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RESEARCH IN NUCLEAR PHYSICS

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L TANDEM VAN de GRAAFF ACCELERATOR

O. E. Johnson, R. P. Scharenberg, P. C. Simms

R. M. Steffen and D. J. Tendam

A. ACCELERATOR INSTALLATION

D. J. Tendam

Planning for the Van de Graaff accelerator installation looks forward to beginning operation in early 1969. The time schedule is:

November, 1966	:	Order accelerator.
June, 1967	:	Let contract for accelerator building.
June, 1967	:	Start building construction.
November, 1967	:	Delivery of accelerator tank.
September, 1968	:	Completion of building.
September, 1968	:	Delivery of accelerator components.
October, 1968	:	Start installation of accelerator.
March, 1969	:	Accelerator in operation.

The work is proceeding in accord with this schedule. Contract negotiations with the High Voltage Engineering Corporation were completed on November 10, 1966 and the Model FN Tandem Van de Graaff accelerator is under construction at the factory. The final plans and specifications for the building were completed on April 10, 1967, bids for construction were received on May 26, and the Purdue Board of Trustees awarded construction contracts on June 3.

The Accelerator Building will be completely underground and connected to the Physics Building by means of tunnels. It will provide adequate facilities for operation of the accelerator and eight laboratories for nuclear

physics and nuclear chemistry research, as well as twelve offices for graduate students and post-doctoral research associates. Adequate space for future developments and installation of ion sources and injectors is also included. Figs. 1 and 2 show the floor plans.

B. BEAM TRANSPORT SYSTEM

Studies of beam handling systems are under way and it is anticipated that a contract for the purchase of a suitable system will be made within the next several weeks.

Figure 3 shows details of the beam transport system. Initially, three beam lines will be installed. Provisions have been made to install four additional beam lines at a later date.

In order to avoid the inconvenience and expense of filling liquid-nitrogen traps, no diffusion pumps will be used in the beam handling system. A turbo molecular pump and ion pumps will be used throughout. At present the details of the vacuum and radiation interlock system are being prepared.

Planning for auxiliary research equipment will begin in the near future.

C. GENERAL

To strengthen our nuclear structure research group, a nuclear theorist, Dr. Yeong E. Kim, will join our staff in September, 1967 and Dr. Roderick G. Kerr, an experimentalist with extensive tandem Van de Graaff experience at the University of Wisconsin, will join us in February, 1968. Both men will hold the rank of assistant professor of physics.

II. NUCLEAR REACTION STUDIES

Cyclotron. (D. J. Tendam). The cyclotron is operating satisfactorily and no major modifications have been made during the past year. No major

Fig. 1. SUB. BASEMENT PLAN

Fig. 2. BASEMENT FLOOR PLAN

repairs have been needed.

A. ELASTIC AND INELASTIC SCATTERING OF 9.8-MeV DEUTERONS FROM P^{31}

B. T. Lucas and O. E. Johnson

The study has been terminated and no extension is anticipated. A full report of this investigation has been published.^{1,2}

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1. B. T. Lucas and O. E. Johnson, Phys. Rev. 145, 887 (1966).
 2. See appended document No. 1 (Reprint).

B. OPTICAL-MODEL AND DISTORTED-WAVE ANALYSES OF SOME 18-MeV ALPHA-PARTICLE SCATTERING CROSS SECTIONS FOR A^{40} , S^{32} , P^{31} , Na^{23} , AND Ne^{20}

B. T. Lucas, S. W. Cosper*, and O. E. Johnson

This investigation, which has been briefly described in Progress Report No. 16, has been completed. A description of this study and its results have been published elsewhere.^{1,2}

*Present address: Lawrence Radiation Laboratory, University of California, Berkeley, California.

1. B. T. Lucas, S. W. Cosper, and O. E. Johnson, Phys. Rev. 144, 972 (1966).
2. See appended document No. 2 (Reprint).

C. MEASUREMENTS AND DWBA ANALYSES OF THE 18.7-MeV
DIFFERENTIAL CROSS SECTIONS FOR THE $(\alpha, d_{0,1})$ REACTIONS
ON Na^{23} , Al^{27} , AND P^{31}

B. B. Srivastava and O. E. Johnson

Details concerning the measurements of the angular distributions for the 18.7-MeV $(\alpha, d_{0,1})$ reactions on Na^{23} , Al^{27} , and P^{31} have been reported earlier in Progress Report Nos. 15 and 16. The shapes of these six (α, d) angular distributions may be characterized by combinations of the following general features: (1) either (a) well-defined and pronounced oscillatory structure or (b) washed-out undulatory behavior; (2) either (a) strong forward-angle peaking without pronounced backward-angle peaking or (b) the reverse behavior. The shape of the angular distribution in each case suggests a significant direct-reaction contribution.

An investigation of the applicability of Tobocman's¹ zero-range DWBA knockout and stripping formalisms in the description of these reactions has been carried out using the direct-reaction code of Gibbs et al.²

The results of the analysis of the P^{31} data were described in Progress Report No. 16. These data were analyzed in terms of the knockout model only and good agreement between the experimental and theoretical angular distributions was achieved. The analysis indicated that the (α, d_0) and

-
1. W. Tobocman, Theory of Direct Nuclear Reactions (Oxford University Press, London, 1961), p. 30.
 2. W. R. Gibbs, V. A. Madsen, J. A. Miller, W. Tobocman, E. C. Cox, and L. Mowry, Natl. Aeron. Space Admin. Tech. Note No. TN-D2170 (1964).

(α, d_1) reactions correspond to angular momentum transfers of 2 and 0, respectively. A complete report on the P^{31} investigation has been published.^{3, 4}

In the analyses of the Na^{23} data, the gross features of both angular distributions could be marginally reproduced by the knockout model but not by the stripping model. The knockout analysis indicates that both of these $(\alpha, d_{0,1})$ transitions correspond to angular momentum transfers of 2. A report of the results of Na^{23} investigation which is based on the attached preprint⁵ has been accepted for publication.⁶

In the analyses of the Al^{27} data, except for a good stripping-model fit to the (α, d_1) angular distribution, the fits achieved reproduce only the gross features of the experimental angular distributions. The general quality of these fits precludes any reasonably objective conclusion as to whether a knockout or a stripping model provides a better description of the data. The knockout analysis indicates that the (α, d_0) reaction corresponds to mixed angular momentum transfers of 2 and 4, while the dominant contributions to the (α, d_1) reaction cross section correspond either to an angular momentum transfer of 4 or to a mixture of 0 and 4. The stripping analysis indicates that in the (α, d_0) and (α, d_1) reactions the dominant contributions correspond to angular momentum transfers of 2 and 4, respectively. The results of the Al^{27} investigation are described in detail

-
3. B. B. Srivastava, S. W. Cosper, and O. E. Johnson, *Phys. Rev.* 153, 1221 (1967).
 4. See appended document No. 3 (Reprint).
 5. See appended document No. 4 (Preprint).
 6. B. B. Srivastava and O. E. Johnson, *Phys. Rev.* (in press, scheduled for April 20, 1967 issue).

in the attached preprint.⁷

On the basis of the results of these investigations, it is concluded that the applicability of Tobocman's formalisms in the description of these (α , d) reactions is marginal.

7. See appended document No. 5 (Preprint).

D. STUDIES OF THE (α , p) REACTION ON N^{14} , P^{31} AND S^{32} AT 19 MeV

D. L. Deardorff and O. E. Johnson

The investigation of the (α , p) reaction has been extended from the original study on S^{32} (See Progress Report No. 16.) to include N^{14} and P^{31} . The 18.7-MeV differential cross sections for the (α , p) reactions leading to the gnd., 0.871-, 3.058-, and 3.846-MeV states of O^{17} and the gnd., 2.13-, and 3.30-MeV states of S^{34} have been measured over the approximate angular range from 10° to 170° . The proton spectra were determined using a spectrometer system incorporating an (E, ΔE) counter telescope, a multi-channel pulse-height analyzer, and a simple particle identification system. The N^{14} targets were produced by the thermal vacuum sublimation of Melamine (various thicknesses from 200 to 900 $\mu\text{g}/\text{cm}^2$) onto thin ($\sim 15 \mu\text{g}/\text{cm}^2$) Formvar films. The P^{31} targets were prepared by the thermal vacuum evaporation of red phosphorus (603 and 640 $\mu\text{g}/\text{cm}^2$) onto similar thin Formvar films.

The angular distributions for the $P^{31}(\alpha, p_{0,1,2}) S^{34}$ show: forward angle peaking; a weak, washed-out oscillatory structure, and no tendency to peak at backward angles. The $S^{32}(\alpha, p_{0,1}) Cl^{35}$ angular distributions show similar characteristics except that there is a tendency toward moderate backward-angle peaking. The $S^{32}(\alpha, p_2) Cl^{35}$ angular distribution shows a very pronounced oscillatory behavior backward of 90° . The $N^{14}(\alpha, p_{0,1,2}) O^{17}$ angular distributions differ from one another in detail but are somewhat oscillatory with backward peaking.

Knockout and stripping DWBA analyses of these $(\alpha, p_{0,1,2})$ angular distributions for P^{31} and S^{32} have been completed using the formalism due to Tobocman.^{1,2} In spite of the extensive parametrization of these models, the experimental data could only be marginally reproduced. A comparison of these angular distributions with those measured at other incident energies indicates that the shape of the angular distributions may, in the vicinity of 19 MeV, be a strong function of energy. This is generally interpreted as indicating the presence of a large compound-nucleus contribution to the cross section. The applicability of the DWBA presupposes the dominance of the direct-reaction mechanism. A detail report on these studies and the conclusions drawn is presently in preparation.

Analyses of the $N^{14}(\alpha, p_{0,1,2}) O^{17}$ reactions are complicated by uncertainties in the entrance- and exit-channel descriptions. To date, analyses of these data have not been initiated.

-
1. W. Tobocman, Theory of Direct Nuclear Reactions (Oxford University Press, London, 1961), p. 30.
 2. W. R. Gibbs, V. A. Madsen, J. A. Miller, W. Tobocman, E. C. Cox, and L. Mowry, Natl. Aeron. Space Admin. Tech. Note No. TN-D2170 (1964).

E. OPTICAL-MODEL ANALYSES OF He^3 AND He^4 ELASTIC SCATTERING FROM C^{12} , N^{14} , AND O^{16}

D. R. Ober, B. T. Lucas, and O. E. Johnson

In order to provide entrance- and exit-channel optical model descriptions for the DWBA analyses of various reactions under study in this laboratory, various angular distributions for the elastic scattering of He^3 and He^4 have been measured and/or analyzed. In particular, the 13.95-MeV (He^3 , He^3) angular distributions for C^{12} , N^{14} , and O^{16} were measured and analyzed, and the previously measured (He^4 , He^4) angular distributions for C^{12} at 18.0 MeV¹ and 17.5 MeV², N^{14} at 19.2 MeV³, and O^{16} at 18.3 MeV¹ were analyzed. The analyses were performed assuming a four-parameter complex optical-model potential with either a Saxon, Saxon (S-S) or Saxon, Saxon-derivative (S-SD) shapes. A summary of the results of these analyses is given in Table I.

The $\text{C}^{12}(\text{He}^3, \text{He}^3) \text{C}^{12}$ angular distribution exhibits rather washed-out structure in contrast to the $\text{C}^{12}(\text{He}^4, \text{He}^4) \text{C}^{12}$ results. Three sets of parameters were obtained for both the S-S and S-D potentials. Those for the S-SD potential yielded better over-all representations of the data with that of Set No. 5 the best.

-
1. J. C. Corelli, E. Bleuler, and D. J. Tendam, *Phys. Rev.* 116, 1184 (1959), and E. Bleuler (private communication).
 2. W. D. Ploughe, Ph.D. Thesis, Purdue University, 1961 (L.C.: Mic. 61-5755, University Microfilms, Inc., Ann Arbor, Mich.), and *Phys. Rev.* 122, 1232 (1961).
 3. E. B. Carter, G. E. Mitchell, and R. H. Davis, *Phys. Rev.* 133, B1421 (1964).

The $N^{14}(He^3, He^3) N^{14}$ experimental cross section exhibits a rather washed-out structure similar to the $C^{12}(He^3, He^3) C^{12}$ data. Three sets of OM parameters for the S-S potential were found that yielded satisfactory fits to the data. No fits of comparable quality were found using the S-SD potential.

The $O^{16}(He^3, He^3) O^{16}$ angular distribution has a structure similar to those for C^{12} and N^{14} for angles less than about 85° . For larger angles, a well-defined oscillatory structure with pronounced backward angle peaking is observed. The S-SD parameters yield the best over-all fits; however, the quality of the fits at backward angles tend to indicate that the S-S potential is more appropriate. The best fits for the S-S and S-SD potentials are obtained for OM parameter Set Nos. 1 and 4, respectively.

Each of the two sets of S-S parameters listed for the $C^{12}(He^4, He^4) C^{12}$ reaction at each energy yield approximately equivalent fits to the experimental data. No satisfactory fits were found using the S-SD potential. It should be mentioned that even though the fitting procedure used only the forward angle data, the backward angle behavior of the angular distribution was predicted surprisingly well.

The four sets of S-S parameters found for the $N^{14}(He^4, He^4) N^{14}$ angular distribution yield approximately equivalent fits; however, that provided by Set No. 2 is judged best. Although the calculated curves reproduced the forward angle structure quite well, they failed to reproduce the washed-out oscillatory behavior at large angles. Markedly inferior fits were obtained using the S-SD potential.

Similar analyses of the $O^{16}(He^4, He^4) O^{16}$ data are in progress.

TABLE I. SUMMARY OF OPTICAL MODEL PARAMETERS FOR He^3
AND He^4 ELASTIC SCATTERING FROM C^{12} , N^{14} , AND O^{16}

Nucleus	E_{Lab} (MeV)	Pot.	Set	V_0 (MeV)	W_0 (MeV)	D (F)	r_0 (F)	Angular Range ^a
He^3 Scattering _b								
C^{12}	13.95	S-S	1	39.18	7.33	0.649	1.731	18.7-114.3
			2	100.38	15.22	0.624	1.379	(18.7-114.3)
			3	168.76	18.64	0.608	1.328	
		S-SD	4	50.35	6.16	0.776	1.442	
			5	108.23	10.26	0.703	1.301	
			6	189.12	14.41	0.663	1.212	
N^{14}	13.95	S-S	1	39.02	7.40	0.662	1.672	21.2-102.4
			2	74.09	16.05	0.538	1.726	(21.2-102.4)
			3	126.94	22.14	0.527	1.616	
O^{16}	13.95	S-S	1	40.72	9.42	0.654	1.662	17.8-171.9
			2	136.67	19.31	0.624	1.461	(17.8-115.5)
			3	159.76	21.98	0.699	1.322	
		S-SD	4	48.36	9.00	0.766	1.475	
			5	94.14	14.24	0.735	1.378	
			6	154.28	19.45	0.708	1.313	
α Scattering ^c								
C^{12}	17.50	S-S	1	123.54	4.92	0.677	1.557	22.3-168.5
			2	184.94	5.87	0.658	1.489	(22.3-112.0)
C^{12}	18.0	S-S	1	105.42	5.74	0.736	1.599	13.3-173.3
			2	159.01	6.17	0.709	1.540	(13.3- 88.3)
N^{14}	19.2	S-S	1	24.87	4.22	0.594	1.864	12.8-172.8
			2	54.87	5.14	0.569	1.748	(12.8- 99.0)
			3	94.55	5.88	0.579	1.643	
			4	149.79	7.03	0.572	1.537	

- ^a The upper pair of angles defines the angular range of the experimental distribution and the lower pair, in parentheses, indicates the angular range over which searches were performed in attempting to fit the data.
- ^b These data were measured at this laboratory during the past year.
- ^c See References 1, 2, and 3.

F. SOME (He^3, α) REACTIONS ON C^{12} AND O^{16} AT 13.95 MeV

D. R. Ober and O. E. Johnson

The 13.95-MeV differential cross sections for the (He^3, α) reactions leading to the gnd., 2.00-, 4.32-, and 4.81-MeV states of C^{11} and the gnd., and 6.16-MeV states of O^{15} were measured over the angular ranges 15° - 95° and 15° - 170° , respectively. The carbon target was a $220 \mu\text{g}/\text{cm}^2$ self-supporting carbon foil. The oxygen target was a $520 \mu\text{g}/\text{cm}^2$ Mylar film which had an oxygen content of $170 \mu\text{g}/\text{cm}^2$. The charged-particle spectra were accumulated using four silicon surface-barrier detectors mounted in a multi-detector assembly with defining apertures spaced 10° apart; hence, observations were made at four angles simultaneously. The signals from the detector assembly were sent into an electronic gating and routing system which controlled and fed a two-dimensional pulse-height analyzer such that the four differential spectra could be accumulated separately and simultaneously.

For C^{12} , the $(\text{He}^3, \alpha_{1,2,3})$ angular distributions exhibit pronounced oscillatory structure; however, the (He^3, α_0) angular distribution has a washed-out structure, particularly forward of 90° . DWBA analyses, assuming a knockout model, have been initiated. Preliminary results indicate that the theoretical predictions for the angular distributions corresponding to the $(\text{He}^3, \alpha_{1,3})$ reactions agree reasonably well with experimental results, but the predictions for the $(\text{He}^3, \alpha_{0,2})$ reactions bear little resemblance to the experimental results.

For O^{16} , the $(\text{He}^3, \alpha_{0,3})$ angular distributions are both oscillatory in character. Analyses of this data will be started in the near future.

G. MEASUREMENTS AND DWBA ANALYSES OF SOME 13.9-MeV
DIFFERENTIAL CROSS SECTIONS FOR THE $N^{14}(\text{He}^3, \alpha) N^{13}$
REACTIONS

B. T. Lucas, D. R. Ober, and O. E. Johnson

The (He^3, α) differential cross sections leading to the gnd., 2.367-, (3.51+3.56)-, 6.38-, and (7.18+7.42)-MeV states of N^{13} have been measured at an incident He^3 -energy of 13.9 MeV. The spectrometer system used to measure the particle spectra has been described in Sec. F.

Energy spectra were accumulated at 2.5° intervals over a laboratory angular range from 17.5° to 90° and 5° intervals from 90° to 170° . The experimental differential (He^3, α) cross sections corresponding to states in N^{13} at 0, 2.367, 6.38, and (7.18+7.42) MeV all exhibit a pronounced oscillatory structure, suggesting that a direct-reaction mechanism is dominant. The cross section corresponding to the transition leading to the (3.51+3.56)-MeV doublet displays a somewhat more washed-out structure. All angular distributions display a definite forward-angle peaking, and those leading to the gnd., 2.367-, and (3.51+3.56)-MeV states of N^{13} show evidence of strong backward peaking. The experimental cross sections also indicate that the transitions leading to the odd parity states in N^{13} are considerably enhanced over those leading to the even parity states.

The experimental angular distributions corresponding to transitions to the gnd., 2.367-, and 6.38-MeV states have been analyzed within

the framework of the distorted-wave theory as formulated by Tobocman¹ using a knockout model to describe the reaction mechanism. Reasonably good fits to the experimental data were obtained using cutoff radii equal to or slightly greater than the nuclear radius.

A complete report on this investigation is presently being prepared and upon completion will be submitted for publication.

-
1. W. Tobocman, Theory of Direct Nuclear Reactions (Oxford University Press, London, 1961), p. 30.

H. DWBA ANALYSES OF THE $\text{Na}^{23}(\text{d}, \alpha_{0,1,2}) \text{Ne}^{21}$ REACTIONS AT 9.2 MeV

B. T. Lucas and O. E. Johnson

The angular distributions previously measured at this laboratory for the $\text{Na}^{23}(\text{d}, \alpha) \text{Ne}^{21}$ reactions leading to the gnd., 0.35- and 3.51-MeV states of Ne^{21} were analyzed within the framework of the distorted-wave theory as formulated by Tobocman². A simple knockout model was used in which Na^{23} is represented by an alpha particle bound to an inert F^{19} core, and Ne^{21} is represented by a deuteron bound to the same core. The entrance- and exit-channel optical-model parameters used were those

-
1. S. W. Cospers, B. T. Lucas, and O. E. Johnson, *Phys. Rev.* **139**, B763 (1965).
 2. W. Tobocman, Theory of Direct Nuclear Reactions (Oxford University Press, London, 1961), p. 30.

derived through analyses and measurements performed by Cosper³ and Lucas⁴, respectively, at this laboratory. The resulting fit to the ground-state angular distribution, although marginally reproducing the gross features of the experimental cross section, is of poor quality. The fit of the 0.350-MeV state angular distribution is somewhat better, although the calculated curve failed to reproduce one rather well-defined experimental maximum. No correspondence whatsoever could be achieved between the theoretical and experimental angular distribution corresponding to the 3.51-MeV state of Ne²¹.

It appears that this model is inadequate for the description of these Na²³(d, α)Ne²¹ reactions at 9.2 MeV. No direct extension of this work is anticipated.

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3. S. W. Cosper, Ph.D. Thesis, Purdue University, 1965 (University Microfilms, Inc., Ann Arbor, Michigan).
 4. B. T. Lucas, S. W. Cosper, and O. E. Johnson, Phys. Rev. 144, 972 (1966).

I. INVESTIGATION OF THE LOW-ENERGY TRIPLET LEVELS IN THE ¹⁹F NUCLEUS BY MEANS OF THE ELASTIC AND IN- ELASTIC SCATTERING OF 18.4-MeV ALPHA PARTICLES

C. L. Wiley

The relative cross sections and the corresponding angular distributions for the ground state ($\frac{1}{2}^+$) and 0.197-MeV state ($5/2^+$) of ¹⁹F have been

reduced to the center-of-mass system. The behavior of these angular distributions is consistent with the predictions of the Blair Phase Rule, i.e., the oscillations of the 0.197-MeV-state angular distribution are out of phase with the oscillations of the ground-state angular distribution.¹ Furthermore, at back angles these angular distributions display the washed-out diffraction-like pattern which has been observed in the angular distributions of other light odd-A nuclei.² It is believed that the probability for a transition to the 0.110-MeV state ($\frac{1}{2}^-$) of ^{19}F is very small since no tracks corresponding to this transition were found in the nuclear-track emulsions.

The extraction of the raw data for the angular distributions corresponding to the third through the sixth excited states of ^{19}F is nearing completion, and the reduction of this data to relative center-of-mass cross sections is in progress.

The determination of a consistent value for the effective target thickness has heretofore been impossible because of the rapid and severe deterioration of the fluorinated target under alpha-particle bombardment. This difficulty has precluded the calculation of absolute cross sections. However, the preliminary results of a recent experimental investigation in this laboratory suggest that it will be possible to circumvent the target-deterioration problem so that absolute differential cross sections can be obtained from the alpha-particle scattering experiment. This work is in progress.

1. J. S. Blair, Phys. Rev. 115, 928 (1959).

2. B. T. Lucas, S. W. Cosper, and O. E. Johnson, Phys. Rev. 144, 972 (1966).

III. COULOMB EXCITATION STUDIES

The experiments described in this section were performed at the Tandem Van de Graaff installation of the Argonne National Laboratory.

A. OBSERVATION OF THE REORIENTATION EFFECT

G. Schilling, J. W. Tippie, R. P. Scharenberg

1. Measurements of Electric Quadrupole Moments of Excited Nuclear States

The electric quadrupole moment of the 0.558 MeV state in Cd^{114} has been measured by studying the reorientation effect on the differential inelastic scattering cross section of incident heavy ions. A preliminary analysis of the data gives $Q_{22} = -0.6 \pm 0.1$ (experimental) ± 0.06 (theoretical) barns. The theoretical uncertainty arises from higher order corrections due to coupling to other states of higher energy. (See next section).

The experiment was performed with a 25 MeV O^{16} beam from the Tandem Van de Graaff accelerator at Argonne National Laboratory. The scattered ions were detected with silicon surface-barrier detectors set at the desired scattering angles from 55° to 160° . Inelastic ions which Coulomb-excited the 0.558 MeV state were separated by gating the detected ions with the de-excitation γ -rays detected in a $5'' \times 4''$ NaI(Tl) scintillator mounted directly above the target, as shown in Fig. 1.¹ Each detector

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1. The gating efficiency is not identical for each scattering angle, but a correction is calculated by independently measuring the scintillator efficiency for radiation incident at different angles with a collimated source and measuring the correlation of the de-excitation γ -radiation with respect to the beam with a separate movable scintillator during the experiment.

DETECTOR-BEAM GEOMETRY

Figure 1

thus measures the number of inelastically scattered ions per elastic ion at the given scattering angle, which is just the differential excitation probability. The results are shown in Fig. 2. The reorientation effect causes an increasing deviation from first-order Coulomb excitation theory toward the back scattering angles which is evident in the figure. The sign and magnitude of the deviation depend directly on the sign and magnitude of the quadrupole moment, allowing it to be determined.

The Cd^{114} results are to be submitted to Physical Review Letters. The experimental technique developed here will be used to continue the investigation of electric quadrupole moments of excited nuclear states throughout the periodic table.

2. Target Preparation

J. W. Tippie

Preparation of $100\text{-}300\text{ }\mu\text{g}/\text{cm}^2$ Cd^{114} targets on $75\text{ }\mu\text{g}/\text{cm}^2$ Cu backings have continued. A number of problems with this technique have been overcome.

Two vacuum chambers pumped by Vac-ion pumps have been built to store targets. This has greatly improved the target life in storage. Also we now have less trouble with target breakage when exposed to the beam. Apparently the Cu backings oxidize slowly and cause the target to shrink.

Another problem has been that of the target coming loose from the copper holder. Glue did not work very well because of its shrinkage on drying. It was found that coating the target holder with silicon rubber around the edge and allowing it to cure before mounting the target solved the problem.

Fig. 2. Reorientation effect in Cd^{114}

Self-supporting iron targets of between 75 and $300 \mu\text{g}/\text{cm}^2$ have been prepared for reorientation-effect experiments. The targets were prepared by evaporating iron by the electron-beam - cold-crucible technique onto KC-coated slides heated to 400°C . The hot substrate temperature was found necessary to stress-relieve the iron film. Foils prepared on room-temperature substrates were found to break up into small pieces of $\sim 1 \text{ mm}$ when the target was floated. Foils deposited on the hot substrate are easily floated in pieces as large as one-inch square.

3. Equipment Development

D. Grissmer

Thirteen vacuum-tube input pre-amplifiers capable of being used both with silicon and germanium detectors were constructed. A resolution of 6 keV for the 662 keV gamma ray of Cs^{137} was obtained with a lithium-drifted germanium detector and the pre-amplifier. Eight of these pre-amplifiers were packaged with power supply and detector bias supply to be used with the scattering chamber at Argonne.

The 18" scattering chamber, constructed at Purdue, has been installed on the beam line of the Tandem Van de Graaff accelerator at Argonne. The chamber is evacuated with newly-built pumping system consisting of a 4" oil diffusion pump, liquid nitrogen cryo-baffle, and valve. The assembly is permanently affixed to the chamber and looks into the chamber through a $3\frac{1}{2}$ " side porthole. A vacuum of 2×10^{-6} torr, is achieved inside the chamber after a few hours of pumping.

A new chamber top was designed and constructed to house a 9" x 4" NaI (Tl) crystal. A beryllium window is used as an interface between the chamber and crystal to minimize absorption of gamma rays. The new crystal will give more than twice the present coincidence counting rate in measurement of excited-state quadrupole moments.

The efficiency of the crystal as a function of incident gamma-ray angle has been measured for 6 energies between .5 and 1.3 Mev in 3° intervals.

A small test chamber (18" dia. x 4" height) has been prepared for testing of coincidence electronics with 4 solid-state ion detectors and a gamma crystal. This allows a check-out of equipment going to Argonne National Laboratory.

4. Computer Programs for Data Analysis at Argonne National Laboratory

J. W. Tippie and R. P. Scharenberg

Two programs have been written in order to obtain quick analysis of experimental data during the reorientation-effect experiments at the Argonne National Laboratory.

The first program is used on-line with the ASI-210 computer located in the experimental area at the Argonne Tandem Laboratory. This program reads data from the paper tape punched by the analyzer. The data is then listed, plotted, and a number of quantities are calculated which indicate the general character of the data. Also the data is punched onto cards for later computer analysis. Substantial portions of this program were written in ASI Assembly Language in order to conserve space in core, and also because some of the required operations were not possible within the structure of Fortran.

The second program is used off-line on the ASI-2100 to calculate the excitation probabilities and to make a least-squares fit of the experimental excitation probabilities to theoretical curves in order to determine the quadrupole moment. This program was written in Fortran II. A second version of this program was also written in Fortran IV for use at Purdue on the IBM 7094 computer.

Both of these programs were written so as to provide fast checks on the data while the experiment is in progress.

5. Computer Program for Multiple Coulomb Excitation and the Effects of Higher Levels on the Reorientation Effect

J. W. Tippie and R. P. Scharenberg

A modified version of the Multiple Coulomb Excitation program of Winther and de Boer¹ has been implemented. Modifications were made principally in the input section to facilitate calculating angular distributions of the inelastically scattered ions. The program has been used in the fitting of the 25 MeV O^{16} on Cd^{114} experimental data described elsewhere in this report. In these fits the effect of levels above the first 2^+ level have been neglected.

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1. A. Winther and J. de Boer, "A Computer Program for Multiple Coulomb Excitation", Tech. Report, Calif. Inst. of Tech., Nov. 18, 1965.

The effects of these higher levels for Cd^{114} have been investigated with the aid of the Winther-de Boer program. The magnitudes of most of the E2 matrix elements associated with these higher levels have been measured by Stelson and McGowan²; however, the signs are not known. For 25 MeV O^{16} ions incident on Cd^{114} the unknown signs of these matrix elements result in a theoretical uncertainty in the measured quadrupole moment of the first 2^+ state of from 10 to 15%.

From an experimental point of view it would be advantageous to be able to determine the relative signs of these higher matrix elements. The Winther-de Boer program has been used to investigate this possibility for Cd^{114} .

The level structure of Cd^{114} is shown in Fig. 1. It was found that the signs of the matrix elements associated with the 0^+ and 4^+ levels do not appreciably affect the excitation probability of the first 2^+ level. Figure 2 shows the effects of the signs of the matrix elements associated with the two higher 2^+ level. In Fig. 2 the percentage effect on the excitation probability of the first 2^+ level at 160° (laboratory angle) caused by opposite signs of the matrix elements associated with the higher 2^+ levels is plotted against O^{16} beam energy. The dashed curves includes coupling to level 4 only.

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2. P. H. Stelson and F. K. McGowan, Phys. Rev. 110, 989 (1958) and Phys. Rev. 121, 209 (1961) ; F. K. McGowan, et al., Bull. Am. Phys. Soc. 9, 107 (1964).

Fig. 1. Level Structure of Cd^{114}

%EFFECT ON EXCITATION PROBABILITY

Fig. 2. Modification of the excitation probability of level 2 due to coupling to higher 2^+ states (level 4 and 7)

The solid curves includes coupling to levels 4 and 7. The sign in parentheses is the relative sign between M_{1S} and M_{S2} for level S where M_{rs} is the E2 matrix element between level r and s. The effect of different values of the quadrupole moment for the first 2^+ level has only very slight effects on these curves.

On the basis of Fig. 2 it appears that it would be possible to determine some of these unknown signs if the excitation probability can be measured to .5 to 1% for energies between 25 and 40 MeV 16 . This may become possible with the new Argonne Tandem and the larger gamma detector presently being installed.

IV. ANGULAR CORRELATION AND INTERNAL HYPERFINE FIELD STUDIES

A. CONVERSION ELECTRON PARTICLE PARAMETERS IN THE DECAY OF Eu^{152} AND $\text{Eu}^{154*†}$

H. M. Nasir, Z. W. Grabowski, and R. M. Steffen

The internal conversion electron particle parameters of several fast low-energy E2 transitions in the deformed nuclei Sm^{152} and Gd^{154} were determined by comparing the e^- - γ directional correlations and γ - γ directional correlations displayed by the same sources. Special attention

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

† See appended document No. 6 (Preprint).

was paid to eliminate the effects of scattering in the source, and the corrections caused by the presence of extranuclear perturbations of the directional correlations were carefully studied. The results are:
 0.122 MeV transition in Sm^{152} ; $b_2(E2, K) = 1.60 \pm 0.05$, $b_2(E2, L^-) = 1.03 \pm 0.05$; 0.245 MeV transition in Sm^{152} ; $b_2(E2, K) = 1.71 \pm 0.04$; 0.344 MeV transition in Gd^{154} ; $b_2(E2, K) = 1.57 \pm 0.13$; 0.123 MeV transition in Gd^{154} ; $b_2(E2, K) = 1.38 \pm 0.07$. The two-particle parameters of the 0.122 MeV ground state transition in Sm^{152} are about 15 percent lower, that of the 0.123 MeV ground state transition in Gd^{154} is 25 percent lower, than the theoretical predictions for finite-size nuclei. The particle parameters of the 0.245 MeV and of the 0.344 MeV transitions agree with the theoretical values within experimental errors.

B. CONVERSION-ELECTRON-GAMMA DIRECTIONAL CORRELATIONS IN Tm^{169} AND Lu^{175}

H. M. Nasir, Z. W. Grabowski and R. M. Steffen

The angular correlation table of the lens-spectrometer has been modified to accommodate a moveable cryostat and a Ge(Li) gamma detector. Measurements of $e^- - \gamma$ directional correlations have been started, where the high resolution of the Ge(Li) detector is essential.

The particle parameters of the conversion electrons are computed from the measured $e^- - \gamma$ directional correlation and from the corresponding $\gamma - \gamma$ directional correlation. The particle parameters of γ -transitions in Tm^{169} and Lu^{175} are being studied.

The result A was obtained with the Ge(Li) gamma detector; the result B was obtained with the Na I (Tl) detector.

The $\gamma(177) - \gamma(131)$ directional correlation, as measured with two Ge(Li) detectors is (see section IV-F of this progress report) :

$$W(\theta) = 1 + (0.253 \pm 0.008) P_2(\cos \theta) + (0.036 \pm 0.010) P_4(\cos \theta)$$

From these measurements the K-particle parameter of the 131 keV transition was computed:

$$b_2(131 ; K) = 1.93 \pm 0.10$$

This value is in fair agreement with the previously reported results within limits of error, but it seems to indicate a somewhat larger particle parameter than earlier measurements.¹ The theoretical value for a pure E2 transition is : $b_2(E2;K) = 1.85$.

According to the γ - γ directional correlation measurements, the coefficient of the $P_4(\cos \theta)$ term is of the order of a few percent. The theoretical $b_4(E2;K)$ particle parameter is $b_4(E2;K) = -1$. The search for a $P_4(\cos \theta)$ term in the e^- - γ directional correlation is in progress.

1. Z. W. Grabowski, J. E. Thun, M. S. El-Nesr and W. K. Hamilton,
Z. Physik 167, 111 (1962).

The decay of Yb^{175} to Lu^{175} is shown in Fig. 2. The particle parameter

Fig. 2. Decay Scheme of Yb^{175}

of the 282 keV transition, which presumably is an E1 transition with a small M2 admixture, has been measured before^{2,3}. Two rather different values of the particle parameter were reported $b_2(282, K) = +0.06 \pm 0.12^1$ and $b_2(282, K) = +0.27 \pm 0.06^2$. Both these values disagree strongly with the theoretical value, $b_2(E1; K) = -1.52$, which does not include dynamic penetration effects.

The Yb^{175} sources were prepared by means of an isotope separator, hence the corrections for scattering effects in the extremely thin sources were negligibly small. The result of the $e^- - \gamma$ directional correlation

2. J. E. Thun, Z. Grabowski, M. S. El-Nesr, Nuclear Phys. 29, 1 (1962).
3. J. E. Thun, Nuclear Phys. A91, 653 (1967).

measurement on the $K(282)-\gamma(114)$ cascade is:

$$W(\theta) = 1 + (0.10 \pm 0.05) P_2(\cos \theta)$$

The measurement of the corresponding γ - γ directional correlation is in progress.

If one takes the γ - γ directional correlation results of Thun et al.², the particle parameter extracted from the present measurements is:

$$b_2(282;K) = + 0.04 \pm 0.02$$

The result indicates, that there is definitely a large discrepancy with theory. The investigation of this discrepancy is in progress.

C. PRECISION MEASUREMENT OF THE K, L, AND M CONVERSION ELECTRON PARTICLE PARAMETERS IN Pb^{207}

D. L. Coppage and R. M. Steffen

During the past year, the e^- - γ directional correlation equipment has been variously modified, especially in the electronics. Early in the year, the original amplifiers were replaced by multimode amplifiers with selectable integration and differentiation time constants in order to improve the system energy resolution and possibly the cross-over timing accuracy. At the same time a new pulse-height analyzer was added, increasing the number of data channels from one to two. The original preamplifier for

the Si(Li) electron detector was replaced by a very low-noise preamplifier utilizing a three-FET input which significantly improved the system in spite of the relatively large capacitance associated with the $200 \text{ mm}^2 \times 1 \text{ mm}$ Si(Li) detector and its leads. For the 624 keV K-conversion line in Cs^{137} , the overall resolution is about 6 keV FWHM or about 1%. The last major change has been the replacement of the original scaling equipment and output registers with an automatic data recording system¹ which transfers the data to punched paper tape. The paper tape can then be easily converted to IBM data processing cards for computer analysis.

The principal subject under investigation this year has been the precise determination of the particle parameters for the K and L shell conversion lines in the 1064 keV and 570 keV transitions in the decay of Bi^{207} (Fig. 1).

Fig. 1. Decay of Bi^{207} to Pb^{207}

1. P. C. Simms, Research in Nuclear Physics, Progress Report No. 16 (COO-1420-124).

The case of the L-conversion line is of particular interest because of the simplicity in the experimental design as a result of the good high-energy resolution of our solid-state detector and because of the recent availability of theoretical values for the three L-subshells calculated for the exact case of interest by a general computer program developed by H. C. Pauli². A typical electron-conversion spectrum of the 1064 keV transition taken with a RIDL 400 Channel Multichannel Analyzer is shown in Fig. 2.

A very thin but weak source for the electron conversion studies was made by the electrodeposition onto a 1 mil nickel backing of about 3 μ c of Bi²⁰⁷ from a carrier-free Bismuth nitrate solution. Technical difficulties have so far prevented the preparation of a stronger source of the same type. As a result the data on the comparatively weak 570 keV L-shell conversion line is incomplete because of the excessive time demanded for reasonable statistics. A computer program incorporating a linear least-squares fit routine was developed for the analysis and statistical testing of the experimental data. The results so far are indicated in Table I which gives the experimental values for the different possible directional correlation parameters corrected for the finite size of the detectors. The 1064-570 keV γ -e⁻ cascade parameters are not corrected for a small amount of a competing cascade. The theoretical values shown are calculated on the basis of a pure 1064 M 4-570 E2 cascade. They are not sensitive to the small admixture of E5 in the 1064 keV M4 transition which has been reported

2. H. C. Pauli, see Section VI, A of this Progress Report.

Fig. 2. Conversion electrons of the 1064 keV transition measured with $\text{Si}(\text{Li})$ detector

recently³, and the experimental quantities are consistent with both possibilities. A γ - γ directional correlation experiment to investigate this detail is in preparation.

TABLE 1. Directional Correlation Results for the 1064-570 keV Cascade

1064-570	$A_{22}(\text{exp})$	$A_{22}(\text{Theory})^a$	$A_{44}(\text{Exp})$	$A_{44}(\text{Theory})^a$
K- γ	0.237(3)	0.231	-0.034(4)	-0.0227
$L_{\text{ToT}}^{-\gamma}$	0.239(6) ^b	0.229	0.012(8) ^b	-0.022
γ -K	0.267(6)	0.263	-0.006(7)	-0.009
γ - L_{ToT}	0.22(2) ^b	0.232	0.006(30) ^b	-0.013

^aCalculated for this case using the computer program of reference 2.

^bThese values are not corrected for a possible small admixture of M-shell electrons.

Using the theoretical parameter for a pure M4-E2 γ - γ directional correlation gives the experimentally-derived b-parameters shown in Table 2.

3. P. Kleinheinz, et al., Nuclear Physics A93, (1967) p. 63-73.

TABLE 2. Preliminary Values for the 1064 and 570 keV K- and L-shell b-parameters

	$b_2(\text{Exp})$	$b_2(\text{Theory})^a$
$b_2(\text{E2;K})$	1.21(3)	1.19
$b_2(\text{E2;L}_{\text{ToT}})$	1.01(9)	1.049
$b_2(\text{M4;K})$	1.07(1)	1.047
$b_2(\text{M4;L}_{\text{ToT}})$	1.08(3)	1.03

^aCalculated for this case using the computer program of reference 2.

Inclusion of a small E5 admixture to the 1064 M4 transition could change these results by a few percent at most.

The experiments are still in progress.

D. ENERGY DEPENDENCE OF BETA-GAMMA CIRCULAR POLARIZATION

P. C. Simms, D. Ohlms, J. Bosken

The instrument to be used in this experiment has been completed, and calibration measurements are in progress. A circular polarization analyzer magnet was available when the project was started. An automatic control for the magnet has been built which will reverse the magnetic field or degauss the magnet. The control unit can be operated manually or operated automatically from the data system master control. A new set of lead collimators was built to optimize the circular polarization analysis for the isotopes which we plan to study. A computer program was written to calculate the efficiency of

the circular polarization analyzer.

A new vacuum chamber has been built so that special beta detectors with good energy resolution can be used. The beta detectors are well-type plastic scintillators which minimize back scattering. These detectors mounted on RCA 8575 P. M. tubes give 9% energy resolution for 1 MeV electrons. The angular dependence of the beta-gamma circular polarization can also be measured with this chamber.

The most important feature of the new electronic system developed for this experiment is that data can be recorded at a very high rate and prepared for direct computer processing. The system is also very stable so that systematic errors are minimized. Commercial high-voltage stabilizers are used on both the beta and gamma scintillation detectors. The beta detector presented a problem for the stabilizer system since there is no sharp peak in a beta spectrum for the stabilizer to lock on. To overcome this problem, a small NaI scintillator which contains an alpha source was attached to the beta detector P. M. tube. The scintillator serves as a light pulser which gives a signal approximately 30 times larger than the beta particles. The output of the beta detector goes to two D. D. L. amplifiers. One amplifier is set for high gain and used 100 nsec delay lines. This amplifier can feed the beta energy analysis system at counting rates in excess of 1 MHz. Of course, the large NaI pulse overloads this amplifier quite badly. A special linear amplifier was developed for high counting rate and overload conditions. (See electronic instrument section of this report.) The other linear amplifier passes the NaI pulses to the stabilizer system. Since the beta pulses are so much smaller than the NaI pulses, the very

high beta counting rate does not effect the stabilizer.

Fast timing pulses from the beta and gamma detectors are taken to a high rate, good resolution time-to-amplitude converter(see electronics section). This time converter is used with two single-channel analyzers to record the true and accidental counting rates at the same time. With this technique very strong sources and high counting rates can be used. In fact for a given source strength, the best statistical results are obtained with a one-to-one true-to-chance ratio.

The pulses from the beta linear amplifier go to a fast SCA which defines the overall range of beta energies to be observed. These pulses also go to a fast linear gate and pulse-stretcher which is controlled by the fast coincidence system. When a true or accidental pulse is recorded, the linear gate is opened, the pulse is stretched from 100 nsec to 1 μ sec and sent to a 400-channel pulse-height analyzer which determines the beta particle energy. The true and accidental pulses are routed to different parts of the MCA memory.

In addition to the data stored in the multichannel analyzer, all of the other important counting rates are recorded by an automatic scaler system. (see Purdue Progress Report No. 16.) All of the data is automatically punched on paper tape for computer processing. The entire system runs continuously and normally only requires brief daily checks and data removal.

E. β - γ DIRECTIONAL CORRELATIONS IN THE DECAY OF Sb^{124}

S. Cipolla, Z. Grabowski and R. M. Steffen

The β - γ directional correlation involving the first forbidden 2.31 MeV β -transition of Sb^{124} (See Fig. 1) is well known¹ and the nuclear matrix

Fig. 1. Decay of $60d \text{ Sb}^{124}$

elements contributing to this transition have been determined with remarkable precision.^{2,3} The β - γ directional correlations involving the 1.59 MeV β -transition is fairly well known⁴ because the β - γ directional correlation with the 1.325 MeV cross-over transition can be observed. The measurement of the β - γ directional correlation involving the 0.720 MeV gamma transition,

1. R. M. Steffen, Phys. Rev. 124, 145 (1961).
2. P. Alexander and R. M. Steffen, Phys. Rev. 124, 1175 (1961).
3. R. M. Steffen, Proceedings of the Symposium on Solid State and Nuclear Physics, Calcutta (India) 1965.
4. R. S. Raghavan, Z. W. Grabowski and R. M. Steffen, Phys. Rev. 139, B1, (1965).

however, must be corrected for the presence of the 1.672 MeV β -transition which was only recently discovered⁵ and was believed to be very weak. Very recent measurements⁶ however, have shown, that the intensity of this beta branch is comparable to the intensity of the 1.59 MeV β -transition. In order to separate the two β - γ directional correlations the high resolution of the Ge(Li) detectors must be employed.

The β - γ directional correlation equipment was modified by replacing the 3" x 3" Na I (Tl) scintillation detector by a 5 mm thick planar Ge(Li) detector. The 0.720 MeV and 0.645 MeV gamma lines are very well separated with this detector and thus the β (1.59 MeV) - γ (0.72 MeV) directional correlation and the β (1.67 MeV) - γ (0.645 MeV) directional correlation can be observed independently. The counting rates, however, are small and very long measuring periods are required to accumulate statistically significant data.

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

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5. M. J. Glaubmann and J. D. Oberholtzer, Phys. Rev. 135, B1313 (1964).
 6. P. Stelson, private communication.

TABLE 1

 Sb^{124} β - γ DIRECTIONAL CORRELATION

E_γ (Me V)	E_β (Me V.)	A_{22}^*
0.722	1.150	0.1407 ± 0.0140
	1.250	0.1625 ± 0.0224
	1.350	0.1131 ± 0.0584
	1.500	0.1884 ± 0.0580
0.645	1.150	-0.0746 ± 0.0184
	1.250	-0.0663 ± 0.0323
	1.350	-0.0604 ± 0.0215
	1.500	-0.1284 ± 0.0520

* A_{22} is not corrected for size of source.

The measurements are still in progress.

F. GAMMA-GAMMA DIRECTIONAL CORRELATIONS IN THE

DECAY OF Yb^{169} to Tm^{169}

A. Becker and R. M. Steffen

The ground state rotational band of the Tm^{169} nucleus is reasonably well understood. The Nilsson orbital assigned to this band is $\frac{1}{2}^+ [411]$. The properties of this band are influenced by the decoupling of the intrinsic angular momentum from the rotational motion which appears in $K = \frac{1}{2}$ rotational bands.

An extensive comparison can be made between the predicted and the experimentally observed properties of the Tm^{169} levels. Several electromagnetic properties of these levels, however, are not known at all, or are only insufficiently known. One example is the $E2/M1$ mixing ratio of the 20.8 keV transition (See Fig. 1).

Fig. 1. The decay scheme of Tb^{169} and Tm^{169}

In addition, more precise determinations of the magnetic moments of the various excited states and of the mixing ratios of some of the electromagnetic transitions are desirable. Also, a reinvestigation of the presence of possible penetration effects in internal conversion seems to be in order.

The gamma energies involved in the $\text{Yb}^{169} - \text{Tm}^{169}$ are ideally suited for precise directional correlation experiments with two Ge(Li) detectors.

The recently constructed γ - γ directional correlation apparatus employing two Ge(Li) detectors has been modified by the inclusion of a larger-volume germanium detector and a two-parameter multichannel analyzer. The detector, of 6 cm^2 cross-sectional area and 5.5 mm depletion depth, was fabricated at the laboratory and replaces an RCA Victor, Ltd., SJGG 5-35 germanium detector, with a slight improvement in resolution and approximately an 80% increase in effective volume.

The two-parameter multichannel analyzer, a Victoreen SCIPP 1632-2P, enables the simultaneous measurement of the precise energy of each of the two gamma-rays in coincidence, enabling the interpolation beneath the coincidence peak to eliminate background due to Compton-scattered events that are quite prevalent with low-volume germanium detectors. In addition, the use of a double-pulse, coincidence routing circuit enables the simultaneous accumulation of the total (i. e., true plus accidental) coincidences and the accidental coincidences, enabling, by a channel-by-channel subtraction of the two sections, the determination of the true-coincidence spectrum.

To facilitate analysis of the data derived from the output of the multichannel analyzer, computer programs have been developed to provide sorting, statistical testing, normalization, and compensation for possible gain and baseline shifts.

The sources used for the measurement of the Tm^{169} gamma-gamma directional correlations were dilute solutions of Yb Cl_3 in HCl . The results for the correlation coefficients of the various Tm^{169} cascades are:

<u>177 keV - 130 keV</u>	:	$A_{22} = 0.253 \pm 0.008$
		$A_{44} = 0.023 \pm 0.012$
<u>198 keV - 110 keV</u>	:	$A_{22} = 0.338 \pm 0.007$
		$A_{44} = 0.018 \pm 0.011$

These correlation coefficients are in fair agreement with previous scintillation counter measurements¹. The mixing ratio of the 198 keV transition is

$$\delta(198) = \frac{\langle \frac{5}{2} \parallel E2 \parallel \frac{7}{2} \rangle}{\langle \frac{5}{2} \parallel M1 \parallel \frac{7}{2} \rangle} = 0.30 \pm 0.03$$

In order to determine the mixing ratio $\delta(20.8)$ of the 20.8 keV radiation, the 177 keV - 110 keV (1-3) directional correlation was found:

$$A_{22} = -0.314 \pm 0.010$$

$$A_{44} = 0.036 \pm 0.010$$

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1. Z. Grabowski, J. E. Thun, M. S. El-Nesr and W. D. Hamilton,
Z. Physik 167, 111 (1962).

and the mixing ratio $\delta^2(\gamma_2)$ was extracted from the cross-over factors U_{kk} in the expression for the (1-3) directional correlation coefficient, $A_{kk}(\gamma_1 - \gamma_3) = A_k(\gamma_1) U_{kk}(\gamma_2) A_k(\gamma_3)$, yielding the value

$$\delta^2(20.8 \text{ keV}) = 0.00 \pm 0.05$$

A search was made for a 194 keV line in coincidence with the 130 keV transition,² and a upper limit of 10^{-4} was put on the ratio of the intensities of the possible 194 keV line to the 177 keV line in a coincidence spectrum gated by the 130 keV transition.

Measurements of the magnetic moments of the various excited states of Tm^{169} are in progress.

2. Johansson, S. A. E., Phys. Rev. 100, 838 (1955).

G. INTERNAL MAGNETIC FIELD ON Hf NUCLEI IN A FERROMAGNETIC LATTICE

A. J. Becker and R. M. Steffen

The magnitude and direction of the internal magnetic field acting at Hf nuclei embedded in a ferromagnetic lattice is of interest not only to the nuclear physicist who can use this information to measure the g-factors of short lived states in Hf, but also to the solid-state physicist.

Since, at present, it is not possible to calculate from first principles the internal hyperfine fields at the nuclei of impurities dissolved in a

ferromagnetic material, the systematic trends of these fields with atomic number is of great interest. Figure 1 shows the internal magnetic field acting at the nuclei of various atoms embedded in iron as a function of atomic number Z . Most of the internal fields were measured at low temperatures. The fields measured at room temperature are indicated by double circles. Hence the systematic trends discussed below are only of a qualitative nature, since results obtained at different temperatures are compared with each other.

From the theoretical point of view the hyperfine fields of rare earth atoms in iron are of particular interest, and the study of the magnitude of the internal field as the inner shells of transition elements are filled is desirable. The 4f-shell is filled starting with $Z = 70$ (Yb), and the 5d-shell becomes occupied as Z increases beyond this point. The internal magnetic field at Yb-nuclei in iron is $H_{int} = -720 \text{ kG}$. With one electron in the 5d shell in Lu, the field is $H_{int} = -338 \text{ kG}$, then it rises to about -700 kG in Ta, W and Re with 3, 4 and 5 electrons, respectively in the 5d shell. In Os with 6 electrons in the 5d shell, i. e., where the 5d shell has one electron more than the half-filled shell, the field reverses abruptly to $H_{int} = +1130$. A similar phenomenon occurs in the filling of the 4f shell: a sign reversal of H_{int} occurs between Eu and Gd. In this case, however, the 4f shell is only half filled in both Eu and Gd, but the latter atom has one electron in the 5d shell. The indications are that the 5d electrons play a major role for the sign and magnitude of the internal fields in this region. Hence, a systematic study of the internal fields for impurity atoms from $Z = 57$ to $Z = 83$ in iron is desirable.

Fig. 1. Magnetic hyperfine field at nuclei of impurity atoms in an iron lattice

The internal fields of Tb, Ho, Tm, Hf and Tl are not known. In the following the determination of H_{int} for Hf in iron is discussed. The measurement of the internal field of Tm in iron is in progress.

The magnitude and sign of the Hf nucleus in a metallic iron lattice at room temperature was measured by observing the Larmor precession angle in the $9/2^+$ (208 keV) $9/2^-$ (113 keV) $7/2^-$ gamma-gamma directional correlation in Hf^{177} using a source of Lu^{177} in an iron foil (See Fig. 2).

Fig. 2. The decay of Lu^{177} to Hf^{177}

The stable isotope Lu^{176} was placed in an isotope separator and bombarded with 140 kV acceleration into an iron foil, which was then placed in a reactor. This foil was then inserted between the poles of a small, ~ 1000 Gauss electromagnet and used as the source for the gamma-gamma directional correlation measurement. The activity due to the radioactive iron isotopes produced in the reactor is substantially bypassed by the use of the two high-resolution germanium

detectors. These detectors have the added advantage that they are not affected by the external magnetic field acting on the foil.

The directional correlations of the 208 keV - 113 keV cascade were measured with the external field up along the axis of rotation of the movable detector, and also with it reversed.

The lifetime of the intermediate state involved in this cascade is $\tau = (7.5 \pm 0.2) 10^{-10}$ sec. and the coincidence circuit resolving time is 30 nano seconds. Hence the integral perturbed correlation is observed, which is given by

$$W(\theta, \tau) = 1 + A_{22} P_2 (\cos (\theta - \omega \tau)) \quad (1)$$

where the Larmor frequency ω depends on the effective magnetic field H_{int} acting on the Hf^{177} nucleus in the intermediate state with the g-factor g:

$$\omega = g \frac{H_{int}}{\hbar} \mu_N \quad (2)$$

where μ_N is the nuclear magneton. The $P_4(\cos \theta)$ term in the directional correlation is negligibly small.

The gamma-gamma directional correlation was measured at 7 different angles and a least-square fit method was used to determine A_{22} and $\omega\tau$.

A difficulty has arisen since the shifts are not symmetric in the two cases of field up and field down, the two values being $(+ 16 \pm 3)$ deg. and (-10 ± 3) deg. respectively. An investigation is in progress to determine the source of this asymmetry, and the preamplifiers, each with a

vacuum tube in the input, are suspect.

The experimental values of the correlation coefficients show that the

$$A_{22} = -0.120 \pm 0.007$$

$$A_{44} = 0.012 \pm 0.009$$

directional correlation is also slightly perturbed by a non-magnetic interaction (e. g. static quadrupole interaction).

Using the average value of the shift of the directional correlation, we obtain

$$\omega\tau = -0.23 \pm 0.04$$

The g -factor of the 113 keV excited state of Hf^{177} is well known from measurements with a known field produced by a large electromagnet.¹

$$g = 0.229 \pm 0.005$$

The effective internal magnetic field H_{int} , as computed from eq. (2), is:

$$H_{\text{int}} = - (280 \pm 50) \text{ k Gauss}$$

This value of the magnetic hyperfine field acting on Hf-nuclei in iron shows that the magnitude of the internal field goes through a minimum near $Z = 72$.

1. For references see K. Alder and R. M. Steffen, Am. Rev. Nuclear Sci. 14, 403 (1964).

H. THE g-FACTORS OF 2^+ VIBRATIONAL STATES IN Pt^{192}

Z. W. Grabowski

The directional correlation method is being used for measuring the g-factors of the first (316 keV) and second (612 keV) 2^+ excited states in Pt^{192} . (See Fig. 1) This method is based on the observation of rotation

Fig. 1. Decay of Ir^{192} to Pt^{192}

of the time-integrated correlation pattern of two cascading gamma rays in an external magnetic field.¹ Due to the short half-lives ($\sim 10^{-11}$ sec) of the

1. H. Frauenfelder and R. M. Steffen in "α, β and γ-Ray Spectroscopy," edited by K. Siegbahn, North-Holland Publishing Co. (1965).

vibrational states relatively large magnetic fields are needed for the rotation to be observable. Such a field could be obtained by embedding the radioactive nuclei in the ferromagnetic materials, such as iron, cobalt, or nickel. The hyperfine magnetic fields at the impurity nuclei dissolved in one of these magnetic materials are often of the order of megagauss.² The internal magnetic field in iron is the largest of these three since the hyperfine fields are proportional to the magnetic moment of the host material. Using electron bombardment two sources were prepared by melting spectroscopically pure iridium and iron powder. They differ by the iridium concentration which was 2% (by weight) in the first and 4% in the second source. The diameter of each button was ~ 1 mm. Subsequently the samples were irradiated in the Argonne National Laboratory Reactor at a flux of 5×10^{12} neutrons/cm² sec for 2 hours. The sources were not annealed after irradiation, and the measurements were started about one week after irradiation to allow for the 19 hours activity due to Ir¹⁹⁴ to decay.

In the experimental apparatus two 3" x 3" NaI (Tl) crystals (one of them integrally mounted) were coupled to magnetically shielded photomultipliers. Spectrum stabilizers ("Spectrostat", Cosmic Radiation Labs., Inc. Model 1001) were used in both channels. The source was placed between the pole pieces of a small electromagnet (magnetic field strength ~ 1 kG in a 2 mm gap). The change of the single counting rate under reversal of the magnetic field was measured to be negligible.

2. D. A. Shirley and G. A. Westenbarger, Phys. Rev. 138, A170 (1965).

The coincidences between the 468 keV gamma and the 316 keV gamma ray were recorded at seven different angles for both direction of the magnetic field. The $\omega\tau$ (and A_{22}) were calculated from the experimental data by fitting the

$$W(\theta, \pm B) = \sum_{k=0}^2 G_{kk} A_{kk} P_k [\cos(\theta - \omega\tau)]$$

function to the measured values. The results of the measurements which are available at the present time are listed in the table below.

Table 1. Shift of Ir - Pt γ - γ Directional Correlation.

Source	Field direction	$\omega\tau$	$\overline{\omega\tau}$	A_{22}
2% Ir	up	-0.083 ± 0.028	0.057 ± 0.014	0.099 ± 0.006
	down	0.048 ± 0.015		0.099 ± 0.004
4% Ir	up	-0.0805 ± 0.0096	0.0799 ± 0.0084	0.100 ± 0.002
	down	0.0776 ± 0.019		0.098 ± 0.003

Values for $\overline{\omega\tau}$ listed in the table are weighted averages of each set of measurements with magnetic field up and down.

The measurement with the second source (4% Ir) was also performed with the current in the electromagnet lowered by 15%. The result of this measurement is $\omega\tau = 0.066 \pm 0.006$ which is slightly lower than ^{the} weighted average of the $\overline{\omega\tau}$ values listed in the table. This result, however, is not conclusive due to the relatively large errors assigned to both values. The measurement of the $\omega\tau$ value as a function of the magnetic field is still in progress.

Two results for the $\omega\tau$ value for the 316 keV state were reported by other authors:

$$\omega\tau = 0.063 \pm 0.009^3 \text{ and } \omega\tau = 0.080 \pm 0.005^4$$

The weighted average of the present measurements listed in the table is

$$\omega\tau = 0.073 \pm 0.007$$

This last value gives the g-factor for the 316 keV 2^+ level in Pt^{192}

$$g = 0.226 \pm 0.031$$

For calculation of this value the magnetic field, $H_{\text{int}} = 1320 \pm 80$ kG, was used and the mean life for the 316 keV state was taken to be $\tau = (5.1 \pm 0.4) \times 10^{-11}$ sec, as reported in ref. 5.

The value for the g-factor obtained here is significantly lower than the theoretical value ($g_{\text{th}} = 0.334$) obtained from the model proposed recently by Greiner⁶. The strength of the pairing forces for protons and neutrons used in this calculation was taken from ref. 7.

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3. L. Keszthelyi, L. Berkes, L. Dezsı and L. Pocs, Nucl. Phys. 71, 662 (1965).
 4. Y. K. Agarwal, C. V. K. Baba and S. K. Bhattacharjee, Nucl. Phys. 79, 437 (1965).
 5. A. Schwarzschild, Phys. Rev. 141, 1206 (1966).
 6. W. Greiner, Nucl. Phys. 80, 417 (1966).
 7. E. R. Marshallek and J. O. Rasmussen, Nucl. Phys. 43, 438 (1963).

The measurement of the WT -value for the second excited (612 keV) 2^+ state, which requires an energy resolution of ~ 4 keV in one of the channels and thus application of a Ge(Li) detector, is in progress. According to the predictions of the vibrational model the g -factors of these two 2^+ excited states should be identical. Our previous conclusions, however, obtained from the β - γ directional correlation measurements⁸, show that at least in some cases the vibrational model description is not adequate for the 2^+ states in spherical nuclei.

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8. R. S. Raghavan, Z. W. Grabowski and R. M. Steffen, *Phys. Rev.* **139**, B1 (1965).

L NMR MEASUREMENTS OF INTERNAL HYPERFINE FIELDS OF IMPURITY NUCLEI EMBEDDED IN A FERROMAGNETIC LATTICE

W. C. King, J. W. Tippie and R. P. Scharenberg

The determination of the moments of excited, short-lived nuclear states by angular correlation methods requires very large magnetic fields which are not directly available in the laboratory. The possibility of making such measurements by utilizing the large internal hyperfine fields of impurity nuclei embedded in ferromagnetic samples has led to the desirability of measuring these fields with accuracy. Especially important are measurements of the temperature dependence of the internal fields. For certain solutes, various researchers have found that nuclear magnetic resonance techniques have proven successful in this regard. Such NMR

measurements must be made in the absence of an external magnetic field and require highly sensitive, frequency-modulated spectrometers.

A spectrometer of this type has been built in the laboratory and is undergoing preliminary testing. The spectrometer follows a design originally due to F. N. H. Robinson. The oscillator consists of a tuned-grid, tuned-plate pentode RF amplifier and an overdriven pentode limiter providing the regeneration. The frequency range is 20-60 Mc/s, although plans call for extending the upper limit to the vicinity of 100 Mc/s. The RF level on the sample coil in the grid bank circuit can be varied from 10-200 mv.

In order to overcome the spurious resonances common to spectrometers of this type and to permit unattended frequency sweeps over a range of several megacycles, an automatic frequency control system designed by G. V. H. Wilson has been incorporated in the circuit. This system uses a D. C. chopper stabilized amplifier to monitor the DC component of a rectified RF signal taken from ^{the} anode tank circuit of the RF amplifier. When the RF level changes, due to frequency sweeping, the DC amplifier output makes corresponding adjustments on the bias of varactors in the anode circuit and thereby shifts the anode tank circuit resonance curve to maintain a fairly constant RF level.

The resonance signal is detected at either the first or second harmonic of the modulation frequency by means of a lock-in amplifier.

J. GAMMA-GAMMA DIRECTIONAL CORRELATION MEASUREMENTS WITH Ge(Li) - Na I (Tl) CORRELATION EQUIPMENT

S. J. Cipolla

The β - γ directional correlation apparatus underwent some simple modifications which now enable it also to be used in γ - γ directional correlation work. A liquid-nitrogen-cooled Ge(Li) detector, with the associated elbow-type cryostat and a Simtec P-10 preamplifier, replaced the moveable vacuum chamber plus β -detector. At the axis of the moveable arm was situated the radioactive source mounted on a small centering table. Left unchanged, a 3" x 3", shielded Na I detector served as the other detector of the coincidence spectrometer.

The most important advantages of this configuration are the high-energy resolution and fast response of the Ge(Li) detector and, on the other hand, the high detection efficiency of the Na I detector. Employing these characteristics to our advantage, the Ge(Li) detector, due to its relatively poor detection efficiency, was used to measure low-energy gamma rays, whereas the Na I detector was more useful in detecting high-energy radiation.

Initially, a 2 mm x 18.5 mm (diam.) RCA Ge(Li) detector was used. Later, it was supplanted by a 5 mm x 4 cm² (area) Ge(Li) detector manufactured by Nuclear Diodes, Inc.

Using a dilute chloride solution enclosed in a quartz capillary ampoule 0.25" in length, the directional correlation of the 868-245 cascade in Eu¹⁵² was measured. Careful attention was paid to the various corrections that must be taken into account because of several competing cascades. The various gamma transitions in the decay of Eu¹⁵² are shown in Fig. 1. There

Fig. 1. Decay of Eu^{152} . (Energies in MeV)

Fig. 2. Decay of Ta^{182}

exists a 1210-245 cascade which competes by virtue of Compton-scattered events from the 1210 keV transition falling under the 868 keV peak.

Therefore, the 1210-245 correlation was simultaneously measured which, in itself, yields information on the mixing ratio, of the 1210 keV radiation. Also measured concurrently were the correlations of the 868 keV transition with the Compton-scattered background just above the 245 keV line in energy and just below it in energy. This procedure was necessitated by the existence of the 444-868 cascade, which competes due to Compton-scattered 444 keV photons falling under the 245 keV peak.

First, the 444-868 correlation correction was applied. The end result of this procedure was obtained by averaging the data corrected for the low-energy background and that corrected for the high-energy background. Finally, the 1210-245 correlation correction was applied to these data.

The final results appear in Table 1.

Table 1. γ - γ Directional Correlation Data of Eu^{152} and Ta^{182} .

Isotope	Cascade (keV)	A_{22}	A_{44}	
Eu^{152}	868-245	$+0.1350 \pm 0.0075$	-0.1241 ± 0.0102	a
	1409-122	$+0.232 \pm 0.004$		
	1210-245	-0.1559 ± 0.0082	$+0.0722 \pm 0.0138$	
	1210-122	$+0.0209 \pm 0.0017$	-0.0158 ± 0.0032	b
Ta^{182}	67-1222	$+0.1554 \pm 0.0036$	$+0.0055 \pm 0.0079$	
	67-1122	$+0.0120 \pm 0.0087$	-0.0026 ± 0.0130	
	1122-100	-0.0389 ± 0.0064	$+0.1066 \pm 0.0098$	
	1232-100	$+0.0196 \pm 0.0041$	$+0.0378 \pm 0.0062$	
	152-1122	-0.0863 ± 0.0299	-0.0430 ± 0.0090	
	152-1222	-0.0260 ± 0.0060	-0.0430 ± 0.0090	
	222-1232	-0.0179 ± 0.0106	-0.0130 ± 0.0016	

^a Result corrected for all competing events.

^b Result uncorrected for all competing events.

It was also possible to measure (although indirectly) the $A_{kk}(\gamma)$ coefficients for the 122 keV transition from the first-excited state in Eu^{152} . In coincidence with the 122 keV transition, via a (1-3) cascade, are both the 868 keV and the 1210 keV transitions. Due to the large number of competing cascades in the 868-122 correlations, the analysis was only carried through for the 1210-122 correlation, although both were measured, concurrently with the above experiments. It was necessary later to measure the 1410-122 correlation, since the 1410 keV Compton-scattered photons fall under the 1210 keV peak. As a bonus, this measurement also yields the mixing ratio of the 1410 keV transition. Also in competition is the 1210-245 cascade, as the Compton peak of the 245 keV photon lies directly under the 122 keV line. Graphical analysis must be performed to estimate the contribution of the 245 keV Compton-scattering to the 122 keV peak as well as the contribution of the 1410 keV Compton events to the 868 keV peak. These calculations are still in progress, but tentative results are listed in Table 1. (See pg. 62.)

Several directional correlation measurements were performed in the study of the deformed nucleus Ta^{182} . The object of these measurements was to take advantage of the high resolution inherent to the Ge(Li) detector in determining the $A_{kk}(\gamma)$ coefficients of the directional correlation function. Thereby, we hoped to verify the multipolarities of the γ -transitions and the spin-parity assignments for the energy levels, by calculating the mixing ratios of several transitions. It was practical to measure the following correlations: (see Fig. 2.)

(68-1222, 68-1122) ; (152-1222, 152-1122) ; (222-1232) ; (100-1222, 1122)

Final results are still pending computer analysis, although tentative results for a few of the cascades appear in Table 2.

Table 2. The Mixing Ratio of Some γ -Transitions of Eu^{152} and Ta^{182} .

Isotope	Transition (keV)	δ
Eu^{152}	1409	-0.030 ± 0.005
Ta^{182}	67	-0.13 ± 0.01
	1122	$+7.35 \quad +3.53$ $\quad \quad -0.44$

Computer programs for the Purdue IBM 7094 computer facility have been written to expedite the calculations in the data analysis. Primarily, these involve geometrical and chance coincidence corrections, testing of data on basis of the χ^2 -goodness of fit, least-squares fit to the directional correlation function

$$W(\theta) = \sum_{k=0}^4 A_{kk} P_k(\cos \theta)$$

and corrections due to competing cascades.

K. SHORT LIFETIME MEASUREMENTS

P. C. Simms and H. Kuhlman

A new experimental technique has been developed for measuring the lifetime of excited states. With this system, the centroid-shift method can be applied to many isotopes with a greater accuracy than was previously possible. Two plastic scintillators are used to detect the particles which indicate the formation and decay of the excited state. In the simplest experimental arrangement, one of these plastic scintillators is surrounded by a Na I detector. (The plastic detector is placed in a hole which is drilled through the Na I detector perpendicular to its symmetry axis. The plastic and Na I detectors are viewed by separate P. M. tubes.)

As an example of the method, consider a state where a 0.7 and 1.0 Mev gamma ray are emitted when the state is formed and then decays. Single-channel analyzers connected to the two plastic scintillators are set to record an energy loss between 400 and 450 keV. Either gamma ray can be detected in either scintillator. However, the energy of the scattered gamma ray which leaves the plastic scintillator will depend on the energy of the incident gamma ray. The scattered gamma rays are detected in the Na I scintillator. Thus the plastic detectors cannot distinguish between the particles, but the Na I detector can be used to determine which particle hit which detector.

The plastic detectors are also connected to the inputs of a time-to-amplitude converter. (See electronics section). The output from the time converter is passed to a multichannel analyzer when a separate coincidence circuit indicates that the scattered gamma ray has been recorded in the Na I

detector. A pair of single-channel analyzers connected to the Na I detector determines which particle hit which detector and routes the corresponding time pulse to different sections of the MCA memory. The difference between the centroids of the two time distributions in the MCA will be related to the mean life of the excited state.

There are many advantages to this method. First, the effect is twice the lifetime of the state, since both time distributions are being recorded at the same time. Any shifts in the electronics will effect both distributions in the same way and thus not effect the measurement. The technique can be applied to any state where the gamma rays can be distinguished in a Na I detector. Co^{60} has been used in calibration measurements, and there is no difficulty in distinguishing between the two scattered gamma rays even though the incident gamma rays differ in energy by only 10%. Of course the window settings of the plastic detector single-channel analyzers must be relatively narrow, but this is usually necessary in any arrangement to get good time resolution.

High counting rate linear amplifiers and single-channel analyzers (see electronics section) are used for the plastic detectors so that data is accumulated rapidly. The Na I detector is shielded from direct radiation from the source so that its counting rate will not be excessive. Most measurements will require only a few days to perform.

A computer calculation has been performed to estimate the systematic error in the experiment. Since the incident particles have different energy, their spectrum shapes are not identical. The single-channel analyzers are set to minimize the energy variation across the window. Any remaining

systematic effect due to differences in amplitude walk is estimated by the computer. The flight time of the gamma rays, scintillation light, and photoelectrons have also been considered. In most experiments the systematic error should not introduce an uncertainty of more than 3×10^{-12} seconds. It will be possible to perform beta-gamma as well as gamma-gamma measurements.

V. INSTRUMENTATION

A. ELECTRONIC INSTRUMENT DEVELOPMENT

P. C. Simms

The automatic data recording systems which were described in progress report number 16, have been operating very well. There are now eight systems in use. The TC-33 teletypewriters have presented the only source of trouble. The motor and drive system of these machines require a great deal of maintenance if they run continuously. Thus the data system has been modified so that the TC-33 is automatically turned on and off in the print-out cycle. With this change the data recording systems should require only minor maintenance once per year.

A number of general purpose electronic instruments have been developed.

Instruments with these capabilities are not available commercially. They are packaged in the standard AEC modules so that they can conveniently be used with commercial instruments. All circuits are built on printed circuit boards using low cost plastic transistors and integrated circuits.

Double Delay Line Clipped Linear Amplifier. The most important feature of this amplifier is that delay lines from 100 nanoseconds to 5 microseconds may be used. The delay lines are easy to change in plug-in sockets. Thus the amplifier can be used for extreme high counting rate with short delay lines, or it can be used for high resolution experiments with long delay lines and integrations. The gain can be varied from 700 to 20. With a 1 μ sec integration and full gain the noise at the output is less than 5 mv RMS. The noise goes down linearly with gain. With 1 μ sec delay lines, the amplifier recovers from a 100 times overload pulse in less than 5 μ sec. The area balance of the bipolar pulse and the recovery to baseline can be adjusted for optimum performance.

Single Channel Analyzer. The most important feature of the SCA is that it can process the 100 n sec DDL amplifier pulses at counting rates greater than 1 MHz. Even with these narrow input pulses the definition of the window edges is less than 10 mv. When 750 n sec DDL pulses are used, the definition of the window edge is approximately 3 mv. The output pulse from the SCA can be timed from a zero-crossing pickoff or from low level leading edge discriminator. The leading edge and zero-crossing levels are independently adjustable. Since the window edges are so sharp, a very narrow window and leading edge timing can be used to give timing resolution of approximately 5 n sec with high resolution detectors.

P M Tube Head and Preamplifier. This instrument is intended for high counting rate experiments. Transistor voltage regulators are used for the last four high current dynodes. This arrangement reduces the P. M. gain

shift at high counting rates by an order of magnitude. A linear preamp is included which has a dynamic range of greater than 10 volts and a rise time of less than 10 n sec. A fast amplifier is also included for timing pulses.

Multicoincidence Module. This is a general purpose instrument for moderate speed coincidence work. Each of the 4 input channels has a delay which is variable from 50 n sec to 1 millisecond. The inputs can be connected to either of two coincident circuits by movable plugs. Many arrangements are possible. For example the instrument can be connected as a quadruple coincidence, two double coincidence, 2 triple coincidence with two channels common, etc. The resolving time is adjustable from 10 n sec to 1 millisecond.

Time-to-Amplitude Converter. This instrument is designed for very fast resolving time work. The time range of the instrument can be adjusted from 20 n sec to 1 μ sec. The time resolution is less than 0.1% of the full scale time. The integral linearity and stability of the instrument is less than 0.1%. The input pulses may be positive or negative, and they do not have to be preshaped. The input sensitivity is 50 mv. No delay lines are used in the instrument. The start input can accept counting rates larger than 1 MHz, and the stop input can accept counting rates above 50 MHz. There is no output pulse if a stop pulse does not occur within the selected time range following a start pulse.

Voltage and Current Monitor. This module indicates the current and voltage being taken from the AEC standard power supplies. This is considered necessary to use the power supplies efficiently and to avoid overloading the power supplies in high counting rate experiments. The module also contains a safety circuit which turns off all of the power supplies if one supply fails. This will prevent damage to modules which are using the power supply system.

B. FABRICATION OF LITHIUM-DRIFTED GERMANIUM DETECTORS

A. J. Becker

The need for lithium-drifted germanium detectors for high-resolution gamma-ray spectroscopy has prompted the development of a fabrication technique and apparatus. Up to the present, all attempts have been to form planar detectors of up to 6 mm depletion depth, this value being a reasonable upper limit from rise-time considerations. Three crystals cut from a Sylvania horizontally-grown ingot have been successfully drifted, and one cut from a Hoboken vertically-grown ingot is in the final stages of drifting. Two of the Sylvania crystals have been fully prepared and give quite satisfactory results. The larger one, with 6 cm^2 surface area and 5.5 mm depletion depth, is presently being used on the γ - γ directional correlation apparatus. Measurements using it with an Ortec Model 118 FET preamplifier, an Ortec Model 220 linear amplifier, and a Victoreen SCIPP 1600-channel multichannel analyzer have produced a system resolution of 2.7 Kev FWHM for the Cs^{137} 664 Kev γ -ray line.

The cylindrical shape of the Hoboken germanium ingot makes it especially suitable for use in the fabrication of open-ended coaxial detectors. Present work involves the modification of the existing apparatus and techniques to enable the manufacture of these large-volume, higher-efficiency detectors.

VI. THEORY

A. CALCULATIONS OF INTERNAL CONVERSION COEFFICIENTS AND PARTICLE PARAMETERS FOR FINITE SIZE NUCLEI

H. C. Pauli

The major goal of this work was the computation of the conversion coefficients and particle parameters of electrons ejected from the M-subshells. In addition a complete computer program for calculations of the K- and L-shell particle parameters was prepared.

In these calculations the screening of the atomic electrons as well as all finite nuclear size effects were taken into account. The M-shell calculations are the first of its kind.

With the final program it is possible and economical to compute the internal conversion coefficient or particle parameter of any of the K, L, or M subshells for each nuclear transition directly, avoiding the detour of interpolating from tabulated values. The next section contains an outline of the necessary computer time. Extensive check calculations for the investigation of the numerical stability and the precision of the routines for all parameter values were performed. Several variational calculations, investigating the influence of the atomic screening assuming different screening models like

the Thomas-Fermi-Dirac model or non-relativistic Hartree-Fock calculations were made. Some selected results of these calculations will be published soon.

The total program consists of about 200 statements divided into 44 subroutines and the main program, and is thus too voluminous to be described here in detail. We shall restrict ourselves to an outline of some selected routines.

The main program CONVER is a control program and collects — besides several input statements and output routines — mainly the working routines

-SCRENF
-EIGENV
-CONTIN
-ICC
-PAPA

which are explained below.

The input consists of 5 - 7 cards defining the nuclear charges and masses, the multipolarities, the transition energies and the subshells, for which internal conversion coefficients and/or particle parameters have to be computed. They contain also the experimental electron-binding energies of the K-, L- and M-subshells. The output of the program (tape, cards or printer) can be regulated via input control indices. The subroutine SCRENF computes the atomic screening function using the Thomas-Fermi-Dirac model for the desired nuclear charge and stores it (Time: 14 sec). The computer times are given for the IBM 7094.

The subroutine EIGENV computes the eigen-value and the eigen-functions of the bounded electron moving in the screened atomic potential (solution of the relativistic Dirac equation) and stores them. (Time: 8 sec for K-shell, 14 sec for M_I -shell.)

The subroutine CONTIN computes the wave function of the ejected electron (moving in the screened atomic potential) and simultaneously computes the radial conversion matrix elements. The normalization and determination of the phase is performed also by this routine (Time: 8 - 20 sec for each partial wave, depending on the energy).

Using these matrix elements, the internal conversion coefficients are determined by the subroutine ICC and the particle parameters by the subroutine PAPA (Time ~ 0.1 sec).

Usually, the calculation of one conversion coefficient and/or particle parameter will not take more than $\frac{1}{2}$ -minute of an IBM 7094 computer and with this computer time it seems to be economical to compute each value directly, avoiding any interpolation procedure and error. The whole program is written in IBM FORTRAN-IV and uses only the most common library subroutines. The necessary computer memory storage is about 2700 words. Thus with the exception of the I/O routines, which can be modified easily, the program is compatible with all high-speed computers.

B. QUANTUM MECHANICAL MODEL OF MÖSSBAUER LINE NARROWING^{*†}

Samuel M. Harris

A model for Mössbauer radiation is developed which includes both radiation and lattice relaxation processes. The model describes an initially excited nucleus in an excited lattice. Both radiation and relaxation phenomena are treated in lowest order so that a quantum mechanical solution is possible. It is found that under certain conditions, Mössbauer lines result which are narrower than the natural line although line broadening is the more usual effect of lattice relaxation. The maximum narrowing in this approximation never exceeds 36% of the natural width.

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

† See appended document No. 7.

C. ROTATIONAL STATES OF DEFORMED NUCLEI

Samuel M.-Harris

Properties of deformed nuclei are being investigated. We assume a Wood-Saxon, deformed potential. This is a more realistic choice than the usual harmonic oscillator-Wilsson model. We are calculating the moment of inertia I including pairing correlations via the cranking model. We hope to estimate the contribution to I arising from Coriolis coupling to the continuum. The collective gyromagnetic ratio and quadrupole moment are also being considered with the aim of achieving self-consistency, i.e. insisting that the calculated quadrupole moment agrees with the initially assumed deformation.

APPENDED DOCUMENTS

P = Preprint

R = Reprint

1. Elastic and Inelastic Scattering of 9.8-MeV Deuterons from P^{31} ,
B. T. Lucas and O. E. Johnson, Phys. Rev. 145, 887 (1966). (R)
2. Optical-Model and Distorted-Wave Analyses of Some 18-MeV Alpha-
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3. Study of the $P^{31}(\alpha, d_{0,1})S^{33}$ Reactions at 18.7 MeV, B. B. Srivastava,
S. W. Cospers, and O. E. Johnson, Phys. Rev. 153, 1221 (1967). (R).
4. Measurement and DWBA Analyses of the 18.7-MeV Cross Sections
for the $Na^{23}(\alpha, d_{0,1})Mg^{25}$ Reactions, B. B. Srivastava and O. E.
Johnson. (P)
5. Measurement and DWBA Analyses of the 18.7-MeV Cross Sections
for the $Al^{27}(\alpha, d_{0,1})Si^{29}$ Reactions, B. B. Srivastava and O. E.
Johnson. (P)
6. Conversion Electron Particle Parameters in the Decay of Eu^{152} and
 Eu^{154} , H. M. Nasir, Z. W. Grabowski, and R. M. Steffen. (P)
7. Quantum Mechanical Model of Mössbauer Line Narrowing, S. M. Harris.
(P)
8. Decay of Eu^{145} , John C. Hill, Phys. Rev. 153, 4 (1967). (R)

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July 1, 1966 to June 30, 1967

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1. Study of the $P^{31}(\alpha, d_{0,1})S^{33}$ Reactions at 18.7 MeV, B. B. Srivastava, S. W. Cosper and O. E. Johnson, Phys. Rev. 153, 1221 (1967).
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Measurement and DWBA Analyses of the 18.7-MeV Cross Sections for the $Na^{23}(\alpha, d_{0,1})Mg^{25}$ Reactions, B. B. Srivastava and O. E. Johnson.
(Physical Review)

Measurement and DWBA Analyses of the 18.7-MeV Cross Sections for the $Al^{27}(\alpha, d_{0,1})Si^{29}$ Reactions, B. B. Srivastava and O. E. Johnson.
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Conversion Electron Particle Parameters in the Decay of Eu^{152} and Eu^{154} ,
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Quantum Mechanical Model of Mössbauer Line Narrowing, S. M. Harris.
(Physical Review)