Elastic and Inelastic Scattering of Alpha Particles by N^{14}†

W. D. PLOUGHE*
Purdue University, Lafayette, Indiana

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The absolute differential cross section for the elastic and inelastic scattering of 19.2-Mev alpha particles by N^{14} was measured as a function of the scattering angle. The forward part of the ground-state angular distribution was fitted with the black-nucleus diffraction model of Blair using an interaction radius of 5.89×10^{-13} cm. The angular distribution for the $Q=-3.95$-Mev group was fitted with $[j_2(qR)]^2$ using an interaction radius of $R=5.9\times10^{-13}$ cm. With the same interaction radius, a best fit to the data for the unresolved doublet, $Q=-4.91$ and -5.10 Mev, was obtained using the sum $[j_1(qR)]^2+[j_3(qR)]^2$. The best fit by odd-order spherical Bessel functions is consistent with the assignment of negative parity to both the 4.91- and 5.10-Mev levels.

INTRODUCTION

THIS investigation is the most recent part of a program to study the scattering of 19-Mev alpha particles from light and medium heavy nuclei. The differential scattering cross section of C, O, S, Ne, Al, Cu, and Ag have been discussed in earlier reports.[1–4] Here are reported the angular distributions of alpha particles scattered elastically and inelastically from N^{14} nuclei. The levels of N^{14} studied by inelastic scattering are the (1^+) 3.95-Mev state and the (0^-) 4.91-Mev and $(2^{(-)})$ 5.10-Mev unresolved doublet. The 0^+, $T=1$ state at 2.31 Mev is only weakly excited by alpha-particle scattering.

The experimental arrangement used in this work has been adequately described in references 2 and 4. The only improvement over the previous work is that a new analyzing slit system which defines the direction of the scattered alpha particles has been built and used. The alpha particles were detected in 100-micron $E1$ Ilford nuclear emulsion plates. These are placed every 2.5° from 10° to 170° except for 17.5°. At 17.5° slits are provided on each side of the beam for two monitor counters instead of the single monitor used previously.

The energy of the incident beam was determined by measuring the energy of the alpha-particle beam from the cyclotron by a 55-deg analyzing magnet and then correcting for the energy lost in the Mylar entrance window and the nitrogen gas. This value was compared with the energy obtained from measurement of the residual range of the elastically scattered alpha particles in the photographic plates to which was added the energy lost in the exit gas and window. These measurements give 19.20±0.05 Mev for the energy at the center of the gas chamber. The quoted error includes the 20-kev rms beam spread[5] due to the finite geometry of the entrance and exit slits of the analyzing magnet and the uncertainty in the energy losses. The target thickness varied from 20 kev at 90° to 120 kev at the extreme forward and backward angles.

ELASTIC SCATTERING

The angular distribution of the elastically scattered alpha particles is given by the dots in Fig. 1. The solid curve is a line drawn through the experimental points while the dashed line is the Rutherford differential cross section. The statistical accuracy of the experimental points is 6% or better. The second-order geometry and multiple-scattering corrections[4] have been

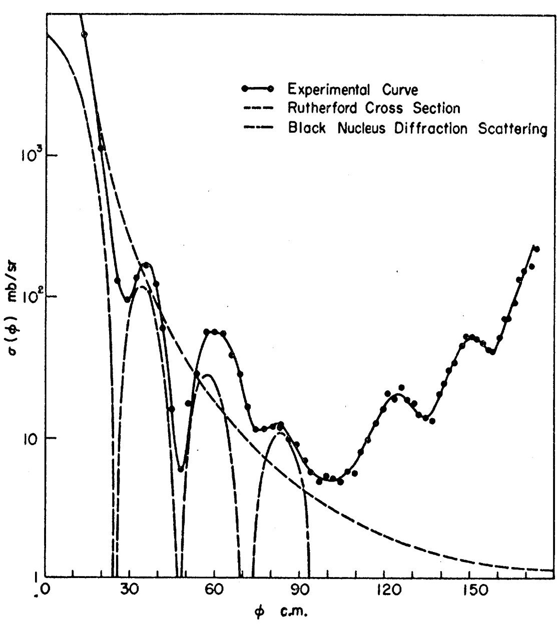

FIG. 1. $N^{14}(\alpha,\alpha)N^{14}$ ground-state angular distribution showing the Rutherford scattering cross section by the dashed curve and the best-fit Blair curve for black-nucleus diffraction scattering by the dot-dashed curve. The interaction radius is 5.89×10^{-13} cm.

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* Now at Ohio State University, Columbus, Ohio.

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calculated at a number of points, and the total correction was always less than 1%. This was considered to be negligible compared to the statistical inaccuracy. The absolute accuracy is ±5% of the differential cross section. This arises from uncertainties in the total beam charge collected and in the knowledge of the geometrical factors. The angular position is known to ±0.1°.

The elastic angular distribution shows the oscillatory nature of the differential cross section as has been found in alpha particles elastically scattered from other light nuclei.[3,4,6] The differential cross section for elastic scattering from a black nucleus may be expressed according to Blair[7–9] by

$$\frac{d\sigma}{d\Omega}=(kR^2)^2\left[\frac{J_1(2kR\sin\frac{1}{2}\phi)}{2kR\sin\frac{1}{2}\phi}\right]^2. \qquad (1)$$

In this equation k is the wave number of the alpha particle, and R, the interaction radius, is adjusted to fit the position of the minima. The dot-dashed curve of Fig. 1 is a plot of Eq. (1) with $R=5.89\times10^{-13}$ cm. The value of the cross section given by Eq. (1) is consistently smaller than the measured cross section. At 40 Mev the experimental data of Yavin and Farwell[6] show good agreement at the maxima with Eq. (1) for angles less than 90° when the interaction radius is taken to be 5.37×10^{-13} cm. No interpretation has been given for the increase in cross section for angles greater than about 90°.

In Fig. 2 the ratio $\sigma_{\text{el}}/\sigma_{\text{R}}$, where σ_{el} is the elastic cross section and σ_{R} is the Rutherford cross section, is shown for a number of nuclei. This is the same as Fig. 16 of Corelli *et al.*[4] with the addition of the nitrogen data. For the light nuclei a general rise in the backward direction is observed. The lower the atomic number, the higher is this increase. There is, however, a remarkable difference between the angular distributions for spin-zero nuclei and those for N^{14} and Al^{27}. For the even-even nuclei investigated, a pronounced oscillatory pattern is superimposed on the general rise at large angles, whereas nitrogen shows only very slight oscillations and aluminum a somewhat irregular behavior. It would seem that the usual central optical potential[10] could not explain this difference in the angular distributions.

The angular distributions of elastically scattered 18-Mev alpha particles by C^{12}, O^{16}, and Ne^{20} have been fitted with Eq. (1) and yield values of 6.31×10^{-13} cm, 5.76×10^{-13} cm, and 6.11×10^{-13} cm, respectively, for the radii.[11] These values are comparable with the value of 5.89×10^{-13} cm obtained for N^{14}. An explanation for the increase of the interaction radius for $A<16$ has yet to be given.

INELASTIC SCATTERING

The angular distribution of the alpha particles inelastically scattered from N^{14}, leaving the residual N^{14} nucleus in the (1^+) 3.95-Mev excited state, is shown in Fig. 3. The errors associated with the points are shown in the figure. The main contributions come from statistical errors, less than 10%, and the subtraction of the background. The background subtraction was particularly difficult at the extreme forward angles. Following Austern, Butler, and McManus,[12] since Blair[8] does not treat the case of odd-odd nuclei, the data were fitted with

$$d\sigma/d\Omega\propto\sum_l A_l[j_l(qR)]^2, \qquad (2)$$

where $\mathbf{q}=\mathbf{k}_i-\mathbf{k}_f$, R is adjusted to fit the observed

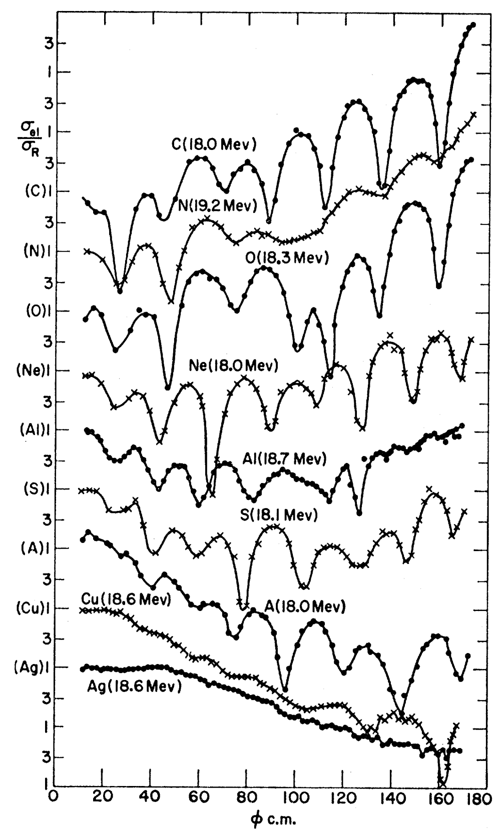

FIG. 2. Ratio of the elastic scattering cross section to the Rutherford cross section at 18 to 19 Mev for a number of light elements.

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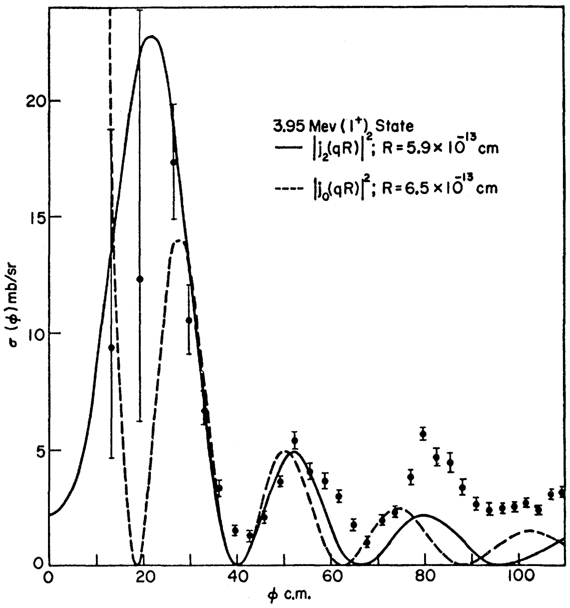

FIG. 3. $N^{14}(\alpha,\alpha)N^{14*}$ (3.95 Mev) angular distribution showing the $[j_l(qR)]^2$ fit. The solid curve is for $l=2$ and $R=5.9\times10^{-13}$ cm, and the dashed curve is for $l=0$ and $R=6.5\times10^{-13}$ cm.

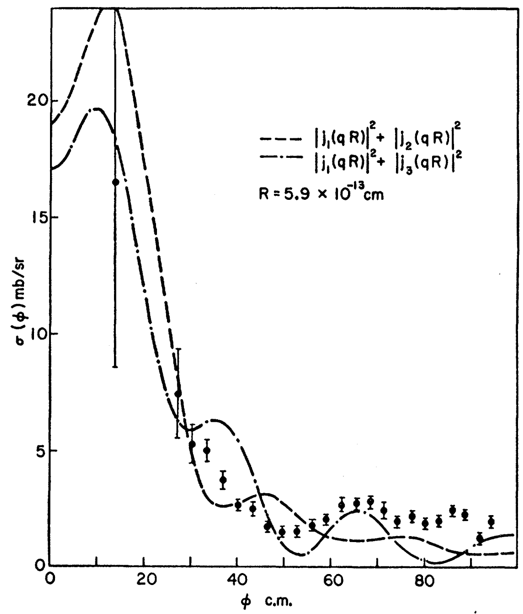

FIG. 4. $N^{14}(\alpha,\alpha)N^{14*}$ (4.91–5.10 Mev unresolved doublet) angular distribution showing the attempted fit with $\Sigma A_l[j_l(qR)]^2$. The dashed curve is for $l=1$ and 2, and the dot-dashed curve is for $l=1$ and 3. The coefficients are taken to be equal.

minima, and l is given by the inequality

$$|\mathbf{J}_i+\mathbf{J}_f|_{\min}\leq l\leq J_i+J_f. \quad (3)$$

With the additional requirement that l must be odd or even according to whether a parity change does or does not exist between the initial and the final state, $l=0$ or 2 is allowed for the transition from the (1^+) ground state to the (1^+) 3.95-Mev second excited state. The solid curve of Fig. 3 is for $l=2$ and $R=5.9\times10^{-13}$ cm while the dashed curve corresponds to the values of $l=0$ and $R=6.5\times10^{-13}$ cm. It is evident from Fig. 3 that $l=2$, without any contribution from $l=0$, gives a reasonable fit to the data.

The experimental techniques used were not capable of resolving the 4.91–5.10 Mev doublet. The angular distribution of alpha particles which leave the N^{14} nucleus in one of these states is shown in Fig. 4. Assuming the spins and parities of the 4.91- and 5.10-Mev states to be given by 0^- and 2^-, respectively,[13] the allowed l values are $l=1$ for the 4.91-Mev level and $l=1$ and 3 for the 5.10-Mev level. Thus the angular distribution given by Eq. (2), using the previously determined $R=5.9\times10^{-13}$ cm, should be a sum over $l=1$ and 3. The sum (using equal coefficients) is shown by the dot-dashed curve in Fig. 4.

However, there is some doubt about the negative parity assignment to the 5.10-Mev level.[13,14] If the parity should be positive, then $l=2$ is allowed, and the angular distribution is given by summing Eq. (2) over 1 and 2. This is shown by the dashed curve of Fig. 4 where the coefficients are again taken to be equal. Comparison of the two cases shows the data not to be inconsistent with the preferred assignment of negative parity given by Warburton and Pinkston.[13]

Evidence was sought for the alpha-particle excitation of the $(0^+, T=1)$ 2.31-Mev level which is forbidden both by conservation of isotopic spin and by Eq. (3), i.e., l forbidden. Careful investigation at 72.5° (lab) indicate that the intensity of the 2.31-Mev state is less than 5% of that of the 3.95-Mev state at the same angle. However, the evidence at 10° (lab) indicates that here the intensity of the two states might be comparable. The low intensity of these groups compared to the elastic scattering at this angle does not permit unambiguous interpretation by the experimental technique used.

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