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Properties of the ^{208}Po($0^+, T = 22$) Double Isobaric Analog State

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Pion double charge exchange has been used to populate the double isobaric analog state (DIAS) in ^{208}Po with use of the doubly magic target ^{208}Pb. The DIAS was found at an excitation energy of 32.46 ± 0.17 MeV with a width of 0.85 ± 0.40 MeV. The excitation energy of the DIAS can be used along with the energy of the isobaric analog state to determine separately the linear and the quadratic terms of the isobaric-multiplet-mass equation. The resulting linear and quadratic terms are $b = -31.6 \pm 3.7$ MeV and $c = 0.33 \pm 0.09$ MeV, respectively.

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Although the double isobaric analog state (DIAS) has been known to exist in light nuclei for two decades,[1] it has been observed only twice in heavy nuclei.[2,3] Consequently, very little is known about the properties of this state in heavy nuclei. In order to observe the DIAS, one needs a probe which selectivity excites the DIAS with respect to the high level density of lower isospin, $T_<$, background states. The only known suitable reaction is pion-induced double charge exchange (DCX) at energies above the $\Delta_{3,3}$ resonance.[3] In this Letter we report the observation of the DIAS of the ^{208}Pb ground state using the DCX reaction at an incident pion energy $T_\pi = 295$ MeV.

The measurements were made using the EPICS facility, modified for studying DCX,[4] at the Clinton P. Anderson Meson Physics Facility. The target was a 600-mg/cm^2 rolled metallic lead foil isotopically enriched in ^{208}Pb to $> 99\%$. The pion beam used for these measurements had an intensity of 4×10^8 π^+/sec. Because of problems with field-trimming magnets in the pion channel and contributions from energy straggling in the target the energy resolution was ~ 800 keV full width at half maximum.

An excitation energy spectrum measured at $\theta_{\text{lab}} = 5°$ for DCX on ^{208}Pb is shown in Fig. 1. Also shown in the figure is a fit to the DIAS. For this fit the background was assumed to have an exponential form and the resonance was fitted with a Breit-Wigner shape folded with the experimental line shape as measured in elastic scattering. This fit yielded a width, $\Gamma_{A2} = 0.85$

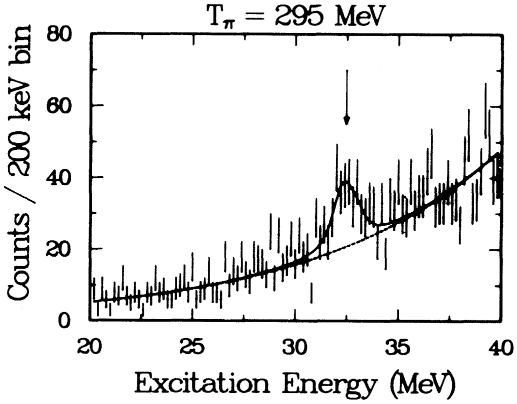

FIG. 1. Double-charge-exchange spectrum of ^{208}Pb(π^+, π^-)^{208}Po. The arrow indicates the fitted location of the double isobaric analog state. The solid line is the fit to the spectrum and the dashed line is the fitted background.

± 0.40 MeV, a resonance energy, $E_{A2} = 32.46 \pm 0.17$ MeV in ^{208}Po, and a cross section, $d\sigma/d\Omega = 1.09 \pm 0.29$ μb/sr, for this state. This cross section is in agreement with established DCX systematics.[3]

Both the energy and width, Γ_{A1}, of the isobaric analog state (IAR) have previously been measured.[5-7] In the absence of significant three-body charge-dependent forces, the masses of the DIAS, the IAR, and the parent state can be fitted using the isobaric-multiplet-mass equation,[8]

$$M(T_z) = a + bT_z + cT_z^2, \tag{1}$$

where $M(T_z)$ are the masses of the members of an isobaric multiplet and T_z is the z component of the isospin for the state.

The nuclear mass differences between the IAR and the parent state, Δ_1, and between the DIAS and the parent, Δ_2, are given by Eq. (1) as

$$\begin{aligned} \Delta_1 &= M(T) - M(T-1) = b + c(2T-1), \\ \Delta_2 &= M(T) - M(T-2) = 2b + c(4T-4). \end{aligned} \tag{2}$$

The mass differences obtained using the measured excitation energies for the IAR and the DIAS and the known ground-state masses[9] are $\Delta_1 = -17.533 \pm 0.006$ MeV and $\Delta_2 = -35.72 \pm 0.17$ MeV. Solving Eqs. (2) for b and c using these mass differences gives $b = -31.6 \pm 3.7$ MeV and $c = 0.33 \pm 0.09$ MeV. The errors in b and c are highly correlated because of the precise knowledge of Δ_1.

A simple estimate for b and c can be obtained by calculating the Coulomb energy of a uniformly charged sphere

$$E_c = \tfrac{3}{5} e^2 Z(Z-1)/R_c. \tag{3}$$

Using $Z = (A - 2T_z)/2$ gives

$$\begin{aligned} b &= -\tfrac{3}{5}(e^2/R_c)(A-1) + M_n - M_p, \\ c &= \tfrac{3}{5} e^2/R_c, \end{aligned} \tag{4}$$

where $R_c = 1.2A^{1/3}$ and $M_n - M_p$ is the neutron-proton mass difference. This estimate assumes that the probability density of the valence particles is equally distributed over the nuclear volume. This gives $\Delta_1 = -18.9$ MeV and $\Delta_2 = -38.1$ MeV or $b = -24.2$ MeV and $c = 0.123$ MeV. Coulomb displacement energies in heavy nuclei have been explained by decreasing R_c.[10] Although changing R_c can improve the agreement between the predicted and measured Coulomb displacement energies, it will not change the predicted ratio $-b/c \simeq (A-1)$, for which we have measured 97 ± 14. The comparison between these and the measured numbers indicates that more sophisticated models are needed to calculate realistic Coulomb energies.

More realistic neutron and proton densities have been obtained by performing a density-dependent Hartree-Fock calculation for the ground state of ^{208}Pb using the method of Vautherin[11] and Negele and Rinker.[12] These densities were used to calculate $\Delta_1 = -17.520$ MeV and $\Delta_2 = -35.262$ MeV by assuming the valence proton density distributions for both the IAR and the DIAS are the same as the excess neutron density distribution, $\rho_n(\mathbf{r}) - \rho_p(\mathbf{r})$, in ^{208}Pb. These give $b = -22.2$ MeV and $c = 0.111$ MeV. Again, although the calculated Coulomb displacement energies are much closer to the measured ones, the predicted ratio $-b/c = 201$ is in disagreement with the experiment.

The width of the IAR (Γ_{A1}) is due mainly to Coulomb mixing of this resonance with $T_<$ background states. The assumption that this is also true for the DIAS leads to the prediction[13] that $\Gamma_{A2} = 2\Gamma_{A1}$. The width we have obtained for the DIAS of 0.85 ± 0.40 MeV is in agreement with this prediction using the measured $\Gamma_{A1} = 0.231 \pm 0.006$ MeV.

In conclusion, we have measured the width and energy of the DIAS in ^{208}Po. The measured width agrees, within statistics, with a simple prediction based on the width of the IAR. The energies of the DIAS and the IAR have been used to extract the linear and quadratic coefficients of the isobaric-multiplet-mass equation. The ratio of these coefficients and their magnitudes disagree with predictions based on simple models.

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