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PREFACE

This Progress Report reviews the research and technical development conducted at the Nuclear Structure Laboratory of Purdue University during the period from June 1, 1969 to May 31, 1970.

The principal activity of the Purdue Nuclear Structure Group during the report period was the completion of the installation of the FN - Tandem Van de Graaff Accelerator in the new Purdue Nuclear Structure Laboratory Building and the completion of the installation of four reaction and scattering chambers in the experimental target area.

Coulomb excitation and nuclear reaction experiments have been started with the Purdue Tandem Accelerator. The research activities in nuclear spectroscopy using radioactive isotopes were continued.

Research at the Purdue Nuclear Structure Laboratory is performed by the faculty, postdoctoral research associates and graduate students of the Department of Physics of Purdue University. Support is provided by the State of Indiana and the U. S. Atomic Energy Commission.

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I. COMPLETION OF INSTALLATION OF THE PURDUE FN-TANDEM VAN DE GRAAFF

1. Accelerator Installation

The High Voltage Engineering Corporation supervision of the installation and testing of the accelerator was completed on August 1, 1969. Certain components from HVEC were not satisfactorily operational at that time and are still being worked on by HVEC. These will be discussed in Section II - 2.

2. Installation of Beam Lines

The original installation consisted of the seven-port switching magnet and quadrupoles and hardware for three beam lines. In view of the varied interests of the Nuclear Structure Group, more beam lines were soon needed. Some components were purchased from HVEC and others were constructed locally, and two additional lines are now fully operational. The remaining two lines will be installed during the coming year.

Figure 1 shows a view of the present target room installations

Fig. 1. Shows View of the Present Target Room Installation

II. OPERATION OF AND DEVELOPMENT WORK ON THE TANDEM ACCELERATOR

1. Accelerator Operation

The accelerator has been operated on a 24 hour - 5 day / week basis as requested for experimental programs. Short periods were used for certain machine developments and modifications as described in Section II - 2 and 4. Protons, deuterons, oxygen and sulphur were accelerated as follows:

Protons	-	46%
Deuterons	-	11%
Oxygen	-	33%
Sulphur	-	10%

2. Modifications and Additions

a) Ion Source

The standard HVEC duoplasmatron negative ion source still suffers from many of the same problems that plagued the original design. Four sources were installed by HVEC before one would operate reliably enough for acceptance tests. Most of the problems have been with the internal cooling oil line fittings which leak and are poorly designed for holding high voltages. This was a problem which HVEC was unable to solve in any long-lasting manner and caused considerable source maintenance on the average of every 1 - 2 weeks. We have eliminated the problem by welding flexible hoses to the cooling lines and making all breakable connections outside the vacuum chamber. The one necessary internal connection was replaced by a fitting of our own design and construction. Source maintenance intervals

have now increased to greater than $1\frac{1}{2}$ months.

b) Vacuum Systems

A small oil diffusion pump has been placed just outside the source magnet box to pump away as much of the source gas as possible before entering the acceleration tubes.

The two large mercury diffusion pumps at the ends of the accelerator used large amounts of liquid nitrogen for trapping the mercury and required periodic shut-down for maintenance. These pumping modules have been replaced by turbomolecular pumps which operate quite reliably with very little maintenance.

c) Control System

The slit - feedback system as supplied by HVEC has been another low reliability component. This has recently been replaced by a commercial unit[†] modeled after the Rutgers - Bell system. This system has greater reliability and in addition provides control from the generating voltmeter and capacitive pick - offs.

d) Interlock Systems

Work has continued on implementing the radiation safety and vacuum protection interlock systems. The target room beam lines have been equipped with locally - built interlock controls which permit opening only one beam tube at a time, only under good vacuum conditions. The controls also protect the vacuum pumps and accelerator from vacuum accidents.

e) Beam Scanners

The beam profile monitoring system for the target room as supplied by HVEC has operated less than one month since installation. This is a new

model from HVEC which despite their efforts still has many "bugs" in it. Several components have failed repeatedly and the system is currently at HVEC for a complete re-work.

† Model 9024 - Spectromagnetics Inc., Hayward, California

3. Development of Ion Source for Negative He - Ions

R. G. Kerr and L. G. Keller

Construction of a helium ion source for the Tandem Accelerator is nearing completion. With its installation beams of both ^3He and ^4He will be available for nuclear structure studies.

The design of the ion source is similar to several already in operation at other Tandem Laboratories. The production of negative helium ions for injection into the accelerator is accomplished by passing positive ions, extracted from a standard duoplasmatron, through a canal containing lithium vapor. The basic elements of the source can be seen in the accompanying figures. Electrodes are mounted on shielded alumina insulators which key into an optical bench.

A vacuum chamber built for the development and testing of the ion source duplicates the essential dimensions of the ion source housing at the low energy end of the accelerator. When the helium source is installed on the accelerator, the vacuum chamber and its support apparatus will be available for future ion source developments.

Fig. 2. Shows View of the Ion Source Stand

Fig. 3. Shows Inside View of the Negative He Ion Source

4. Development of Heavy Ion Beams

W. Lutz, R. P. Scharenberg, P. Sioshansi and J. Thomson

The development of heavy ion beams is required for several of the experimental programs which are discussed in this Progress Report. Many of the experiments discussed in Chapter V were only possible as a result of these beam developments.

a) O^{16} beam. We have obtained O^{16} beams in this laboratory using the standard duo-plasmatron ion source. This is done regularly using the Pt - mesh — $Ba CO_3$ filament technique introduced by Mook at the Oak Ridge National Laboratory. A freshly prepared filament will outgas and an O^+ beam can be extracted from the ion source with a typical intensity of about 2 μa . Thus it is not difficult to obtain various charge state beams in the PNSL Tandem Van de Graaff accelerator. A few of the various beams we have used in experiments are listed below.

<u>Energy</u>	<u>Charge State</u>	<u>Typical Current</u>
25 MeV	4^+	20 - 200 n.a.
30 MeV	5^+	100 n.a.
42 MeV	6^+	50 n.a.
60 MeV	7^+	10 - 20 n.a.

b) S^{32} beam. The determination of static quadrupole moments of nuclear states by Coulomb excitation requires heavy ion beams. We have developed S^{32} beams for these experiments. A simple gas manifold system was constructed which will handle various gases which can be mixed with H_2 , the dominant fuel for the duo-plasmatron ion source. When H_2S is used as the impurity

gas, the ion source will deliver a .5 to 2 μ a S^- beam to the accelerator. This is sufficient to provide 10 to 40 n.a. of 56 MeV S ions on target. The principal difficulty is a Ta filament life of only 24 hours. This beam development benefited from the experience and advice obtained from the Rochester Nuclear Structure Laboratory.

5. Digital Volt Meter

W. Lutz, R. P. Scharenberg, P. Sioshansi and J. Thomson

Because of the various possible charge states possible when negative heavy ion beams are injected, both energy and momentum must be determined to uniquely identify the particular beam. We have installed a precision digital read-out system for the generating voltmeter system. This requires a preamplifier and digital voltmeter. The system is calibrated using the analyzing magnet and running various proton beam energies. This system which we have also used at the Argonne National Laboratory machine is very reliable and aids the machine operators in finding the correct beams. Ion beam masses are confirmed by the kinematics in scattering the beam by a thin gold target.

III. INSTRUMENTATION FOR EXPERIMENTS WITH TANDEM ACCELERATOR

1. 18" General Purpose Scattering Chamber

F. A. Rickey and D. L. McShan

For use as a general purpose scattering chamber, an 18" Ortec scattering chamber has been installed on the 15° Left beam line. The scattering chamber as supplied by Ortec is equipped with a rotating bottom plate and a hemispherical top cover.

The vacuum system installed on the chamber is based on an Ultec "BoostiVac" system. This is a 150 liter/sec ion pump, with a titanium sublimator surrounded by a cryogenic sleeve incorporated into the body of the pump. In order to obtain higher pumping speeds the cryogenic sleeve is cooled by a Freon 22 single - stage refrigerator. With this cooling the pumping speed of the pump using the sublimator is approximately 900 liter/sec. In normal use the chamber is roughed out with a Roots blower assembly to a pressure of 5×10^{-5} Torr. The "BoostiVac" assembly then rapidly reduces the pressure to about 10^{-6} Torr, at which time the titanium sublimator is turned off to prolong filament life. Typical operating pressures in the scattering chamber are approximately 6×10^{-7} Torr. A four inch gate valve has been installed between the pump and the chamber. This valve can be operated either manually or pneumatically. A protection circuit has been installed so that the valve closes automatically if the pressure becomes too high in the system. A protective grounding system has also been installed on the chamber. Ion pumps involve potential differences inside the pump of approximately 5000 volts. The pump itself is normally

grounded to protect personnel. The chamber is, however, electrically isolated from ground, and during the start-up of the pump the plasma sheath from the pump extends into the chamber, producing lethal voltages on chamber surfaces. During this start-up operation the chamber is automatically grounded by the protective circuit.

Other instrumentation has been involved with beam definition and measurement. The collimators supplied with the Ortec chamber are simply circular apertures. An adjustable slit system has been installed which defines a rectangular beam profile. The beam striking each of the four jaws of a slit assembly can be monitored separately. The signals from the two horizontal defining slits (left and right) are fed into a differential amplifier. The difference current obtained is used to measure the left-right position of the beam on the slits. A discriminator circuit has been constructed which produces a d.c. level shift if the difference current exceeds a preset (and adjustable) level; that is, if the beam wanders too far to the left or to the right. A similar system monitors the current on the top and bottom slits. The difference readings have been found to be very useful in maximizing the beam on target, and the discriminator signals have been used to close linear gates in the data processing system when the beam wanders from its desired position. This feature has been found to be necessary if accurately reproducible data is to be collected.

A detector cooling system has been placed in operation. The Freon 22 refrigerator which cools the pump is also used to cool an alcohol bath in a closed dewar flask. The chilled alcohol is then forced through a line which passes through the baseplate of the chamber, and is in good thermal contact with the detector mounts. The alcohol is then returned to the alcohol bath

where it is re-chilled. The circulating pump is an ordinary electric fuel pump from an automotive supply store. The detector mounts are brass for good thermal conductivity, and are isolated thermally from the baseplate of the chamber. The semiconductor detectors are then cooled by thermal contact with the detector mounts. The cooling system is simple to operate, and maintains the detectors at approximately -30° C. The rotating baseplate of the Ortec chamber has been found to be particularly suited to this cooling method, since all the detectors are fixed on the baseplate.

The chamber has been in routine use since the early part of September.

2. 30" Scattering Chamber

O. E. Johnson

Experience gained using the 30" scattering chamber in the preliminary stages of the (d,α) - reaction investigation has suggested that, for reasons of achieving acceptable beam optics, the following steps must be taken :

(1) the chamber - to - quadrupole distance should be increased; (2) a new beam - collimation system must be designed and constructed; (3) horizontal and vertical steering magnets should be incorporated in the beam transport system; and (4) the Faraday cup assembly should be modified and relocated at a greater distance from the chamber. Work is in progress which will insure that these things will be accomplished in the near future.

3. Coulomb Excitation Scattering Chamber

W. Lutz, R. P. Scharenberg, P. Sioshansi and J. Thomson

The 18" scattering chamber which was built in this laboratory and then was used at the Argonne National Laboratory, has been returned to Purdue and has been installed in the Left - 45° beam line. We have introduced modifications in the chamber at this time. The principal internal modification is a precision ring which allows accurate angle determinations in the Coulomb excitation work. The ring provides accurately machined apertures at the various laboratory angles. A Freon refrigeration system for the trap of the chamber diffusion pump system has been installed and allows continuous pumping of the chamber.

A novel modification in the collimation system of this beam line is provided by coating the Ta collimation aperture with a vacuum-evaporated layer of natural bismuth. The Bi-coating produces a very marked decrease in the background radiation that is caused by the Coulomb excitation of the nuclei in the apertures. This change has made it possible to execute experiments where signal-to-noise conditions were previously unacceptable.

To improve the fraction of the analyzed beam that is transmitted through the collimation systems, horizontal and vertical steering magnets have been designed, tested, and installed on the Left 45° and 0° beam lines.

4. Multiple - Coulomb Excitation Chamber

W. Lutz, Z. W. Grabowski, R. P. Scharenberg,

P. Sioshansi, R. M. Steffen, and R. Wheeler

A multiple Coulomb excitation chamber is nearing final completion and will be installed on the 0° beam line. The chamber is a 4" diameter x $\frac{1}{8}$ " thick aluminum cylinder containing an annular surface barrier detector concentric with the beam axis in the backscatter direction, a surface barrier detector to monitor integrated counting time, and a rotatable target ladder. The chamber is mounted at the center of a standard angular correlation table with a movable arm capable of carrying a NaI(Tl) or a Ge(Li) detector. With this geometry it is possible to measure precise correlations between de-excitation γ -rays into an angle greater than 30° from the back direction and projectiles backscattered into the annular detector. Beam spot position is defined by a two hole collimator system mounted on the table. Background γ -radiation from ions hitting the collimators has been significantly reduced by coating standard tantalum collimators with Bi^{209} using electrolysis and vacuum deposition methods. The beam line has been fitted with electromagnetic lenses and steerers and an optical viewer to aid in bringing the beam on target.

5. Electronics

a. A Sum - Delay Amplifier and Gate Generator *

P. C. Simms

The sum - delay amplifier and the gate generator are in separate single-width NIM modules. The amplifier has five input channels which can be switched in or out. The delay can be switch selected to be 0, 1, or 2 μ sec. The gate generator is very flexible. It will accept almost any type of input signal and produce an output pulse which can be adjusted to meet most gating requirements. One frequent use of the instrument is to observe the performance of an electronic system while an experiment is being performed.

* Abstract of paper published in The Review of Scientific Instruments, 40, No. 2, 285 - 287 (1969). (See Document No. C00-1746-12)

b. A Flexible Coincidence System *

P. C. Simms

A flexible system is described which will provide coincidence resolving times from 5 nsec to milliseconds. The instrument is contained in a double-width NIM module. There are four input channels and two coincidence circuits which can be connected for many coincidence configurations. Several applications are discussed including a method for measuring true and accidental coincidences simultaneously.

* Abstract of paper published in Nuclear Instruments and Methods, 70, 311-316 (1969). (See Document No. C00-1746-11)

c. Pool Electronics for Accelerator Experiments

P. C. Simms

In order to make the best possible use of the available funds, an electronic instrumentation pool for accelerator experiments has been set up. Fifty-one different NIM modules were obtained as demonstrators from various manufacturers. These instruments were carefully tested to determine which instruments give the best performance. After these tests, a basic set of instruments was purchased.

The electronics pool was supplemented with general purpose instruments which were constructed in the laboratory using designs which had been developed previously. The following is a list of instruments that were constructed.

- 5 double delay line clipped linear amplifiers
- 5 timed single channel analyzers
- 4 flexible coincidence modules
- 8 delay and gate generators
- 5 sum delay amplifiers
- 3 high voltage distribution and monitor modules
- 5 monitor and protection modules for NIM power bins
- 1 counting system with automatic printing capability (50 decades).

Three of these instruments have been described in published papers.

(See previous sections).

6. On-Line Computer Facility

F. A. Rickey, P. C. Simms, and R. M. Steffen

An extensive study was made of small digital computers to select the best system for an on-line data accumulation and processing system. We restricted our attention to systems which would have complete hardware and software available and would be ready to operate when installed by the manufacturer. From the available systems we selected the system which would provide the utmost flexibility for future expansion.

These conditions were met by a Digital Equipment Corporation PDP-15/30 Computer. The system was purchased with the following components.

- a) Central processor with hardware multiply and divide, automatic priority interrupt, and memory protection.
- b) 16 K, 18-bit, 800-ns core memory
- c) 2 Teletypewriters for foreground-background
- d) High speed paper tape punch and reader
- e) 3 Special purpose magnetic tape transports
- f) 1 General purpose magnetic tape transport
- g) CRT display with light pen
- h) Dual ADC and interface for multiplex or two parameter analysis

A request has been made to the AEC to purchase the following additions to the system from funds which are available in our current contract.

- a) 8 K core memory
- b) Line printer
- c) Card reader

A large variety of software is available for this system from Digital Equipment Corporation and from the other nuclear research laboratories which use DEC computers. The two primary limitations of the system are lack of floating point hardware and the short word length (18-bits). Since we do not intend to use the computer for complex calculations, these limitations will not be important. An important limitation is that the interface supplied with the system will only accept two ADC's. A more versatile interface is being designed in our laboratory.

IV. NUCLEAR REACTION STUDIES

1. Study of the $C^{12}(d,\alpha)B^{10}$ Reaction in the 12-MeV Region

O. E. Johnson and T. F. Yang

Angular distributions for the $C^{12}(d,\alpha)B^{10}$ reactions which produce the ground, 0.717-, 2.15-, and 3.58-MeV states of B^{10} were measured at deuteron energies of 11.90, 12.00, and 12.10 MeV. The differential cross sections were determined at 5° intervals over a laboratory angular range from about 25° to at least 120° . In addition a 50-keV excitation function was measured over the energy interval from 11.50 to 12.65 MeV at the laboratory angles 40° , 50° , 60° , and 70° . An electronic spectrometer system, which utilized silicon surface barrier detectors, was used to measure the α -particle spectra. A single self-supporting carbon-foil target with a nominal areal density of $70 \mu\text{g}/\text{cm}^2$ was used throughout the course of the measurements.

The excitation functions all display rather strong energy dependences which indicate that the compound nucleus mechanism is a non-negligible contributor to the (d,α) reaction cross sections throughout the energy region under consideration. While the general quality and precision of the data is not as high as might be desired, these data strongly suggest that there may be large numbers of resonances in the excitation function which could be observed in a higher resolution experiment. Due to these energy dependences the specific shapes of the angular distributions change from one energy to another, however, the following general features do persist:

(1) a general oscillatory behavior ranging from a washed-out structure to

one with deep minima; (2) a clear asymmetry with respect to 90° . In addition, forward - and/or backward - angle peaking is displayed by various of the angular distributions. In combination, these features strongly suggest that a direct - reaction mechanism is a substantial contributor to the (d,α) reaction cross sections. It is clear that the extension of this investigation will require the accumulation of much more data of considerably higher quality than has been yielded by this initial series of measurements.

2. Study of Nuclear Structure by (p,p') , (p,γ) , and $(p,p'\gamma)$ Reaction

F. A. Rickey and D. L. McShan

The study of the effect of core excitations on the excited states of deformed odd - A nuclei has been pursued during the last year. The work has involved isobaric analogue resonances in the elastic and inelastic scattering of protons from an Erbium 168 target. This particular nucleus was chosen because known core excitations are low in energy, the Coulomb energy is relatively low, and separated isotopes were available enriched to 99% in ^{168}Er .

Analogue resonances have been observed in excitation functions covering the range from 9.4 to 11.5 MeV; however, much of the work to date has been concerned with improving experimental techniques so that weak resonances can be clearly observed. In deformed nuclei many resonances overlap, and are weak since the single - particle widths are spread over states in a given rotational band.

The basic experimental technique has involved directing a proton beam from the tandem accelerator into the 18" Ortec scattering chamber, and detecting the protons scattered from an ^{168}Er target at angles of 90° , 125° , 141° , and 170° . These angles have been selected because 90° , 125° , and 141° correspond to zeros of Legendre polynomials for odd ℓ - transfer, $\ell = 1$, and

$\ell = 3$ respectively. At 170° all ℓ - transfers contribute.

The four detectors are 50mm^2 lithium - drifted silicon detectors with a depletion depth of 3 mm. The detectors are cooled to -30°C using the method described in section III. 1 of this report. Thermoelectric cooling was at first used, but the ultimate temperatures reached were higher. Detector collimation was such that roughly equal counting rates were obtained at all angles; the largest solid angle subtended being about 3×10^{-3} steradian.

The Er_2O_3 target was prepared by electron - beam evaporating the separated oxide onto a carbon backing to a thickness of $200 - 300 \mu\text{g}/\text{cm}^2$.

A block diagram of the electronics used in this experiment is shown in Fig. 1. The system consists of four identical linear processing sections (only one is shown in the block diagram), plus bookkeeping and routing circuits. The basic scheme of operation is simple. Whenever an event is recognized in one of the detectors, the processed linear signal is subsequently presented to one ADC of a Nuclear Data 160 two - dimensional analyzer, and a pulse whose height identifies the particular detector is simultaneously presented to the other ADC. Thus by means of their analogue routing scheme the data from a particular detector are stored in one of the eight channel slices of the memory of the 512 MCA. The bookkeeping circuits guarantee that only one pair of linear and analogue signals is presented to the analyzer until the data has been stored and the analyzer has recovered. The heart of this system is an exclusive - or gate. This gate identifies the detector producing the signal, prevents events from more than one detector reaching the analyzer simultaneously, and prevents any signal from reaching the analyzer if the preset count has been reached if the analyzer is busy,

FOUR DETECTOR ELECTRONICS

FIGURE 1

or if the output from the beam slit discriminator (described in section III.1 of this report) indicates that the beam has wandered on the target. The exclusive - or gate is also used to handle dead - time measurements, since the dead - time of the gate is equivalent to the total dead - time in the system.

This experimental system gives very good energy resolution. The best energy resolution that has been obtained was 10 keV FWHM for a 100 nano-amp beam of 10 MeV protons incident on target. With increased beam currents the routine energy resolution of 15 keV FWHM is sufficient to clearly resolve the ground state of Er^{168} from the first excited state at 79.5 keV, as is seen in Fig. 2. At present the 0^+ , 2^+ , 4^+ , and 6^+ states of the ground state rotational band as well as the 2^+ and 3^+ states of the γ vibrational band can be observed in the spectra, and excitation functions for these states are being obtained. Other excited states are being searched for at higher energies.

Much of the experimental work to date has been directed toward obtaining smooth reproducible excitation functions below the expected resonances. Part of the data obtained with the present system are shown in Fig. 3. The first resonances are observed at about 10.5 MeV, which are clearly odd parity resonances since the 90° excitation functions are smooth. The small excursions of the resonances in the elastic channel indicate the need for reliable data, and have prompted much of the development work performed during the last year.

Fig. 2. $\text{Er}^{168} (p, p') \text{Er}^{168}^*$
 90° Lab. Angle Incident Energy 10 MeV

Fig. 3. Excitation Functions for Reaction $\text{Er}^{168}(\text{p}, \text{p}')$

V. COULOMB EXCITATION STUDIES

1. Reorientation Experiments on Medium Heavy Nuclei

W. Lutz, R. P. Scharenberg, P. Sioshansi, and J. Thomson

We are continuing our program to measure quadrupole moments of excited nuclear states with the Coulomb Excitation technique. We have made experimental improvements which include better angle definition and reduction of gamma background radiation from the collimating system. The availability of S^{32} beams increased the reorientation effect substantially and allows the possibility of cross - checks between experiments involving different projectiles. We have also improved our measurements of the de-excitation gamma radiation angular distributions as a function of the target nucleus recoil energy which allows better finite size counter corrections. These correction measurements have now been completed for the Pd, Ge, and Fe experiments.

2. Measurements of the Static Quadrupole Moment of the First Excited 2^+ States of the Nuclei Pd^{106} and Pd^{110} by Heavy Ion Coulomb Excitation *

R. Beyer,[†] R. P. Scharenberg, and J. Thomson

The static quadrupole moments of the 511.7 keV 2^+ state in Pd^{106} and the 373.8 keV 2^+ state in Pd^{110} have been determined by employing Coulomb excitation techniques. Foils ($\sim 175 \mu\text{g}/\text{cm}^2$) of separated Pd isotopes were bombarded with 25 and 30 MeV O^{16} ions and 55 and 56 MeV S^{32} ions from the Purdue University and Argonne National Laboratory Tandem accelerators. The

angular distributions of the inelastically scattered ions were measured in coincidence with the de-excitation gamma rays to determine the relative excitation probabilities. The experimental data were fitted using the Winther-de Boer Multiple Coulomb Excitation Program so that the sign and magnitude of the static quadrupole moment could be extracted. The effect of higher excited states on the excitation probability of the 2^+ state has been calculated using the matrix elements determined by Robinson et al. and the Winther-de Boer program. Self consistency of the oxygen and sulfur data suggests that the excitation via the second 2^+ state interferes constructively so as to increase the excitation probability. With this choice for the interference via the second 2^+ state, the values of the static quadrupole moments are $Q_{22} = -.458 \pm .059$ barns for Pd^{106} and $Q_{22} = -.483 \pm .049$ barns for Pd^{110} . If the excitation via the second 2^+ state interferes destructively, the values of the static quadrupole moments are $Q_{22} = -.282 \pm .059$ barns for Pd^{106} and $Q_{22} = -.266 \pm .049$ barns for Pd^{110} .

* Abstract of paper submitted to The Physical Review for publication

(See Document No. C00-1746-32)

† Present address: Wittenberg University, Springfield, Ohio

3. Coulomb and Nuclear Effects in Reorientation Experiments on Fe^{56}

W. Lutz, R. P. Scharenberg, P. Sioshansi, and J. Thomson

In order to further investigate the validity of the reorientation effect mechanism in heavy ion Coulomb excitation, we have undertaken to measure the inelastic differential cross section for various ions which

excite the first 2^+ state in Fe^{56} at various energies above and below the Coulomb barrier. Fe^{56} was chosen for this investigation because we have found that it exhibits a large reorientation effect consistent with a quadrupole moment near the rotational value. We have measured the differential cross section for excitation of the first 2^+ state in Fe^{56} at 25, 27.5, 30, 32.5 and 35 MeV. At 30 MeV and below, the data are consistent with a reorientation effect mechanism, at 32.5 and 35 MeV we find large deviations which are not consistent with higher order Coulomb excitation effects. Of particular interest is the relationship between the inelastic Coulomb excitation contribution and the possible nuclear reaction mechanisms which are present. Further work with heavier ions (S^{32}) is required to elucidate these relationships.

VI. ANGULAR CORRELATION AND HYPERFINE FIELD STUDIES

1. Determination of the E2/M1 Multipole Mixing Ratios

of the Gamma Transitions in Cd^{110} *

K. S. Krane and R. M. Steffen

The multipole character and E2/M1 mixing ratios of all gamma transitions following the decay of $\text{Ag}^{110\text{m}}$ to Cd^{110} have been determined by measuring the 1 - 2, 1 - 3, and 1 - 4 directional correlations using two 30cc coaxial Ge(Li) detectors in conjunction with a multichannel coincidence gating system. The analysis of the data clearly demonstrated the necessity for careful investigations of the effects of the Compton background on directional correlation measurements using Ge(Li) detectors. The directional correlation functions for mixed gamma - gamma cascades are given in terms of explicitly defined reduced matrix elements and their ratios $\delta(\gamma_n)$. The analysis of the 25 measured directional correlations yielded a consistent set of E2/M1 mixing ratios for all mixed multipole transitions. The E2/M1 amplitude ratios $\delta(\gamma_n) = \langle I_{n+1} \| \vec{j}_N \vec{A}_2^E \| I_n \rangle / \langle I_{n+1} \| \vec{j}_N \vec{A}_1^M \| I_n \rangle$ for the Cd^{110} gamma rays are (energies are in keV): $\delta(447) = -0.45 \pm 0.20$, $\delta(620) = -0.80 \pm 0.50$, $\delta(678) = -0.25 \pm 0.20$, $\delta(687) = -1.1 \pm 0.8$, $\delta(707) = -1.0 \pm 0.3$, $\delta(818) = -1.20 \pm 0.15$, $\delta(1384) = -0.37 \pm 0.03$, $\delta(1505) = -0.55 \pm 0.10$. In terms of the multipole moments $\langle I_{n+1} \| \mathcal{M}(\pi L) \| I_n \rangle$ of Bohr and Mottelson the E2/M1 moment ratios $\Delta = \langle I_{n+1} \| \mathcal{M}(E2) \| I_n \rangle / \langle I_{n+1} \| \mathcal{M}(M1) \| I_n \rangle$ in natural units ($\hbar = m = c = 1$) are: $\Delta(447) = 3.0 \pm 1.3$, $\Delta(620) = -3.8 \pm 2.4$, $\Delta(678) = -1.09 \pm 0.88$, $\Delta(687) = -4.7 \pm 3.4$, $\Delta(707) = -4.2 \pm 1.3$, $\Delta(818) = -4.3 \pm 0.5$, $\Delta(1384) = -0.79 \pm 0.06$, $\Delta(1505) = -1.08 \pm 0.20$.

* Abstract of paper submitted to and accepted by The Physical Review

2. E2/M1 Mixing Ratios of Gamma Transitions

in Even - Even Nuclei in the Os - Pt Region *

K. S. Krane and R. M. Steffen

An investigation of the E2/M1 multipole mixing ratios of gamma transitions in even - even osmium and platinum isotopes has been recently completed in order to test the predictions of the pairing - plus - quadrupole theory of Kumar and Baranger^{1,2}.

Measurements have been made of gamma transitions in $^{186,188,190}\text{Os}$ populated in the decay of $^{186,188,190}\text{Ir}$; the radioactive iridium isotopes were produced by the $\text{Re}(\alpha, \text{xn})$ reactions. The states of $^{194,196}\text{Pt}$ were populated in the decay of $^{194,196}\text{Au}$; the gold isotopes were produced by the $\text{Pt}(\text{d}, \text{xn})$ reactions. In all cases chemical procedures were employed to obtain sources in liquid form (acid solutions).

The equipment employed for the measurement consisted of two coaxial 30 - cc Ge(Li) detectors and appropriate electronic equipment for high - resolution pulse - height analysis and timing analysis. Directional angular correlations were measured by accumulating in a multichannel analyzer spectra in coincidence with the $2^+ - 0^+$ transition at various angles; corrections for effects due to the Compton background lying beneath peaks of interest were likewise measured. The resulting angular correlation coefficients were then analyzed to determine the appropriate E2/M1 mixing ratios³. The following results were obtained (predictions of Kumar - Baranger theory² are also listed)

* A report of these measurements has been presented at the Washington Meeting of the American Physical Society, April, 1970 (see Document No. C00-1746-35).

Isotope	Transition (keV)	δ Experimental	δ Kumar - Baranger
^{186}Os	630	$-10 \begin{smallmatrix} +3 \\ -10 \end{smallmatrix}$	- 14.7
	773	$-12 \begin{smallmatrix} +4 \\ -8 \end{smallmatrix}$	- 13.5
^{188}Os	478	-12.3 ± 2.8	- 9.5
	635	-6.9 ± 3.2	- 10.5
^{190}Os	371	-8.5 ± 1.0	- 7.6
	569	-9.0 ± 1.5	- 9.9
^{194}Pt	293	14.3 ± 2.1	19.9
^{196}Pt	333	-6.5 ± 0.3	-101.4

The general agreement of the measured values with the predicted ones is excellent.

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3. Quadrupole / Dipole Mixing Ratios of Gamma Transitions

in the Deformed Nucleus ^{160}Dy

K. S. Krane and R. M. Steffen

In order to obtain detailed information regarding the nature of the excited states of ^{160}Dy , a nucleus with a strongly deformed equilibrium shape, directional correlation measurements have been carried out on the gamma rays from states in ^{160}Dy populated through the decay of ^{160}Tb .

The use of high - resolution Ge(Li) detectors and appropriate electronics were necessary to resolve the many gamma transitions present. Measurements were carried out both by counting coincidences between pairs of gamma rays and by accumulating coincidence spectra in a multichannel analyzer.

Because the spins and parities of the excited states of ^{160}Dy are reasonably well established, knowledge of the directional correlation coefficients can lead to information regarding the multipole mixing ratios of the gamma transitions. The following values were obtained for the mixing ratios (those marked by asterisks are E2/M1 ; others are M2/E1) :

Transition (keV)	Mixing Ratio
215	- 0.18 ± 0.10
299	0.005 ± 0.010
392	0.01 ± 0.06
879 *	- 13.5 ± 3.0
962 *	- 18.0 ± 5.0
1176	- 0.02 ± 0.02
1272	0.03 ± 0.03

The results are consistent with the predictions of the rotational model, assuming band mixing in the negative - parity states.

4. g - Factors of the First Two Excited 2^+ States in Pt^{192} *

Z. W. Grabowski

The g - factors of the first and the second excited 2^+ state in Pt^{192} have been measured by observing the integral rotation of the directional correlation pattern in the internal magnetic field acting on Pt nuclei implanted in an iron host. Both values, $g_{316} = 0.27 \pm 0.02$ and $g_{612} = 0.30 \begin{smallmatrix} + 0.06 \\ - 0.04 \end{smallmatrix}$ are higher than those predicted by the pairing - plus - quadrupole model of Kumar and Baranger.

* Abstract of paper accepted for publication in The Physical Review.

(See Document No. COO-1746-25)

5. Large Magnetic Hyperfine Interaction Following the Electron - Capture - Induced Coulomb Fragmentation of Molecules

S. J. Cipolla* and R. M. Steffen

In this work the large magnetic hyperfine fields (of the order of 10^8 gauss) that are expected to be present in strongly ionized atoms following electron capture decay and the ensuing Coulomb fragmentation of molecules¹ are investigated and the possibility of using these fields for g - factor measurements² on extremely short - lived nuclear states ($\tau < 10^{-12}$ s) is explored.

The electron capture process creates a hole in the K or L shell and causes the atomic shell to be in a highly excited state. The hole is rapidly filled and moves towards the outer shells in emitting radiation but mostly by radiationless Auger transitions which create more holes.³

In a free or quasi-free (gas at low pressure) medium-heavy atom the holes reach the outermost shells in about 10^{-14} sec. and any further decay must proceed by radiation with lifetimes in the optical region. Hence, a highly ionized atomic shell, which persists for about 10^{-8} s, surrounds the nucleus whose decay has been initiated by the electron capture process. The unquenched electron orbitals of the ionized atom can produce large magnetic fields (of the order of 10^8 gauss) at the site of the decaying nucleus and the resulting hyperfine interaction is expected to cause strong perturbations of the directional correlations of gamma rays that follow the electron capture decay, even if the lifetime of the intermediate nuclear state involved in the angular correlation measurement is very short ($\tau \sim 10^{-12}$ s). Evidence of this effect has been observed in gaseous Xenon sources.⁴

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If the ionized atom is a part of a molecule, some of the charge will be transferred to its partner, and Coulomb repulsion between the highly charged constituents will lead to a disruption of the molecule (Coulomb fragmentation).¹ Again strong hyperfine interactions are expected to be present in the still highly charged fragments.

If the decaying atom is in a liquid or a metallic environment, the strongly ionized state of the atomic shell is short lived (less than 10^{-12} sec.) and, in general, the hyperfine interaction in the atomic ground state is small. In addition the orbitals in a solid are quenched thus further reducing the hyperfine interaction.

In order to investigate the hyperfine effects following Coulomb fragmentation, the directional correlation of the Fe^{58} gamma rays (see inset of Fig. 1) was measured using gaseous sources of $\text{Co}^{58}\text{Cl}_2$. From the attenuation of the directional correlation the average hyperfine interaction in the 0.8105 MeV $I = 2^+$ state of Fe^{58} with 7×10^{-12} s half-life was determined.

The gaseous Co Cl_2 sources were prepared⁵ by drying Co Cl_2 in a quartz vacuum system and distilling it into a quartz ampoule of about 0.2 ml volume. The sealed ampoule was then heated to 1050°C , where the Co Cl_2 was totally volatilized, the pressure being about 0.5 atm. The directional correlation of the 0.865 MeV - 0.810 MeV gamma rays of Fe^{58} displayed by gaseous, liquid and metal sources were measured with NaI(Tl) counters.

The results of the measurements are shown in Fig. 1. Curve A is the directional correlation observed with a metallic Co^{58} source, a solid $\text{Co}^{58}\text{Cl}_2$ source and an aqueous Co Cl_2 solution source. The directional correlations displayed by these three sources are identical. Curve B shows the directional correlation observed with the gaseous Co Cl_2 source

Fig. 1. Directional Correlation of the Fe⁵⁸ Gamma Rays Displayed by Solid, Liquid, and Gaseous Sources of Co⁵⁸

during the first 20 hours after heating was started. After about a day of keeping the Co Cl_2 (gaseous) source at a temperature of 1050°C the directional correlation slowly (within a few days) changed to the pattern displayed by the solid Co Cl_2 source (curve A). This effect was traced to adsorption of the Co Cl_2 molecules on the walls of the quartz ampoule.

A least-squares fit analysis of the coincidence data to the directional correlation function³

$$W(\theta) = 1 + \hat{G}_{22} A_{22} P_2(\cos \theta) + \hat{G}_{44} A_{44} P_4(\cos \theta) \quad (1)$$

yielded the correlation coefficients $\hat{G}_{kk} A_{kk}$ which are listed in Table I. The coefficients were carefully corrected for the finite size of source and detectors.

The directional correlation of the Fe^{58} gamma rays displayed by the liquid and solid sources is not expected to be perturbed by extranuclear fields, and the attenuation coefficients³ $\hat{G}_{kk}$ in the directional correlation function (1) are therefore assumed to be equal to unity $\hat{G}_{22} = \hat{G}_{44} = 1$. The experimental values of A_{kk} are consistent with an E2/M1 mixing ratio δ of the 865 keV gamma transition of

$$\delta(865) = \frac{\langle 2 \| \vec{j}_N \vec{A}_2^{(E)} \| 2 \rangle}{\langle 2 \| \vec{j}_N \vec{A}_1^{(M)} \| 2 \rangle} = -0.95 \pm 0.05 \quad (2)$$

where the reduced matrix elements have been explicitly defined in reference 6. The value of δ agrees with recent measurements⁷ but disagrees with an older set of data.⁸

From the attenuation factors $\hat{G}_{kk}$ observed with the (fresh) gaseous sources the average hyperfine coupling constant $\bar{a}$ can be estimated.

TABLE I. DIRECTIONAL CORRELATION OF THE Fe^{58} GAMMA RAYS

Source	$\hat{G}_{22} A_{22}$	$\hat{G}_{44} A_{44}$	$\hat{G}_{22}$	$\hat{G}_{44}$
Dilute Aqueous Solution of Co Cl_2	0.465 ± 0.008	0.124 ± 0.014	1.00 (assumed)	1.00 (assumed)
Solid Co Cl_2	0.460 ± 0.009	0.130 ± 0.016	1.00 (assumed)	1.00 (assumed)
Gaseous Co Cl_2 (< 20 hours after heating)	0.34 ± 0.01	0.02 ± 0.02	0.73 ± 0.03	0.15 ± 0.15
Gaseous Co Cl_2 (about 2 days after heating)	0.40 ± 0.01	0.06 ± 0.02	0.86 ± 0.03	0.46 ± 0.16

Assuming that the hyperfine interaction is mainly caused by a magnetic $I - J$ coupling and that electronic states of $J = \frac{1}{2}$, $\frac{3}{2}$, and $\frac{5}{2}$ contribute with about equal intensity to the hyperfine interaction, one obtains $\bar{a} \geq 10^{11} \text{ sec}^{-1}$. This value of $\bar{a}$ corresponds to a magnitude of the average magnetic hyperfine field acting on the Fe^{58} nuclei of about 10^8 gauss.

The presence of such strong magnetic hyperfine fields following Coulomb fragmentation induced by electron capture offers interesting possibilities for the measurement of g -factors of short lived ($< 10^{-12} \text{ sec}$) excited nuclear states. Application of external magnetic fields in a decoupling (longitudinal field) or a spin precession (transverse field) scheme could be used to align the electronic states and an extraction of reasonably accurate values of nuclear g -factors for very short lived nuclear states may be feasible.

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6. Angular Momenta of the 1.770 MeV Excited States of Pd^{108}

R. M. Steffen

Little is known about the 1.770 MeV excited state of Pd^{108} . (See Fig. 1). On the basis of the decay characteristics of $\text{Ag}^{108\text{m}}$ a very tentative spin assignment of $I = 5^+$ or 6^+ has been made. No angular correlation measurements have been performed on any of the Pd^{108} gamma-gamma cascades because of the difficulties to produce sufficiently strong and pure sources of the long-lived Ag^{108} isomer. ($T_{1/2} > 5$ years). The angular momenta of the first three excited states of Pd^{108} are known from Coulomb excitation experiments and indicate that Pd^{108} has some of the characteristics of a vibrational nuclei, e.g. the occurrence of the 0^+ , 2^+ , 4^+ two-phonon triplet at about 1 MeV. Within the framework of the vibrational model the 1.770 MeV state is expected to be a member of the three-phonon quintuplet of spin 0^+ , 2^+ , 3^+ , 4^+ or 6^+ .

A reasonably strong source ($\sim 3 \mu\text{c}$) of $\text{Ag}^{108\text{m}}$ was made available to us through the courtesy of Dr. M. Bunker of the Los Alamos Scientific Laboratory.* In order to confirm the spin assignments of the 0.434 MeV and the 1.049 MeV excited states and to determine the spin of the 1.770 MeV excited state of Pd^{108} all the directional correlations involving any pairs of the 0.434 MeV, 0.615 MeV and 0.722 MeV gamma transitions were measured.

The results, for the directional correlation coefficients A_{22} and A_{44} in the correlation function

$$W(\theta) = 1 + A_{22} P_2(\cos \theta) + A_{44} P_4(\cos \theta)$$

corrected for the finite sizes of the detectors and of the metallic $\text{Ag}^{108\text{m}}$ source are shown in Table I together with the theoretical A_{kk} computed for

EC 90% > 6.4

IT 10%

Fig. 1. Decay of Ag^{108m}

a variety of spin assignments.

It is clear from an inspection of the data provided in Table I, that only the spin sequence 6 - 4 - 2 - 0 is consistent with the experimental data if pure quadrupole radiation is assumed. Taking into consideration the possibility of mixed E2/M1 transitions for the $5^+ \rightarrow 4^+$ and $3^+ \rightarrow 4^+$ gamma transitions does not give A_{22} and A_{44} values which are consistent with the experimental results. Hence, the present experiment clearly yields a spin 6^+ for the 1.770 MeV excited state of Pd^{108} and confirms the 4^+ and 2^+ spin assignments to the 1.049 MeV and 0.434 MeV excited states, respectively.

* The author is greatly indebted to Dr. M. Bunker of the Los Alamos Scientific Laboratory for the loan of the $\text{Ag}^{108\text{m}}$ source

TABLE I. DIRECTIONAL CORRELATION COEFFICIENTS OF THE Pd^{108} γ - γ CASCADES

γ - γ Cascade (Energies in keV)	Experimental Values	Theoretical Values for $I_1 - I_2 - I_3 - I_4$ Cascades and Pure Quadrupole Radiations		
		6 - 4 - 2 - 0	5 - 4 - 2 - 0	3 - 4 - 2 - 0
722 - 615	$A_{22} = 0.101 \pm 0.002$	0.102	- 0.128	+ 0.020
	$A_{44} = 0.008 \pm 0.003$	0.009	- 0.059	- 0.184
722 - 434	$A_{22} = 0.102 \pm 0.002$	0.102	- 0.128	+ 0.020
	$A_{44} = 0.007 \pm 0.003$	0.009	- 0.059	- 0.184
615 - 434	$A_{22} = 0.100 \pm 0.002$	0.102	0.102	0.102
	$A_{44} = 0.009 \pm 0.003$	0.009	0.009	0.009

7. Gamma - Gamma Directional Correlation Measurements in Te^{124}

K. S. Krane and Z. W. Grabowski

In our previous measurements of $\beta - \gamma$ directional correlations in the decay of Sb^{124} we were able to calculate the mixing ratio of the 722 keV gamma transition¹. This measurement gave $-2.8 \leq \delta_{722} \leq -1.0$ [†]. This δ -value was in agreement with the experimental value $|\delta_{722}| \approx 1$ obtained by Lindquist and Marklund², but disagreed with the value $\delta_{722} = -4.1 \pm 0.6$ obtained from $\beta - \gamma - \gamma$ measurement by Glaubman and Oberholtzer³. The $\beta - \gamma$ directional correlation measurements by Paul⁴ are not precise enough to distinguish between δ_{722} -values in the region $-5.0 \leq \delta_{722} \leq -0.7$. The $\gamma - \gamma$ measurements by Dorikens - Vanpraet et al. performed with scintillation detectors involve large corrections due to unresolved cascades⁵. They favored $\delta_{722} \approx -2.4$. The measurements of Stelson⁶ which were performed using a Ge(Li) - NaI(Tl) combination of detectors yield $\delta_{722} = -3.4 \pm 0.6$. Our measurements of the 722 γ - 603 γ cascade were performed using a combination of Ge(Li) - NaI(Tl) and two coaxial Ge(Li) detectors; the purpose was to improve the accuracy of the measured mixing ratio of the 722 keV transition in Te^{124} .

A least - squares fit of the Ge(Li) - NaI(Tl) measurements for the 722 keV - 603 keV $\gamma - \gamma$ cascade gave

$$W(\theta) = 1 + (0.152 \pm 0.008) P_2(\cos \theta) + (0.304 \pm 0.012) P_4(\cos \theta) .$$

This correlation function is consistent with

$$\delta_{722} = -3.3 \pm 0.1 .$$

The directional correlation function obtained from the Ge(Li) - Ge(Li) measurements

$$W(\theta) = 1 + (0.130 \pm 0.015) P_2(\cos \theta) + (0.295 \pm 0.020) P_4(\cos \theta)$$

gives

$$\delta_{722} = -3.7 \pm 0.3$$

It is interesting to compare these values with the mixing ratios of the $2^{+1} \rightarrow 2^{+}$ transitions in Te^{122} ($\delta_{693} \approx -3.6^{2,7}$), and Te^{126} ($\delta_{750} \approx -7^{7,8}$) which differ only by a pair of neutrons from the Te^{124} nucleus. The δ -values for the $2^{+1} \rightarrow 2^{+}$ transitions (corrected for the energy differences) are in good agreement for Te^{122} and Te^{124} nuclei. The $|\delta(2^{+1} \rightarrow 2^{+})|$ value for Te^{126} seems high. If the effect is real, it would mean some E2 enhancement produced when the neutron number in Te is changing from $N = 72$ to $N = 74$.

In addition, the 645 γ -603 γ , 1691 γ -603 γ and 2091 γ -603 γ correlations in Te^{124} have been measured. The results are summarized in the table together with the results of other authors (quoted here for comparison). It is worth mentioning that the result of directional correlation measurement for the 645 γ -603 γ cascade is in agreement with both $I = 4$ (645 keV transition pure quadrupole) and $I = 3$ (645 keV transition almost pure dipole; $\delta \approx -0.2$) spin assignment for the 1248 keV level. On the basis of the systematics of the excited states of even-even nuclei in this mass region and the absence of the direct feeding to this level from the I^{124} decay, the $I = 4$ assignment is preferred. However, the conversion coefficient measurements for the 645 keV transition⁹ when combined with the directional correlation result seems to favor the spin 3 assignment to the 1248 keV level in Te^{124} .

† All the δ values $\left(\delta = \frac{\langle ||E2|| \rangle}{\langle ||M1|| \rangle} \right)$ are defined in agreement with the notation proposed by Krane and Steffen¹².

TABLE

Cascade	$A_{22} \pm \Delta A_{22}$	$A_{44} \pm \Delta A_{44}$	Ref.
645 keV - 603 keV	0.12 ± 0.04	0.0 ± 0.05	6
	0.099 ± 0.005	0.007 ± 0.008	present, Ge - NaI
	0.121 ± 0.025	0.010 ± 0.030	present, Ge - Ge
1691 keV - 603 keV	-0.063 ± 0.004	-0.009 ± 0.006	5
	-0.072 ± 0.005	-0.007 ± 0.005	11
	-0.099 ± 0.026	$+ 0.03 \pm 0.03$	6
	-0.060 ± 0.006	0.0 ± 0.008	present, Ge - NaI
	-0.064 ± 0.020	-0.005 ± 0.025	present, Ge - Ge
2091 keV - 603 keV	-0.058 ± 0.005	0.001 ± 0.005	10
	-0.052 ± 0.012	0.037 ± 0.018	5
	-0.069 ± 0.015	0.004 ± 0.020	present (preliminary)

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8. Angular Distribution of Conversion Electrons *

R. M. Steffen

The angular (directional and polarization) distribution of internal conversion electrons emitted from oriented nuclear states will be discussed. The oriented nuclear states may be produced by low temperature orientation, by nuclear reactions or by the observation of a preceding radiation (angular correlation). A survey of the theory of the conversion electron particle parameters which characterize the angular distributions of conversion electrons will be presented and the influence of penetration effects and of E0 transitions on the angular distributions will be discussed.

Experimental results for the conversion particle parameters will be reviewed from the point of view of testing the internal conversion theory and from the point of view of extracting information about nuclear parameters.

In general, the agreement between experimental and theoretical particle parameters for unretarded pure multipole transitions is excellent. In several experimental investigations of fast E2 transitions, however, the K- and L- conversion particle parameters were found to be about 15 percent smaller than the theoretical predictions.

The study of particle parameters has revealed the existence of strong penetration effects in many retarded M1 transitions, and in several cases where the selection rules permit, E0 transitions have been found.

The experimental problems in measuring angular distributions of conversion electrons will be discussed. In particular the feasibility of observing conversion electron directional distributions in (p, xn) and (α, xn)

reactions for the study of neutron deficient isotopes will be considered.

* Abstract of invited paper presented at the International Conference on Radioactivity in Nuclear Spectroscopy, Nashville, Tennessee (August 11 - 15, 1969). (See Document No. COO-1746-26)

9. Investigation of Anomalous E2 Conversion Particle Parameters

J. Holm and R. M. Steffen

Construction work on an addition to the Physics Building has interfered seriously with the use of the magnetic electron spectrometer during the past year, and in addition has on several occasions precipitated malfunctions of the spectrometer. Most seriously, the resolution of the spectrometer has deteriorated; in view of the continuing construction, it was decided to postpone a complete realignment of the spectrometer until late summer or fall, when the new wing of the Physics Building will be completed.

As an alternative, a planar Si(Li) detector, 2.0 cm^2 by 2.0 mm depth, was purchased from Simtec, Ltd. Also, it was decided to build a new chamber for this detector for two reasons. First, the chamber which had been used for similar measurements in the past had serious problems with vacuum. Second, the angular correlation table which had been used previously for electron studies is to be replaced by a new table which will be compatible with the other experimental setups used in our laboratory; the new electron

chamber is designed with this new table in mind. A new aluminum chamber for conversion electron measurements using solid state detectors was constructed. The vacuum achieved in the chamber is better than 10^{-6} torr, very adequate for our purposes.

The first measurements with this silicon electron spectrometer was a test measurement on the well known Bi^{207} nucleus. A resolution (FWHM) of 6 keV on the 1063 keV K-electron and 5 keV on the 570 keV K-electron was obtained. The K-electrons are cleanly separated from the electrons from higher shells, and the L and M lines are easily distinguished.

In order to do fast timing TAC measurements with the magnetic spectrometer the old 10 stage 6342A photomultiplier tube was replaced with a 14 stage 6810A tube. This tube and its preamplifier provide a fast pulse suitable for timing. All of the electronic components necessary for a fast timing TAC coincidence system for use with the magnetic spectrometer have been tested. At the present time a large number of those components are being used with the new silicon electron spectrometer.

and a total of 10^5 counts per angle was collected for three independent angles. After correction for the finite solid angle of the detectors, the result for the angular correlation function is found to be

$$W(\theta) = 1 + (0.0046 \pm 0.0040) P_2(\cos \theta) .$$

Since both the 98.5 keV transition and the 30.8 keV transition are mixed M1 + E2, additional information is needed in order to extract the mixing ratios. Törnkvist et al.² recently completed a measurement of the 30.8 keV $L_{II} - 98.5$ keV γ angular correlation, and Thun et al.³ have reported an upper bound of $Q_{30.8} < 7 \times 10^{-4}$ where $Q_{30.8}$ is the fraction of E2 in the 30.8 keV transitions.

Since the ratio $R = A_{22}(30.8 L_{II} - 98.5 \gamma) / A_{22}(30.8 \gamma - 98.5 \gamma)$ depends only on $\delta_{30.8}$, one can combine the measured $A_{22}(L_{II} - \gamma)$ of reference 2 with the $A_{22}(\gamma - \gamma)$ of this work to determine an experimental value of R which can then be compared with theoretical estimates of $R(\delta)$ as a function of $\delta_{30.8}$. Using the internal conversion coefficients and particle parameters derived from the tables of Hager and Seltzer⁴ and the restriction that $Q_{30.8} < 7 \times 10^{-4}$, one finds that

$$\delta_{30.8} = +0.062 \pm 0.032 .$$

Using the experimental value of $A_{22}(30.8 \gamma - 98.5 \gamma)$, this value for $\delta_{30.8}$, and the known fact that the 98.5 keV transition is predominately M1, one can derive a value for $\delta_{30.8}$ of

$$\delta_{30.8} = +0.04 \pm 0.02 .$$

The comparison of these results with earlier results is given in Table I, where it can be seen that these results are in general agreement with previous

results though somewhat smaller. A larger result for $\delta_{98.5}$ would require a smaller $A_{22}(\gamma - \gamma)$ or a larger $\delta_{30.8}$. A small $\delta_{30.8}$ might be explained by the presence of electron scattering in the source over and above that actually corrected. However, since R is very sensitive to $\delta_{30.8}$ in this region, the correction to $A_{22}(L_{II} - \gamma)$ would be almost a factor of 4 which may be possible but which seems unlikely.

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TABLE I. SUMMARY OF RESULTS AND COMPARISON WITH PREVIOUS RESULTS

	$\delta_{30.8}$	$Q_{30.8}$	$\delta_{98.5}$	$Q_{98.5}$
This work	$+ 0.0062 \pm 0.0032$	$(.4 \pm .4) \cdot 10^{-4}^*$	$+ 0.04 \pm 0.02$	$(.16 \pm .16) \cdot 10^{-2}^*$
Törnkqvist et al. ²	$+ .012 \pm 0.004$	$(1.4 \pm 1.0) \cdot 10^{-4}^*$		
Ashery et al. ⁵			$+ 0.129 \pm 0.026$	$(1.6 \pm .6) \cdot 10^{-2}^*$
Nielsen (cited in ref. 2)			$+ 0.17 \pm 0.03$	$(2.8 \pm 1.0) \cdot 10^{-2}^*$
Toburen et al. (cited in ref. 2)				$(1 \pm 1) \cdot 10^{-2}$
McGowan et al. ⁶ and Blaugrund ⁷			$0.16 \pm 0.05^\dagger$	

* Values derived from corresponding δ .

$^\dagger |\delta|$ derived from τ and $B(E2)^2$

11. Precise Measurement of the Hg^{203} β - γ Directional Correlation

S. J. Cipolla* and R. M. Steffen

Precise measurements of the β - γ directional correlation of Hg^{203} are desirable in view of the use of the β - γ cascade in parity impurity measurements.¹⁻³ Attempts are being made^{2,3} to observe a $\cos \theta$ in the β - γ directional distribution which would give evidence of an E1 admixture to the M1 + E2 transition of 279 keV in Tl^{203} . Since the magnitude of this term is expected to be very small (about 10^{-4}) exact corrections for the anisotropy of the regular $P_2(\cos \theta)$ term of the first-forbidden β - γ directional correlation of Hg^{203} are important and an exact knowledge of this β - γ directional correlation is indispensable.

Using the multichannel β - γ directional correlation equipment described in earlier publications⁵, the Hg^{203} sources were prepared by evaporation and were approximately $100\mu\text{g}/\text{cm}^2$ thick with a $240\mu\text{g}/\text{cm}^2$ Mylar backing. The measurements extended over a period of three months in order to accumulate satisfactory statistical accuracy. Corrections for finite solid angles were applied. The corrections for backscattering effects were negligibly small.

The results for the anisotropy coefficient $A_{22}(W)$ in the β - γ directional correlation function $W(\theta) = 1 + A_{22}(W) P_2(\cos \theta)$ are shown in Fig. 1.

The agreement with a previous less accurate measurement reported by us is satisfactory but disagrees with the large anisotropy reported by Bashandy et al.⁷.

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Fig. 1. Anisotropy Coefficient $A_{22}(W)$ of the $\text{Hg}^{203} \beta - \gamma$ Correlation as a Function of Energy in (in units of mc^2)

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12. $e^- - \gamma$ and $\gamma - \gamma$ Directional Correlation Measurements in Ta^{181}

Z. W. Grabowski and F. T. Avignone, III [†]

a) Particle parameters for the 133 keV E2 transition in Ta^{181} . The 133K - 428 γ and 133(L+M) - 482 γ angular correlations in Ta^{181} have been measured in order to determine the particle parameters for the 133 keV transition. The levels in Ta^{181} were populated by the β -decay of Hf^{181} (43 d.).

It had been shown previously that the particle parameters for the 122 keV transition in Sm^{152} and for the 123 keV transition in Gd^{154} (both of pure E2 character) deviate somewhat from theoretically predicted values¹. Measurements agreeing with theory have been reported² (which, however, are not consistent among themselves) but the recent careful measurement of the $b_2(122K)$ parameter in Sm^{152} by H. Blumberg et al.³ confirmed the existence of a deviation of about 7%. Because both transitions with anomalous particle parameters are low energy transitions in strongly deformed nuclei, it is of interest to investigate some similar cases. The 133 keV E2 transition in the highly deformed Ta^{181} seems to be a good candidate. In addition, this transition has a hindrance factor of about 400 (indicating the effectiveness of the Nilsson asymptotic selection rules), and an unusually high value for the E2 transition probability. The K and (L+M) particle parameters were evaluated from $e^- - \gamma$ and $\gamma - \gamma$ directional correlation measurements using the same source. Thus, the values obtained are independent of the

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133 keV - 482 keV correlations due to the long lifetime ($\sim 10^{-8}$ sec) of the intermediate 482 keV state.

The experimental values

$$b_2(133K) = \frac{A_{22}(133K - 482\gamma)}{A_{22}(133\gamma - 482\gamma)} = \frac{-0.138 \pm 0.004}{-0.077 \pm 0.002} = 1.79 \pm 0.11 ,$$

and

$$b_2(133LM) = \frac{A_{22}(133LM - 482\gamma)}{A_{22}(133\gamma - 482\gamma)} = \frac{-0.091 \pm 0.005}{-0.077 \pm 0.002} = 1.18 \pm 0.10$$

are both in good agreement with the theoretically calculated $b_2^{th}(133K) = 1.82$ and $b_2(133LM) = 1.21$, respectively⁴. The very good agreement between the ratio of the $e^- - \gamma$ results

$$\frac{A_{22}(133K - 482\gamma)}{A_{22}(133LM - 482\gamma)} = 1.52 \pm 0.12 \quad \text{as compared with}$$

$$\text{the theoretical value } \left(\frac{b_2(133K)}{b_2(133LM)} \right)_{th} = 1.50 \quad \text{suggests}$$

that no attenuation due to electron scattering in the source was present.

b. Mixing ratio of the 482 keV transition. The strongly retarded 482 keV transition in Ta^{181} ($H(M1) = 2.5 \times 10^6$; $H(E2) = 35$) shows strong penetration effects in the internal conversion process⁵ and therefore it can be used for testing the conservation of parity in strong interaction⁶. Because the theoretical analysis of both effects requires the knowledge of the mixing ratio δ for this transition, the accurate determination of this quantity is of importance. The recent value measured by Bodensadt⁷ ($\delta_{482} = 5.0 \pm 0.2$) differs considerably from that reported by Davies and Hamilton⁸ ($\delta_{482} = 7.2^{+1.8}_{-1.5}$).

We have remeasured the $133\gamma - 482\gamma$ correlation using as a source a HF - solution of Hf^9 . The experimental value of the correlation function

$$W(\theta) = 1 + (-0.295 \pm 0.005) P_2(\cos \theta) + (-0.069 \pm 0.008) P_4(\cos \theta)$$

gives for the value of δ

$$\delta_{482} = 5.8 \begin{matrix} + 0.3 \\ - 0.2 \end{matrix} *$$

In calculating this δ value the $\sim 0.5\%$ contribution from the $133\gamma - 476\gamma$ correlation was not taken into account. This correction will lower the δ_{482} value by about 3%.

c. Mixing ratio of the 136 keV transition. Direct measurement of the mixing ratio of the 136 keV transition using the directional correlation method requires very good resolution in at least one detector (≤ 3 keV). Probably for this reason the value of δ_{136} was not measured previously using this technique. Our measurement of the $346\gamma - 136\gamma$ cascade using Ge(Li) coaxial - NaI(Tl) detectors combination and liquid Hf - source yields

$$\delta_{136} = 0.37 \pm 0.01 .$$

This value of δ_{136} corresponds to $(12.0 \pm 0.6)\%$ E2 contribution which is lower than the value $(16.0 \pm 1.5)\%$ obtained from Coulomb excitation measurements¹¹.

In progress at the present time are measurements on the 1 - 3 $133\gamma - (346\gamma) - 136\gamma$ correlation which will allow independent calculation of δ_{136} and also measurements on the $133\gamma - 346\gamma$ cascade to confirm the E2 character of the 346 keV transition.

* All values of δ are in the notation proposed by Krane and Steffen¹⁰.

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13. Ferromagnetic Nuclear Resonance and Hyperfine Fields in Fe and Ni

W. King, Z. W. Grabowski, and R. P. Scharenberg

The push - pull marginal oscillator has been used to observe the known Co in Ni resonance at 112 MHz at room temperature. This resonance was initially observed in a commercially prepared powdered alloy sample of 0.5 at. % Co in Ni and subsequently in two samples prepared in this laboratory by electron beam melting. The latter samples were annealed for an hour at 1000°C and the resonance signal was observed to be approximately 1000 times stronger after the annealing. Using this known Co resonance the various parameters affecting sensitivity in the oscillator - spectrometer were optimized. The Co resonance signal was also observed on a self - quenched super - regenerative oscillator.

Using both oscillators a search was made at room temperature for the Os¹⁸⁹ resonance in a sample containing 0.4 at. % enriched Os¹⁸⁹ and 99.6 at. % nickel. This resonance was not observed and a subsequent electron microprobe analysis of the sample revealed that the alloy was not homogeneous. This was in contradiction with an earlier but less reliable X-ray diffraction measurement. A second Os - Ni alloy was prepared using un - enriched osmium. The alloy was melted for a total time of about 25 minutes and was established by electron microprobe analysis to be homogeneous. The resonance, however, was still not observable in this alloy. Because of the low natural isotopic abundance of Os¹⁸⁹, it was necessary to make the alloy with about 1.35 at. % Os, and this is believed to have been a contributing factor in the failure to see the resonance in this sample. (Various measurements have indicated that optimum resonance signals are observed for concentrations of about 0.5 at. %

in the "impurity" atom.)

It was not possible to obtain a further quantity of Os^{189} and consequently the decision was made to prepare an alloy with available Os^{187} in iron. This alloy has been prepared in the laboratory (0.37 at. % osmium - Os^{187} - enrichment 45%) and the osmium 187 resonance has been observed in recent preliminary measurements at a frequency of $(107.02 \pm .08)$ MHz at room temperature (22°C). The linewidth is approximately 500 kc. The frequency is roughly consistent with what would be expected on the basis of the 4.2°K measurement of the resonance by Kontani and Itoh¹ and the temperature dependence of the iron saturation magnetization - indicating that the alloy does not exhibit any local moment behavior similar to that observed by Koi and Tsujimura and Jaccarino, et al., for the case of Mn^{55} in iron.^{2,3}

An Os^{187} in nickel alloy is currently being prepared in the laboratory and a search will be made for the osmium resonance in this sample.

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14. The Hyperfine Interaction of Tm - ions

Implanted in a Ferromagnetic Host

A. J. Becker,[†] K. S. Krane, and R. M. Steffen

The hyperfine interaction experienced by Tm nuclei embedded in an iron lattice has been found to be very complex. (See section 8 of Chapter IV of Progress Report No. 2, COO-1746-24). Static and time - dependent magnetic interactions as well as quadrupole interactions are responsible for perturbing the gamma - gamma directional correlations of the 198 - 110 keV and the 177 - 130 keV cascades.

The time - dependent magnetic interaction is due to a spin - relaxation mechanism characterized by a relaxation constant λ which is temperature - dependent and gives rise to an attenuation of the $\gamma - \gamma$ directional correlation anisotropy. The Tm - ions embedded in a ferromagnetic host also experience a non - vanishing expectation value $\langle H_z \rangle$ of the z - component of the magnetic hyperfine field, the z - axis being parallel to the external magnetic field that polarizes the ferromagnetic lattice. This quasi - static field results in a azimuthal shift $\Delta \theta$ of the directional correlation pattern. The time - integrated directional correlation is then of the form:

$$W(\theta) = 1 + \hat{G}_{22} A_{22} P_{22}(\cos(\theta - \Delta \theta))$$

if $A_{kk} = 0$ for $k > 2$.

The attenuation coefficient $\hat{G}_{22} = \frac{1}{1 + \lambda \tau}$ depends only on λ if $\Delta \theta \ll 1$.

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The angular shift $\Delta\theta$ is related to the lifetime τ and the g -factor of the intermediate state of the γ - γ cascade under investigation:

$$\hat{G}_{22} \tan 2\Delta\theta = 2\omega\tau = 2g\mu_N \langle H_z \rangle \tau / \hbar .$$

Using the equipment described in Progress Reports No. 1 and No. 2, the directional correlations of the 198 keV - 110 keV and the 1.77 keV - 131 keV gamma - gamma cascades in Tm^{169} were simultaneously measured as a function of temperature of the magnetized Yb^{169} - Fe source. The results are summarized in Table I. It should be noted that one source was used for experiments No. 1 to No. 8, and one other source was used for experiments No. 9 to No. 12.

Several interesting facts emerge from the analysis of the data.

1. Heating the source causes irreversible changes in the anisotropy (relaxation) and the angular shift ($\langle H_z \rangle$) of the directional correlation, indicating migration of the Yb^{169} nuclei to the grain boundaries in the Fe - lattice. (Experiments No. 1 to 8 in Table I).
2. Cooling the Yb^{169} - Fe source results in an expected increase of the relaxation constants λ_1 and an increase in $\langle H_z \rangle$. The effects are completely reversible. (Experiments No. 9 to 12).
3. The ratio of the two relaxation constants λ_2 and λ_1 is about the same, independent of temperature as one would expect: $\lambda_2/\lambda_1 \approx 2$. From the known g -factors of the two different intermediate nuclear states involved in the two cascades one would expect: $\lambda_2/\lambda_1 = (g_2/g_1)^2 \approx 2.2$.
4. The ratio of the Larmor frequencies ω_2/ω_1 is temperature dependent for $T > 298^\circ\text{K}$. For low temperatures the ratio is constant: $\omega_2/\omega_1 = 0.65 \pm 0.10$. However, this ratio is very different from the expected value $\omega_2/\omega_1 = g_2/g_1 = 1.5$. This discrepancy is difficult to explain,

Table I. Temperature dependence of the γ - γ directional correlation of Tm^{169} embedded in an Fe lattice

Exp. No.	Temp. °K	198 keV - 110 keV, $\tau_1 = 91 \times 10^{-12}$ sec					177 keV - 131 keV, $\tau_2 = 460 \times 10^{-12}$ sec				
		A_{22} ± 0.005	$\hat{G}_{22}$ ± 0.02	λ_{1-} $\times 10^8 \text{ s}^{-1}$	$\Delta\theta$ 0	ω_1 $\times 10^7 \text{ s}^{-1}$	A_{22} ± 0.005	$\hat{G}_{22}$ ± 0.02	λ_2 $\times 10^8 \text{ s}^{-1}$	$\Delta\theta$ 0	ω_2 $\times 10^7 \text{ s}^{-1}$
1	298	0.322	0.96	4±2	2.1±0.5	40±10	0.206	0.73	8±2	3.6±0.6	19±3
2	398	0.313	0.94	6±2	3.8±0.5	72±11	0.214	0.76	7±2	2.3±0.5	12±3
3	498	0.320	0.96	4±2	1.6±0.5	30±10	0.228	0.81	5±2	2.8±0.5	13±3
4	298	0.328	0.98	2±2	0.7±0.5	13±9	0.216	0.76	7±2	2.8±0.5	14±3
5	598	0.334	1.00	0±2	0.6±0.5	11±9	0.255	0.90	2±2	1.0±0.5	4±2
6	298	0.324	0.97	3±2	0.4±0.5	8±9	0.231	0.82	5±2	1.5±0.5	7±3
7	698	0.330	0.99	1±2	0.2±0.5	4±9	0.270	0.96	1±2	0.3±0.5	1±2
8	298	0.322	0.96	4±2	0.1±0.5	2±10	0.248	0.88	3±2	0±0.5	0±2
9	298	0.319	0.95	5±2	2.7±0.3	55±6	0.176	0.62	13.5±1	5.9±0.5	36±4
10	77	0.285	0.86	17.5±2	4.2±0.5	93±10	0.114	0.40	33±1	6.4±1.0	60±10
11	298	0.320	0.96	4±2	2.8±0.3	57±6	0.176	0.62	13.5±1	6.2±0.5	38±4
12	77	0.283	0.85	19±2	4.1±0.5	92±10	0.117	0.41	31±1	5.3±0.7	48±6

unless one assumes that for a short time following the formation of the intermediate states of the Tm^{169} γ - γ cascades, a very strong transient $\langle H_z \rangle$ field exists which decays very rapidly (in less than about 10^{-11} sec.).

VII. STUDY OF FIRST - FORBIDDEN BETA TRANSITIONS1. Beta Decay Matrix Elements of La^{140} and the Implications
for Isobaric Analogue States *

H. A. Smith and P. C. Simms

Experimental data is used to determine the first forbidden matrix elements for the 2.2 MeV beta transition of La^{140} . The results show that the matrix element ratio $(\int \vec{\alpha} / \int i\vec{r})$ does not agree with the usual theoretical prediction which assumes the Ahrens-Feenberg approximation. The size of the experimental vector matrix element ratio can be understood on the basis of significant off-diagonal contributions in the Coulomb Hamiltonian. The CVC theory is used to show that the measured matrix element ratio implies that there will be no pure isobaric analogue to the ground state of La^{140} . In addition, the contribution of third forbidden matrix elements to the transition is investigated.

* Abstract of paper submitted to and accepted by The Physical Review

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2. Energy Dependent Beta - Gamma Circular Polarization of La^{140} *

D. E. Ohlms,[†] J. J. Bosken[‡] and P. C. Simms

The beta-gamma circular polarization has been measured as a function of the beta particle energy for La^{140} and for Co^{60} . The Co^{60} results confirm that P_γ is proportional to v/c . The results for the 2.2 MeV transition of La^{140} shows that the original prediction for the vector matrix element ratio is not correct for this transition. However, the results are consistent with predictions based on the CVC theory if the approach suggested by Damgaard and Winther is followed. This interpretation yields information on third forbidden matrix elements.

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3. Analysis of Beta Decay Matrix Elements

P. C. Simms, H. A. Smith, and J. S. Schweitzer

The work on La^{140} referred to in sections 1 and 2 has shown that first forbidden beta decay matrix elements can be influenced by off-diagonal contributions in the Coulomb Hamiltonian. These same off-diagonal terms contribute to the impurity mixing of the isobaric analogue to the parent state of the beta transition. Therefore careful investigation of the first forbidden matrix elements gives detailed information on the nuclear structure of the states involved in the beta transition and the corresponding isobaric analogue state.

This investigation has been continued by determining matrix elements for a number of other nuclei. In all cases beta-gamma circular polarization, directional correlation, and beta spectrum shape data have been used. Additional information which was used will be noted when each isotope is considered. The present analysis for these isotopes is more accurate than previously reported results for several reasons. Contributions from higher order matrix elements and screening of atomic electrons have been included. The off-diagonal elements of the Coulomb Hamiltonian have not been neglected. Recent experimental data has been included to set better limits on the matrix elements.

The following ratio of beta matrix elements is affected by the off-diagonal elements of the Coulomb Hamiltonian.

$$\Lambda \equiv \frac{\int \vec{\alpha}}{\int i\vec{r}} = \Lambda_0 \pm \frac{\alpha Z}{2\rho} (0.6 - \lambda) \quad \text{for } \beta^{\mp}$$

Λ_0 is the value of the matrix element ratio obtained from conserved vector current theory if the off-diagonal contribution of the Coulomb Hamiltonian is neglected, and

$$\alpha = 1/137$$

$$Z = \text{charge of the daughter nucleus}$$

$$\rho = \text{nuclear radius in natural units}$$

If λ is equal to 0.6 then the off-diagonal elements do not affect Λ . The parameter λ also provides information about the nuclear structure because it is equal to the ratio of a higher order to a first order matrix element

$$\lambda = \frac{\int \vec{r} (r/\rho)^2}{\int \vec{r}}$$

The following general connection can be made between the beta decay matrix elements and isobaric analogue states: the degree of mixing in the isobaric analogue state due to the Coulomb force should be proportional to $(0.6 - \lambda)$.

The most important features of the results can be seen easily by using a simplified notation. $M(\Delta J)$ will be used to indicate the relative size of the matrix elements that cause a change of angular momentum ΔJ in the beta transition. The parameter η gives the absolute size of the matrix elements on a scale where complete overlap of the wave functions would give a matrix element equal to $\sqrt{2}$, i.e. $\langle f | 0_p | i \rangle = \eta M(\Delta J)$.

a) Sb¹²⁴ 2.3 MeV transition. The analysis yields well defined matrix elements and shows that there must be large contributions from the off-diagonal elements of the Coulomb Hamiltonian (λ large). In addition, the matrix elements are unusually small (η small).

$$\begin{aligned}\eta &\approx 0.02 & |\lambda| &> 3 \\ M(0) &= 0 & M(2) &\approx 10M(1)\end{aligned}$$

From the analysis we also learned that a more precise measurement of the $\beta - \gamma$ directional correlation could set limits on the magnitude of λ . We are studying the feasibility of performing this measurement.

b) Sb¹²² 1.4 MeV transition. Sb¹²² illustrates that a change of two neutrons can make a dramatic difference. The matrix elements are an order of magnitude larger than Sb¹²⁴; they are all approximately the same size, and the contribution of the off-diagonal elements can not be large

$$\begin{aligned}\eta &\approx 0.1 & \lambda &= +0.6 \pm 1.0 \\ M(0) &\approx M(1) \approx M(2)\end{aligned}$$

c) Au¹⁹⁸ 0.96 MeV transition. An unusually large amount of data is available on this isotope. In addition to the usual experimental data, data on the longitudinal polarization of the beta particles and the angular distribution of gamma rays from oriented nuclei were used. Au¹⁹⁸ is a classical example of a nucleus where the terms which are enhanced by the Coulomb field dominate the transition probability (usually referred to as the ξ approximation). When this is true, it is almost impossible to set good limits of error on the matrix elements even though a large variety of accurate data is available as in the case of Au¹⁹⁸.

Two different types of matrix element sets were obtained:

$$\begin{aligned}\text{Set 1 :} & \quad \eta \approx 0.1 & \lambda &= 0.6 \\ & M(0) \approx M(1) \approx M(2)\end{aligned}$$

$$\begin{aligned}\text{Set 2 :} & \quad \eta \approx 0.1 & \lambda &> 2 \\ & M(0) \approx M(1) \approx 10M(2)\end{aligned}$$

4. Beta - Gamma Circular Polarization of As^{76}

P. C. Simms and H. A. Smith

An analysis of the data which is currently available for the 2.4 MeV transition of As^{76} has shown that good limits of error can be established on the matrix elements of this transition by performing a precise measurement of the energy dependence of the beta - gamma circular polarization P_γ . However, since we expect that P_γ will be $\leq 10\%$, this is a very difficult experiment. Most of this contract period has been used to improve the circular polarization analyzer and to make preliminary runs on As^{76} .

The major improvement which was necessary was to further reduce the effect of the magnetic field on the photomultiplier tubes. The problem turned out to be quite subtle because the magnetic field affected the shape of the photomultiplier pulse more than it affected the total charge in the pulse. This means that the coincidence counting rate was more sensitive to the magnetic field than the single counting rate. The required modifications have been completed and the instrument can now measure the $\beta - \gamma$ circular polarization correlation of As^{76} with a 1% accuracy. Final measurements are underway, and the experiment should be finished before the end of the contract period.

5. Matrix Element Determinations for Hindered Beta Transitions

in ^{124}Sb and ^{160}Tb *

S. J. Cipolla[†] and R. M. Steffen

Beta-gamma directional correlation measurements as a function of beta-energy have been made on the cascades $\beta(1.590)\text{-}\gamma(0.722)$ and $\beta(1.667)\text{-}\gamma(0.645)$ in the decay of ^{124}Sb and on the cascades $\beta(1.750)\text{-}\gamma(0.087)$ and $\beta(1.540)\text{-}\gamma(0.197)$ in the decay of ^{160}Tb . A high-resolution Ge(Li) gamma detector was used, providing a significant improvement in the accuracy of the measurements. The data and the ft values are used to determine the nuclear matrix elements for the 1.590 MeV beta transition and for the 1.750 MeV beta transition. In each case, two sets of matrix elements were found to fit the data well, and arguments based on the CVC theory and nuclear models are used to select the best set. The matrix elements are compared with those measured for hindered beta transitions in other nuclei. The matrix-element analyses of the 1.667 MeV transition in ^{124}Sb and the 1.540 MeV transition in ^{160}Tb both met with difficulties.

RADIOACTIVITY ^{124}Sb [from $^{123}\text{Sb}(n,\gamma)$] ; ^{160}Tb [from $^{159}\text{Tb}(n,\gamma)$] ;
measured $\beta\gamma(\theta)$; deduced β -decay matrix elements.

* Abstract of paper published in Nuclear Physics A143, 404 (1970).

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VIII. ULTRA SHORT LIFE - TIME MEASUREMENTS

P. C. Simms and G. J. Smith

The instrument used in this experiment has been completely redesigned in order to decrease the time required to measure a life - time by more than a factor of 10. This improvement was necessary so that life - times can be measured for states excited with the accelerator in a few hours rather than a few days. A brief review of the method will be necessary in order to understand the changes that have been made. Consider a simple gamma cascade where a 1 MeV gamma ray is followed by a 0.5 MeV gamma ray. The purpose of the experiment is to measure the life - time of the intermediate state. Two fast plastic scintillators are connected to a start - stop type time - to - amplitude converter (TAC). A single channel analyzer for each detector is set on the Compton distribution of the lower energy gamma ray. Therefore both detectors can respond to either gamma ray. The TAC produces two time distributions. When the first gamma ray is detected in the start channel and the second gamma ray is detected in the stop channel, the associated time distribution is shifted toward larger time by the mean life τ of the intermediate state. When the gamma rays are reversed, the time distribution is shifted towards shorter time by τ . Therefore the difference between the two time distributions is equal to 2τ .

Since all of the interactions in the plastic detector are due to Compton scattering, the energy of the incident gamma ray can be determined by absorbing the scattered gamma ray in a NaI detector. The plastic detector is located in a hole drilled through a 3 x 3 inch NaI detector so that there is a high probability of absorbing the scattered gamma ray.

The energy of the gamma rays is needed in order to identify the two time distributions so that they can be recorded separately. With this system the timing (plastic) detectors can not distinguish between the two gamma rays so the possibility of systematic timing errors is minimized. Nevertheless the two time distributions can be separated because the total energy of the gamma ray is absorbed in the NaI - plastic detector combination.

The new electronic system which has been developed for this experiment is shown in Fig. 1. The anode pulses from the timing photomultipliers are connected to constant fraction discriminators (CFD) to further reduce systematic errors which are caused by a difference in the average energy deposited in the plastic scintillators by the two gamma rays. Single channel analyzers (SCA) 2 and 3 divide the accepted portion of the Compton distribution into two intervals. An output from double coincidence circuit (DC) 1 indicates that a scattered gamma ray has been detected in coincidence with a timing signal. Single channel analyzers 3 and 4 select the low and high energy gamma rays, respectively, from the NaI - plastic sum spectrum. These SCA's are not activated unless a double coincidence (DC1) occurs.

Triple coincidence circuits (TC) A1 and A2 respond when a low energy gamma ray is recorded in channel A and a high energy gamma ray is recorded in channel B. TC - A1 responds if the timing signal in channel A is in the lower part of the Compton distribution. TC - A2 responds to events in the upper part of the Compton distribution. A similar system is provided in channel B to process events when the two gamma rays are reversed. Four time distributions can be recognized. There are two time distributions for $+\tau$ and two for $-\tau$. The two distributions in a pair differ only by the amount of energy deposited in the timing detectors. Thus the difference in

FIGURE 1. BLOCK DIAGRAM OF ULTRA SHORT LIFE - TIME ELECTRONICS

The following notation is used

DDL LA = double delay line clipped linear amplifier

ZC SCA = zero crossing single channel analyzer

CFD = constant fraction discriminator

DC = double coincidence

TC = triple coincidence

SSCA = strobed single channel analyzer

R = router

S = scaler

TAC = time - to - amplitude converter

ADC = analogue - to - digital converter

the centroids of the two distributions in a pair provides a measure of the residual amplitude walk in the timing detectors. This information is used to correct the results and to indicate when the constant fraction discriminators need to be adjusted.

TC - 3 provides a gate to open the analogue - to - digital converter (ADC) if DC A1 and B1 signify a complete event in coincidence with a time conversion. The linear time output of the TAC is converted to a number by the ADC. The average value of this number is equal to the centroid of the time distribution.. The average value is obtained by summing the address pulses from the ADC on a scaler. The number of separate address trains are recorded on a second scaler. The total address divided by the number of address trains is equal to the average address or centroid. Since four time distributions must be recorded, there are four routers (R) which direct the address train to four pairs of scalers (S).

The four time distributions could be recorded on a multichannel analyzer, but then the centroids must be calculated by hand or at a later time with a computer. The system we are using is both less expensive and much faster. The centroids are obtained automatically. This is particularly important when a large number of centroids are run while adjusting the constant fraction discriminators.

In the original version of the instrument, it was necessary to restrict the timing detector SCA window to 10% of the Compton distribution. With the better amplitude walk correction and better energy analysis provided by the new system, 50% of the Compton distribution can usually be used. Thus there is a factor of 25 (5 for each detector) increase in the data accumulation rate.

The characteristics of the new system are the following: any state which can be identified with the energy resolution provided by NaI detectors can be studied. The life - time can be measured with an accuracy of 10^{-13} sec. or 2% for larger life - times. Most measurements will require less than 24 hours.

IX. NUCLEAR THEORY

1. Off-Energy - Shell t - Matrix for Local Potentials

with Singular Core Interactions *

Y. E. Kim

As a preliminary to studying three - body problem involving local two - particle potentials with singular core interactions, we have derived and numerically studied an integral equation for the complete off-energy-shell t-matrix for the associated two - particle scattering. The core interaction is described by the boundary condition model (specified energy-independent logarithmic derivative of the radial wave function at the core radius). The t-matrix for a hard-core and a local outside potential is obtained from our formalism as a special limiting case. Numerical solutions of the integral equation for the special case of the Herzfeld potential (hard core with a square well outside) are found to agree well with the exact t-matrix. These results are published in The Physical Review¹.

The above derivation of an integral equation formalism, which gives the complete off-energy-shell t-matrix for two - body scattering via local potentials with singular core interactions, is generalized to include the effects of tensor and Coulomb forces for the purpose of applying the formalism to the calculation of three - nucleon bound - state and scattering parameters using the Faddeev formalism and realistic nucleon - nucleon forces. A detailed description of this work is reported in AEC Document No. C00-1746-37.

* Work done in collaboration with A. Tubis, Department of Physics, Purdue University.

1. Y. E. Kim and A. Tubis, Phys. Rev. I C, 414 (1970). (AEC Document No. C00-1746-28).

2. Three - Body Problem with Local Hard - Core Potentials *

Y. E. Kim

The Faddeev formalism has been used to compute the ground - state energy of the triton for a simple model in which the nucleon - nucleon force is given by a spin-independent s-wave Herzfeld potential (hard core with outside square well). The effective nucleon - nucleon potential used corresponds to the usual weighted average of triplet and singlet potential strengths. The two variable Faddeev equation is solved using the complete off-shell t-matrix given by : (1) an exact analytic expression, and (2) an integral equation formalism¹ recently proposed. The approximate product integration method² was used in solving numerically the two - variable integral equation (Faddeev equation). Three - body calculations based on both evaluations of two - body t-matrix lead to a triton binding energy of 8.13 MeV with about 0.5% accuracy. Detailed description is given in AEC Document No. COO-1746-29.

* Work done in collaboration with A. Tubis, Department of Physics, Purdue University.

1. Y. E. Kim and A. Tubis, Phys. Rev. I C, 414 (1970). See the preceding report 1.
2. Y. E. Kim, J. Math. Phys. 10, 1491 (1969); Phys. Letters 29B, 411 (1969).

3. Faddeev Equations for Realistic Three - Nucleon Systems *

E. P. Harper and Y. E. Kim

A complete angular - momentum reduction of the Faddeev equations has been carried out for the case of realistic, non-relativistic three - nucleon systems with (local and / or non-local) interactions having general spin, isospin and velocity dependence. Antisymmetrization of states with respect to particle exchange is properly accounted for by using properties of the permutation group and the isospin formalism. Expressions for the Faddeev equations in the form of coupled two - variable integral equations are obtained in two different coupling schemes; $J - j$ [coupling of the (relative orbital plus total spin) angular momentum of a nucleon pair with the total angular momentum of the third nucleon (in the center-of-mass system) to give the total angular momentum in the center-of-mass system] ; and $\mathcal{L} - \mathcal{S}$ [coupling of the total orbital angular momentum (relative orbital angular momentum of nucleon pair plus the orbital angular momentum of the third nucleon) in the center-of-mass system with the total spin angular momentum (total spin angular momentum of a nucleon pair with the spin angular momentum of the third nucleon) to give the total angular momentum in the center-of-mass system]. For the special case of separable two - nucleon interactions, our results can be used to reduce the Faddeev equations to a set of coupled integral equations in one continuous variable. The results of this work are described in AEC Document No. C00-1746-36.

* Work done in collaboration with A. Tubis, Department of Physics, Purdue University.

4. Two - Nucleon Transfer Reactions *

Samuel M. Harris

Assuming isospin conservation, we perform an analysis of the two nucleon transfer reactions (p,t) and $(p,^3\text{He})$ on a target with isospin T_i going to analog final states with $T_f = T_i$. Formulas for the relevant cross sections are given which explicitly show the isospin dependence of the transferred pair. When restricted to $T = 1$ pair transfer, our result is more general than that recently derived by Hardy, Brunnader, and Cerny.

* Abstract of paper published in The Physical Review 1C, 362 (1970).

(See Document No. COO-1746-30)

5. A Simple Model for Overlapping Resonances *

Samuel M. Harris

We investigate the resonant lineshape in the presence of two overlapping resonances. A simple one-dimensional model is employed for the scattering of massless particles by a heavy target. It is assumed that the scattering process may proceed via either of two resonant states which are allowed to have arbitrary separation and widths. If we limit ourselves to only one open channel for resonance decay, then the scattering cross section exhibits two maxima (at ω_1 and ω_2 , the positions of the resonances) and an intermediate zero. We further investigate the time-dependent decay of the resonant states and find that two special resonance combinations can be constructed which exhibit a simple exponential decay

modulated by a sinusoidal component. Pure exponential decay does not occur when the resonances overlap. The lineshape problem is extended to include the possibility of many open channels, and the cross section for that case is presented.

* Abstract of paper submitted to Nuovo Cimento for publication.

(See Document No. C00-1746-38)

6. Application of Soluble Many - Body Problem

Samuel M. Harris

The work described in the 1969 Progress Report has not been appreciably extended. We are still at the stage therein described -- the formalism for the three - body case has been fully developed, the matrix elements have been explicitly written down, but the extensive numerical work still remains to be done. Conclusion of this work will be postponed until further support in this research can be obtained.

LIST OF PUBLICATIONS

June 1, 1969 to May 31, 1970

a) Papers Published

1. COO-1746-9 Mixing Ratios of Transitions in the Decay of Ir^{192} .
Zbigniew W. Grabowski. The Physical Review 183,
1019 - 1024 (1969).
2. COO-1746-20 Solution of the Faddeev Equation for Local Potentials
by Approximate Product-Integration. Y. E. Kim.
Journal of Mathematical Physics 10, 1491 - 1494 (1969).
3. COO-1746-21 Energy Dependent Beta - Gamma Circular Polarization of
 La^{140} . D. E. Ohlms, J. J. Bosken and P. C. Simms.
The Physical Review (approximately May, 1970).
4. COO-1746-22 Comparison of Solutions of the Faddeev Equation with
Variational Results for a Yukawa Potential. Y. E.
Kim. Physics Letters 29B, Number 7, 411-413 (1969).
5. COO-1746-23 Determination of the Quadrupole Moments of First
Excited 2^+ States in Cd^{114} and Fe^{56} by Coulomb Exci-
tation. G. Schilling, R. P. Scharenberg, and J. W.
Tippie. The Physical Review (approximately May, 1970).
6. COO-1746-26 Angular Distributions of Conversion Electrons. R. M.
Steffen. Proceedings of the Conference on Radio-
activity in Nuclear Spectroscopy, Nashville, Tennessee,
(August 11 - 15, 1969).
7. COO-1746-27 Matrix Element Determinations for Hindered Beta Tran-
sitions in ^{124}Sb and ^{160}Tb . S. J. Cipolla and R. M.
Steffen. Nuclear Physics A143, 404 - 428 (1970).
8. COO-1746-28 Off - Energy - Shell t - Matrix for Local Potentials with
Singular Core Interactions. Y. E. Kim and A. Tubis.
The Physical Review, Vol. I C, 414 (1970).

9. COO-1746-29 Three - Body Problem with Local Hard - Core Potentials. Y. E. Kim and A. Tubis. The Physical Review (May, 1970).
10. COO-1746-30 Two - Nucleon Transfer Reactions. Samuel M. Harris. The Physical Review, Vol. I C, 362 (1970).
11. COO-1746-33 Beta Decay Matrix Elements of La^{140} and the Implications for Isobaric Analogue States. H. A. Smith and P. C. Simms. The Physical Review (May, 1970).

b) Papers Submitted for Publication

12. COO-1746-25 g - Factors of the First Two Excited 2^+ States in Pt^{192} . Z. W. Grabowski. (Submitted to and accepted by The Physical Review).
13. COO-1746-31 Determination of the E2/M1 Multipole Mixing Ratios of the Gamma Transitions in Cd^{110} . K. S. Krane and R. M. Steffen. (Submitted to and accepted by The Physical Review).
14. COO-1746-32 Measurements of the Static Quadrupole Moment of the First Excited 2^+ States of the Nuclei Pd^{106} and Pd^{110} by Heavy Ion Coulomb Excitation. R. Beyer, R. P. Scharenberg, and J. Thomson. (Submitted to The Physical Review).
15. COO-1746-36 Faddeev Equations for Realistic Three - Nucleon Systems I. Complete Angular - Momentum Reduction and Antisymmetrization of States. E. P. Harper, Y. E. Kim and A. Tubis. (Submitted to The Physical Review).
16. COO-1746-37 Off - Energy - Shell t - Matrix for Local Potentials with Singular Core Interactions II. Tensor and Coulomb Forces. Y. E. Kim and A. Tubis. (Submitted to The Physical Review).

17. COO-1746-38 A Simple Model for Overlapping Resonances. Samuel M. Harris. (Submitted to Nuovo Cimento).

c) Abstracts of Papers Presented at Meetings of the American Physical Society

18. COO-1746-31 E2/M1 Multipole Mixing Ratios of Gamma Transitions in Cd^{110} . K. S. Krane and R. M. Steffen. BAPS 15, 63 (1970).
19. COO-1746-32 Static Quadrupole Moment of the First Excited 2^+ States in Pd^{106} and Pd^{110} Determined by Coulomb Excitation. R. W. Beyer, R. P. Scharenberg, and J. A. Thomson. BAPS 15, 100 (1970).
20. COO-1746-34 Source Temperature Effects on Perturbed γ - γ Directional Correlations for ^{169}Tm in Iron. A. J. Becker and R. M. Steffen. BAPS 15, 101 (1970).
21. COO-1746-35 E2/M1 Mixing Ratios of Gamma Transitions Observed in the Region of $A = 190$. K. S. Krane and R. M. Steffen. BAPS 15, 545 (1970).

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