A-UR-73-1656

Conf-731112-15

COMPUTERIZED SYSTEMS FOR ULTRALOW TEMPERATURE POLARIZED
NUCLEI TIME REVERSAL AND PARITY EXPERIMENTS*

Larry E. Handy and William A. Steyert

Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico 87544

Summary

Experiments for studying nuclear polarization phenomena at ultralow temperatures require extreme precision in the collected data. The polarization of the applied field must be changed periodically and the data from gamma-ray spectra must be reduced as the experiment progresses. These experiments sometime run for days in order to obtain good statistical data and to reduce any errors induced by the system instrumentation. This paper describes a computerized system used to automate the necessary control and data handling functions for this class of experiment.

Introduction

Radioactive nuclei are polarized via their hyperfine interaction as a dilute impurity in a ferromagnetic host (or sometimes as paramagnets in a gold host). In studying polarization phenomena the host is cooled to 20 mK using a ^3He - ^4He dilution refrigerator so that the hyperfine interaction energy splitting is comparable with the thermal energy, kT. The alignment of the interaction is pointed along the direction of the ferromagnet polarization which is, in turn, in the direction of an externally applied field of 3000 oersteds. This field is produced by two orthogonal sets of superconducting Helmholtz coil pairs, shown in Fig. 1, which are computer controlled.

Figure 2 is a diagram showing the main parts of the system in block form. When the radioactive host-impurity source has been installed and cooled to 20 mK, the computer takes control of the experiment. It turns on two ADCs which are receiving pulses from two gamma ray detectors [NaI(Tl) or GE(Li)] which are located outside the cryostat 4 cm from the source. The computer accumulates a pulse height spectrum for a predetermined length of real time. It then analyzes the spectrum by locating the exact center and determining the integral of the area under a predetermined set of γ -ray energy peaks. This integral is then divided by the ADC live times to calculate a counting rate for the particular γ -rays of interest. It then rotates the magnetic field by 180° thus reversing the nuclear orientation. A new spectrum is accumulated and again the γ -peaks of interest are integrated. The field is rotated by 180° again and new data acquired, etc. As the runs are completed, the computer compares the counting rates for one nuclear orientation to the opposite nuclear orientation. It prints out differences, error limits, and χ^2 (a measure of non-statistical fluctuations in the data). Each day as many as 200 field reversals have been made, and experiments are run continuously for as long as 2 weeks. Statistically significant precision of 10^{-5} is obtainable.¹

Fig. 1. Cryostat assembly with coils (Magnet A and Magnet B) and detectors arranged for horizontal polarization.

For parity measurements the detectors are placed on opposite sides of the source along the nuclear horizontal alignment axis and the two sets of data are analyzed by the computer. Any forward-backward γ -ray asymmetry reflects parity non-conservation in the nucleon-nucleon interaction. The system can be used either with or without coincidence requirements when making these parity studies.

For time reversal measurements a different set of coils is used and the nuclei are polarized in a vertical direction. The two detectors are placed in the horizontal plane but at 135° with respect to each other. Coincidence operation of the system must be used, and data is stored and analyzed in a manner similar to that for parity measurements. Counting rate differences between upward and downward pointing nuclear orientations indicate time reversal noninvariance.

System Functional Description

As shown in Fig. 1, a ^3He - ^4He dilution refrigerator provides cooling of the source to 20 mK or below. This refrigerator operates by the continuous circulation of ^3He which, when the ^3He dissolves into the ^4He , provides the refrigeration (^3He dissolving into ^4He is a heat absorbing process).

The dilute impurity radioactive nuclei of the cold source are polarized because of their hyperfine interaction with the polarized conducting electrons of the ferromagnetic hosts. The effective hyperfine fields of

*Work performed under the auspices of the U.S. Atomic Energy Commission.

Fig. 2. System block diagram.

0.1 to 10 MOe are sufficient to cause hyperfine splitting of the nuclear magnetic sublevels which are comparable with the thermal energy kT , so that nuclear alignment along the ferromagnetic host polarization direction results.

The signals from the two gamma-ray detectors which are located at specific locations with respect to the polarized source under study are sent to timing SCAs and ADCs as shown in Fig. 2. The signals from each detector go to two different timing SCAs; one SCA looks at the "entire spectrum" and the second SCA spans a "particular peak" only. The output from the "entire spectrum" SCA of No. 1 detector and the output from the "particular peak" SCA of No. 2 detector are sent to a coincidence circuit which gates ADC-1. The coincidence output is also routed to the interface to be used for determining core location of data storage. The signals from the "particular peak" SCAs are also routed to 16-bit scalars which allow the computer to continually monitor each one and determine if SCA counting rates are changing because of some instrumentation problem. The output of the "entire spectrum" SCA also goes to a decade counter which allows only every tenth pulse to gate ADC-1, thus keeping the analyzer dead time low. It can be seen from Fig. 2 that symmetry exists between detector No. 1 and No. 2, and all circuitry associated with one detector is the same for the other.

The dead time pulses from the ADCs are routed to the interface and live timers. The live timers are actually gated on for the period of the dead time pulses. The outputs of the timers are stored in 16-bit scalars until the computer requires that data for calculations.

The interface is a two-way communication channel between the various devices in the system and the Nova computer. The computer records the time that the ADC has been alive for the preset real time counting period. It also records number of times that the "particular peak" timing SCAs have been triggered. At the end of the preset counting period (typically 5 to 20 minutes) the computer calculates the required counting rates as

follows. Knowing the approximate position of a peak of interest the computer will then calculate the location of the centroid to the nearest 1/10 channel and add up the counts a preset number of channels above and below that center. It will also add 1/2 the number of counts for a preset number of channels further away from the center (this avoids a sharp cutoff, and the arbitrariness of giving one channel full weight and the one next to it zero weight). The total count calculated in this way is then divided by the live time to form the counting rate. Backgrounds in a particular region of the spectra are also integrated. At the end of a series of polarization reversals the computer calculates the exact average center of the peak to the nearest 1/100 of a channel. Any systematic gain changes with field direction would be readily apparent from these numbers.

The calculations and data reduction above are made while the magnetic field is being reversed for the next run. This reversal is controlled with signals from the interface.

The scope and plotter display the spectrum received from the ADCs. The interface sends the stored digital information from the computer to the DACs. When the plotter is being used a closed loop system is utilized.

Interface Details

The interface design between the ADCs and the Nova computer is dictated by consideration of data transfer rates. If this transfer was executed by conventional program control for addressing different sections of core memory for certain banks of spectral data, the process would be quite slow. Instead, we have chosen to use the processor data channel to convey both the data to be stored, and the "code" for storage location. In this way the data is transferred automatically and rapidly, using only one processor cycle per word.

The details of Fig. 3 show how this is accomplished. The four most significant bits from an ADC go to a 4-bit binary adder. The other four bits to the binary adder

Fig. 3. Details of interface between ADCs and computer. Although present experiments require only two ADCs, provision has been made for a third ADC in future experiments.

are derived in the following manner. The leading edge of the dead time pulse of an ADC triggers a 1.5 usec one-shot whose output is ANDed with the coincidence pulse associated with that ADC. If an output pulse occurs, the leading edge sets a flip-flop whose output goes to a plug-in jack connector on a programmable panel. This panel consists of four two-input OR gates where one input on each gate is a 1-pole double-throw toggle switch. The second input comes from a plug-in jack connector. The outputs of the four OR gates are the inputs to the binary adder and correspond to the four most significant bits of the particular ADC of interest. The programmability of this circuit is that a jumper can be used between the coincidence jack and any one of the four inputs of the OR gates. Also, the switches can be set to enable any combination of the four outputs and by using this scheme, any fixed amount

can be added to the output data of the ADC thereby storing the coincidence spectrum in a certain section of core memory location. When the data has been strobed onto the computer bus, the computer via the interface sends a data-accepted pulse to the ADC and also resets the coincidence flip-flop. If a coincidence did not occur but the ADC did analyze a pulse from the "entire spectrum" detector, the data would be stored in a different section of core memory than that of the coincidence spectrum.

Figure 4 shows the interrupt priority circuit for the ADCs. The $\overline{KQENB}$ signal is generated in every processor cycle, and if any one of the ADCs has sent a DATA READY signal to the interface, the leading edge of $\overline{KQENB}$ sets the respective flip-flop. The flip-flop sends a data channel request interrupt (DCHRI) signal to

Fig. 4. Interrupt priority circuit.

the computer and also disables a NAND gate which gives that particular ADC priority over other ADCs farther down the bus that might be requesting the data channel. When the computer receives DCHP it sends out a data channel input (DCHP IN) signal which goes to the priority sensing part of the circuit and initiates an ENABLE DATA signal to the ADC with highest priority. In this system, the priority circuit is designed so that the ADC closest to the interface on the bus has higher priority than the next one down the bus.

A simplified schematic of the live timer is shown in Fig. 5. The 1 MHz clock goes to the NAND gates that are gated on for the period of the dead time pulses from the ADCs. The live timer records every usec of dead time but only every 100 usec count is sent to a 16-bit scaler. The two decade dividers are needed because these experiments run for long periods of time and the dead times can be quite long.

Fig. 5. Simplified schematic of live timer.

After a preselected real time period of data taking a signal from the computer initiates a polarity reversal sequence for the coil pairs. This signal is sent to the interface, D8 of Fig. 6, and sets a flip-flop which energizes a holding relay that starts the motor which drives variacs of the two magnet power supplies. This causes the magnetic field to rotate by gradually increasing the current in the 90° set of coils and simultaneously decreasing the current in the 0° pair. When the current is zero in the 0° pair and maximum in the 90° pair, the polarity of the 0° pair is reversed by a 2-pole double-throw relay. With the field at this 90° position, the motor receives a reversing signal from the interface (D9) which starts to energize the 0° pair (now in the opposite direction) and gradually reduces the 90° pair to zero current.

Fig. 6. Details of interface between computer and magnetic field control and between computer and display devices.

The time required for the full 180° rotation is 40 seconds. At the 90° and 0° position there are precision limit switches that break the circuit of the holding relays.

This slow rotation of the magnetic field results in much less magnetic hysteresis energy dissipation in the radioactive source than would a simple field reversal.

The display oscilloscope and Houston plotter are not programmed to operate simultaneously. When the computer has been instructed for oscilloscope display of the spectrum, the stored data is sent to the Y DAC (see Fig. 6) for the vertical deflection. For every Y DAC output, the computer adds one to the X DAC input for incremental movement to display the complete spectrum. Lines DATO A and DATO B control this sequence.

The same information is taken from the Y DAC when the plotter is being used, but the X DAC output must be fixed at 2 V or more or the plotter will not step. At the end of each plot point cycle, the plotter is automatically incremented to accept the new data point and a plot-completed signal is sent to the interface which tells the computer it is ready for a new data point.

The interface has eight 16-bit scalars with parallel output buffer registers and multiplexers that are addressable by the computer (not shown in the figures). This particular experiment uses two ADCs but the instrumentation was designed for three with the idea that it be versatile and useful in many different experiments. This system has proven reliable and required almost no maintenance in its 2 1/2 years of operation.

Experimental Results

To study parity violation in γ -decay, detectors are placed on opposite sides of the source along the horizontal nuclear polarization axis and the computer analyses the resulting γ -ray spectra in terms of differences of counting rate when the nuclei are pointed towards or away from a detector. Since the nuclei are pointed toward one detector and away from the other during any one counting period, many sources of error tend to cancel when one detector is compared to the other. For instance, if the source were to warm slightly, counting rates in both detectors would change the same

amount, but a comparison between the detectors would not give any false forward-backward asymmetry.

A large parity-violating forward-backward γ -ray asymmetry of $1.7 \pm 0.2\%$ was seen with this apparatus in the case of the 501 keV transition in ^{180}Hf . This shows in a completely unambiguous manner that the weak interaction contribution to the inter-nucleon interactions inside a nucleus is of first order in the weak coupling constant rather than second order. This is one of the prime experiments supporting the Feynman & Gell-Mann theory of the weak interactions.

On the other hand, time reversal measurements using this apparatus have failed to show time reversal violation in the case of ^{180}Hf even though some of the models for time reversal violation in the fundamental interactions would lead to such a prediction. The experimental measurement of asymmetry in γ - γ coincidence with nuclei pointed up compared to down was $(2.8 \pm 5.1) \times 10^{-4}$.

Acknowledgement

The authors give thanks to Richard Hiebert for contributing many ideas and help in preparing this paper. Special thanks also go to the following people: James Gallagher for suggesting the use of the fast adders and the divide-by-ten circuit, Ken Krane and B. T. Murdoch for help in checking out the hardware and software, and Ron Jones for the software.

References

1. The following are a few examples of the work carried out utilizing this system:
K. S. Krane, J. R. Sites, and W. A. Steyert, "Ultra-low Temperature Rotating Nuclear Polarization System," *Rev. Sci. Instr.* **42**, 1475 (1971).
K. S. Krane, C. E. Olsen, J. R. Sites, and W. A. Steyert, "Parity-Violating Asymmetry of the 501-keV Gamma Ray Emitted in Decay of ^{180}Hf ," *Phys. Rev. C* **4**, 1906 (1971).
K. S. Krane, J. R. Sites, and W. A. Steyert, "Nuclear Structure and Parity Mixing in the Decays from Oriented ^{182}Ta ," *Phys. Rev. C* **5**, 1104 (1972).
K. S. Krane, C. E. Olsen, and W. A. Steyert, "Parity Mixing and the Nuclear Structure of ^{181}Ta , ^{180}W and Nuclear Spin-Lattice Relaxation Following the Decays of Oriented ^{181}Ta , ^{180}W , ^{180}Re ," *Phys. Rev. C* **7**, 263 (1973).
K. S. Krane, B. T. Murdoch, and W. A. Steyert, "Approach to Magnetic Saturation of Impurities on Iron: Effects on Nuclear Alignment, Perturbed Angular Correlation, Mossbauer, and γ -Ray Thermometry Measurements," *Phys. Rev. Letters* **30**, 321 (1973).
2. R. P. Feynman and M. Gell-Mann, "Theory of the Fermi Interaction," *Phys. Rev. C* **109**, 193 (1958).
3. B. T. Murdoch, C. E. Olsen, W. A. Steyert, and K. S. Krane, to be published.