally true of heavy ion parameterizations of the type in Table I. Because of the semiclassical nature of heavy ion scattering [7] it may be possible to associate loosely a value of ℓ^2 with a peak at some energy through an impact parameter representation, but it is not correct to identify the peaks with states of the ion-ion system.* These peaks are the result of refractive interference effects and do not persist at other angles for a given energy.

However in at least two cases of ion-ion scattering ($^{12}\text{C}-^{12}\text{C}$ and $^{16}\text{O}-^{16}\text{O}$ elastic scattering) narrower structures (intermediate structure) of 0.5-1.0 MeV width have been observed which do persist at all angles and can be identified as resonances of high angular momentum. The success of the single-channel optical model in describing the gross structure has led to recent interest in a coupled channels approach based upon a simple macroscopic interaction between the nuclei to study other aspects of the heavy ion reaction [9-11]. In particular, the Frankfurt group has had success in describing some of the intermediate structure in terms of the coupling between partial waves in the elastic channel with single-particle resonances (or quasi-bound states when they are below the

* This is in contrast to the assumptions in the recent conjecture by Arima, Scharff-Goldhaber and McVoy, who followed the idea that the gross structures correspond to high angular momentum states of the compound system [8].

partial wave barrier) in the inelastic channels* [11]. A necessary condition in their calculation has been that the effective interaction in the inelastic channels must be purely real. We can here understand the need for this requirement. The point is that without a nearly vanishing absorptive part to the inelastic diagonal potentials, there simply are not sharp states of definite angular momentum with sufficient amplitude to produce an effect. We have investigated this point in some detail. Fig. 2 shows the locations of the single-particle resonances in the real potential of table 1. The dashed curve corresponds to the real energy-dependent strength of the potential. For some radial quantum number, n , there are sharp single-particle resonances at 21 and 27 MeV.** Resonances at 24 and 30 MeV for quantum number $n + 1$ are too broad to be distinguished. For our coupled-channel calculations we used an imaginary strength of -1 MeV which is consistent with other coupled-channels work for the $^{12}\text{C}-^{12}\text{C}$ reaction [10]. The inelastic channels are those with a single nucleus excited to a 2^+ state with Q values corresponding to the energy difference of the single-particle resonances and the coupling form factors are those given by a macroscopic deformed potential [12]. With this coupling even for extreme values of the coupling strengths no strong coupling to a particular l value was observed and no intermediate structure was produced.

Because, even for such a weak absorption, no single-particle resonance exists, intermediate structure cannot be produced because single l values are

* The Frankfurt group has been unable to produce such intermediate structure in the $^{12}\text{C}-^{12}\text{C}$ elastic excitation function above $E_{\text{c.m.}} \cong 20$ MeV but this is expected to be remedied when the mutual excitation of both nuclei is properly taken into account.

** There is also a sharp $l=14$ resonance at 16 MeV not shown in the figure.

not favored at a given energy in either the elastic or the inelastic channels. This is further supported by the fact it was possible to produce intermediate structure by special treatment of the $\ell=14, 16$ and 18 partial waves simultaneously. Fig. 3 shows that by paring off the coupling so that it is strongly localized in the region where these partial waves have maximum amplitude, broad intermediate structures were produced. As can be seen in fig. 3, this structure is much too broad to correspond to the $^{12}\text{C}-^{12}\text{C}$ data. Because the interferences of these partial waves for non-zero absorption provide such broad structure, we conclude that it is not possible to explain the intermediate structure in this model without absorption in the inelastic channels sufficiently small to allow the existence of structure which can be identified with a definite angular momentum.

Some work has already provided some insight as to why this absorption could be small [13,2] and we look to further developments in this direction.

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Table 1

Optical model parameters. Strengths given in MeV and radii and diffusenesses in F. This parameterization has been used to fit the ^{12}C - ^{12}C elastic scattering gross structure between 10 and 30 MeV [4].

Real potential	$-(14.0 + 0.8 E_{\text{cm}} - 0.0067 E_{\text{cm}}^2)$	$1.35(A_t^{1/3} + A_p^{1/3})$	0.35
Imag. potential	$-(1.8 - 0.05 E_{\text{cm}} + 0.005 E_{\text{cm}}^2)$	$1.40(A_t^{1/3} + A_p^{1/3})$	0.35

Figure Captions

Fig. 1 Elastic scattering from a potential with parameters of table 1.

On left are 90° excitation functions from real and complex potentials.

On right are the corresponding S-matrix elements.

Fig. 2 Single-particle character of Woods-Saxon potential of radius,

$R=6.2 F$, and with diffuseness, $a=0.35 F$. Dashed curve corresponds

to the real strength given in table 1. 90° elastic excitation

function is given in lower curve.

Fig. 3 Coupled-channels calculation with coupling between 0^+ and 2^+ members

of ground-state rotational level, $\beta R=3F$. Lower curve contrasts

$\ell=16$ and $\ell=18$ partial wave potential with the surface-peaked coupling

form factor. Solid and dashed curve gives normal form factor. Solid

curve alone is form factor pared off to the surface and produces the

90° excitation functions shown in upper figure.