nuclear structure research

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RESEARCH IN NUCLEAR PHYSICS

Progress Report No. 2

June 15, 1969

MASTER

Contract AT(11-1)1746

between

Purdue Research Foundation

and

United States Atomic Energy Commission

P2115

department of physics
purdue university

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RESEARCH IN NUCLEAR PHYSICS

Progress Report No. 2

Period: June 1, 1968 - May 31, 1969

Nuclear Structure Laboratory
Purdue University
Lafayette, Indiana

Contract AT(11-1)1746
between
Purdue Research Foundation
and
United States Atomic Energy Commission

June 15, 1969

R. M. Steffen
Professor of Physics
Principal Investigator

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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, 1968 to May 31, 1969.

The principal activity of the Purdue Nuclear Structure Group during the report period was the installation of the FN-Tandem Van de Graaff Accelerator in the new Purdue Nuclear Structure Laboratory Building.

Operation of the Purdue Cyclotron was discontinued in August, 1968 and the cyclotron has been completely dismantled.

The research activities in nuclear spectroscopy using radioactive isotopes and the Coulomb excitation experiments with the Tandem accelerator of the Argonne National Laboratory were continued and are being reported here.

Research at the Purdue Nuclear Structure Laboratory is performed by the faculty 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. INSTALLATION OF FN-TANDEM VAN-de-GRAAFF ACCELERATOR

1. Completion of Nuclear Structure Laboratory Building

The new Nuclear Structure Laboratory Building was essentially completed by December 15, 1968, and occupation of the building started at that date. The construction schedule was delayed by more than three months due to a plumber strike in summer 1968.

The floor plans of the building, which is completely underground, have been shown in Progress Report No. 17 (COO-1420-134, June 15, 1967). The building provides adequate space for future expansion of the accelerator facilities and has 5 data rooms, 8 laboratories, 12 offices, and large computer and laboratory assembly areas. Figure 1 shows a view of the accelerator room with the accelerator tank installed.

2. Installation of Tandem Van-de-Graaff Accelerator

Delivery of the main accelerator components began December 10 and the last truck-load arrived December 18, 1968. The remainder of December and the first part of January, 1969, were spent uncrating and setting up the major components. Assembly of the column and components began in early January. Upon close inspection two glass chips were found in one of the column sections. HVEC (High Voltage Engineering Corporation) was unwilling to guarantee such a column for long term, so that section was shipped back to HVEC for rebuilding. This delayed the column building somewhat until the section was returned on January 30. Otherwise construction inside the tank progressed satisfactorily and the column was compressed on February 12.

FIG. 1. ACCELERATOR ROOM

Purdue had contracted with HVEC for installation of the accelerator and target room components. HVEC then subcontracted the plumbing and wiring. This arrangement was not completely satisfactory since the subcontractors were not adequately supervised by HVEC. Many mistakes were made, particularly in the insulating-gas plumbing, which had to be later corrected with considerable loss in time.

The assembly of the beam extensions outside the tank was hampered to a great extent by vacuum leaks. This accelerator had not been preassembled at HVEC and some difficulty was to be expected, but many leaks showed up in completely assembled components which were supposedly leak-free. The last of these was repaired May 1.

Inside the tank everything went well except for drive motor difficulties. The motor was first tested under belt tension on March 21. After about one minute the motor started to smoke. It was stopped and it was found that the windings were essentially short-circuited to the case. A replacement arrived March 28. It appeared to have defective bearings and was run external to the tank for checkout. Bearing temperatures rose rapidly and the motor was badly out of balance. We rejected it. A third motor from a new vendor (H. K. Porter) arrived April 14. It ran smoothly and quietly with no load. Under belt tension, however, it ran well for 19 minutes and then started making loud noises. It was stopped and disassembled. Large pieces of the rotor and stator had been torn apart. The vendor's representative told us that it was one of three prototypes and had been assembled under less than optimum conditions. A fourth motor (from Louis Allis) arrived and was installed April 22. It appears to be good and is running well at present.

The duoplasmatron ion source has given considerable trouble, mostly with leaks. The whole source has been replaced once. Currently the source is producing enough beam for the acceptance tests even though there is evidence of cooling-oil leaks inside the vacuum box. A new source will be installed after being bench tested at HVEC.

After the insulating gas was delivered, a strange substance was found in the lines leading from the compressor to the gas storage cylinders. It was a dry clay-like residue which was finally traced to the "lectrofilter" on the compressor discharge. It appeared that this substance had been in the filter when it was delivered. The filter has been cleaned by the vendor and replaced, and the gas lines have been cleaned. An additional filter has been placed in the line to protect the accelerator from any of this substance which may be in the storage cylinders. None was found in the accelerator tank after the first filling.

A small amount of beam (1μ amp) was obtained through the accelerator on May 9. The tank had to be opened soon afterward to repair the foil stripper. This took only two days and the machine has been running well since then. The first of the acceptance tests were run on May 16. It appears that most of the acceptance tests can be run during the first part of June. It is expected that the accelerator will be ready for nuclear research experiments by July 1, 1969.

3. Installation of Beam Lines

The installation of three beam lines (45° , 0° , -45°) has been completed by the Purdue Nuclear Structure Group. The three quadrupole focussing magnets and the vacuum hardware has been furnished by the High

Voltage Engineering Company. The central high vacuum pump which serves all three beam lines is a molecular pump manufactured by Welch. On each side of the switching magnet a General Electric Ion pump has been installed. In order to avoid the inconvenience and expense of filling liquid-nitrogen traps, no oil or mercury diffusion pumps are used in the beam line vacuum system. A schematic diagram of the beam transport system has been shown in Progress Report No. 17 (COO-1420-134, June 15, 1967). Figure 2 shows a picture of the target room with the three beam lines.

Fixed stands for an optical precision telescope and a laser are being installed for the geometrical alignment of the beam lines and the scattering chambers.

The hardware for two additional beam lines has been ordered and these beam lines will be installed in the near future.

4. Ion Source Development

Components and materials are being procured for the construction of a test bench for ion sources. The test bench will be used for the development of heavy ion beams for Coulomb Excitation experiments. A helium source will also be developed using lithium vapor for electron attachment. The helium source will be a separate unit which will be mounted on the source box opposite the standard duoplasmatron.

5. Cable System for Tandem Van-de-Graaff Accelerator

A cable system has been installed to connect all of the target room positions to twelve data collection locations. A number of precautions were taken to prevent noise pick-up in the system. Shielded bundles of

FIG. 2. TARGET ROOM WITH THREE BEAM LINES INSTALLED

coaxial cables were obtained from Consolidated Wire Corporation. The outside shield of each bundle of cables was grounded at one point in the center of the cable system. The shields of the individual coaxial cables are grounded only at the data collection end of the cables. This arrangement provides double protection against noise pick-up and also prevents ground loops.

All of the cables from the target room and the data collection rooms come together at a central switching location. (The bundle shields are grounded at this point). The cables from the target room are connected to coaxial jacks which are mounted on an insulated panel. (The panel must be insulated because the individual cable shields are grounded only at the data room ends). Thus any data collection location can be conveniently connected to any target position at this interconnection panel.

There are twelve sets of cables for the data collection rooms and seven sets for the target room. Each set contains the following cables:

- 24 RG 62/U signal cables
- 8 RG 59/U high voltage cables
- 4 RG 58/U high frequency cables
- 18 Twisted-pair control wires.

6. Interlock and Radiation Monitor System

a) Tandem Accelerator Interlock System

With minor exceptions, this accelerator interlock system remained unchanged from that purchased from the High Voltage Engineering Corporation. One of these exceptions being the addition of rotating/flashing type warning lights used to indicate the starting and operation of the accelerator.

b) Emergency (Scramble) Interlock System

An independent interlock system was provided in order that the complete accelerator shutdown could be manually performed for conditions not otherwise protected. This was accomplished by the strategic placement of "Emergency Stop" button switches throughout the accelerator and target rooms.

c) Door Monitor and Interlock System

The major components of this system are a card actuated multiple switch, an audible alarm system, an interlock "map" panel to indicate the state of all doors, and a set of prepunched cards.

This system is based on the one currently in use at the P-9 Laboratory at Los Alamos, New Mexico.

A prepunched card may be selected by the Laboratory Radiation Protection Supervisor which will control appropriate interlocking devices according to particular radiation conditions. Each device will actuate two (2) SPDT microswitches such that when the device is closed, a closed contact applies 24 VDC to a green indicator light indicating a closed state in the appropriate position on the map panel. Opening the device will remove power from the green indicator and apply it to a DC coupled gate of a silicon controlled rectifier (SCR). There is a yellow indicator light in series with the SCR which will be illuminated when the SCR conducts. This indicator is reset by opening the anode power source to the SCR. If the device is open, the indicator will not reset. If the device is closed, it may be reset at the map panel. The DC coupled gate signals of the SCR's are filtered to prevent false triggering. They are also capacity coupled to diodes or gates which trigger a one shot gong audible indicator used to

signify the opening of a device. By using capacity coupling to the gong, the opening of other devices will also trigger a one shot pulse to the gong. Other diode gate lines may be connected to operate beam stops, control the accelerator belt charge, or to shut off the accelerator drive motor.

d) Radiation Monitor Interlock System

This is undoubtedly the most important link in the overall tandem accelerator safety interlock system and therefore must have all its conditions satisfied in order to operate either the accelerator or any other device throughout the laboratory. The radiation detectors are manufactured by the Nuclear Measurements Corporation, Indianapolis, Indiana, and are linked to the complete system by means of the prepunched card operated multiple switch. Each detector has a local meter to indicate the radiation level as well as audible and visual alarms. These are also remoted to the main operating console. The detectors have been modified to provide three (3) discriminator level outputs (low, safe, and excessive) which are used to control the accelerator and to limit access in appropriate areas.

7. Vacuum Interlock System

A fail-safe vacuum interlock system has been designed which will provide a high degree of protection for the accelerator and vacuum system against vacuum catastrophes precipitated by utility interruption, pump failures, and human error. The system also affords a maximum measure of protection for the "in-use" experimental setup.

II. INSTRUMENTATION FOR EXPERIMENTS WITH TANDEM ACCELERATOR

1. 18" General Purpose Scattering Chamber

F. A. Rickey and D. L. McShan

In order to provide facilities for performing a wide variety of scattering experiments, an Ortec 18" scattering chamber has been purchased. This chamber is particularly well suited for performing accurate angular distributions for charged particle reactions, and will complement the special purpose chambers for Coulomb excitation and charged-particle-gamma ray work.

The chamber has been instrumented to satisfy several basic requirements; clean vacuum, low background, cooled detectors, and flexible targeting.

The vacuum system is based on an Ultek 1000 liter per second "Boostivac" pump. The basic pump is a 150 l/sec ion pump. This pump attains good vacuums in the 10^{-7} - 10^{-8} Torr range, and avoids the contaminants introduced by conventional diffusion pumps. Since the cycle time on a conventional ion pump is long, the pump is equipped with a supplementary titanium sublimation unit for speed in the pumpout stage.

In order to reduce the background associated with scattering from the Faraday cup, the cup has been modified so that it is mounted some distance away from the scattering chamber on a standard 2" beam pipe. The distance can be changed easily to satisfy different requirements.

Provision has been made for cooling detectors with thermal-electric devices. The basic requirement for the use of these coolers is that an adequate heat sink be provided, and this has been accomplished by installing

cooling lines for the baseplate of the chamber.

A ladder has been designed to accept four targets. This target ladder can be removed from the chamber without breaking vacuum in the chamber.

2. 30" Scattering Chamber

O. E. Johnson

The 30" scattering chamber which had been designed and constructed for use with the Purdue University cyclotron together with various of its accessory units have been described in Progress Reports Nos. 11 through 16. The chamber and its accessories are now being modified for use with the Tandem Van-de-Graaff accelerator. Although extensive modifications are planned for the future, the following initial alterations are in progress: (1) the electrical isolation of the chamber and various of its component parts; (2) the improvement of the vacuum system particularly with respect to pump-down time; (3) the reworking of existing counter assemblies such that the solid state detectors may be cooled; (4) the refinement of the beam collimation system; (5) the adaptation of the chamber supporting structure and control circuitry to meet the requirements of the new laboratory.

3. Coulomb Excitation Scattering Chamber

R. P. Scharenberg

The 18" chamber designed for reorientation effect studies, which is operative at the Argonne National Laboratory, will be installed at the Purdue

Tandem at the earliest practical moment after acceptance of the machine. The necessary hardware adjustments are underway.

4. Particle-Gamma Reaction Scattering Chamber

Z. W. Grabowski, F. A. Rickey, R. P. Scharenberg, and R. M. Steffen

A small (6") scattering chamber for measurements of the gamma angular distribution in particle-gamma reactions, multiple Coulomb excitation, and $(\alpha; xn)$ reactions is under construction. An annular solid state detector is used to observe the back-scattered ions in coincidence with the gamma radiation. A Ge(Li) detector, which can be rotated about the target position will be used to observe the gamma radiation emitted from the axially oriented nuclear states.

5. Electronics

a) Particle-Identification System

O. E. Johnson

An electronic spectrometer system with a particle identification capability which can accommodate two independent $(E, \Delta E)$ counter telescopes and utilizes, on a time-sharing basis, a two-dimensional multi-channel pulse-height analyzer and a single particle identification unit is presently in development. The identification of particle-type (p, d, t, He^3 , or He^4) will be made on the basis of a range-energy or a $(Ex\Delta E)$ -mass criterion. The "simultaneous" determination of the individual differential spectra of three reaction particle-types at two separate angles of observation will be possible. Selective storage in the analyzer memory of up to

six spectra according to particle-type and observation-angle will be accomplished by means of analog routing. The component electronic units are presently being assembled and tested. It is expected that the spectrometer system will be ready for use by late summer.

b) Miscellaneous Electronics Modules

P. C. Simms

The following instruments have been built for general use in the Tandem accelerator electronics pool. These instruments have been described in previous progress reports.

- 6 Double Delay Line Clipped Linear Amplifiers
- 6 Single Channel Analyzers
- 4 Multiple Coincidence Systems
- 3 Twin Single Channel Analyzers
- 2 Sum-Delay Amplifiers
- 2 Gate Generators
- 2 High Voltage Distribution and Monitor Modules
- 1 Scaler System with Automatic Printout (50 digit - 10 input channels)

III COULOMB EXCITATION STUDIES

The reorientation effect studies, from which the sign and magnitude of the static quadrupole moment of excited nuclear states can be obtained, have been carried out for a number of nuclei. Primary interest centers on a critical evaluation of the reorientation effect. However, studies of the quadrupole moments of excited 2^+ states at our present level of understanding are being made in various regions of the periodic table.

1. Determination of the Quadrupole Moments of First Excited 2^+ States in Cd^{114} and Fe^{56} by Coulomb Excitation *

G. Schilling,[†] R. P. Scharenberg, and J. W. Tippie[‡]

The differential Coulomb excitation probability of the 0.558 MeV 2^+ excited state in ^{114}Cd and the 0.847 MeV 2^+ excited state in ^{56}Fe have been measured by Coulomb exciting with ^{16}O ions of 25 and 30 MeV incident energy. Inelastically scattered ions were separated from ions scattered elastically by requiring a coincidence with a deexcitation γ -ray detected in a large scintillator placed close to the target. The differential excitation probability was interpreted in terms of the reorientation effect to yield the static electric quadrupole moments for the 0.558 MeV 2^+ state in ^{114}Cd , $Q_{22} = -0.64 \pm 0.19 \times 10^{-24} \text{ cm}^2$, and for the 0.847 MeV 2^+ state in ^{56}Fe , $Q_{22} = -0.345 \pm 0.054 \times 10^{-24} \text{ cm}^2$.

* Abstract of paper submitted to The Physical Review, Document No. COO-1746-23. (Preprint)

[†] Present address: Department of Physics, University of Notre Dame, Notre Dame, Indiana.

[‡] Present address: Argonne National Laboratory, Argonne, Illinois

2. Static Quadrupole Moments of First Excited 2^+ States
in Ge^{74} and Ge^{76} Determined by Coulomb Excitation*

R. P. Scharenberg, R. Beyer, and D. Grisemer[†]

The static quadrupole moment of the 596 - keV 2^+ state in Ge^{74} and the static quadrupole moment of the 563 - keV 2^+ state in Ge^{76} have been determined employing Coulomb excitation techniques. Thin (200 $\mu\text{g}/\text{cm}^2$) separated isotope targets were bombarded by 25 MeV O^{16} ions from the Argonne National Laboratory Tandem Accelerator. From these measurements we obtain $Q = (-0.12 \pm 0.16) \times 10^{-24} \text{ cm}^2$ for the static quadrupole moment of the 596 - keV 2^+ state in Ge^{74} and $Q = (-0.03 \pm 0.17 \times 10^{-24} \text{ cm}^2$ for the static quadrupole moment of the 563 - keV 2^+ state in Ge^{76} . The experimental inelastic ion angular distribution data have been fitted using the de Boer - Winther multiple Coulomb excitation computer code. In this analysis only the interaction of the ground state with the excited 2^+ state has been taken into account. The uncertainties arising from coupling to higher states has been estimated and is included in the quoted errors.

* The paper describing this work has been presented at the Washington Meeting of the American Physical Society, April, 1969. See Document No. COO-1746-19. This work is being prepared for publication.

[†] Present Address: Research Analysis Corporation, Washington, D. C.

3. Critical Evaluation of Reorientation Effect

R. W. Beyer, J. A. Thomson, and R. P. Scharenberg

A critical evaluation of the reorientation effect requires a measurement where theoretical interest and experimental conditions are both favorable. We have combined our investigation of the Pd isotopes using 25 MeV O^{16} and 55 MeV S^{32} projectiles produced by the Argonne National Laboratory Tandem accelerator. Progress has been made in the development of the ion-gamma-ray coincidence technique because of better angle definition, and a careful investigation of perturbation effects. We find that substantial $M_{22} \geq .5$ reorientation effects are obtained for excited 2^+ states in Pd^{100} , Pd^{108} , and Pd^{110} , and that there are no gross inconsistencies between the O^{16} and S^{32} measurements.

The perturbation of the ion-gamma angular distribution as a function of ion scattering angle for the Pd^{110} case where $G_2 \approx 0.5$ and only a negligibly small $G_2(\theta_{ion})$ variation has been observed. We believe that careful measurements of a large reorientation effect $M_{22} \approx 1$ will provide a critical evaluation with respect to the presence of competing effects, such as excitation via the giant dipole resonance. Introduction of very heavy ion beams with $A \geq 40$ would help to elucidate the situation.

IV. ANGULAR CORRELATION AND HYPERFINE FIELD STUDIES

1. M1 - E2 Mixing Ratios and Conversion Electron

Particle Parameters for the Electromagnetic Transitions in As^{75} *

A. J. Becker and R. M. Steffen

Measurements have been made of the gamma-gamma and the conversion-electron-gamma directional correlations of the 121 - 280 keV and the 136 - 265 keV cascades in As^{75} following the decay of Se^{75} . High-resolution Ge(Li) and Si(Li) detector systems were used exclusively, providing a significant degree of independence of these results from the effects of competing cascades. The Si(Li) electron spectrometer included a cooled FET preamplifier to enhance its operation. The data are used to obtain the gamma multipole mixing ratios δ and the internal conversion particle parameters b_2 for transitions in As^{75} . A precise definition of the mixing ratios in terms of emission reduced matrix elements is given in order to determine their sign unequivocally so that a comparison with theoretical predictions will be unambiguous. The results are: $\delta(280) = -0.392 \pm 0.011$, $\delta(265) = -0.06 \pm 0.02$, $b_2(\text{E1}; 121\text{K}) = -1.96 \pm 0.04$, $b_2(\text{E1}; 136\text{K}) = -1.87 \pm 0.23$. These values for the mixing ratios are discussed in light of those obtained in other experiments, and a comparison is presented of the results for the particle parameters with the theoretical predictions based on the point - and the finite - size - nucleus pictures.

*

Abstract of paper published in The Physical Review 181 (1969)

See Document No. COO-1746-10 (Preprint)

2. Measurement of Gamma Transition Mixing Ratios

in the Decay of ^{110m}Ag *

K. S. Krane and R. M. Steffen

Mixing ratios of the gamma transition in ^{110}Cd populated by the decay of 253-day ^{110m}Ag have been measured by the method of $\gamma - \gamma$ directional correlations. Coaxial Ge(Li) detectors (ORTEC, 30 cm³) have provided sufficiently good resolution (3.5 keV for ^{60}Co) so that it was possible to separate all known lines of the ^{110m}Ag gamma spectrum. The automated angular correlation equipment was designed to simultaneously measure 4 $\gamma - \gamma$ directional correlations and to accumulate true and accidental coincidence rates simultaneously. A block diagram of the electronics is shown in Fig. 1.

Data were accumulated at 11 angle positions and, after statistical analysis, was fit to the correlation function:

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

Q_{22} and Q_{44} are the corrections for finite angular resolution of the detectors and the directional correlation coefficients of the cascade $I_1(L_1, L_1') - I_2(L_2, L_2') I_3$ are given by:

$$A_{kk} = A_k(\gamma_1) A_k(\gamma_2)$$

where

$$A_k(\gamma_1) = \frac{F_k(L_1 L_1' I_1 I_2) + (-1)^{L_1+L_1'} 2\delta(\gamma_1) F_k(L_1 L_1' I_1 I_2) + \delta^2(\gamma_1) F_k(L_1' L_1' I_1 I_2)}{1 + \delta^2(\gamma_1)}$$

Fig. 1 . Block Diagram of Multiple Angular Correlation Electronics

and

$$A_k(\gamma_2) = \frac{F_k(L_2 L_2' I_3 I_2) + 2\delta(\gamma_2) F_k(L_2 L_2' I_3 I_2) + \delta^2(\gamma_2) F_k(L_2' L_2' I_3 I_2)}{1 + \delta^2(\gamma_2)}$$

when the mixing ratios are defined in terms of reduced emission matrix elements:

$$\delta = \frac{\langle f \| L' \| i \rangle}{\langle f \| L \| i \rangle}$$

The least-squares method can be applied to obtain the best values of A_{22} and A_{44} ; however, when this is in turn solved for δ , one obtains a quadratic equation with 2 roots. To eliminate this ambiguity, a routine has been devised which treats δ as the only parameter in $W(\theta)$ and extracts δ by weighted non-linear regression. This yields one unambiguous value of δ which can then be checked against the separately extracted directional correlation coefficients.

The ^{110}Cd level scheme is well known through previous $\gamma - \gamma$ correlation and internal conversion measurements (Ref. 1-6). In addition, the mixing ratios of the 1.38 and 1.50 MeV transitions are well established. (Ref. 2,3,5).

A liquid AgNO_3 in HNO_3 source was prepared with a strength of 0.5 mc. Interior dimensions of the source holder were 1.5 mm diameter by 9 mm length.

The results of the measurements are shown in Table I. The mixing ratios given are calculated directly from the measured data. Good agreement is obtained for the 1384 keV and 1505 keV lines, but results for the 818 keV line are not in agreement with what one would expect for a $2^+ - 2^+$ transition from a 2 phonon to a 1 phonon state. It was observed that large

Table 1. E2/M1 Mixing Ratios of γ Radiation in Cd^{110}

Gamma Ray Energy (keV)	In Coincidence With	A_{22}	A_{44}	δ
620	764 - 885	$-.067 \pm .007$	$.000 \pm .020$	$\pm 0.9 \pm 1.0$
677	885	$.072 \pm .010$	$.016 \pm .020$	0.35 ± 0.03
687	764	$-.120 \pm .015$	$-.008 \pm .018$	-0.14 ± 0.02
706	{ 744	$-.174 \pm .014$	$-.006 \pm .022$	-0.15 ± 0.03
		$-.096 \pm .010$	$.009 \pm .016$	-0.09 ± 0.03
			Avg.	-0.12 ± 0.03
818	658	$.038 \pm .015$	$.048 \pm .015$	0.27 ± 0.02
1384	885	$-.284 \pm .009$	$-.009 \pm .010$	-0.35 ± 0.01
1505	{ 658	$-.388 \pm .020$	$-.032 \pm .025$	-0.48 ± 0.02
		$-.192 \pm .022$	$-.020 \pm .049$	-0.42 ± 0.06
			Avg.	-0.46 ± 0.03

corrections must be made to account for the Compton background under each peak, and measurements are currently under way to determine the exact magnitude of such corrections.

* A report of these measurements was presented at the Washington meeting of the American Physical Society, April, 1969. See Document No. COO-1746-17.

1. A. C. Knipper, Proc. Phys. Soc. (London) 71, 77 (1958)
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3. Mixing Ratios of Transitions in the Decay of Ir^{192} *

Z. W. Grabowski

Mixing ratios of the 485 keV transition in Os^{192} and the 296 keV, 308 keV, and 604 keV transitions in Pt^{192} populated from the decay of Ir^{192} were measured using the γ - γ directional correlation method. In addition, the 468 keV - 316 keV, 589 keV - 612 keV, 885 keV - 316 keV, and 1063 keV - 316 keV γ - γ directional correlations in Pt^{192} have been remeasured. Coaxial and planar Ge(Li) detectors and NaI(Tl) scintillation detectors were used in different combinations depending on the energy resolution required for a particular measurement. The results for the

mixing ratios are $\delta_{485} = + (10.9^{+2.1}_{-1.5})$, $\delta_{296} = - (9.1^{+2.7}_{-1.7})$, $\delta_{308} = - (9.9 \pm 1.0)$ and $\delta_{604} = + (2.0 \pm 0.2)$. The overall agreement of the signs as well as the absolute values of the mixing ratios with predictions of the pairing-plus-quadrupole model of Kumar and Baranger is good.

* Abstract of paper submitted for publication in The Physical Review.
See Document No. COO-1746-9 (Preprint)

4. Nuclear g-Factor of the 612 keV Level in Pt¹⁹²*

Z. W. Grabowski

Measurement of the g-factor of the second excited 2^+ state in Pt¹⁹² has been completed. The sources were prepared by melting spectroscopically pure iridium and iron powder using the electron bombardment technique (diameters of the melted spheres were 1.0 - 1.5 mm). To check the reproducibility of the results three different sources were used for the measurements, and the rotations of the 465 γ -316 γ and 308 γ -612 γ directional correlations were measured simultaneously. The iridium concentration was ~2% and ~4% (two samples) by weight. The magnetic saturation was checked by measuring the rotation of the 465 γ -316 γ correlation (through the first excited state) as a function of the current in the electromagnet. An integrally mounted 3"x3" NaI(Tl) - coaxial Ge(Li) detector (25 cm³) combination was used for the measurements. The w_T 's were calculated from the experimental data (taken at seven different angles) by fitting the function

$$W(\theta, \pm B) = \sum_{k=0} G_{22} A_{kk} P_k [(\cos(\theta - \Delta\theta_k))]$$

to the measured values.

The results for the $\omega\tau$'s, which due to the lack of attenuation ($G_{22}=G_{44}=1$) are identical with the angle of rotation of the directional correlation pattern $\Delta\theta$, are:

Source	$\omega\tau_{316}$	$\omega\tau_{612}$
1 (4% Ir)	0.075 ± 0.005	0.040 ± 0.010
2 (2% Ir)	0.080 ± 0.003	0.036 ± 0.010
3 (4% Ir)	0.081 ± 0.003	0.035 ± 0.005
Weighted Average	0.080 ± 0.002	0.036 ± 0.004

Using $B_{int} = 1250 \pm 30 \text{ kG}^1)$ and $\tau_{316} = (5.1 \pm 0.4) \times 10^{-11} \text{ sec}^2)$ one obtains for the g-factor of the 316 keV level

$$g_{316} = 0.26 \pm 0.03.$$

The same hyperfine field on Pt in iron with the mean-life $\tau_{612} = (2.7 \pm 0.6) \times 10^{-11}$ as measured by I. Berkes ³⁾ gives

$$g_{612} = 0.22 \pm 0.06.$$

The corresponding theoretical values as calculated on the basis of the pairing-plus-quadrupole model by Kumar and Baranger ⁴⁾ are $(g_{316})_{th} = 0.213$ and $(g_{612})_{th} = 0.220$. The model proposed by Greiner ⁵⁾ gives $g_{316} = g_{612} = 0.334$ for both first and second excited 2^+ states in Pt^{192} .

* A paper describing this work has been submitted to the International Conference on Properties of Nuclear States, Montreal, August 25-30 (1969). See Document No. COO-1746-25.

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5. Measurement of g-Factors of Excited States in ^{160}Dy

K. S. Krane and R. M. Steffen

Perturbed γ - γ directional correlation measurements are used to measure g-factors of excited states in ^{160}Dy populated by the beta decay of 70-day ^{160}Tb . A source of ^{160}Tb imbedded in an iron foil is used in order to take advantage of the large internal fields in iron. The apparatus used was described in section 2 of this chapter.

The directional correlation data are fitted to a function of the form:

$$W(\theta) = \sum_k Q_{kk} G_{kk} A_{kk} P_k(\cos(\theta - \Delta\theta))$$

where Q_{kk} are the corrections for the finite angular resolution of the detectors, A_{kk} are the directional correlation coefficients, G_{kk} are the attenuation factors for the correlation, and $\Delta\theta$ is the rotation of the correlation pattern. For a pure magnetic interaction,

$$\Delta\theta = \omega\tau = g \frac{\mu_o}{\hbar} B\tau.$$

Preliminary results for the $2^{nd} 2^+$ state using the 299-966 cascade are as follows:

$$A_{22} = .238 \pm .008 \qquad \Delta \theta = 2.0^\circ \pm 1.5^\circ$$

Further measurements are in progress.

6. Measurement of γ - Mixing Ratios and g-Factors of Excited States of Even Pt and Os Isotopes

K. S. Krane and R. M. Steffen

A systematic investigation is currently in progress of the γ - mixing ratios and of the g-factors of excited states of heavy even-even nuclei in the $A \sim 190$ region in order to test the theory of Kumar and Baranger^{1, 2}. The method employed is that of perturbed γ - γ directional correlations on nuclei imbedded in an iron lattice; the iron host is required so that the large internal magnetic fields (order 1 megagauss) can offset the short lifetimes of the excited states (order 10 - 100 ps) to produce measurable rotations of the correlation pattern.

The platinum excited states are populated by the decay of radioactive Au^{194} and Au^{196} produced by the $Pt(d, n) Au$ reaction; the osmium states are populated in the decays of Ir^{188} and Ir^{190} produced by the $Re(\alpha, n) Ir$ reaction. Chemical separation procedures are then used to obtain the desired materials, which are then melted with iron to form pellets.

The angular correlation equipment has been described elsewhere in this report (section IV. 2).

Preliminary results on the unperturbed correlations are as follows:

		A_{22}	A_{44}
Os^{188}	478 - 155	$-.073 \pm .040$	$0.176 \pm .059$
	1210 - 633	$-.248 \pm .080$	$.200 \pm .121$
Os^{190}	371 - 187	$-.080 \pm .086$	$.219 \pm .013$
	407 - 361	$-.022 \pm .012$	$.090 \pm .020$
	557 - 605	$.098 \pm .010$	$-.001 \pm .016$
	569 - 187	$-.274 \pm .011$	$-.020 \pm .017$
Pt^{194}	294 - 328	$-.063 \pm .020$	$.296 \pm .030$
Pt^{196}	333 - 356	$.046 \pm .007$	$.317 \pm .011$

The investigation is still in progress.

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7. g - Factors of the Excited States of As^{75}

A. J. Becker and R. M. Steffen

The precise determination of the gamma-gamma unperturbed directional correlations for the 121 - 280 keV and the 136 - 265 keV cascades in As^{75} following the decay of Se^{75} (see section IV.1 of this report) permits the investigation of the hyperfine magnetic interaction experienced by As in an iron lattice, with the goal of the determination of the magnetic moments of the 265 keV and the 280 keV states of As^{75} . An investigation of an effective means of source preparation is in progress.

A method has been devised for the electroplating of metallic selenium onto a fine iron wire. The diffusion of the selenium into the iron lattice is complicated severely by the former's low melting point and high chemical activity. An apparatus is presently under development to enable this diffusion. Further investigations are planned to ensure that the selenium concentration within the iron is sufficiently small so that each selenium atom is influenced solely by its neighboring iron lattice. Only in this way will the hyperfine magnetic interaction be suitable for perturbed directional - correlation measurements.

8. Effects of Temperature Variations on the Directional Correlation of Two Cascades of Tm^{169} in Iron

A. J. Becker and R. M. Steffen

Previous studies¹⁾ of the hyperfine interaction experienced by thulium nuclei embedded in an iron lattice have been extended to include its dependence on temperature. As before, the gamma-gamma perturbed directional correlations of the 198 - 110 keV and the 177 - 130 keV cascades of Tm^{169} have been investigated using high-resolution planar Ge(Li) detectors²⁾. The sources, thin strips cut from an iron foil into which stable Yb^{168} had been implanted with an isotope separator and which then were irradiated in a high-flux reactor, are polarized by means of a small electromagnet.

The results¹⁾ of the room temperature measurements on identically prepared sources indicated three simultaneous phenomena: the magnetic dipole interaction, an electric quadrupole interaction, and lattice relaxation.

Since the lattice relaxation is strongly temperature dependent, its contribution to the total interaction should be identifiable by varying the temperature.

Two devices have been constructed to allow the measurement of the directional correlation while the source is at other than room temperature. The first is a simple oven which surrounds but is thermally insulated from the pole pieces of the electromagnet and which can elevate the source temperature to 450°C . A vacuum chamber with a cold finger connected to a liquid-nitrogen reservoir has also been built, and is readily adaptable to use with liquid helium. In both the oven and the cryogenic chamber the source strip is in good proximity to the pole pieces of the electromagnet, and scattering and absorption of the gamma rays in the units have been minimized. At present measurements have been made using the oven only.

Past experiments¹⁾ involving annealing the source at $600\text{--}700^{\circ}\text{C}$ have shown an almost total restoration of the unperturbed correlation, a result believed to be due to the migration of the highly mobile Yb atoms to grain boundaries within the iron foil, where the effects of the lattice are minimized. Thus if increasing the source temperature brings about a decreasing perturbation, the causes could be either a change in the lattice vibrations, or this migration, or both. To identify the correct mechanisms, the measurements alternated between those with the source at an elevated temperature and those with it at room temperature. In this way the reversibility of the phenomenon was tested.

A preliminary analysis of the data has shown the anticipated tendency towards the unperturbed correlation with increasing temperature, with only a partial return to the original room-temperature perturbation after the heating.

Thus both the change in the lattice vibrations and the migration to grain boundaries seem to be in evidence, and low-temperature measurements, using the chamber described above, are planned to isolate further the effects of the lattice motion.

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9. Nuclear Magnetic Resonance of Impurity Atoms in Fe

W. C. King and R. P. Scharenberg

After finding the Rh^{103} in Fe resonance at room temperature, a search was begun for the Os^{189} in Ni resonance at room temperature. A sample of 0.5 atomic percent Os^{189} in Ni was prepared by electron-beam melting quantities of isotopically enriched Os^{189} powder and pure Ni powder. The resultant alloy was converted to powder form by filing and subsequently annealed under vacuum at 1000°C .

The Robinson oscillator used in previous measurements was modified in order to permit oscillation in a frequency range around 95 MHz, where the room temperature Os^{189} in Ni resonance is expected on the basis of 4°K NMR measurements reported by Kontani and Itoh¹⁾.

An extensive unsuccessful search was made for the resonance using the Robinson oscillator. The very different melting points of Os and Ni suggested the possibility that a solid solution of Os in Ni had not been formed in the melting process; but subsequent X-ray diffraction measurements on the sample, though not fully conclusive, indicated that the desired

solid solution had been formed.

The decision was made to seek hopefully greater oscillator sensitivity by building another oscillator more specifically designed for the very difficult frequency range around 100 MHz. Toward this end, a tuned-grid, tuned-plate, push-pull marginal oscillator designed by T. Kushida²⁾ was constructed. The Kushida oscillator was found to be very susceptible to parasitic oscillation and stable operation was very troublesome. Consequently, another push-pull marginal oscillator designed by H. R. Moore and H. Hopper³⁾ has been constructed and is undergoing testing. The oscillator appears suitable, although several problems persist at the present time.

In order to check the operation of the oscillator, a sample of 0.5 atomic percent Co in Ni has been prepared (particle size less than 20 microns) and a search is being made for the Co resonance at 112 MHz. This resonance has been observed and studied previously at room temperature with this type of oscillator and detection system⁴⁾.

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10. Investigation of Anomalous E2 Conversion Particle Parameters

J. Holm and R. M. Steffen

The magnetic spectrometer has been modified to accept a Ge(Li) detector on the angular correlation table. The first change, this required was the replacing of the earth's field compensating coils with a new set of coils of such size and geometry that the Ge(Li) detector and its necessary liquid nitrogen reservoir could be accommodated. The coils chosen are "bent-head" field coils¹⁾. The shape and size of these coils produces a field homogeneous to 1% throughout a cylindrical volume 16.7" in diameter by 56.8" long. These new coils improve the resolution of the spectrometer to 3.6% at 73.5 keV as compared to about 5% for the old coils, and eliminate the ghost peaks present with no earth's field compensation. Other associated changes were the construction of a new detector cryostat, and modification of the motor drive which changes the detector's position.

We have made preliminary investigations concerning several isotopes with anomalous particle parameters. The decays of ^{182}Ta to ^{182}W , ^{192}Ir to ^{192}Pt , and ^{168}Tm to ^{168}Er , as well as a remeasurement, now with the Ge(Li) detector, of ^{152}Eu to ^{152}Sm and ^{152}Gd , are being considered for thorough study. We are presently working on certain experimental problems associated with these and other isotopes.

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11. Angular Correlation Studies in $\text{Sn}^{117\text{m}}$, $\text{Hg}^{197\text{m}}$, and Au^{195}

D. L. Coppage and R. M. Steffen

The angular correlation parameters of the 159 keV M4 - 158 keV M1 cascade in the decay of $\text{Sn}^{117\text{m}}$ were measured using a modified angular correlation apparatus consisting of the standard arrangement of a stationary cooled Si(Li) electron detector and a NaI gamma detector plus an additional NaI gamma detector at one or the other of the angles 90° or 270° . With the addition of the necessary electronics, the simultaneous measurement of the γ - γ , e_K - γ , and e_L - γ angular correlations was made possible. The source was prepared by evaporating $\text{Sn}^{116}\text{O}_2$, which had been irradiated in the maximum neutron flux at the Oak Ridge reactor for a month, onto a very thin self-supporting film of aluminum whose thickness was approximately $50 \mu\text{g}/\text{cm}^2$. A general computer program developed during the past year for running on the IBM 360, MOD 44 was used to analyze the data statistically for detection of illegal data, to make the necessary half life corrections, to find the experimental angular correlation, and then to determine the parameters by a linear least square fit of the data to the angular correlation function. The results of the data analysis for almost all of the $\text{Sn}^{117\text{m}}$ measurements are presented below.

1.	159K - 158 γ	$W(\theta) = 1 - 0.1432 \text{ (9) } P_2(\cos \theta)$
2.	159 (L+M) - 158 γ	$W(\theta) = 1 - 0.1381 \text{ (9) } P_2(\cos \theta)$
3.	159 γ - 158 γ	$W(\theta) = 1 - 0.141 \text{ (29) } P_2(\cos \theta)$

The errors quoted are essentially the standard deviations from the parameter means calculated from samples of more than 20 members. The values of the parameters are not corrected for the effect of the source size

or source thickness both of which should be less than about 1%. Compared with expected values and previous results¹⁾, the parameter values are low and a search for possible reasons is in progress.

Measurements were also made of the angular correlation coefficients of the 165 keV M4 - 134 keV E2 cascade in $\text{Hg}^{197\text{m}}$. The source was prepared by distilling $\text{Hg}^{197\text{m}}$ from gold bombarded with approximately 9 MeV deuterons from the Purdue University cyclotron onto a backing of silver coated, $\frac{1}{4}$ mil mylar²⁾. The measurements were made using the standard angular correlation table with a stationary cooled Si(Li) electron detector and a NaI gamma detector. The electronics were modified into a fast-slow system to take advantage of the superior resolution of the unipolar mode of the amplifier. The general computer program mentioned before was used to analyze the data, the results of which are presented below for about half the data analyzed.

1. 165L - 134 γ $W(\theta) = 1 + 0.150(20) P_2(\cos \theta) - 0.013(25) P_4(\cos \theta)$
2. 165M - 134 γ $W(\theta) = 1 + 0.152(34) P_2(\cos \theta) - 0.007(49) P_4(\cos \theta)$

As before the errors quoted are the sample standard deviations from samples of about 10 values and the parameters are not corrected for a possible 1% source size effect. In order to investigate the kinds of perturbing interactions showing up and perhaps make possible a measurement of the b - parameters in spite of the attenuation, the measurement of the very weak 165 γ - 134 γ angular correlation was undertaken on the high-resolution gamma-gamma angular correlation apparatus described in Progress Report No. 1 (COO-1746-8) June 15, 1968, p. 72. Analysis of this data is not complete.

A preliminary measurement to indicate feasibility was made on the

12. Conversion - Electron Particle Parameters for the 111 keV

Transition in W^{184}

R. Doubt[†], W. D. Hamilton[†], and Z. W. Grabowski

In a previously published article¹⁾ the existence of significant deviations from the theoretical values of the particle parameters was confirmed for the low energy E2 transitions in Sm^{152} and Gd^{154} nuclei. The reason for this "anomaly" is rather obscure as effects due to the nonspherical nuclear charge distribution seem too small to explain the deviations. It was therefore considered worthwhile to investigate another similar transition in search for some systematical behavior.

The W^{184} nucleus was chosen for the present experiment since its structure resembles rather closely the structure of the Sm^{152} and Gd^{154} nuclei.

The levels in W^{184} were populated from the decay of Re^{184} (see Fig. 1) which was produced in the (p, n) (and also (d, 2n)) reaction on W^{184} .

Fig. 1. Decay of Re^{184}

After chemical separation rhenium was electroplated on thin aluminum backing. The particle parameters for the 111 keV transition were calculated from $e^- - \gamma$ and $\gamma - \gamma$ directional correlations measured with the same source. The preliminary results of the experiment are :

Cascade	$G_{22} A_{22}$	$G_{44} A_{44}$
111 $e_k - 793\gamma$	-0.028 ± 0.006	-0.063 ± 0.012
111 $e_k - 896\gamma$	-0.129 ± 0.019	0.036 ± 0.018
111 $e_L - 793\gamma$	-0.004 ± 0.007	0.031 ± 0.008
111 $e_L - 896\gamma$	-0.122 ± 0.011	0.001 ± 0.016
111 $\gamma - 793\gamma$	-0.023 ± 0.006	0.141 ± 0.014
111 $\gamma - 896\gamma$	-0.136 ± 0.004	-0.010 ± 0.020

The $G_{22} A_{22}$ and $G_{44} A_{44}$ are the coefficients in the directional correlation function in the form

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

The b_2^k and b_2^L particle parameters for the 111 keV transition calculated from the above results are :

$$(b_2^k)_{\text{exp}} = 1.53 \pm 0.04$$

$$(b_2^L)_{\text{exp}} = 0.90 \pm 0.08 .$$

Theoretically calculated values for the particle parameters are $b_2^k = 1.846$ and $b_2^L = 1.220^2$). Both of the experimentally measured particle parameters for the 111 keV E2 transition in W^{184} are about 20% lower

than theoretically predicted. As the 111 keV transition is always the second in a cascade, larger attenuation (due to the external fields) of the $e^- - \gamma$ directional correlations as compared to the $\gamma - \gamma$ results is very unlikely. The fact that approximately the same effect was observed for the K and L conversion electrons ($\Delta E \approx 58$ keV) also rules out the possibility of smearing out the electron-gamma correlation due to scattering in the source.

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13. $\beta - \gamma$ Directional Correlation Measurements on Sb^{124} and Tb^{160} *

S. J. Cipolla

The $\beta - \gamma$ directional correlation measurements on Sb^{124} and Tb^{160} have been completed. The results can be summarized as follows (Abstract of Ph. D. Thesis of S. J. Cipolla) :

Beta-Gamma Directional Correlations involving the first-forbidden β transitions of $W_0 = 1.590$ MeV and $W_0 = 1.667$ MeV in the decay of Sb^{124} to the two-phonon excited levels of Te^{124} were investigated using a spectrometer composed of a Ge(Li) γ detector and a scintillation β detector. The 1.590 MeV β transition showed a very anisotropic directional correlation with a prominent energy dependence, while the directional

correlation of the 1.667 MeV β transition was much less anisotropic and its small anisotropy seemed to be independent of energy.

Beta-Gamma directional correlation measurements of the cascades $\beta(1.750) - \gamma(0.087)$ and $\beta(1.540) - \gamma(0.197)$ in the decay of the deformed nucleus Tb^{160} to Dy^{160} were performed with the same instrument for the purpose of testing the predictions of the K-selection rule. The results for the $\beta(1.750) - \gamma(0.087)$ directional correlation can be interpreted to show that $\int iB_{ij}$ is enhanced, which is in agreement with nuclear model expectations. However, the analysis of the $\beta(1.540) - \gamma(0.197)$ directional correlation measurement was not successful, and speculations are presented to explain this result.

* A paper for publication is in preparation. The results of this investigation have been reported at the Washington Meeting of the American Physical Society, April, 1969. See Document No. COO-1746-18.

V. NUCLEAR MATRIX ELEMENTS FOR FIRST-FORBIDDEN

BETA TRANSITIONS

1. Beta Matrix Elements and CVC Theory

D. E. Ohlms, J. J. Bosken, H. A. Smith, and P. C. Simms

It has been suggested that the CVC theory can be used to predict the ratio of certain first-forbidden beta decay matrix elements. There are two reasons why it is important to experimentally check the validity of the CVC ratio prediction. First, if the procedure is valid, it would simplify the matrix element analysis for first-forbidden beta transitions. Second, there are several simple assumptions which are involved in predicting the matrix element ratio. If it can be shown that a complex quantity like a beta transition matrix element can be predicted by making simple approximations, important progress has been made in understanding the beta decay process.

Previous work^{1, 2)} by our research group has shown that energy dependent, beta-gamma circular polarization measurements on Rb^{86} and La^{140} would provide good tests for the CVC ratio. These experiments have been completed and they yield the following results.

$$\text{Rb}^{86} \quad \Lambda_{\text{CVC}}^E = 0.36 \pm .04$$

$$\text{La}^{140} \quad \Lambda_{\text{CVC}}^E = 0.30 \pm .05$$

When Λ_{CVC}^E is defined as the ratio of the relativistic matrix element $\int \vec{\alpha}$ to the radial matrix element $\int (\vec{r} / \rho)$

$$\Lambda_{\text{CVC}} = \frac{\int \alpha}{\int (\vec{r}/\rho)} \quad (1)$$

The first proposal to use the CVC theory to predict the ratio of nuclear matrix elements was made by Fujita³⁾.

$$\Lambda_{\text{CVC}} = \pm 1.2 \alpha Z + \rho (\pm 2.5 + W_0) \quad \text{for } \beta^\mp \quad (2)$$

where α is the fine structure constant, and Z is the nuclear charge of the daughter nucleus. The end point energy W_0 and the nuclear radius ρ are expressed in natural units. This formula gives the following predictions for Rb^{86} and La^{140}

$$\text{Rb}_b^{86} \quad \Lambda_{\text{CVC}}^{\text{T}} = 0.34$$

$$\text{La}_a^{140} \quad \Lambda_{\text{CVC}}^{\text{T}} = 0.55$$

It is evident that the experimental and theoretical values of the CVC ratio agree quite well for Rb^{86} , but they are definitely not in agreement for La^{140} .

A more recent approach to the use of the CVC theory has been made by Damgaard and Winther⁴⁾. They give the following formula:

$$\Lambda_{\text{CVC}}^{\text{T}} = \pm \frac{\alpha Z}{2} (2.4 - \lambda) + \rho (\pm 2.5 + W_0) \quad \text{for } \beta^\mp \quad (3)$$

The additional parameter λ is the ratio of third and first-forbidden radial matrix elements.

$$\lambda = \frac{\int \vec{r} (\vec{r}/\rho)^2}{\int \vec{r}} \quad (4)$$

There is only one difference between the derivation of Fujita and that of Damgaard and Winther. Fujita assumed that the difference in Coulomb energy between the initial and final state of the beta transition could be

calculated by treating the nuclei as uniformly charged spheres. Damgaard and Winther did not make this restriction. The parameter λ enters to account for the fact that the difference in Coulomb energy may depend on the radial distribution of the nuclear charge which is altered by the beta transition.

The third forbidden matrix element $\int \vec{r}(\vec{r}/\rho)^2$ is present not only in Λ_{CVC} but also in the theoretical formulas for the beta transition probability. After it was found that the simple prediction of Fujita did not agree with the La^{140} results, the contribution of the third forbidden matrix elements were included, and the data were reanalyzed. The analysis was performed as a function of the parameter λ , and it was found that for λ equal to 2.52 the experimental and theoretical value of the CVC ratio agree.

$$\lambda = 2.52 \quad \Lambda_{\text{CVC}}^{\text{T}} = 0.146 \quad \Lambda_{\text{CVC}}^{\text{E}} = 0.139 \pm .015$$

The experimental result for Rb^{86} is in good agreement with the prediction of Damgaard and Winther for a value of $\lambda = 0.6$ (notice that when $\lambda = 0.6$ the two methods give the same prediction for Λ_{CVC}).

It is evident that the approach suggested by Fujita is not generally valid. Further, the formula of Damgaard and Winther cannot be used to predict the CVC ratio unless λ can be predicted by a nuclear model calculation. However, the formula of Damgaard and Winther can be used to determine λ when enough experimental data are available to measure the matrix element ratio. This provides another piece of information which is sensitive to the details of the nuclear structure.

A large amount of additional data have been analyzed for the following nuclei: As^{76} , Rb^{84} , Sb^{122} , Sb^{124} , and I^{126} . However, the results are not

as definite as in the case of Rb^{86} and La^{140} . Additional experiments are being planned so that these isotopes also may be fully analyzed.

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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 CVC ratio of nuclear matrix elements 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 requires that there are third forbidden matrix elements present which are larger than the first forbidden matrix elements.

* Abstract of a paper submitted to The Physical Review. See Document No. COO-1746-21 (Preprint)

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VI. MEASUREMENT OF ULTRA-SHORT NUCLEAR LIFETIMES

P. C. Simms

A number of short life-time measurements have been completed using the new technique which was described in the last Progress Report (COO-1746-8). The following results were obtained : Mean Life

First excited state of	Ni ⁶⁰	$(1.4 \pm 0.7) \times 10^{-12} \text{ s}$
First excited state of	Ti ⁴⁶	$(3.8 \pm 0.4) \times 10^{-12} \text{ s}$
First excited state of	Cd ¹¹⁴	$(11.4 \pm 1.0) \times 10^{-12} \text{ s}$
First excited state of	Pt ¹⁹²	$(38 \pm 1.0) \times 10^{-12} \text{ s}$
Second excited state of	Pt ¹⁹²	$(11 \pm 3.0) \times 10^{-12} \text{ s}$

This experiment was temporarily discontinued early in the contract period because of the extra work involved with the installation of the Tandem accelerator.

VII. THEORY

I. Nuclear Three-Body Problems

Y. E. Kim

Major research efforts have been centered around the investigation of practical methods for solving the non-relativistic three-body problem. A new numerical method of solving the Faddeev equation for local potentials has been developed and tested. A detailed description of the method and of its justification is given in a report (Document No. COO-1746-20) which will be published in an August issue of Journal of Mathematical Physics.

The accuracy of our method is tested for the simplest case of three spinless Bosons interacting through a local Yukawa potential. Our calculated binding energies are consistent with other recent results of variational calculations, thus confirming the accuracy and practicality of our method. The detailed comparison and significance of our results are described in a report (Document No. COO-1746-22) which is being submitted to Physics Letters for publication.

The following are the abstracts of two reports :

(1) Document No. COO-1746-20. "Solution of the Faddeev Equation for Local Potentials by Approximate Product-Integration." A practical method of solving the Faddeev equation for short-range local potentials is proposed. The method consists of (a) transforming the Faddeev equation into a form in which the inhomogeneous term satisfies a Hölder condition and then (b) solving the resultant two-variable integral equations by approximate product-integration.

(2) Document No. COO-1746-22. "Comparison of Solutions of the Faddeev Equation with Variational Results for a Local Yukawa Potential." A recently proposed method of solving the Faddeev equation is tested by calculating the binding energies of three spinless Bosons with a local Yukawa potential. The calculated results are in agreement with results of variational calculations. The method is suitable for applications of the Faddeev equation to more complicated three-body problems.

2. Application of Solvable Many-Body Problem

S. M. Harris

We have continued our investigation of the exactly solvable many-body problem, the case of two-body harmonic interactions. In particular, we have explicitly written down the wavefunctions of the low-lying states of the three-nucleon system with harmonic two-body interactions. These states may be used as a truncated basis for calculations involving realistic nucleon-nucleon potentials.

Both ${}^3\text{H}$ and ${}^3\text{He}$ have $\frac{1}{2}^+(T=1)$ ground states. The three-body harmonic oscillator ground state is a symmetric S-state. The first excited state is a negative parity P-state with mixed permutation symmetric. The second excited state corresponds to mixed symmetry S and D, symmetric S and D, and anti-symmetric P-states, all with positive parity. All even parity states except the symmetric D are components of the three nucleon ground state.

We evaluate matrix elements of a realistic Hamiltonian (including central and tensor forces but excluding hard cores) in this basis. After diagonalizing the H-matrix, we obtain the binding energy and wavefunction expansion of

the ground state (and excited $J^\pi = \frac{1}{2}^+$, $T = \frac{1}{2}$ states). Once we have specified the N - N interaction, the only parameter entering is the oscillator parameter which characterizes our basis. This parameter may be varied to minimize the ground state energy.

All matrix elements have been calculated and the numerical work should be finished shortly.

3. Vibrational Nuclei

S. M. Harris

Preliminary efforts to generalize the simple vibrational model to the case of large amplitude vibrations have not been promising, and this work was not pursued.

PROJECT PERSONNEL

Senior Research Staff

R. M. Steffen (Principal Investigator)
Z. W. Grabowski
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Y. E. Kim
S. M. Harris
O. E. Johnson (From Feb. 1, 1969)
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R. P. Scharenberg
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Post-Doctoral Research Associates

A. J. Becker

Graduate Students

R. W. Beyer
J. J. Bosken (Until Jan. 31, 1969)
C. H. Burgess (Feb. 1 to March 31, 1969)
S. J. Cipolla (no salary charged to contract)
D. L. Coppage
D. W. Grissmer (Until Dec. 31, 1968)
E. P. Harper (Since Feb. 1, 1969)
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H. A. Kuhlman (Until Sept. 10, 1968)
D. L. McShan (Since Feb. 1, 1969)
J. A. Morman (Since Sept. 4, 1968)
D. E. Ohlms (Until March 31, 1969)
G. J. Smith (Since Feb. 1, 1969)
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J. A. Thomson (Since Feb. 1, 1969)

Technical Staff

J. R. McCall, Tandem Engineering Supervisor

F. Hobough, Tandem Technician

B. D. Michaels, Tandem Technician (Since Feb. 1, 1969)

R. A. Dunham, Electronics Technician

Undergraduate Technicians (Part-time)

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Clerical and Administrative Staff

Mrs. K. Schatz, Secretary

C. S. Snethen, Secretary (Part-time)

LIST OF PUBLICATIONS

June 1, 1968 to May 31, 1969

a) Papers Published

COO-1746-10	M1 - E2 Mixing Ratios and Conversion Electron Particle Parameters for the Electromagnetic Transitions in As^{75} . A. J. Becker and R. M. Steffen. The Physical Review <u>181</u> , (May 20, 1969)
COO-1746-11	A Flexible Coincidence System. P. C. Simms. Nuclear Instruments and Methods (approximately May, 1969)
COO-1746-12	A Sum-Delay Amplifier and Gate Generator. P. C. Simms. Review of Scientific Instruments <u>40</u> , 285 (1969)
COO-1746-13	Low Energy Radiation Detection with Silicon Semiconductor Detectors Using a New Type Preamplifier. Sándor Dési. Nuclear Instruments and Methods (approximately April, 1969)

b) Papers Submitted for Publication

COO-1746-9	Mixing Ratios of Transitions in the Decay of Ir^{192} . Z. W. Grabowski. Submitted to The Physical Review.
COO-1746-16	A New Technique for Direct Measurements of Short Life Times with Subpicosecond Accuracy. P. C. Simms and Henry Kuhlman. Submitted to Physical Review Letters.

- COO-1746-20 The Solution of the Faddeev Equation for Local Potentials by Approximate Product Integration. Y. E. Kim. Submitted to Journal of Mathematical Physics.
- COO-1746-21 Energy Dependence β - γ Circular Polarization of La^{140} . D. E. Ohlms, J. J. Bosken, and P. C. Simms. Submitted to The Physical Review.
- COO-1746-22 Comparison of Solutions of the Faddeev Equation with Variational Results for a Local Yukawa Potential. Y. E. Kim. Submitted to Physics Letters.
- COO-1746-23 Determination of the Quadrupole Moments of First Excited 2^+ States in Cd^{114} and Fe^{56} by Coulomb Excitation. G. Schilling, R. P. Scharenberg, and J. W. Tippie. Submitted to The Physical Review.

c) Abstracts of papers presented at meetings of the American Physical Society

- COO-1746-9 Mixing Ratios of Transitions in the Decay of Ir^{192} . Z. W. Grabowski. BAPS 13, 1468 (1968)
- COO-1746-10 M1 - E2 Mixing Ratios and Conversion Electron Particle Parameters for the Electromagnetic Transitions in As^{75} . A. J. Becker and R. M. Steffen. BAPS 13, 1427 (1968)
- COO-1746-14 Gamma-Gamma Directional-Correlation Measurements of the Hyperfine Field for Tm^{169} in an Iron Lattice. A. J. Becker and R. M. Steffen. BAPS 13, 1470 (1968)
- COO-1746-15 Static Quadrupole Moment of the 847 keV 2^+ State in Fe^{56} Determined by Coulomb Excitation. J. W. Tippie, D. Grissmer, R. P. Scharenberg, and G. Schilling. BAPS 13, 1470 (1968)

- COO-1746-17 E2 - M1 Mixing Ratios of the Gamma Rays Emitted
in the Decay of $\text{Ag}^{110\text{m}} \rightarrow \text{Cd}^{110}$. K. S. Krane and
R. M. Steffen. BAPS 14, 568 (1969)
- COO-1746-18 Beta-Gamma Directional Correlation Measurements
Involving First-Forbidden Beta Transitions Using a
Ge (Li) Detector. S. J. Cipolla. BAPS 14, 568 (1969)
- COO-1746-19 Static Quadrupole Moments of First Excited 2^+ States
in Ge^{74} and Ge^{76} Determined by Coulomb Excitation.
R. P. Scharenberg, R. Beyer, and D. Grissmer.
BAPS 14, 554 (1969)