Asahi Applied Nuclear Physics Laboratory of the Institute of Physical and Chemical Research performs the world's first successful measurement of the electrical quadruplicate polar moment of unstable nuclei

■Outline

Challenges	The signal source that provides the stimulus for examining atomic nuclei using nuclear magnetic resonance techniques must deliver complex waveforms containing multiple frequency components, while modulating their frequency and amplitude in a controlled manner.
Solution	A signal source that accepts long, complex waveforms developed on a PC, and then manipulates the waveforms using built-in sequencing functions was used in the measurement procedure. These capabilities supported researchers' success in measuring the quadruplicate polar moment of unstable nuclei for the first time in the world.
Advantage	Having developed a proven methodology and innovative tools for microscopic observation, researchers can accelerate their inquiries into the physical and chemical phenomena that occur within unstable atomic nuclei.

After successfully using a heavy ion accelerator to generate a variety of unstable atomic nuclei, Asahi Applied Nuclear Physics Laboratory of the Institute of Physical and Chemical Research (RIKEN), an independent governmental corporation, conducted research involving the observation of the internal components of the atomic nucleus. Their work concentrated on measuring the "electromagnetic moment," of the nucleus, one of its essential properties. The project yielded a major breakthrough in nuclear physics.

Research Yields A "First" In the Microscopic Observation of Nuclear Materials

The atomic nuclei of most naturally-occurring materials are considered "stable," since they are made up of protons and neutrons whose mass is substantially equal to one another. A stable nucleus does not tend to transform itself into another type of atomic nucleus.

Conversely, a nucleus that transforms itself into a different kind of nucleus by causing its own disintegration due to emission of rays is known as an "unstable nucleus" or radio isotope.

Although unstable nuclei can be generated artificially, their instability and their fleeting existence leave much to be learned about their physical mechanisms. These same attributes make it difficult to design practical experiments and measurement procedures to test emerging theories.

Using the Nuclear Magnetic Resonance (NMR) Effect to Probe the Structures of Atomic Nuclei

Researchers at the lab used the nuclear magnetic resonance effect to pursue a practical method for measuring the *electrical quadruplicate polar moment* (EQPM) of unstable nuclei. This term describes certain electrical characteristics of the atomic nucleus. The results of a successful EQPM measurement can be used to analyze the quantum behavior of protons and neutrons within the atomic nucleus.

To carry out the EQPM measurement, unstable nuclei whose magnetic polar characteristics are deflected through the production process are led into a material in the presence of a static magnetic field.

Next, to the material, an RF coil applies an oscillating magnetic field perpendicularly to the static magnetic field. A detector is counting beta rays emitted from the unstable nuclei as the frequency of the oscillating field is gradually varied. This enables researchers to observe variations in the beta-ray counts at the NMR frequency.

Mr. Daisuke Kameda, Special Postdoctoral Researcher, Asahi Applied Nuclear Physics Laboratory, the Discovery Research Institute, the Institute of Physical and Chemical Research

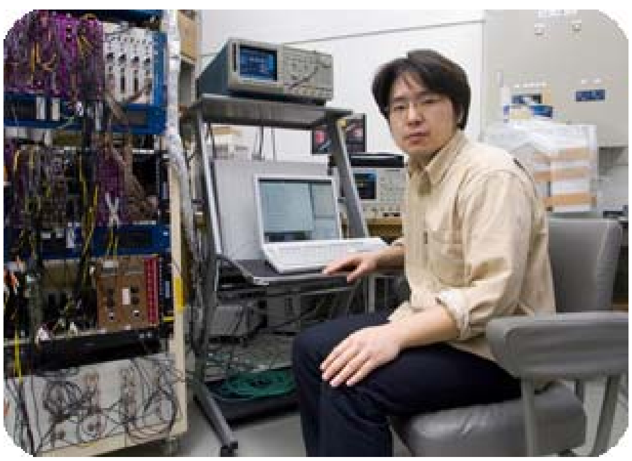
In a conventional process for measuring the NMR effect, only one resonant frequency is generated. With the EQPM approach, multiple resonant frequencies are used.

This characteristic caused a problem, since the variations observed in the detector were noticeably lower when detecting the resonance from multiple frequencies. The research team devised a method for detecting the resonance by simultaneously applying multiple frequencies.

The Search for a Signal Source to Provide Composite Waveforms

To carry out the measurement, it was necessary to drive the oscillatory magnetic field with novel composite signals. This requires a source that can generate RF waveforms containing multiple frequency components. It is essential to sweep the frequencies of these individual RF components simultaneously, and to modulate their frequencies at a controlled rate. The amplitude of the RF components, too, must be modulated. To yield the multiple resonant frequencies required by the process, a composite waveform synthesized from many discrete RF components must be generated.

The number of frequency components that must be generated varies according to the magnitude of the nuclear spin. For example, six frequency components are required for an atomic nucleus having the spin value, 3, as implemented by the research laboratory. Such the experiment requires approximately 10MHz of bandwidth. Specifically, this EQPM research work demanded 7MHz ±20% of bandwidth.



There was no signal source capable of meeting these requirements available in the lab at the time the experiments began. According to Mr. Daisuke Kameda, the Special Postdoctoral Researcher in RIKEN, “None of our conventional function generators could control the composite RF waveforms we needed for our EQPM observations and measurements. We evaluated various waveform generators on the market but determined that most were insufficient in terms of their memory capacity and resolution.”

Fortunately the research laboratory eventually found an optimal solution in the form of a Tektronix AWG615 arbitrary waveform generator. The AWG615 features an extremely high sample rate (up 2.7 gigasamples per second), easily capable of delivering the necessary 7 MHz ±20&% bandwidth. Equally important is the instrument’s record length: 32 million sample points. This enables the AWG615 to store very long, complex waveforms that embody all of the frequency components and modulations (both FM and AM) required for the EQPM research.

Measuring the Electrical Quadruplicate Polar Moment of Unstable Nuclei

The Asahi Applied Nuclear Physics Laboratory of RIKEN has devised a system that initially calculates waveforms on a PC and then loads the waveform into the AWG615 arbitrary waveform generator. The required waveform data is read out sequentially from a waveform library stored in a PC.

In the measurement procedure, it is necessary to use the frequency components in diverse combinations. A sequencing function built into the AWG615 allows waveform components to be accessed in any order using commands such as “Event Jump.” Using this function and others, the EQPM researchers fully exploited the capabilities of the AWG615 arbitrary waveform generator.

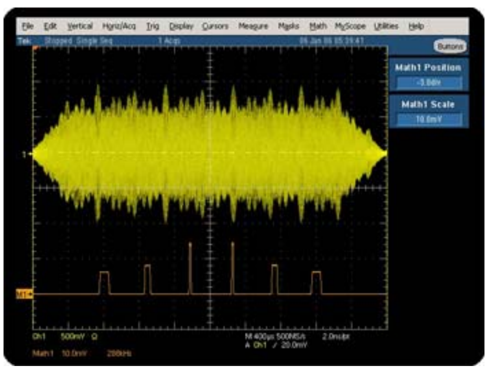
The AWG615 helped the researchers from RIKEN achieve unprecedented success in less than a year after initiating their basic experiments in EQPM measurement. Only six months after the AWG615 was paired with the laboratory’s heavy ion accelerator, and only two months after commencing practical measurement operations, the research staff successfully measured the electrical quadruplicate polar moment of unstable nuclei contained in aluminum—for the first time in the world.

Referring to this remarkable achievement, Mr. Kameda said “Without the AWG615 arbitrary waveform generator, we would have been forced to limit the range of atomic nuclei applicable for our experiment. This might have prevented us from successfully achieving the measurement objective.”

Now that the measurement method has been thoroughly validated, work at RIKEN will accelerate, with a continued focus on measuring unstable nuclei.

As a personal comment on the practical use of the AWG615, Mr. Kameda said "It was very convenient that the AWG615 provided us with flexible sequencing functions which enable easy generation of the patterns we needed. In our practical experiments, we carried out automated measurements via GPIB. On the other hand, during the development stage, the AWG615's screen display was helpful—we were able to instantly view and identify waveforms stored in memory."

The Institute of Physical and Chemical Research takes great pleasure in acknowledging the contribution that the Tektronix AWG615 arbitrary waveform generator has made. It played an important role in their successful measurement of the electrical quadruplicate polar moment of unstable nuclei—the FIRST time this has ever been achieved.



Monitored waveforms of RF pulses generated by the Model AWG615:
The upper portion designates RF pulse waveforms:
The lower portion designates Fourier spectra corresponding to the RF