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COMPARISON OF THE ELASTIC SCATTERING OF ^3He AND ^4He BY ^{40}Ca*

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ABSTRACT

The scattering of ^3He and ^4He from ^{40}Ca has been compared at equal incident momenta. The results indicate that ^3He has a more diffuse interaction than ^4He.

The scattering of medium-energy ^4He ions has been extensively used in the last several years for investigating nuclear properties. The characteristic feature of the scattering is the oscillatory angular distribution, originally explained using a semi-classical "diffraction" model[1)] in which the alpha-particle waves were assumed not to penetrate inside a well-defined interaction radius. As the experiments have become more refined it has become necessary to introduce a new parameter into the analysis to allow for a lack of definition, or "diffuseness" of the interaction radius. ^3He particles are also strongly absorbed, but differ from ^4He in other respects, notably mass, binding energy and spin. We have attempted to bring direct evidence to bear on nuclear interaction radii by comparing the scattering of ^3He and ^4He from the same nucleus under carefully chosen conditions.

Accurate angular distributions showing a characteristic diffraction pattern were already available[2)] for the scattering of 50.9 MeV ^4He by ^{40}Ca.

For the purpose of direct comparisons, the ^{3}He beam energy was chosen as 65.3 MeV to have the same relative momentum in the center-of-mass system as 50.9 MeV ^{4}He. Thus in the absence of the Coulomb interaction the "diffraction" model would give the same angular distribution in both cases.

We bombarded a 1.02 mg/cm^2 natural calcium target with 65.3 MeV ^{3}He ions from the Berkeley 88-inch cyclotron and used a solid-state counter telescope and particle identification to measure the elastic scattering angular distribution between 9° and 64° in the center-of-mass system, with an effective angular resolution of 0.6°. The absolute normalization of each set of measurements is independently known to $\pm$10%.

Both elastic angular distributions have similar diffraction-like patterns with peaks occurring at the same values of the momentum transfer (see fig. 1). The difference in magnitude in the two distributions at small angles is explained by the expected difference in the Coulomb contributions to the scattering. The relatively high diffraction peak in the ^{3}He cross-section at about 60° is evidence that more complex processes than considered here may become important for ^{3}He scattering at larger angles. The aspect of the comparison between the two angular distributions that we want to emphasize here is that the ^{3}He differential cross-section falls more rapidly as a function of angle than the ^{4}He cross-section at small angles. To explain this we analyze in terms of the usual partial-wave expansion.

$$\frac{d\sigma}{d\Omega} = \frac{1}{4k^2}\left|\sum_{\ell} (2\ell+1)(1-\eta_\ell\, e^{2i\sigma_\ell})\, P_\ell(\cos\theta)\right|^2$$

where η_ℓ is the scattering amplitude, σ_ℓ is the Coulomb phase shift, $P_\ell(\cos\theta)$ is a Legendre polynomial and k is the wave number of the incident particle in the center-of-mass system. To perform the analysis we have parameterized the scattering amplitudes in the following way:

$$\eta_\ell = \epsilon - a\frac{\partial\epsilon}{\partial\ell_o} + i\left(-b\frac{\partial\epsilon}{\partial\ell_o} + c\frac{\partial^2\epsilon}{\partial\ell_o^2}\right)$$

where $$\epsilon = \left[1 + \exp\left(\frac{\ell-\ell_o}{\Delta}\right)\right]^{-1}$$

and ℓ_o, Δ, a, b, and c are the fitting parameters.

The real and imaginary parts of the scattering amplitudes η_ℓ as determined by a least squares fit to the data are shown in fig. 2. The important difference between the two projectiles is that for ^{3}He the change in η_ℓ takes place over a larger range of ℓ than for ^{4}He. The possibility that this effect may be due to a spin-orbit interaction has been ruled out by tests using the optical model program Scat-4. By making the usual classical connection between angular momentum and impact parameter i.e., $\ell_o \sim kR_o$, we conclude that the diffuseness of the interaction radius, R_o, for ^{3}He is about 1.5 times greater than that for ^{4}He. However, the interaction radius itself is unchanged in the two reactions. This seems to be in contradiction with previous statements[4)] comparing ^{3}He and ^{4}He scattering. However, similar results have been seen by Venter and Frahn[5)] using an equivalent analysis with a 3 parameter fit to the $\eta\ell$'s. Also, we have recently been informed by Dr. R. H. Bassel that he has independently observed the same phenomenon in comparing optical-model-derived phase shifts from ^{3}He and ^{4}He scattering at a number of lower energies, for a variety of nuclei.

We wish to thank Claude Ellsworth for making the target.

FOOTNOTES AND REFERENCES

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FIGURE CAPTIONS

Fig. 1. The differential cross sections for 50.9 MeV ^{4}He and 65.3 MeV ^{3}He elastic scattering by ^{40}Ca. The curves are generated by the parameterized phase shift analysis described in the text.

Fig. 2. The real and imaginary parts of the scattering amplitudes determined for the ^{40}Ca elastic scattering plotted as a function of the variable ℓ.

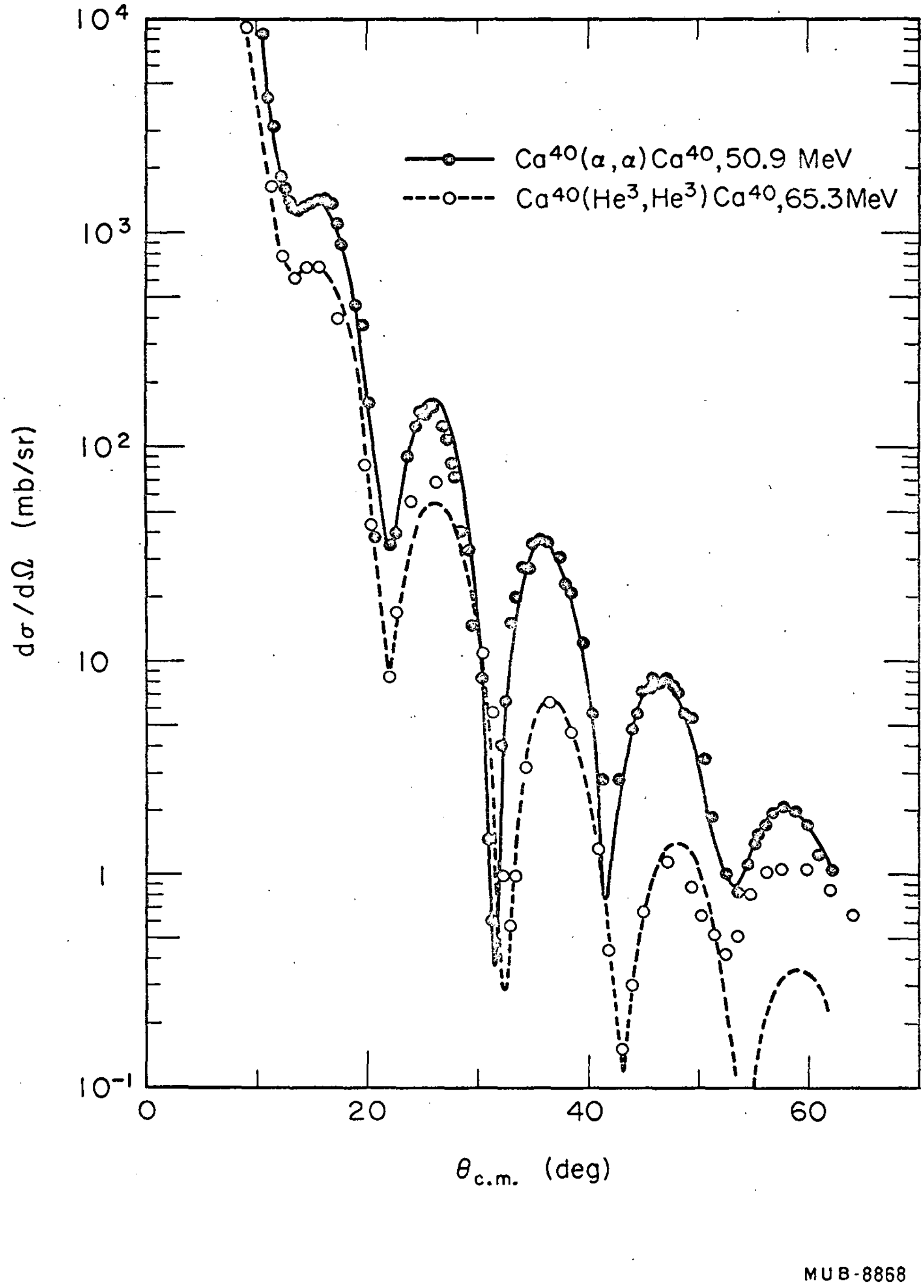
10^4
10^3
10^2
10
1
10^{-1}
0
20
40
60
$Ca^{40}(\alpha,\alpha)Ca^{40}$, 50.9 MeV
$Ca^{40}(He^3,He^3)Ca^{40}$, 65.3MeV
$d\sigma/d\Omega$ (mb/sr)
$\theta_{c.m.}$ (deg)
MUB-8868

Fig. 1

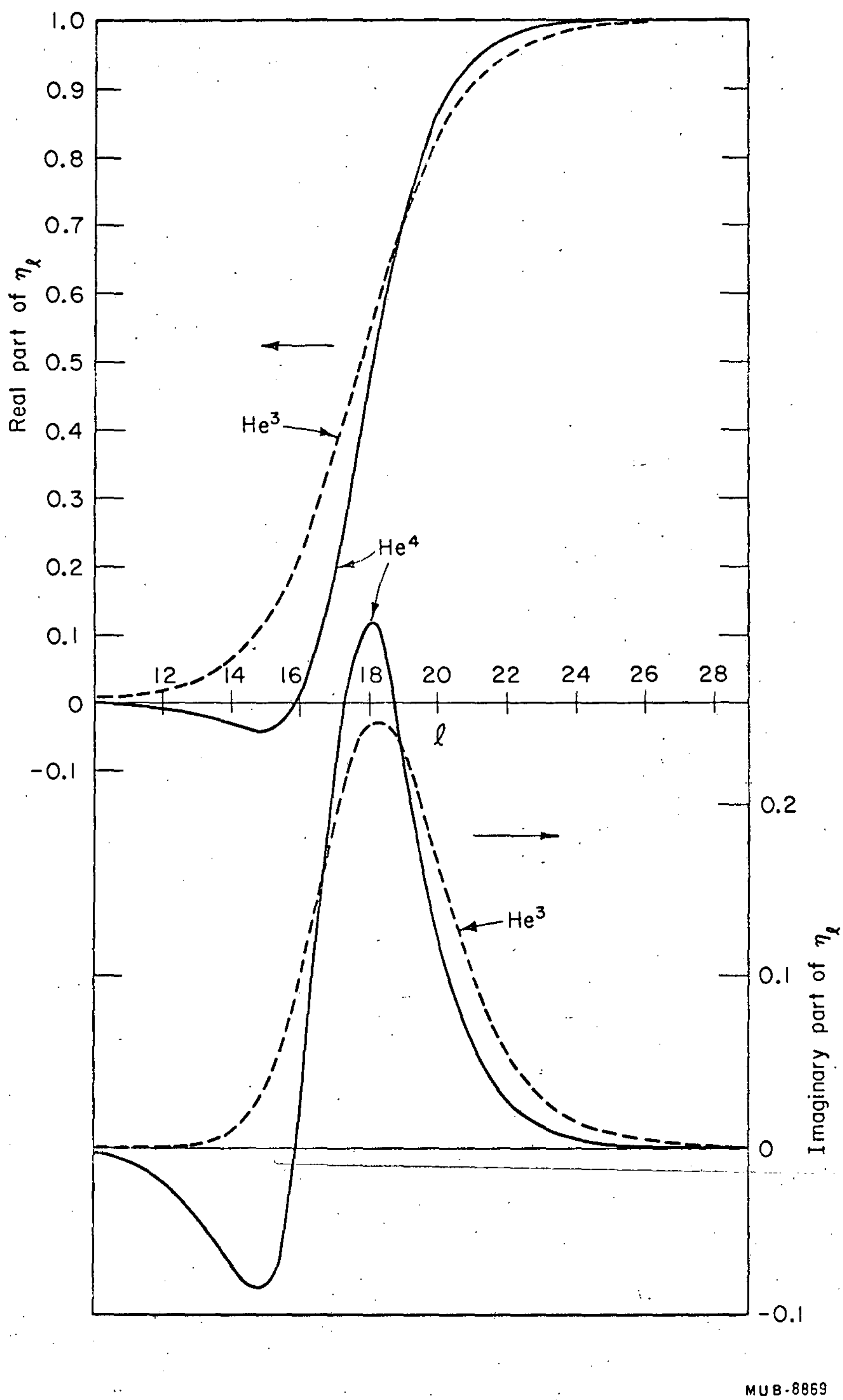
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
Real part of η_ℓ
He³
He⁴
12
14
16
18
20
22
24
26
28
ℓ
He³
0.2
0.1
0
-0.1
Imaginary part of η_ℓ
MUB-8869

Fig. 2