

Magnetic moment measurements - extending isotopic chains beyond the stable elements.

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Abstract. The magnetic moments in many isotopic chains have been systematically measured using the transient field technique on beams of separated isotopes excited in inverse kinematics. Such experiments have provided insight into how the structure of nuclei evolves by successively adding nucleons. Since naturally occurring isotopic chains are relatively short, efforts are underway to make unstable isotopes available. In limited cases the use of an α -particle transfer to beam projectiles has been successfully employed in measurements on unstable nuclei. In this investigation beams of ^{78}Kr and ^{86}Kr were used to measure magnetic moments of excited states in the unstable ^{82}Sr and ^{90}Sr nuclei utilizing the transfer of an α particle from ^{12}C nuclei in the target.

The systematics of nuclei with isotopic chains around the closed neutron shell $N = 50$ are of special interest. A compilation of g factors of the first 2^+ states from Zn ($Z = 30$) to Cd ($Z = 48$) is shown in Figure 1.

At shell closure $N = 50$ the positive large g factors indicate single-particle proton states, while away from this closed neutron shell both protons and neutrons contribute to the wave

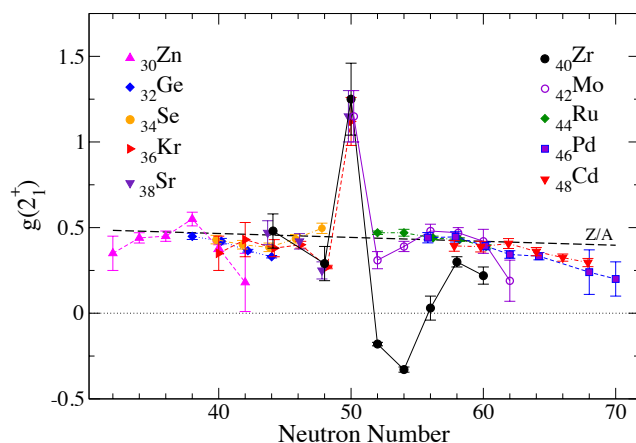


Figure 1. The $g(2^+)$ factors of isotopic chains on both sides of the closed neutron shell $N = 50$.



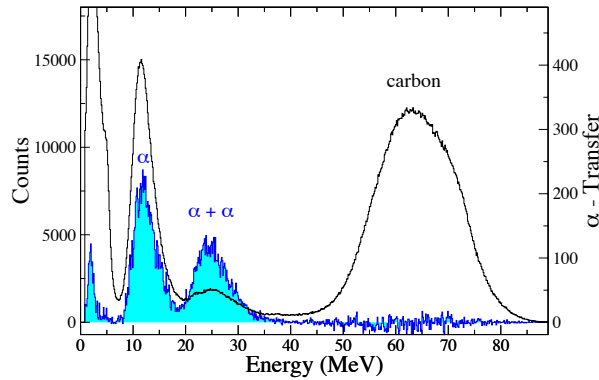


Figure 2. Particle spectrum and insert (shaded area) showing particles in coincidence with γ transitions in ^{90}Sr .

functions. As a matter of fact, most g factors are close to the collective value of Z/A . But Zr with 40 protons clearly stands out. Adding neutrons beyond $N = 50$ results in negative g factors. Obviously, neutron excitation dominates in the structure of these excited Zr states. If this effect were simply attributed to a $2p_{1/2}$ subshell closure for protons at $Z = 40$, a similar behavior may be expected for the neighboring Sr isotopes. At $Z = 38$ the $1f_{5/2}$ shell is complete and for neutron numbers above $N = 50$ negative g factors could be expected.

Experiment

By far the best way to measure the g factors is the Coulomb excitation of projectiles in inverse kinematic conditions followed by the observation of the perturbed angular correlation of the de-exciting γ transitions.

The isotope ^{90}Sr is unstable with a half-life of 28.79 yr. Rare isotope beams are rare and when available have notoriously low intensities. For this experiment ^{90}Sr was produced from a ^{86}Kr beam by pickup of α particles from a ^{12}C target.

The isotopically pure ^{86}Kr beam with 3.2 MeV/A was delivered by the K500 Texas A&M cyclotron. The beam struck a multilayered target composed of carbon (0.9 mg/cm^2), gadolinium (5.0), tantalum (1.1) and copper (5.0). Coulomb excitation of beam projectiles and the α transfer both occur in the carbon layer. The reaction products go forward and traverse the gadolinium and tantalum layers. While the heavier reaction products are stopped in the copper layer of the target, the lighter products – carbon nuclei and α particles from the breakup of the ^8Be – go through and are detected in a conventional particle detector placed 20 mm downstream of the target at zero degrees to the beam. The magnetic interaction happens while the ions traverse the ferromagnetic gadolinium layer.

Experimental details of the transient field technique can be found in References. [1] and [2]. An example of an α -transfer experiment is found in Reference [3]. Four clover HP Ge detectors were used to detect the γ rays. The preamplifier output signals of the particle and γ detectors were digitized. The energies and times were recorded as singles events, from which offline particle – γ coincidence spectra were selected.

In Figure 2 particle spectra associated with both the Coulomb excitation of the beam and the α transfer are shown. Appropriate gates on time and on γ energies were set to produce the α -particle spectrum.

The particle spectrum associated with the α transfer shows two peaks, depending upon whether both α particles from the ^8Be breakup or only one hit the detector. The particle detector is $100 \mu\text{m}$ thick. The α particles ($\sim 40 \text{ MeV}$) and other light particles do not stop in

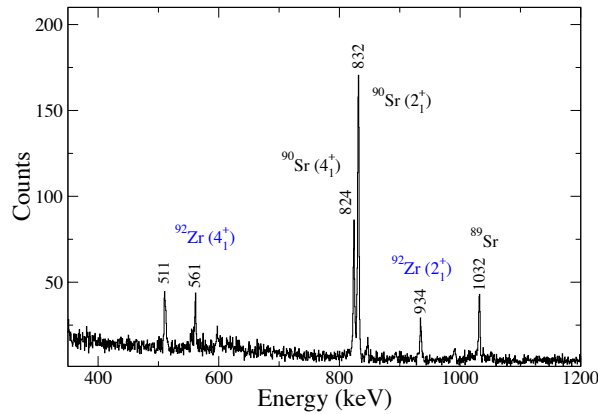


Figure 3. Coincident γ -particle spectrum showing the close proximity of the 4_1^+ and 2_1^+ transitions in ^{90}Sr .

Table 1. Remeasured g factors of low-lying states in ^{86}Kr and ^{78}Kr and previous results from Reference [4].

^{86}Kr	Reference[4]	this work
2_1^+	+1.12(14)	+1.07(6)
4_1^+		+1.07(15)
^{78}Kr		
2_1^+	+0.43(3)	+0.48(2)
4_1^+	+0.46(7)	+0.49(5)
2_2^+	+0.54(10)	+0.53(7)

the detector. They deposit only a small part of their total energy in the depletion layer of the silicon detector.

A coincidence double- $\alpha - \gamma$ spectrum is shown in Figure 3. The γ spectra gated on the single- α peak have a higher background and were not used in the data analysis.

The spectrum in Figure 3 also contains transitions in ^{92}Zr which is produced by a $^{86}\text{Kr}(^{12}\text{C},\alpha 2n)^{92}\text{Zr}$ reaction. This reaction channel is unusually strong for ^{86}Kr . The ^{86}Kr also favors single proton pickup, all of which may be related to its neutron number $N = 50$. Both channels are virtually absent with the ^{78}Kr beam.

The α -transfer reaction is not well studied. No detailed excitation function measurements exist. The onset of the reaction is observed already at slightly below the Coulomb barrier. Above the barrier other reaction channels start to dominate. The intensity ratio of the single- α - to the double- α - particle peak increases with beam energy.

The α -transfer reaction excites the nuclei at higher energies and therefore in higher excited states. Their precession in the transient field and subsequent feeding to the states of interest has to be considered. In addition the α -transfer nuclei have a lower spin alignment than that achieved by Coulomb excitation, which reduces the sensitivity of the precession measurement.

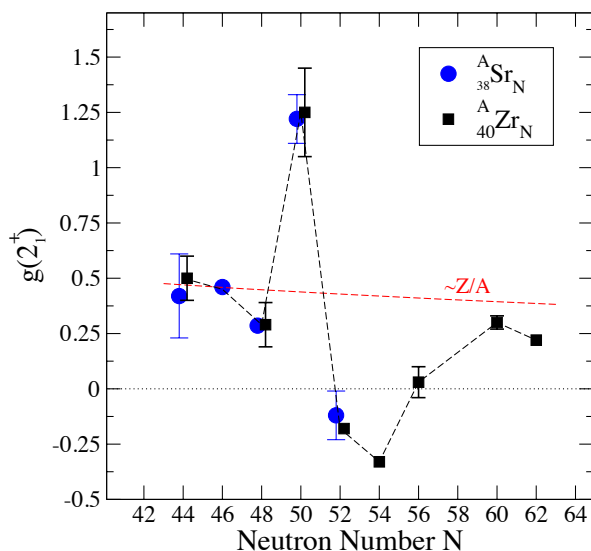


Figure 4. The g factors of the newly extended Sr chain.

Results

The Coulomb excitation of ^{86}Kr and ^{78}Kr were measured simultaneously with the $^{86}\text{Kr}(^{12}\text{C}, 2\alpha)^{90}\text{Sr}$ and $^{78}\text{Kr}(^{12}\text{C}, 2\alpha)^{82}\text{Sr}$ reactions. The Kr results are in excellent agreement with an earlier measurement [4] (Table 1). The $g(4_1^+)$ factor of ^{86}Kr is measured for the first time.

The $g(2_1^+)$ of ^{90}Sr (Figure 4 at $N = 52$) is negative or close to zero suggesting that, like in Zr, neutrons dominate in the wave function of the first excited state and the protons tend to stay in the filled $f_{5/2}$ (or $2p_{1/2}$ for Zr) shell. The $g(2_1^+)$ result for ^{82}Sr ($N = 44$) is also shown.

The results presented in this report should be considered preliminary. More measurements were performed and are being analyzed.

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