ABSTRACT

NUCLEAR SPECTROSCOPIC STUDIES OF SOME SHORT-LIVED AND NEUTRON DEFICIENT Ga AND Zn ISOTOPES

By

Gregg Carl Giesler

The decay schemes of ^{63}Zn, ^{62}Zn and ^{63}Ga were investigated by high-resolution γ-ray spectroscopy in an effort to further elucidate their nuclear properties. Also, a search for β-delayed α emission from the light Ga isotopes was conducted.

Such γ-ray spectroscopic techniques as Ge(Li) singles, Ge(Li)-Ge(Li) megachannel coincidence, Ge(Li)-NaI(Tl) coincidence, and Ge(Li)-time coincidence techniques have been utilized to study these isotopes. A He-jet thermalizer was utilized in the search for β-delayed α emission. Several programs written for data analysis are presented.

Forty-five γ rays have been assigned to the decay of 38.4-minute ^{63}Zn and have been incorporated into a decay scheme containing 24 levels with energies of 0, 669.71, 962.14, 1327.0, 1412.07, 1546.8, 1860.9, 1865.7, 2012.0, 2062.3, 2081.4, 2093.5, 2336.8, 2497.5, 2512.5, 2536.2, 2697.0, 2717.2, 2780.1, 2857.8, 2889.5, 3044.0, and 3100.3 keV. A search for γ rays with energies above 700 keV from the decay of 9.3-hour ^{62}Zn was conducted and six were found at energies of 881.4, 915.6, 1142.5, 1280.8, 1389.1, and 1429.9 keV. They were placed in a decay scheme containing seventeen γ-rays and ten levels with energies of 0, 40.94, 243.44, 287.98, 548.41, 637.53, 915.6, 1142.5, 1280.8, and 1429.9 keV. The decay of 32.4-second ^{63}Ga has sixteen γ rays which were placed

in a decay scheme containing nine levels with energies of 0, 193.0, 248.0, 627.1, 637.0, 650.1, 1065.2, 1395.4, and 1691.7 keV.

Spin and parity assignments for the nuclear states investigated are based on log ft values, relative γ-ray intensities to states of known spin and parity and charged particle scattering results.

A survey of and comparison with previously reported Ge(Li) detector results and with charged particle scattering results is presented for these isotopes. The structures of the low-lying states in these nuclei are discussed and compared with theoretical calculations and systematics of the region.

A search for β-delayed α emission from the short-lived (<5 sec) Ga isotopes through ^{60}Ga was conducted. The γ-ray and α-particle spectra from the nuclei produced are presented. An upper limit of ten parts per million was placed on β-delayed α branching from the decay of these nuclei.

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Chapter I

INTRODUCTION

Any study of the nucleus involves the use of many models, since no one model fits more than a small number of nuclei. Although these models vary widely in their description of the nucleus, they are all semi-empirical, that is, require a number of experimentally determined parameters in order to make any predictions. Therefore, any improvement in quality or quantity of the experimental results will not only aid in improving the results obtained from the model, but also aid in the further development of the model and the description of nuclei as a whole.

One of the most useful methods of obtaining information about nuclear properties is γ-ray spectroscopy. With the development of Ge(Li) detectors with their present efficiency and resolution, even the very weak γ rays in a complex spectrum can be seen and easily resolved from their neighbors. As a result, decay schemes previously considered relatively simple have become much more complex. γ-ray spectroscopy, therefore, has become an important part of the study of nuclear properties.

The nuclear shell model is one of the more popular models used to describe the nucleus. The nucleus, according to this model, is like an atom with the protons and neutrons individually going around in their own orbits. In addition, closed shells occur at neutron or proton "magic" numbers of 2, 8, 20, 28, 50, 82, and 126. It is found that this model only works well near these closed shells. Accordingly,

most of the study of this model has occurred in the following regions: nuclei with fewer than 23 protons, those with 28 protons, 50 neutrons or protons, 82 neutrons, and nuclei in the region of the ^{208}Pb doubly closed shell.

A primary interest is in the region with fewer than 23 protons, since in this region the β stability line lies on or near $N=Z$. Here also there is an abundance of doubly closed shells, and each closed shell consists of at most three low spin orbits which makes the calculations relatively easy. The stable isotopes of calcium which go from the doubly magic ^{40}Ca to the also doubly magic ^{48}Ca are found at the upper end of this region.

One more doubly magic nucleus occurs near this region, ^{56}Ni. It is different from the others because it is unstable to β decay and rather far from the line of β stability. The two closed shells are the $1f_{7/2}$ for both protons and neutrons. In the region immediately beyond this nucleus are the $2p_{1/2}$, $2p_{3/2}$, $1f_{5/2}$ and $1g_{9/2}$ orbits, which, even when considering only the lowest levels populated, require a complex set of calculations. Coupled with the complexity of the calculations is the small amount of information available about the isotopes just above this doubly closed shell. The present investigation is intended to help provide information about some of the nuclei outside this doubly closed shell.

In Figure 1, the portion of the Chart of the Nuclides covering this region is shown. When Nurmia and Fink (Nu65) reported the discovery

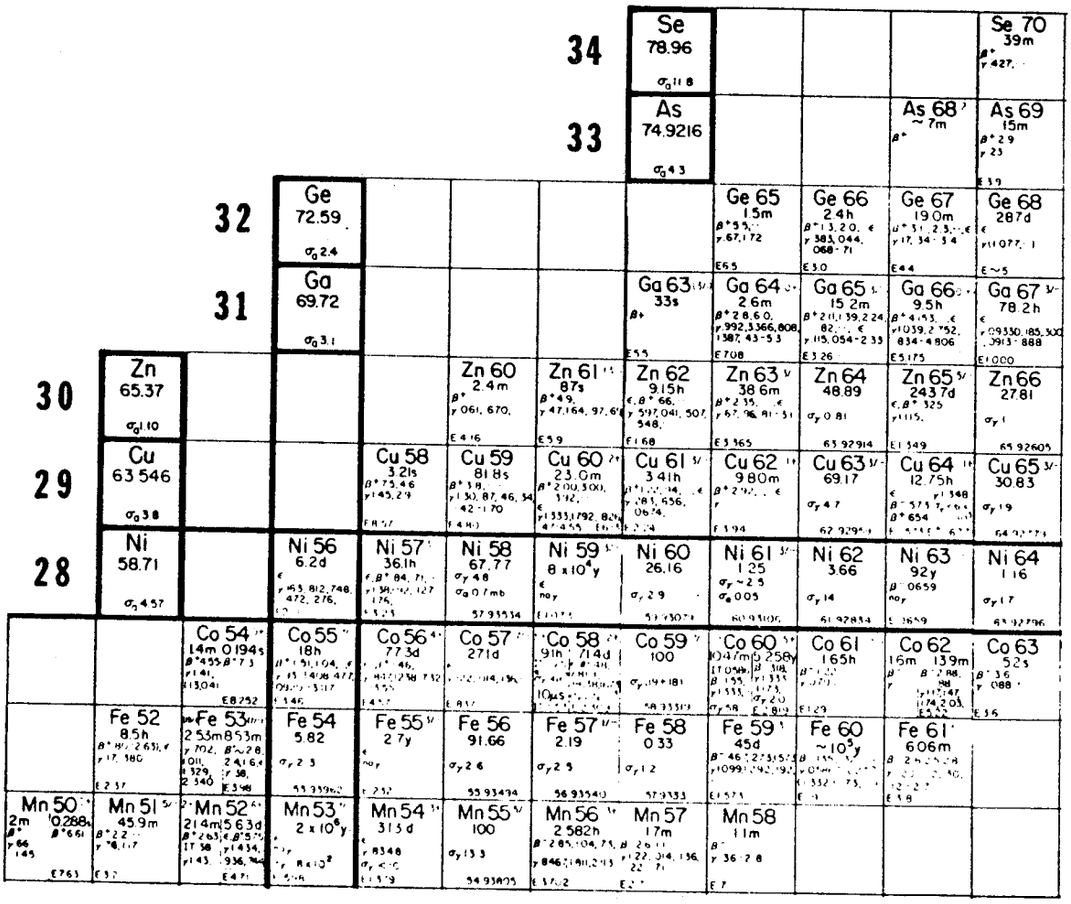

Fig. 1. Portion of the Chart of the Nuclides, including the copper-zinc-gallium region of interest in this thesis. Taken from the Chart of the Nuclides compiled by the Knolls Atomic Power Laboratory, Tenth Edition.

of ^{63}Ga, they mentioned the possibility of β-delayed α emission in this region. According to the calculations of Taagepera and Nurmia (Ta61), ^{63}Ga as well as the lighter Ga isotopes should all be β-delayed α emitters. Nurmia and Fink did not, however, report a decay scheme for the ^{63}Ga. This region of the neutron deficient Zn and Ga isotopes holds strong promise of providing valuable information that can be used for the application of the shell model to this region.

In Chapter II many of the techniques used in the course of this study of both the γ-ray decay and a search for β-delayed α emission in this region are discussed. Included in this chapter is the chemical separation used in the study of the decay of the Zn isotopes.

After the data are obtained, they must be analyzed to obtain the energies and relative intensities. The methods used for this analysis are described in Chapter III. Various computer programs written for or adapted for the XDS Sigma 7 computer at the Michigan State University Cyclotron Laboratory were used to sort the megachannel coincidence data, analyze the many singles spectra, and finally calculate the parameters needed for the final decay schemes.

The Ge(Li)-Ge(Li) megachannel coincidence system discussed in Chapter II has several interesting characteristics that have been studied further. These include the effects of the Compton scattering between detectors and the possibility of using the data obtained from a γ-γ coincidence experiment as γ-sum coincidence data. A study of these characteristics and the results are discussed in Chapter IV.

The results of this study of the neutron deficient Ga and Zn isotopes are described in the following chapters. Several interesting

results that were obtained in the study of ^{63}Zn comprise Chapter V. Chapter VI describes results obtained from a study of ^{62}Zn in a search for γ transitions above 700 keV. The decay of 33 second ^{63}Ga is described in Chapter VII. Chapter VIII presents the results obtained in the search for β delayed α emission in the light Ga isotopes.

Finally, in Chapter IX, these results and their application to this region of light Zn and Ga isotopes are discussed.

CHAPTER II

EXPERIMENTAL APPARATUS AND TECHNIQUES

Each of the isotopes of Zn and Ga studied in this investigation decayed by position emission and electron capture to states in its daughter. The excited states in the daughter in general then decayed by γ emission to the ground state. To study the γ emission and thereby learn about the excited states, many different techniques, both standard ones and newly-developed ones, were utilized. Some of the excited states also have the possibility of decaying by α emission. In order to examine this possibility, some new techniques were utilized to collect the radioactive parent so that this β-delayed α emission could be more precisely studied. This chapter describes the techniques and apparatus used for the data acquisition. Section 2.1. describes the γ-ray spectrometer systems used and the techniques involved in their utilization. In Section 2.2. the α spectrometer and the He jet thermalizer used to prepare the α sources and short-lived γ sources are described. Some of the experiments performed studying the decays of ^{62}Zn and ^{63}Zn required the chemical separation of the Zn from the Cu targets. This separation is described in Section 2.3.

2.1. γ-Ray Spectrometers

With the development of Ge(Li) detectors great interest developed in the examination of new decay schemes as well as many old ones. These decay schemes became more and more refined as Ge(Li) detectors with greater efficiencies and better resolution were developed. In the period of the four years involved in this study, the Ge(Li) γ-ray spectrometers used have gone from one with a resolution of ≈5.6 keV FWHM for the 1332-keV γ of ^{60}Co and an efficiency of <<1% as compared to a 7.6×7.6 cm NaI(Tl) detector with the source 25 cm from the detector to a Ge(Li) detector with a resolution of 2.1 keV FWHM and an efficiency of 10.4%.

The γ-ray spectrometers were not the only instruments to improve greatly over these few years. Many improvements have been added to the amplifiers used with these systems, including such developments as adjustable base-line restoration and pole-zero cancellation. Last but not least, the multichannel analyzers (MCA) have also shown vast improvements in going from a hardwired MCA with 1024 channels and a digitizing rate of 4 MHz to computer interfaced analog-to-digital converters (ADC) with 8192 channels and a digitizing rate of 50 MHz. The preamplifiers improved from room temperature FET's mounted in external units to ones with cooled FET's mounted along with the detector (with a corresponding decrease in noise).

2.1.1. Ge(Li) Singles Spectrometers

A typical γ-ray singles spectrometer system used in this study consisted of a Ge(Li) detector and its bias supply, a charge sensitive FET preamp, a spectroscopy amplifier, an ADC, and some type of memory

storage unit plus its associated readout. Almost all of the electronics equipment are in modular form and are mutually compatible so that equipment from various manufacturers may be used together for a particular experiment.

A variety of different Ge(Li) detectors were used for the experiments in this study. In Table 1 some of the detectors used are listed along with their characteristics. Since each detector is different, the choice of which detector to use for a particular experiment depended on several considerations. Some of them are the relative experimental importance of resolution to efficiency, the count rate involved, and, of course, whether the desired detector is in use for another experiment running concurrently. Another important consideration is whether we possessed the desired detector at the time of the experiment, since the detectors represent the improvements in the state-of-the-art over a period of several years.

The spectroscopy amplifiers which were used contain several features to improve the resolution, especially at higher count rates. Both unipolar and bipolar output pulses shaped with various time constants ranging from 0.25 μsec to 4 μsec can be obtained with various maximum amplitudes of either polarity for use as an input to an ADC or for timing purposes. These amplifiers have highly linear amplification responses and include such features as adjustable pole-zero cancellation, base-line restoration, and DC offset.

The use of pole-zero cancellation permits precise elimination of undershoot on the amplifier pulse after first differentation. This becomes important at higher count rates because succeeding pulses

Table 1. Ge(Li) Detector Characteristics

Manufacturer	Shape	Efficiency[a]	Resolution[b]	Peak to Compton Ratio	Preamp FET
MSU Cyclotron Lab.	Trapezoidal	0.42%	5.6 keV	4.5 to 1	room temperature
Nuclear Diodes	Trapezoidal	2.0%	3.4 keV	8 to 1	room temperature
Nuclear Diodes	Trapezoidal	2.5%	2.2 keV	16.5 to 1	cooled
ORTEC	True Coaxial	3.6%	2.0 keV	22 to 1	room temperature
ORTEC	True Coaxial	4.6%	1.9 keV	24 to 1	room temperature
Nuclear Diodes	True Coaxial	10.4%	2.1 keV	38 to 1	cooled

[a]With respect to the 1332 keV peak of ^{60}Co at 25 cm from a 7.6×7.6-cm NaI(Tl) detector.

[b]FWHM for the 1332 keV peak of ^{60}Co.

may fall into the undershoot and will have an apparent area smaller than the actual area, thus causing a loss in resolution. Base-line restoration also improves resolution at higher count rates by restoring the undershoot of the amplifier signals to a DC base-line after all other shaping has been performed. This improves the resolution by reducing the pileup distortion that is produced when one pulse occurs in the undershoot of another. The DC level adjustment matches the DC level of the amplifier unipolar output to the DC level of the direct input to the ADC. This input bypasses the ADC internal base-line restorer, amplifier, and pulse amplitude discriminator stages, thus lessening the distortion of the input pulse. Also eliminated is the fixed delay (1.25 μsec) added to each pulse to allow time for the discriminators to operate. Eliminating this delay allows a higher count rate for the same ADC dead time.

In this laboratory a variety of analyzers has been used for data acquisition and represents the change in the state-of-the-art over several years. Some of their characteristics are listed in Table 2. With the interfacing of ADC's to a computer, many different modes of data acquisition not available in hardwired analyzers became available. Some of these new modes were used in this study and are discussed in later sections.

2.1.2. Coincidence Spectrometers

Singles experiments are useful in determining the energies and intensities of γ rays from the decay of a nucleus but tell nothing of their placements in the decay scheme. To aid in the placement of these γ transitions, various coincidence experiments were performed.

Table 2. Characteristics of Some ADC's

ADC	Maximum Number of Channels	Digitizing Rate	Memory
Nuclear Data 160	1024	4 MHz	Hard wired
Nuclear Data 2200	4096	16 MHz	Hard wired
Northern Scientific 625	dual 4096	40 MHz	Interfaced to DEC PDP-9
Northern Scientific 629	quadruple 8192	50 MHz	Interfaced to XDS Sigma-7

These include anti-(revealing direct ground state transitions), prompt-(revealing cascade transitions), delayed- (revealing transitions in cascade with states having a measureable lifetime), and 511-511-γ (revealing double escape peaks and β^+-fed levels) coincidence experiments. Descriptions of these techniques are given in the following sections.

2.1.2.A. Ge(Li)-NaI(Tl) Split Annulus Spectrometer

One of the most useful spectrometers at MSU is the 20.3×20.3 cm NaI(Tl) split annulus. Several of its uses in conjunction with a Ge(Li) detector are described by Auble et al. (Au67). In the present study it was used as an anticoincidence spectrometer and a 511-511-γ coincidence spectrometer. Figure 2 gives a block diagram of the electronics used for these experiments.

For the anticoincidence experiment, a 7.6×7.6 cm NaI(Tl) detector was placed inside one end of the annulus tunnel to increase the solid angle subtended by the annulus. A Ge(Li) detector was placed inside the other end of the annulus with the sample between these two detectors, approximately in the center of the annulus. The timing signals from the three NaI(Tl) detectors were combined in an AND/OR gate to produce a timing signal whenever a signal was produced by any of the three NaI(Tl) detectors. An ORTEC universal coincidence unit with the coincidence requirement set to 1 was used for the AND/OR gate. The resolving time control on this unit therefore had no effect. The timing signal from this unit was then required to be in coincidence, within a 110-nsec resolving time, with the timing signal from the Ge(Li)

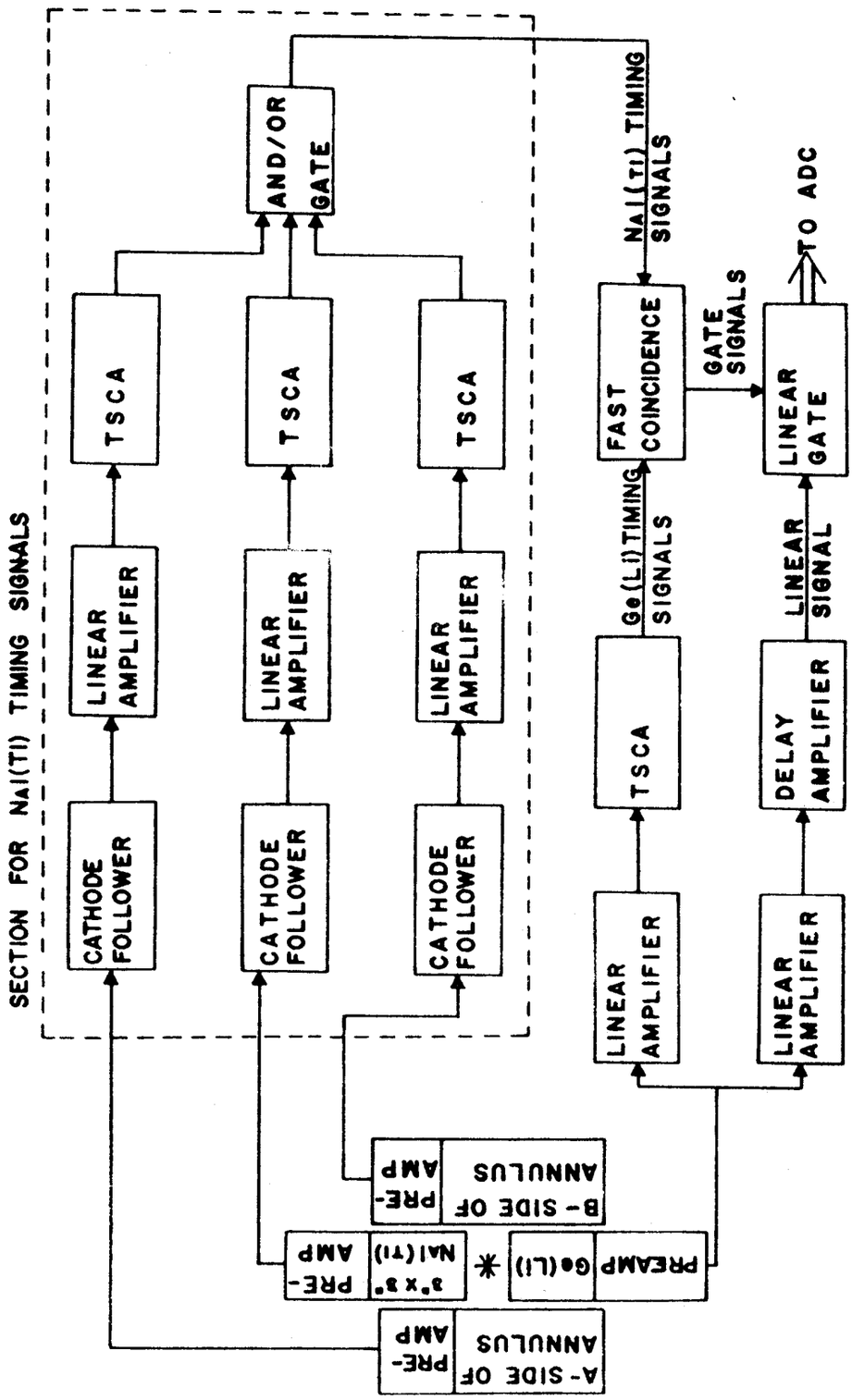

Fig. 2. Experimental setup for recording anti- and 511-511-γ coincidence spectra. For a 511-511-γ coincidence spectrum the TSCA's are adjusted such that the window falls on the 511-keV region and the linear gate is in normal mode. For an anticoincidence spectrum the TSCA's are wide open and the linear gate is in the "anti" mode.

detector. The output from the fast coincidence was used to trigger a linear gate operated in anticoincidence mode.

The 511-511-γ coincidence experiments required the two halves of the annulus to be operated independently with the 7.6×7.6 cm NaI(Tl) detector but with its associated electronics removed from the setup. The TSCA for each annulus half was set to gate on the 511-keV region. A triple coincidence among the annulus halves and the Ge(Li) timing signals was then required. As a result the AND/OR gate was bypassed. These along with operating the linear gate in "normal" mode are the only differences between the two coincidence systems.

2.1.2.B. Ge(Li)-Ge(Li) Megachannel Spectrometer

γ-γ coincidence spectroscopy was first developed in the early 1950's. The coincidence experiment was performed by placing a window on the output of one detector and using this signal to gate the output of the other detector. The result was a one-dimensional spectrum showing everything in coincidence with this window. However, because of the poor resolution of NaI(Tl) detectors, this window was rather wide and allowed coincidences with a wide region of Compton background and with peaks very close to the central peak. As a result it was possible to enhance peaks not in coincidence with the peak of interest.

With the advent of Ge(Li) detectors and their low efficiencies, a NaI(Tl) detector was retained more often than not as the gate detector in a coincidence system. Although the resolution in the resulting one-dimensional spectrum improved, the gate width was still much wider than a photopeak. As Ge(Li) detectors grew in efficiency and improved