CARBON–CARBON ELASTIC SCATTERING*

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Optical model analyses of elastic scattering of heavy ions have been carried out by Porter (1958) for nitrogen-nitrogen, and a preliminary study of the carbon-nitrogen system has been made by Bassel, Melkanoff, and Drisko (Halbert, Hunting, and Zucker 1960). These analyses have shown that the optical model is capable of predicting, to a higher accuracy than the semiclassical models, the heavy ion elastic angular distributions. We have applied the optical model to the symmetrical carbon-carbon system using a Woods-Saxon potential in conjunction with a Coulomb potential modified to allow for the finite size of the interacting nuclei. The Woods-Saxon potential has the form

$$(V+iW)\Big/\left\{1+\exp\left(\frac{r-R}{a}\right)\right\},$$

where the interaction radius R is twice the nuclear radius $r_0A^{1/3}$, and a is the diffuseness parameter. The numerical integration of the radial wave equation was carried out on the computer CSIRAC at the University of Melbourne.

Calculations were made at both $10\cdot0$ and $12\cdot5$ MeV, the results at 10 MeV being given in Figure 1. The discrepancy at small angles is attributed to an uncertainty in experimental normalization (Bromley, Kuehner, and Almqvist 1961). The best fit to the elastic differential cross section was obtained for $V=-25$ MeV, $W=-10$ MeV, $a=0\cdot6$ fermi, and $r_0=1\cdot31$ fermi. Calculations were also carried out for two other values of diffuseness and radius and for one other value of V and W. The results of the variation of diffuseness and radius are shown in Figure 1. Variation of these parameters had a marked effect on the differential cross section, whereas the values of V and W were of little importance. Decreasing the diffuseness had the expected result of raising the cross section due to reflection by the discontinuity in potential. Variation of r_0, on the other hand, produced a change differing from that experienced in nucleon-nucleus scattering. The predominant effect in the elastic scattering of neutrons on increasing the radius is to move the whole diffraction pattern to smaller angles, whereas in the heavy ion case the whole diffraction pattern is lowered on increasing the radius. This lowering of the cross section is also accompanied by a very small shift to higher angles, in contrast with the nucleon-nucleus case. Altering W from 10 to 15 MeV increased the scattering for angles larger than 55° by approximately 10%, whereas changing V from 25 to 30 MeV produced a decrease for angles larger than 40° of approximately 7%. Thus the heavy ions cross section is dependent only on the " external " parameters,

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radius, and diffuseness, while it is relatively unaffected by a large change in the "internal" parameters, V and W. This result demonstrates clearly that the heavy ion "sees" only the edge of the nuclear potential in an elastic scattering event, any ion that penetrated further being absorbed out of the incident channel.

At an energy of 10 MeV the nuclear phase shifts δ_l of the lth order wave are important for $l \leqslant 12$ only, a plot of the real and imaginary parts of the phase shift against l producing a graph exactly similar to that found by Porter for nitrogen-nitrogen scattering and Eisberg and Porter (1961) for alpha scattering.

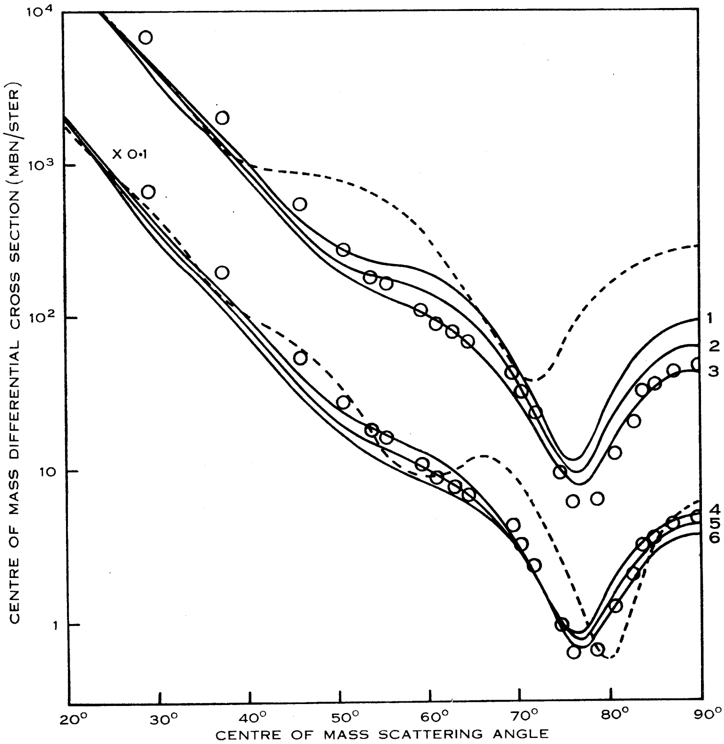

Fig. 1.—$^{12}C+^{12}C$ elastic scattering angular distributions. ○ Experimental; upper dashed curve: point charge Mott scattering; lower dashed curve: best fit Blair model result for $l_{max.}=6$. Curve 1: $a=0\cdot4$ f; 2: $a=0\cdot5$ f; 3: $a=0\cdot6$ f; 4: $R=5\cdot5$ f; 5: $R=6\cdot0$ f; 6: $R=6\cdot5$ f.

Instead of examining the phase shifts as a function of l, it is rather more helpful to consider $\exp(2i\delta_l)$, as it is this quantity which enters into the scattering amplitude formula. The values of $\exp(2i\delta_l)$ for best fit at 10 MeV are given in Table 1.

The results are typical of all those found in heavy ion work where the real part of $\exp(2i\delta_l)$ is initially approximately zero for all low l values, increasing in the vicinity of some $l_{max.}$ to become unity for all large l values. This trend in phase shifts is very similar to that postulated in the modified Blair sharp cut-off model (McIntyre, Wang, and Becker 1960), the original extreme sharp cut-off model (Blair 1954) predicting an elastic differential cross section rather too oscillatory in nature. Figure 1 shows the best fit to the 10 MeV data obtained using the extreme semiclassical model with $l_{\text{max.}}=6$.

TABLE 1

l	Re [exp ($2i\delta_l$)]	Im [exp ($2i\delta_l$)]
0	$-0\cdot0508$	$+0\cdot0023$
2	$-0\cdot0326$	$-0\cdot1646$
4	$+0\cdot0473$	$-0\cdot2088$
6	$+0\cdot2218$	$-0\cdot1355$
8	$+0\cdot5054$	$+0\cdot1223$
10	$+0\cdot8974$	$+0\cdot1540$
12	$+0\cdot9904$	$+0\cdot0393$

The curve of elastic differential cross section as a function of energy exhibits broad oscillations on which are superposed a finer resonant structure (Bromley, Kuehner, and Almqvist 1961) which has been attributed to the formation of quasi-molecular states (Vogt and McManus 1960). We have carried out an optical model calculation at 12·5 MeV to determine whether the broad minimum situated there is in fact a diffraction effect. A fairly good fit was obtained with the observed angular distribution with the same parameters as used at 10 MeV, except for a decrease in diffuseness to 0·4 fermi. The formation of quasi-molecular states might suggest an interaction radius larger than the sum of the carbon radii (Reeves 1960) but this was not found necessary in our calculations.

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