Title
MULTIPOLE DEFORMATION OP 238U

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MULTIPOLE DEFORMATION OF $^{238}$U

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For Reference

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Elastic and inelastic scattering of 50 MeV helium ions from $^{238}_{\text{U}}$ was studied with a high-resolution magnetic spectrometer. Angular distributions for members of the ground state rotational band up to the $8^+$ level were measured. Coupled channels calculations yield 0.022, 0.060, and \(-0.012\) for the deformation parameters $\beta_2$, $\beta_4$, and $\beta_6$ for an optical radius of $1.44\, \text{Å}^{1/3}$ fm. These values are compared with other experimental results.

The ability to measure details of nuclear shapes by means of alpha-particle inelastic scattering has been first demonstrated for permanently deformed rare earth nuclei.\(^1\) Attempts to extend these measurements to the interesting actinide region of permanent deformations have been thwarted by experimental difficulties, mainly the inability of solid state detectors to resolve the more closely spaced energy levels in these nuclei. Meanwhile, several theoretical predictions for the hexadecapole moments of actinide nuclei and a few experimental results using other techniques have been published. The interest in the problem is intensified, however, because both the theoretical
predictions$^{2,3,4}$ and the experimental results$^{5,6}$ show large variations for
the $Y_{40}$ moment of uranium. These experiments determine rather large values
for the deformation parameters, $\beta_L$, when the nuclear radius $R$ is expanded from
an optical radius, $R_0$

$$ R = R_0 (1 + \beta_2 Y_{20} + \beta_4 Y_{40} + \beta_6 Y_{60}) \quad (1) $$

where $Y_{L0}$ are the spherical harmonics.

Our experiment measured the angular distributions in elastic and
inelastic scattering of $50$ MeV alpha particles by $^{238}\text{U}$, utilizing a new
magnetic spectrometer$^7$ for detection of the scattered alphas. Differential
cross sections were measured for levels in the ground state rotational band up
to the $8^+$. The target was made by evaporating $75$ $\mu$g/cm$^2$ of uranium metal on to
a $50$ $\mu$g/cm$^2$ carbon backing. Beams of up to $1$ $\mu$A were prepared by the high
resolution magnetic analysis system, delivered on to the target, and collected
and measured in a Faraday cup. The quantity of beam on target was also
monitored by a solid state detector placed at $20^\circ$ with respect to the incident
beam. Detection of scattered alphas at the focal plane of the spectrometer was
made by a $1$ cm high by $5$ cm long position sensitive silicon detector obtained
from Nuclear Diodes, Inc. The energy resolution of the entire system was $16$
keV at forward angles, changing slowly to $20$ keV at the most backward angles,
where target thickness effects become more important. The data were taken in
two independent runs. Scattering from a target contaminant of about $10\%\ ^{182}\text{W}$
obscured the $^{238}\text{U}$ levels for several angles in the first run. This problem did
not repeat in the second run; the results from the two runs reproduced well
where they could be checked. A sample spectrum from the second run is shown in
Fig. 1.
Because of the limited height (1 cm) of the position sensitive detector and the large vertical magnification of the spectrometer, we were able to detect only about 80% of the scattered particles accepted by our solid angle of $0.7 \times 10^{-3}$ sr. Relative normalization was made by utilizing a special target made by evaporating $200 \mu g/cm^2$ of $^{238}U$ on to a carbon foil in the form of a strip 1 mm in height. This produced a 5 mm high image at the focal surface centered vertically in the detector aperture. A short run on this target was made at every data angle; the data were normalized by comparison of the sum of the elastic and $2^+$ levels with the equivalent sum from the special target. Counting statistics limited the accuracy of the relative normalizations to 2-3% for angles less than $54^\circ$, and ±4-5% for angles greater than that, other sources of error were negligible. Absolute normalization was made by comparing the measured elastic cross sections at small angles, where the scattering is nearly pure Coulomb and insensitive to optical model parameters, to coupled-channels calculations of small angle scattering. This procedure yields an estimated ±1-2% accuracy in the absolute normalizations. In this case, as with the estimations of the errors for the deformation parameters, the errors were determined by visually ascertaining misfits between the data and the calculations.

The resulting angular distributions are shown in Fig. 2. Also shown in Fig. 2 are the results of coupled-channels calculations using the program of Glendenning. The transition amplitude between the various rotational levels are determined by the pure rotational model treatment of the deformed optical potential. Improvements to the fits to the $6^+$ and $8^+$ state were achieved by including a $\beta_8$ term, but it is not included here because we feel it has no
real significance. Expansions and numerical sums were carried to convergence, so that the only approximations involved in the calculation are those inherent in the model itself. The optical parameters chosen were the same as were used in the rare earth work. Varying them by 10-20% in such a way as to preserve the fits did not change the values extracted for the deformation parameters. Estimates of the errors were made by making several independent calculations with altered deformation parameters.

Table I lists the value of the deformation parameters obtained from our work and from other recent theoretical and experimental results. Not listed in the table are the results of Huber from α-decay and the theoretical results of Chasman, both of whom seem to obtain small negative values of $\beta_4$, nor the theoretical results from Ref. 3, who predict positive values of $\beta_4$ ranging from 0.039 to 0.075. Our results are in fair agreement with the theories of Refs. 2 and 3, but do not agree within the quoted errors with the two other experimental values, for $\beta_4$. One should not underestimate the difficulty of extracting precise values of higher-order deformations in Coulomb excitation work, especially since the $\beta_4$ values depend sensitively on very precise values of $\beta_2$. On the other hand, the relationship between the deformation of the nuclear potential that we measure, and the deformation of the mass distribution is not well understood at present. Surely this problem must be solved before differences between proton and neutron deformations can be extracted from the comparison of the two types of data. The discrepancy between the proton and alpha results is not easy to understand, but the lack of an independently derived optical potential and the possibility of exchange effects are potential sources of error for the former, effects that are not expected to contribute to uncertainties in the present experiment.
The authors would like to thank N. K. Glendenning for the use of his program and N. Brown for making the computer calculations. We are grateful to the staff of the 88" cyclotron for their invaluable assistance, and to Claude Ellsworth for fabricating the targets.
FOOTNOTES AND REFERENCES

* Work performed under the auspices of the U. S. Atomic Energy Commission.

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Table I. Table of deformation parameters for this and other work. The parameters are defined by describing the nuclear surface as in Eq. (1). The radius common to all values in the table is $R_0 = 1.2 A^{1/3}$ fm. The values for this experiment are obtained by a second order treatment for radius scaling.$^{10}$

<table>
<thead>
<tr>
<th>$\beta_2$</th>
<th>$\beta_4$</th>
<th>$\beta_6$</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.22 ±0.01</td>
<td>0.06±0.01</td>
<td>-0.012±0.01</td>
<td>This Work</td>
</tr>
<tr>
<td>0.23 ±0.01</td>
<td>0.017 $\begin{cases} +0.015 \ -0.030 \end{cases}$</td>
<td>-0.015</td>
<td>$(p,p')^a$</td>
</tr>
<tr>
<td>0.235±0.006</td>
<td>0.100±0.028</td>
<td>-</td>
<td>Coulomb Excitation$^b$</td>
</tr>
<tr>
<td>0.220</td>
<td>0.071</td>
<td>-</td>
<td>Theory$^c$</td>
</tr>
</tbody>
</table>

Notes:  

a. Ref. 5  
b. Ref. 6  
c. Ref. 2
FIGURE CAPTIONS

Fig. 1. Sample spectrum of the $^{238}$U ($\alpha,\alpha'$) reaction at 48 °(lab).

Fig. 2. Differential cross sections and coupled-channels calculation for $^{238}$U ($\alpha,\alpha'$) at 50 MeV. The optical parameters for the calculation are the same as in Ref. 9. The deformation parameters are given in the text.
Fig. 1
Fig. 2
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