TESTS OF ISOSPIN PURITY IN A=38 NUCLEI VIA COULOMB EXCITATION OF ^{38}Ca

P.D. Cottle[a], M. Fauerbach[a], T. Glasmacher, R.W. Ibbotson, K.W. Kemper[a], B. Pritychenko, H. Scheit[1],
and M. Steiner

The advent of methods for producing radioactive beams and the development of experimental techniques for exploiting these beams have provided new avenues for detailed studies of the isospin symmetry in nuclei. While isospin symmetry is broken by the Coulomb force, the approximate conservation of isospin has been assumed in many nuclear structure calcuations, such as the shell model calculations of Brown, Chung and Wildenthal [1, 2]. In the present work, we report on a measurement of $B(E2;0^+_{gs}\rightarrow 2^+_1)$ in the short-lived ($T_{1/2}=0.44\,s$) nucleus ^{38}Ca using the method of intermediate energy Coulomb excitation of radioactive beams (a review of this technique is given in reference 3). This measurement enables us to examine the isospin purity of the mass 38 system. As pointed out in [4], we can test isospin purity by extracting the isoscalar multipole matrix element M_0 from the present result on ^{38}Ca and the previously measured $B(E2;0^+_{gs}\rightarrow 2^+_1)$ value in the mirror nucleus ^{38}Ar and comparing it to the isoscalar matrix element obtained from the corresponding transition between $T=1$ states in the $N=Z$ nucleus ^{38}K. Our data suggest that these two values of M_0 are not equal and that isospin symmetry is broken to a surprisingly large degree in the mass 38 system. We demonstrate here that an examination of previous measurements on the mass 34 and 42 systems also reveals similar effects. Finally, we discuss experiments which would provide further information on this apparent breakdown in isospin symmetry.

To produce the ^{38}Ca beam, a 80 MeV/nucleon ^{40}Ca beam from the K1200 cyclotron at the National Superconducting Cyclotron Laboratory irradiated a 202 mg/cm^2 target of ^{9}Be located at the mid-acceptance target position of the A1200 fragment separator [5]. The average energy of the ^{38}Ca particles was 56.1 MeV/nucleon. A more detailed description of the experimental and analysis procedures can be found in Ref. [6], which also illustrates the Doppler-shift correction technique used for analysis of the γ-ray spectra.

To determine the $B(E2;0^+_{gs}\rightarrow 2^+_1)$ value for the 2.206 MeV 2^+_1 state, we must find the cross section for direct population of this state. That is, the cross section for production of the 2.206 MeV γ-ray must have the cross section for production of the 1.479 MeV feeding γ-ray (from the 2^+ state at 3.685 MeV) subtracted from it. The cross section for the 2.206 MeV γ-ray is 23.2 ± 4.0 mb. If we subtract the 1.479 MeV γ-ray cross section from the 3.685 MeV cross section, we obtain the cross section for direct population of the 2.206 MeV 2^+ state to be 19.4 ± 4.4 mb. The Alder-Winther analysis then yields $B(E2;0^+_{gs}\rightarrow 2^+)=96\pm 21$ $e^2fm^4=2.52\pm 0.56$ W.u. for the 2.206 MeV state.

The cocktail beam also included significant amounts of the stable nucleus ^{36}Ar, for which it is known that $B(E2;0^+_{gs}\rightarrow 2^+_1)=298\pm 30\ e^2fm^4$ [7]. The result determined here for ^{36}Ar ($310\pm 31\ e^2fm^4$) is consistent with the adopted value, lending confidence to our result for ^{38}Ca.

The result on the 2.206 MeV 2^+ state provides the opportunity to examine isospin symmetry in the mass 38 multiplet. If isospin symmetry is satisfied within a mass multiplet, then the matrix elements of the corresponding electromagnetic transitions in each isobar are related in a straightforward way. A measurement of the matrix element $B(E2;J_i\rightarrow J_f)$ using Coulomb excitation or some other electromagnetic probe provides information on the contribution of the protons to the transition. If the proton multipole matrix element is defined as

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[1] Present address: Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany

$$M_p = \langle J_f || \Sigma_p r_i^\lambda Y_\lambda(\Omega_i) || J_i \rangle, \tag{1}$$

then

$$B(E\lambda; J_i \to J_f) = (M_p)^2/(2J_i+1). \tag{2}$$

The relationship between multipole matrix elements in the neutron/proton and isospin representations yields [4]

$$M_p(T_z) = (1/2)[M_0(T_z) - M_1(T_z)], \tag{3}$$

where $M_0(T_z)$ and $M_1(T_z)$ are the isoscalar and isovector multipole matrix elements, respectively. The assumption of isospin conservation gives the relationships between matrix elements in different isobars

$$M_0(T_z^{'}) = M_0(T_z) \tag{4}$$

$$M_1(T_z^{'}) = M_1(T_z)T_z^{'}/T_z. \tag{5}$$

If two nuclei are mirrors, then $T_z^{'} = -T_z$ and

$$M_0(T_z) = M_p(T_z) + M_p(-T_z) \tag{6}$$

Equation (6) also implies that for the corresponding transition between $T = 1$ states in a $T_z = 0$ nucleus

$$M_p(T_z = 0) = M_0(T = 1)/2. \tag{7}$$

That is, given the assumption of isospin symmetry the value of M_0 extracted from the M_p values in two mirror $T_z = \pm 1$ nuclei should be equal to the value $M_0 = 2M_p$ obtained for the $0^+_{T=1} \to 2^+_{T=1}$ transition in the $T_z = 0$ nucleus. According to reference 4, this comparison provides an experimental test of isospin purity for $A = 4n + 2$ multiplets.

For $A = 38$, a comparison of M_p values in ^{38}Ca and ^{38}Ar yields $M_0 = 3.41(18)$ W.u., while the value of M_0 extracted from the compilation of ref. 7 for the corresponding transition in^{38}K (between the 0.13 and 2.40 MeV $T = 1$ states) is 2.44(50) W.u. The large experimental uncertainty in the value of M_0 obtained for ^{38}K prevents us from drawing a definitive conclusion that isospin symmetry is violated in the mass 38 system. However, the suggestion of broken isospin symmetry is tantalizing enough to provide a strong motivation for improving the experimental value of M_p in ^{38}K.

Comparisons between M_0 values taken from $T_z = \pm 1$ nuclei and the $T = 0$ states of the $T_z = 0$ isobars for $4n + 2$ nuclei in the mass range $A = 22 - 42$ are shown in Fig. 1 (data are taken from ref. 7 and the present work).

In addition to the case of $A = 38$, the error bars for the M_0 results from $T_z = \pm 1$ and $T_z = 0$ nuclei do not quite overlap in two other cases ($A = 34$ and 42), once again suggesting that isospin symmetry might be violated at a surprisingly large level in these mass multiplets. As in the $A = 38$ system, this provides a motivation for remeasuring the M_p values in the nuclei involved. This is particularly true for the $T_z = 0$ isotopes, where the error bars are large for reasons similar to those in^{38}K.

A more detailed report of this work can be found in ref. [8].

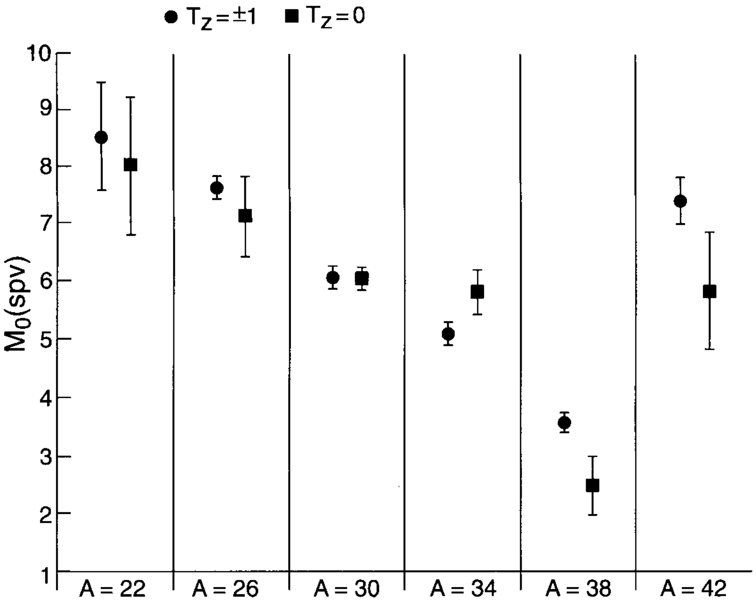

Figure 1: A comparison of isoscalar multipole matrix elements M_0 extracted from the comparison of M_p values for $0_{gs} \rightarrow 2_1^+$ transitions in $T = 1$ nuclei to the M_0 values taken from transitions between $T = 1$ states in $T_z = 0$ nuclei. This comparison allows a test of isospin purity in $A = 4n + 2$ systems.

a. Department of Physics, Florida State University, Tallahassee, FL 32306-4350, USA

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