PHYSICAL REVIEW C VOLUME 11, NUMBER 2 FEBRUARY 1975

Odd-even differences in the elastic scattering of α particles by $A = 62-66$ nuclei*

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(Received 29 October 1974)

Odd-even differences in the elastic scattering of 48 MeV α particles by ^{62,64}Ni, ^{63,65}Cu, and ^{64,66}Zn are well accounted for, up to back angles, by core polarization.

[NUCLEAR REACTIONS ^{62,64}Ni, ^{64,66}Zn(α,α), (α,α'), ^{63,65}Cu(α,α), $E=48$ MeV; measured $\sigma(\theta)$; $\theta=18-172°$, enriched targets; ^{63,65}Cu core mixing deduced.]

Odd-even differences in the angular distributions of α particles elastically scattered by two adjacent nuclei are generally attributed to two different phenomena:
(i) The $I\cdot L$ interaction between the odd-nucleus spin I and the α-particle angular momentum L. Rawitscher[1] and Love[2] have calculated a strength smaller than 0.1 MeV for the $I\cdot L$ potential, in disagreement with the larger values (1.0–2.75 MeV) deduced from optical-model fits[3] of experimental data.
(ii) The scattering from the multipole moments of the odd nucleus[4] (if $I>\frac{1}{2}$). Recently, an explicit formulation of this effect has been derived,[5] in which the elastic cross section for the odd nucleus is expressed as a sum of the elastic scattering for the adjacent even nucleus and of part of the inelastic scattering to the first excited states of the same even nucleus. A satisfactory agreement was found by these authors[5] when comparing the 49.9 MeV α-particle elastic scattering by the nuclei ^{59}Co and ^{60}Ni over the angular range 40°–110° in the center-of-mass system.

The aim of the present experiment was to check the model[5] of Satchler and Fulmer on a large number of nuclei, i.e., ^{62,64}Ni, ^{63,65}Cu, and ^{64,66}Zn, over a wide angular range. The 48 MeV α-particle beam of the University of Louvain isochronous cyclotron (CYCLONE) was successively focused on six self-supporting enriched targets: ^{62}Ni(1.068 mg/cm^2), ^{63}Cu(1.229 mg/cm^2), ^{64}Zn(1.245 mg/cm^2), ^{64}Ni(1.243 mg/cm^2), ^{65}Cu(1.272 mg/cm^2), and ^{66}Zn(1.000 mg/cm^2). The target thickness was measured, with an accuracy of 5%, through the energy loss of α particles from an ^{241}Am source. After scattering by the target, the α particles were detected in an array of 1000 μm thick surface barrier silicon detectors. Conventional electronics was used, including an antipileup circuitry on each detector channel. The over-all energy resolution was 150 keV full width at half-maximum. The detectors solid angles were estimated by measuring the defining slits directly; they are known to ±1%. Angular distributions for the elastic scattering were registered between 18 and 172° in the laboratory system, by 1° (2°) steps, with an angular resolution of 0.3° (1°), over the angular range 18–60° (62–172°). For the four even nuclei, we have also extracted the inelastic scattering cross section to the first 2^+ state.[6]

Let us briefly recall the main statements of Ref. 5. The odd nucleus is considered as a core (the adjacent even nucleus) in its ground state or in its excited levels, plus a spectator particle (or hole) with spin j; other levels than the core ground state are mixed in by the presence of the spectator particle (or hole). In the following, we only consider the contribution of the core ground state and first excited level to the odd-nucleus ground-state wave function, which accordingly takes the form:

$$|\,\text{odd}, IM\rangle = \alpha\,|\,(\text{even},0), j; IM\rangle + \beta_2\,|\,(\text{even},2), j; IM\rangle \tag{1}$$

with $\alpha^2+\beta_2{}^2=1$. Following Satchler and Fulmer's assumption in the calculation of the elastic scattering amplitude,[5] the terms of order $\alpha\beta_2$ in the latter are taken to be equal to the amplitudes for the inelastic scattering to the 2^+ state of the even nucleus. With these hypotheses, the elastic scattering cross section for the odd nucleus is related to

TABLE I. Calculated α^2 values in the spectator model (this work), compared with the intermediate-coupling calculations of Vervier (Ref. 10).

α^2	Core +1 p Spectator [a]	Core +1 p Interm. coupling [b]	Core +1 h Spectator [a]
^{63}Cu	0.74 ± 0.07	0.81 ± 0.06	0.66 ± 0.08
^{65}Cu	0.59 ± 0.07	0.64 ± 0.06	0.66 ± 0.08

[a] This work.
[b] Reference 10.

that for the even core by:

$$\sigma_{el}(\text{odd}) = \sigma_{el}(\text{even}) + \frac{(2\alpha\beta_2)^2}{2L+1}\sigma_{inel}(\text{even},\ 0^+ \rightarrow 2^+) . \qquad (2)$$

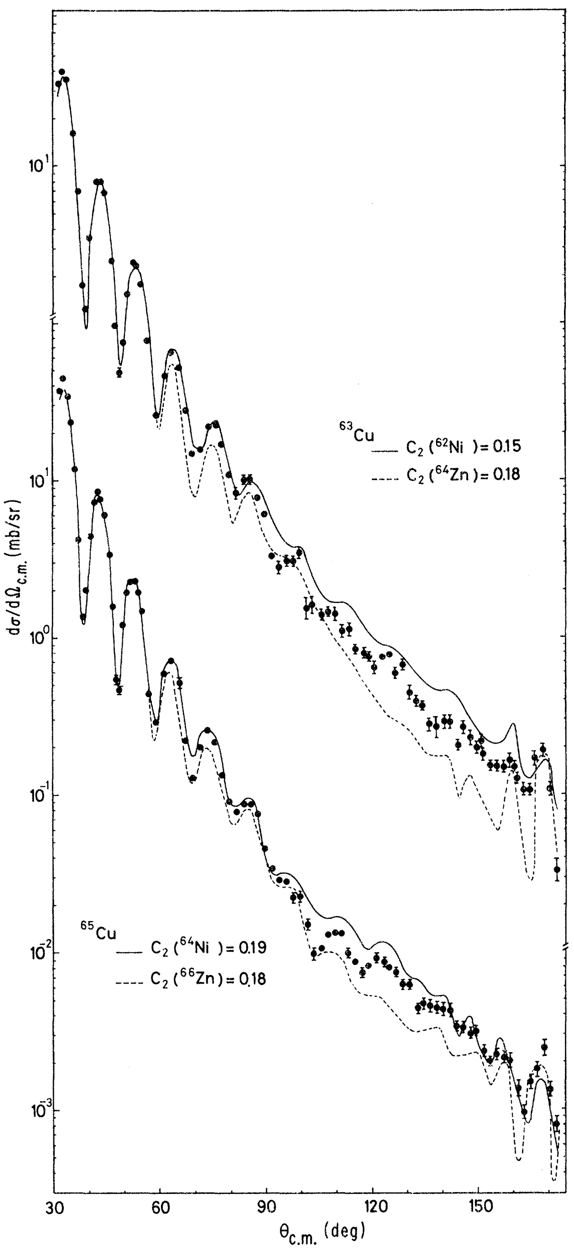

FIG. 1. Experimental and calculated angular distributions for ^{63,65}Cu. The error bars only include statistical errors. The solid curves are computed with the assumption of a ^{62,64}Ni core, the dashed ones, of a ^{64,66}Zn core; the solid curve alone has been drawn at forward angle, where both curves overlap. The C_2 coefficients indicate, for each case, the amount of the inelastic scattering to the 2^+ state which is added to the even nucleus elastic cross section.

The parameters α and β_2 are calculated from the experimental quadrupole moment of the odd nucleus (Q), using its expression in terms of the contributions of the odd valence particle (Q_{val}) and of the core (Q_{core}):

$$Q = Q_{val} + Q_{core} , \qquad (3)$$

$$Q_{val} = \mp \frac{2j-1}{2(j+1)} \langle r^2 \rangle_j \times [\alpha^2 - \beta_2^2 (2I+1) W(IIII; 2L)] , \qquad (4)$$

$$Q_{core} = \alpha\beta_2 \left[\frac{64\pi I(2I-1)}{5(I+1)(2I+3)} \right]^{1/2} \times \langle 2 \| r^2 Y_2 \| 0 \rangle . \qquad (5)$$

In Eq. (4), the minus sign holds for a particle, the plus sign, for a hole, and $\langle r^2 \rangle_j$ is the mean square radius of the valence particle (or hole) orbit. In Eq. (5), the reduced matrix element $\langle 2 \| r^2 Y_2 \| 0 \rangle$ is estimated from the experimental reduced transition probability $B(E2, 2 \rightarrow 0)$ in the even nucleus.

We have calculated the coefficients α and β_2 for $^{63,65}Cu$ in the following way: The nucleus ^{63}Cu was successively represented as a ^{62}Ni core plus a $(2p_{3/2})$ proton particle, and a ^{64}Zn core plus a $(2p_{3/2})$ proton hole; the same was done for ^{65}Cu, starting from ^{64}Ni and ^{66}Zn. Recent values of the quadrupole moments[7] and of the $B(E2)$[8] were used in the calculations. The mean square radius $\langle r^2 \rangle_j$ was estimated from the formula[9]:

$$\langle r^2 \rangle_j = \tfrac{3}{5}(r_0 A^{1/3})^2, \quad \text{with } r_0 = 1.25 .$$

The choice of the r_0 value is of little importance in the calculations, which did not include the hypothesis of an effective charge for the valence particle (or hole), unlike in Ref. 5. Table I summarizes the α^2 values; the indicated errors come from experimental errors on the Q's and $B(E2)$. Our estimate in the particle representation is in good agreement with the core-excited model calculations of Vervier.[10] For the hole representation, the same amount of quadrupole mixing is found for the two Zn cores; this could be related to the fact that $B(E2, 2 \rightarrow 0)$ is nearly the same for ^{64}Zn and ^{66}Zn, giving the same polarizability to the two cores.

Figure 1 shows the calculated elastic scattering angular distributions for $^{63,65}Cu$, compared to the experimental data; we have indicated in the figure the amount C_2 of inelastic scattering admixture, where $C_2 = (2\alpha\beta_2)^2/2L+1$. The agreement is very good at forward angles; for the backward angles, the particle representation is closer to the experimental data than the hole representation; the latter would need more mixing in the wave function. It thus appears that collective effects, as described by Satchler and Fulmer,[5] account fairly well for most of the odd-even differences up to backward angles. Moreover, the reduction of the inelastic scattering to the first $\frac{3}{2}^-$ excited level (1.547 MeV in ^{63}Cu, 1.725 MeV in ^{65}Cu), as predicted in this model, has been experimentally observed in the (α, α') scattering.[11]

We are indebted to Professor J. Vervier for helpful discussions. We wish to thank the cyclotron staff for efficiently running the machine.

*Work supported by Institut Interuniversitaire des Sciences Nucléaires, Brussels, Belgium.

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‡Aspirant du Fonds National de la Recherche Scientifique, Brussels, Belgium.

[1]G. H. Rawitscher, Phys. Rev. C 6, 1212 (1972).

[2]W. G. Love, Nucl. Phys. A226, 319 (1974).

[3]C. B. Fulmer and J. C. Hafele, Bull. Am. Phys. Soc. 16, 646 (1971); R. B. Taylor, N. R. Fletcher, and R. H. Davis, Nucl. Phys. 65, 318 (1968); J. Lega and P. C. Macq, *ibid.* A218, 429 (1974).

[4]G. R. Satchler, Nucl. Phys. 45, 197 (1963).

[5]G. R. Satchler and C. B. Fulmer, Phys. Lett. 50B, 309 (1974).

[6]C. Pirart, Institut de Physique Corpusculaire, Report No. N-74-09 (unpublished).

[7]R. M. Sternheimer, Phys. Rev. A 6, 1702 (1972).

[8]A. Christy and O. Hauser, Nucl. Data A11, 281 (1973); R. L. Auble, Nucl. Data B12, 305 (1974); M. J. Martin and N. Rao, Nucl. Data B2 (No. 6), 43 (1968).

[9]A. Bohr and B. R. Mottelson, K. Dan. Vidensk. Selsk. Mat.-Fys. Medd. 27, No. 16 (1953).

[10]J. Vervier, Nuovo Cimento 28, 1412 (1963).

[11]G. Bruge, J. C. Faivre, M. Barloutaud, H. Faraggi, and J. Saudinos, Phys. Lett. 7, 203 (1963); B. G. Harvey, J. R. Meriwether, A. Bussière, and D. J. Horen, Nucl. Phys. 70, 305 (1965).