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Multipole Deformation of ^{238}U†

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Elastic and inelastic scattering of 50-MeV helium ions from ^{238}U was studied with a high-resolution magnetic spectrometer. We measured angular distributions for members of the ground-state rotational band up to the 8^+ level. Coupled-channels calculations yield 0.022, 0.060, and −0.012 for the respective deformation parameters β_2, β_4, and β_6 for an optical radius of $1.44A^{1/3}$ fm. These values are compared with other experimental results.

The ability to measure details of nuclear shapes by means of α-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[2-4] 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 β_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 α particles by ^{238}U, utilizing a new magnetic spectrometer[7] for detection of the scattered α's. Differential cross sections were measured for levels in the ground-state rotational band up to the 8^+. The target was made by evaporating 75 μg/cm^2 of uranium metal on to a 50-μg/cm^2 carbon backing. Beams of up to 1 μA were prepared by the high-resolution magnetic analysis system, delivered onto 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° with respect to the incident beam. Detection of scattered α's at the focal plane of the spectrometer was made by a 1-cm-high, 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}W obscured the ^{238}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 0.7×10^{-3} sr. Relative normalization was made by utilizing a special target made by evaporating 200 μg/cm^2 of ^{238}U onto 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°, 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.[9] The transition amplitudes between the various rotational levels are deter-

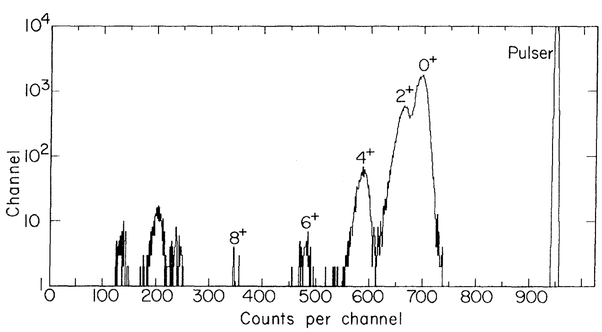

FIG. 1. Sample spectrum of the reaction ^{238}U(α,α') at 48°(lab).

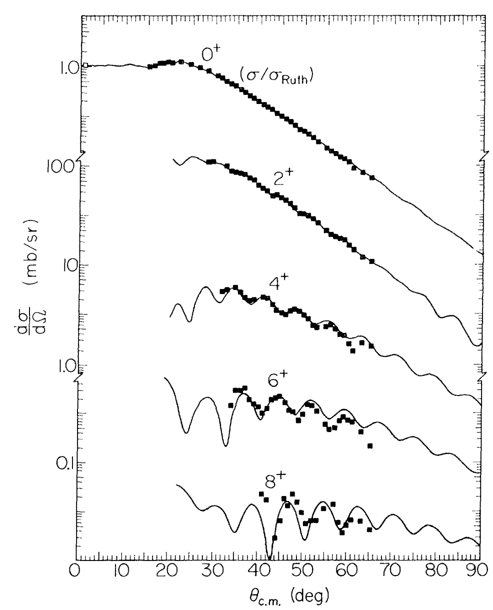

FIG. 2. Differential cross sections and coupled-channels calculation for ^{238}U(α,α') at 50 MeV. The optical parameters for the calculation are the same as in Ref. 8. The deformation parameters are given in the text.

TABLE I. 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 is $R_0 = 1.2A^{1/3}$ fm. The values for this experiment are obtained by a second-order treatment for radius scaling (Ref. 10).

β_2	β_4	β_6	Method
0.22 ± 0.01	0.06 ± 0.01	-0.012 ± 0.01	This work
0.23 ± 0.01	$0.017^{+0.015}_{-0.030}$	-0.015	(p,p') [a]
0.235 ± 0.006	0.100 ± 0.28	⋯	Coulomb excitation[b]
0.220	0.071	⋯	Theory[c]

[a]Ref. 5. [b]Ref. 6. [c]Ref. 2.

mined 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 β_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.[8] 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[11] from α decay and the theoretical results of Chasman,[4] both of whom seem to obtain small negative values of β_4; nor the theoretical results of the authors in Ref. 3 who predict positive values of β_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 β_4. One should not underestimate the difficulty of extracting precise values of higher-order deformations in Coulomb-excitation work,[6] especially since the β_4 values depend sensitively on very precise values of β_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.[12] 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[5] and α results is not easy to understand, but the lack of an independently derived optical potential and the possibility of exchange effects[13] are potential sources of error for the former, effects that are not expected to contribute to uncertainties in the present experiment.

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Neutral-Strange-Particle Production in 205-GeV pp Interactions*

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A bubble-chamber study of proton-proton interactions at 205 GeV yielded 66 K^0's, 28 Λ's, and 2 $\bar{\Lambda}$'s produced in the backward c.m. hemisphere. The cross sections for $p+p \to (\Lambda/\Sigma^0)+$anything and $p+p\to(K^0/\bar{K}^0)+$anything are 3.2 ± 0.6 and 12.9 ± 1.7 mb, respectively. Comparison of the invariant cross section with lower-energy data shows that (Λ/Σ^0) production is consistent with approximate scaling behavior above 28 GeV, whereas the $(K^0/\bar{K}^0)$ invariant cross section has increased considerably between 28 and 205 GeV.

We present results on Λ/Σ^0 and $K^0/\bar{K}^0$ inclusive reactions obtained from an exploratory exposure of the 30-in. hydrogen bubble chamber to 205-GeV protons at the National Accelerator Laboratory. A total of 15 000 pictures were scanned and analyzed as described previously.[1] A second independent examination of all primary interactions yielded first and second scan efficiencies for associated V's of 0.89 ± 0.02 and 0.94 ± 0.02, respectively.

A total of 401 V's pointing to beam-track interactions were found, of which 332 remained after fiducial region[2] cuts were made. These events were measured, up to 3 times if necessary, and the 309 events with successful geometrical reconstruction were kinematically fitted. After visual inspection of ionization densities, 36 of the events remained kinematically ambiguous, and these were mostly high-momentum V's giving a γ fit as well as a K^0, Λ^0, or $\bar{\Lambda}^0$ fit. These events were classified on a statistical basis using the expected transverse momentum ($P_\perp^{\pm}$) distributions of the decay products with respect to the neutral-particle direction.[3] Because of the loss of V's close to the production vertex, a minimum-length ($L_{\min}$) cut of 2 cm for V^0 (K^0, Λ, $\bar{\Lambda}$) decays and 4 cm for γ's was applied and, additionally, a minimum kinematic χ^2 probability