ANL-7312
Physics
AEC Research and
Development Report

CISTI PRICES

H.C. \$ 3.00; MN 65

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

PHYSICS DIVISION SUMMARY REPORT

January—March 1967

Lowell M. Bollinger, Division Director

Preceding Summary Reports:

ANL-7246, Annual Review
ANL-7247, June-August 1966
ANL-7284, September-December 1966

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

FOREWORD

The Physics Summary is issued several times per year for the information of the members of the Division and a limited number of other persons interested in the progress of the work. It includes short reports on highlights of the current research, abstracts or short summaries of oral presentations at meetings, abstracts of papers recently accepted for publication, and publication notices of papers appearing in recent journals and books. Many of these reports cover work still in progress; the results and data they present are therefore preliminary, tentative, and often incomplete.

The research presented in any one issue of the Summary is only a small random sample of the work of the Physics Division. For a comprehensive overview, the reader is referred to the ANL Physics Division Annual Review issued each summer, the most recent being Argonne National Laboratory Report ANL-7246 which reports research in the year ending 31 March 1966.

The issuance of these reports is not intended to constitute publication in any sense of the word. Final results will be submitted for publication in regular professional journals or, in special cases, presented in ANL Topical Reports.

TABLE OF CONTENTS

	<u>Page</u>
I. RESEARCH HIGHLIGHTS	1
<u>Average Widths for High-Energy Radiative Transitions</u>	1
L. M. Bollinger and G. E. Thomas	
<u>Machine Counting of Tracks in Nuclear Emulsions</u>	6
John R. Erskine, Robert H. Vonderohe, Milton D. Machálek, and Norman N. Sobol	
II. REPORTS AT MEETINGS	11
<u>Third Mössbauer Methodology Symposium</u>	11
New York, 29 January 1967	
<u>American Physical Society Meeting</u>	12
New York, 30 January—2 February 1967	
<u>1967 National Particle Accelerator Conference</u>	65
Washington, D.C., 1—3 March 1967	
<u>American Physical Society Meeting</u>	66
Chicago, 27—30 March 1967	
III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATION	69
IV. PUBLICATIONS SINCE THE LAST REPORT	79
<u>Papers and Books</u>	79
<u>Reports at Meetings</u>	81
<u>ANL Topical Report</u>	85
<u>Physics Division Informal Report</u>	85
<u>Student Report</u>	85
V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION	87

I. RESEARCH HIGHLIGHTS

These research highlights are Physics Division contributions to the Physical Research Monthly Report which the Laboratory Director's Office sends to the Division of Research of the U.S. Atomic Energy Commission. They report interesting work that is currently in progress or that has just been completed.

AVERAGE WIDTHS FOR HIGH-ENERGY RADIATIVE TRANSITIONS

L. M. Bollinger and G. E. Thomas

Although the partial radiation widths of the high-energy states excited by neutron capture have been studied for many years, little is known about the average widths of transitions from many initial states to individual final states. The reason is that the broad statistical distribution that governs the widths of the transitions from individual initial states prevents the thermal-neutron-capture gamma rays from giving useful averages, and heretofore it has not been technically feasible to measure the spectra of enough individual neutron resonances to deduce average widths with the required accuracy. We have bypassed these difficulties by measuring directly the average spectrum resulting from capture in many neutron resonances. The initial applications of the new method already have given answers to several questions of physical interest.

Basically, the method of measurement consists in using a Ge-diode gamma-ray spectrometer to observe the capture gamma rays emitted by a B^{10} -surrounded sample that is located inside a nuclear reactor. The boron absorber selectively removes low-energy neutrons, and the $1/E$ spectrum of the incident neutron flux assures a low intensity of energetic neutrons. The combination

limits the energies of the neutrons absorbed in the sample to a band that is broad enough to contain many resonances but narrow enough to preserve the excellent resolution of the Ge diode. A key concept here is that, even though there is a great variability in the magnitude of the contributions from the various resonances that are selected in this way, a meaningful average is obtained if contributions come from enough resonances.

The experiment outlined above, although simple in principle, is not easy to carry out because the capture rate of interest is so small in comparison with various forms of background. The experiment is feasible only because of the high sensitivity of the internal-target facility in the reactor CP-5. In this system, the sample is mounted in the high-flux region of a tube that passes straight through the reactor, tangent to the core. Gamma rays produced by capture of epi-thermal neutrons in the sample are viewed by a lithium-drifted Ge diode located outside of the reactor. A carefully designed collimation system ensures that most of the radiation reaching the detector is from the target of interest.

The validity of the average-spectrum method outlined above was checked by studying the average spectrum of $\text{Pt}^{195}(n, \gamma)\text{Pt}^{196}$ and comparing the resulting average widths for high-energy transitions with the values that were obtained by Jackson (at Saclay on assignment from Argonne) from an observation of 22 individual resonances of Pt^{195} . A typical average spectrum is given in the lower portion of Fig. 1. Here the feature of primary interest is the roughly equal intensities of the γ -ray lines associated with transitions to all the low-energy Pt^{196} states that were observed in the study of individual resonances. This uniformity is in marked contrast to the order-of-magnitude fluctuations from one γ ray to the next that are characteristic of a spectrum from capture in a single resonance—such as the one in the top portion of Fig. 1.

Fig. 1. Comparison between the average pulse-height spectrum from neutron capture in many resonances of platinum (lower portion) and the spectrum from capture in a single resonance (upper portion). The lines labeled Pt^{196} come from the reaction $Pt^{195}(n, \gamma)Pt^{196}$ and the energy label attached to the line is the energy of the final nuclear state for the transition. The lines labeled B^{10} come from the reaction $B^{10}(n, \gamma)B^{11}$, which proceeds with a cross section that is roughly $1/8000$ of that for the $B^{10}(n, \alpha)Li^7$ reaction. At γ -ray energies less than 6.1 MeV, the spectrum is too complex to be interpreted quantitatively.

The B^{10} absorber used to obtain the average spectrum in Fig. 1 was chosen to be of such a thickness ($\frac{1}{8}$ in.) that the neutrons captured in the sample fell within roughly the range of energy studied by Jackson *et al.*¹ with the neutron time-of-flight spectrometer at

¹H. E. Jackson, J. Julien, C. Samour, A. Bloch, C. Lopata, J. Morgenstern, H. Mann, and G. E. Thomas, Phys. Rev. Letters 17, 656 (1966).

TABLE I. Average intensities of high-energy radiative transitions in Pt^{196} .

Gamma-ray energy (MeV)	Final-state energy (keV)	Intensity (arbitrary units)	
		Jackson <u>et al.</u>	This experiment
7.920	0	2.0	2.0
7.564	356	1.2	1.30
7.231	689	1.4	1.34
6.777	1143	0.7	0.73
6.516	1404	1.1	0.91
6.310	1610	. . .	0.76
6.237	1683	. . .	0.90

Saclay. In Table I, the average widths obtained from our spectrum are compared with those of the Saclay group. The agreement is seen to be excellent. In view of this good agreement and from the fact that everything about our data is consistent with what is expected, we conclude that the average-spectrum method is basically sound. The power of the new method may be appreciated by noting that the average-spectrum data were obtained in a single night of measurement with a relatively simple experimental system, whereas many months of measurement with a complex neutron time-of-flight spectrometer are required to obtain the spectra of many individual resonances.

The availability of an entirely new experimental technique provides us with the opportunity to carry out a wide range of significant experiments that are not technically feasible by other methods.

These experiments fall into two classes: (1) studies to determine how the average widths for high-energy (5—10 MeV) radiative transitions depend on various nuclear parameters, and (2) investigations in which

the average spectra are used as a new spectroscopic tool with which to determine the quantum numbers of low-energy nuclear states.

Our initial emphasis is being placed on the study of the behavior of the radiation widths themselves. One such study has been to see how the average widths of high-energy radiative transitions in Pt^{196} depend on the gamma-ray energy E_γ . The experiment is similar to that involved in the measurement of the spectrum in Fig. 1, except that the boron absorber is made much thicker so as to expand the range of neutron energy that is effective in forming the spectrum. The experimental widths that have been obtained are found to be entirely inconsistent with the familiar E_γ^3 dependence that is expected from phase-space considerations alone. On the other hand, the widths are in excellent agreement with the E_γ^5 dependence that is expected if one assumes that the Lorentzian shape of the dipole giant resonance (which peaks at roughly 18 MeV) can be extrapolated to energies in the 6–8-MeV range of interest.

The study of the energy dependence of the radiation widths is illustrative of several problems for which long-sought answers have already been obtained by means of the average-spectrum method. In view of this initial success, it will not be surprising if the average spectra from resonance capture soon replace thermal-capture spectra as the most actively sought data of neutron-capture gamma-ray spectroscopy.

MACHINE COUNTING OF TRACKS IN NUCLEAR EMULSIONS

John R. Erskine, Robert H. Vonderohe, * Milton D. Machálek,
and Norman N. Sobol*

Nuclear emulsions have been used for nearly two decades in the study of nuclear structure, but the analysis by a human scanner has been slow, tedious, and costly. An automatic scanning device that is at least 50 times as fast as a human scanner has recently been designed and built as a joint effort of the Physics and Applied Mathematics Divisions at Argonne National Laboratory. It is the first automatic scanner for nuclear emulsions to take advantage of the versatility and reliability made possible by a digital computer. This machine, which will be installed near the Argonne tandem accelerator, was designed to cope with the increasing flood of data from the new types of magnetic spectrographs now being built.

This device scans large areas of emulsion in the search for the tracks of protons, deuterons, tritons, He^3 nuclei, alpha particles, or other charged particles. Since the length of a track is about equal to the thickness of a human hair, the tracks cannot be seen by the naked eye. Tens of thousands of them typically are embedded in a 2×10-in. strip of emulsion 50 microns thick that has been exposed in a magnetic spectrograph. The position of a track is a measure of the momentum of a charged particle produced in a nuclear reaction.

In the Argonne scanning machine (Fig. 2), a high-resolution lens focuses the tracks on the face of a high-resolution TV camera tube of the image dissector type, mounted below the plate. The over-all resolution achieved by the system is about 6 microns in the emulsion plane. The area scanned at one setting of

* Applied Mathematics Division.

Fig. 2. Machine to scan nuclear track plates. The photograph shows an operator inserting a glass nuclear track plate. The two lamps (only one of which is shown in the diagram) provide dark-field illumination for the plate. The area of emulsion being scanned can be viewed either through the binocular microscope (photograph) or on the display scope (diagram) which shows the picture being transmitted to the computer. The rack of electronic equipment at the left in the photograph contains the computer interface, motor controls, the sweep and focus circuits, and the analog signal-processing circuit.

the track plate is normally 0.5×10 mm, and as soon as this has been covered, a mechanical drive moves the plate to the next position. The signals from the scanning tube go to an analog signal-processing circuit (diagram, Fig. 2) in which they are shaped by a "sine squared" filter.

The position of the center of each signal is determined by a track-centering circuit of the delay-line type. This information is fed to the computer interface, which contains a 13-bit coordinate counter, an 11-bit address counter, a 6-bit scan counter, and a 5-bit base-line counter. From the first two, the position of any object encountered during a sweep is transmitted to the core memory of the computer (a PDP-9 made by the Digital Equipment Corporation). The scan counter moves the sweep over successive regions of the field being scanned. The base-line counter controls the base-line voltage in the track-centering circuits and is automatically adjusted by the computer when the background noise level changes. The digital computer manages the entire system with a program which (1) performs pattern recognition on the information transmitted by the interface to determine the number of tracks in each frame, (2) moves the plate to a new frame or new region of the plate, (3) checks the setting of the base line, (4) reads out (into some output device) the number of tracks counted in a frame and the position of this frame along the plate, and (5) diagnoses troubles by means of a batch of test programs.

The digitalization of the information on a track plate and its use in track recognition is shown pictorially in Fig. 3. At the left is a photomicrograph of the tracks in a small area of an exposed plate; at the right is the computer printout of the digital data recorded for this same area. The computer identifies a cluster of points as a track if they appear to form a line segment of the appropriate length.

Fig. 3. Nuclear tracks from 6-MeV protons striking a 50-microns-thick emulsion at a grazing angle of about 25° : (left) as they appear in the viewing microscope and (right) as seen by the scanner and printed out by a computer-controlled line printer. The two pictures cover very nearly the same set of tracks, which occupy a field of view measuring about 0.6×1.0 mm on the emulsion. The track length is about 90 microns. The electronic scan moves perpendicular to the long dimensions of the tracks (vertically in the figure). Each scan is displaced 10 microns from its predecessor, so a typical track is observed for about 9 scans. The inset shows a single track printed with about 14 times the vertical magnification (i.e., 1 line-printer line to 1.2 microns on the emulsion). The small scatter of points from one scan to the next illustrates the high stability of the scanning device and the beneficial effect of the track-centering circuit. The computer identifies a cluster of points as a track if they appear to form a line segment of the appropriate length.

Fig. 4. Calcomp plot of the number of tracks per scanned strip vs distance along the plate. This final output of the automatic scanning system roughly corresponds to an energy spectrum of particles from a nuclear reaction. The actual energy spectrum could equally well be printed out since the energy calibration of the spectrograph is well known.

At present the system is able to scan a strip of emulsion 10 mm wide by 10 in. long in about 17 min. Figure 4 shows one form of the output from the automatic plate scanner.

II. REPORTS AT MEETINGS

The abstracts and summaries that follow are not necessarily identical to those submitted for the meeting. In some cases, the authors have corrected or expanded abstracts; and summaries of contributed papers commonly have been shortened.

Third Mössbauer Methodology Symposium

New York, 29 January 1967

THE MÖSSBAUER EFFECT IN Cs¹³³

G. J. Perlow

The recoilless nuclear gamma-ray resonance of the 81-keV transition in Cs¹³³ has been observed and a number of experiments have been done and reported to date by the author and his collaborators. The talk will touch on the following subjects: (1) properties of the transition, (2) appearance of the pulse-height spectrum, (3) preparation and properties of the sources, (4) apparatus used in the measurements, and (5) a summary of experiments to date.

Under item (5), the following will be briefly discussed:

(a) the healing of the Auger cascades following electron-capture decay in Ba¹³³, (b) the value of f_s in a barium-aluminum alloy source, (c) the isomer shifts in a variety of substances, (d) the value of f_a and θ_m for Cs metal, (e) search for a spin-density-wave state in Cs metal, and (f) Debye-Waller factor for the cesium halides.

American Physical Society Meeting
New York, 30 January—2 February 1967

LIFETIME OF THE FIRST EXCITED STATE IN Si^{29}

S. I. Baker and R. E. Segel

Bull. Am. Phys. Soc. 12, 91 (January 1967)

The mean life of the $\frac{3}{2}^+$ 1.29-MeV first excited states of Si^{29} , formed in the $\text{Si}^{28}(\text{d}, \text{p})$ reaction at $E_d \approx 3$ MeV, was measured by the attenuated-Doppler-shift method. Spectra in a Ge(Li) crystal were recorded simultaneously in coincidence with 1 proton detector placed so that Si^{29*} nuclei recoiled toward the Ge(Li) (maximum Doppler shift) and with another placed to select recoils giving only a small fraction of the maximum shift. Recoils slowed down in Au gave a shift of $54\% \pm 8\%$ of the full shift (no slowing down). For recoil into vacuum, the shift observed agreed to within experimental error with the calculated ~ 6 -keV full shift. The slowing-down curve (after Lindhard and Scharff) was computed and used to compute a mean life $\tau = (1.3 \pm 0.5) \times 10^{-13}$ sec for the state. For a pure M1 transition (the Si^{29} ground state is $\frac{1}{2}^+$) this implies $|M|^2 = 0.13$ single-particle units. The result overlaps that given by Booth and Wright¹ but not that of Retz-Schmidt *et al.*²

¹E. C. Booth and K. A. Wright, Nucl. Phys. 35, 472 (1962).

²T. W. Retz-Schmidt *et al.*, Compt. Rend. Congr. Intern. Phys. Nucl. Paris, 1964, 396 (1964).

GROUND-STATE DECAY OF THE THIRD EXCITED STATE IN ^{41}Sc

R. C. Bearse, R. E. Segel, and D. H. Youngblood

Bull. Am. Phys. Soc. 12, 92-93 (January 1967)

The transition to the $\frac{7}{2}^-$ ground state from the 2.41-MeV $\frac{3}{2}^-$ 3rd excited state in ^{41}Sc has been sought by observing the $^{40}\text{Ca} + p$ yield curve for ^{41}Sc activity. (^{41}Sc has no bound excited states.) No resonance corresponding to the 3rd excited state was observed in the production of the ^{41}Sc activity; and comparison with the known¹ strength of the capture resonance corresponding to the $\frac{3}{2}^-$ 1st excited state set an upper limit $\Gamma_{\gamma_0} \leq 3 \times 10^{-5} \text{ eV}$ ($|M|^2 \leq 0.02$). This E2 transition is thus severely inhibited and is in contrast to the transition from the 1st excited state where $\Gamma_{\gamma_0} = 1.3 \times 10^{-3} \text{ eV}$ ($|M|^2 = 4.8$). The reduced γ widths are similar to those observed² for the analog states in ^{41}Ca . The model of Gerace and Green³ explains the inhibition of the transition from this state in ^{41}Ca but then predicts the analogous transition in ^{41}Sc to be some 3 times faster than the upper limit found here.

¹D. H. Youngblood, J. P. Aldridge, and C. M. Class, Phys. Letters 18, 291 (1965).

²P. P. Singh, R. E. Segel, S. I. Baker, R. H. Siemssen, and A. E. Blaugrund, Phys. Rev. (to be published).

³W. A. Gerace and A. M. Green, Intern. Conf. Nucl. Phys. Gatlinburg, Tenn., 1966.

POLARIZATION MEASUREMENTS ON SLOW NEUTRONS BY MEANS OF A STERN-GERLACH MAGNET

E. Bieber, V. E. Krohn, and G. R. Ringo

Bull. Am. Phys. Soc. 12, 87 (January 1967)

A polarized neutron beam obtained by total reflection from a magnetized mirror (95% Co, 5% Fe) was analyzed by passing

Fig. 5. Cross section of the Stern-Gerlach magnet.

Fig. 6. Experimentally observed deflection pattern.

reflection of slow neutrons at the surface of the pole tip. It is possible to determine the degree of polarization with an accuracy depending only on the statistical error of the measurement. Figure 6 shows a typical deflection pattern. The degree of polarization was $92 \pm 2\%$ for all parts of the mirror surface and for different reflection angles.

it through an inhomogeneous magnetic field. The system was designed in such a way that even very slow, and therefore strongly deflected, neutrons ($7 \text{ \AA}$ wavelength) could pass through the full length of the magnet without hitting the pole tips. This was achieved by shaping the pole pieces as shown in Fig. 5. The arrangement gives a maximum of the vertical component of the field gradient at about 4 mm above the lower pole tip. The neutrons enter the magnetic field at the position of the highest gradient and are deflected upward or downward into an area with decreasing field gradient; i. e., the deflecting force becomes smaller when the neutrons get closer to the pole tips. So the components of the beam corresponding to the two spin states are completely separated and the measurement is not influenced by absorption or

GAMMA-RAY TRANSITIONS IN F^{20}

D. E. Blatchley and G. E. Thomas

Bull. Am. Phys. Soc. 12, 53 (January 1967)

Gamma-ray transitions in F^{20} following thermal neutron capture in F^{19} have been studied by use of an internal-target facility at the Argonne CP-5 reactor. The measurements were made with a 4-cm³ Ge(Li) detector having a resolution width of 7 keV at 7 MeV. Several de-excitation branches from the capture state have been used to determine the neutron binding energy in F^{20} as 6602 ± 1 keV. The most prominent branch in the decay of the capture state is through a level located 6018 keV above the ground state. Observation of gamma-ray transitions from the capture state and from the level at 6018 keV to the states in F^{20} lying below 1 MeV in excitation lead to the following tentative predictions for the spins of these low-lying levels: 665 MeV (3^+), 828 MeV (4^+), and 984 MeV (2^+).

AVERAGE WIDTHS OF HIGH-ENERGY RADIATIVE TRANSITIONS PRODUCED BY NEUTRON CAPTURE

L. M. Bollinger and G. E. Thomas

Bull. Am. Phys. Soc. 12, 105 (January 1967)

Porter-Thomas fluctuations prevent thermal-neutron-capture γ -ray spectra from yielding average widths of high-energy radiative transitions, and technical problems make it difficult to measure spectra of enough individual resonances to obtain reliable averages. These problems are bypassed in a new technique in which the average spectrum from capture in many resonances is measured directly. The (n, γ) target is placed in the high-flux region of a beam hole that passes near the core of the reactor CP-5. Collimators permit a Ge-diode γ -ray spectrometer outside of the reactor to receive radiation

only from the target. The effects of a B^{10} absorber around the target and of the $1/E$ neutron spectrum combine to limit neutron capture to a broad energy range that includes many resonances. The average spectrum from $Pt^{195}(n, \gamma)$ gives average widths that agree well with those obtained by Jackson *et al.*¹ from spectra of 22 individual resonances. Average capture in W^{182} shows transitions to W^{183} states at 0, 47, and 210 keV. The approximately equal intensity found for these lines refutes recent suggestions that high-energy transitions to these states exhibit selection rules.

¹H. E. Jackson *et al.*, Phys. Rev. Letters 17, 656 (1966).

$(^3\text{He}, \alpha)$ REACTION ON fp-SHELL NUCLEI

D. D. Borlin and T. H. Braid

Bull. Am. Phys. Soc. 12, 92 (January 1967)

The 33-MeV, magnetically-analyzed ^3He beam of the Argonne cyclotron has been used to bombard targets of ^{40}Ca , $^{46,48,50}\text{Ti}$, ^{54}Fe , and $^{64,66,68,70}\text{Zn}$. Angular distributions of alpha-particle groups corresponding to excitations up to 12 MeV in the residual nuclei were obtained in the angular range $15^\circ - 40^\circ$, usually in steps of $2\frac{1}{2}^\circ$. These angular distributions show a distinctive structure for each of the values of orbital-angular-momentum transfer. A j -dependent variation of this structure for transitions involving an angular-momentum transfer of $\ell = 1, 2$, or 3 permitted the assignment of total-angular-momentum values for a number of levels. Nine to twenty-three levels, including some isobaric analog states, were identified for each target.

Optical-model analyses of elastic ^3He and α scattering have been carried out in order to obtain parameter sets for use in

DWBA calculations. Finite range and nonlocality corrections to the DWBA calculations, via the local energy approximation, have been investigated and utilized in the determination of spectroscopic factors. Some difficulty was experienced in the extraction of these values. Solutions of the coupled Lane equations are used in the determination of spectroscopic factors for the analog states. Consistent trends are established for the occupation numbers of the shell-model orbitals.

In summary, the ($^3\text{He}, \alpha$) reaction has been found to be very useful for the observation and identification of levels of excitation for fp-shell nuclei, particularly for the $\ell=3$ and $\ell=4$ transitions, which are more difficult to observe in other neutron pickup reactions. The DWBA theory does not seem to be completely capable of describing the ($^3\text{He}, \alpha$) reaction at 33 MeV incident energy, but it is believed that most of the spectroscopic information obtained is accurate to within the normal limits of confidence placed on predictions of the DWBA theory.

BRANCHING RATIOS OF STATES IN Mg^{25}

R. T. Carpenter* and D. E. Blatchley

Bull. Am. Phys. Soc. 12, 72 (January 1967)

Gamma rays following neutron capture in Mg^{24} have been observed using a 4-cm³ Ge(Li) detector with a resolution of approximately 7 keV for 7-MeV γ rays. By combining existing information on the level structure of Mg^{25} with the yields and precision energy measurements of γ rays obtained in the present work, it is possible to unambiguously assign many of the observed γ rays to unique positions in the Mg^{25} decay scheme. In this way branching

* University of Iowa.

ratios have been determined for 8 states in Mg^{25} in addition to the thermal capture state. The results are in good agreement with previous measurements, where they exist, and are in qualitative agreement with transitions involving analogous states in the mirror nucleus Al^{25} in all cases.

DYNAMIC QUADRUPOLE EFFECTS IN MUONIC ATOMS OF Ho AND Tb

R. E. Coté, W. V. Prestwich, C. C. Trail, * R. A. Carrigan, Jr.,† A. Gaigalas,† R. B. Sutton,† and S. Raboy‡
Bull. Am. Phys. Soc. 12, 75 (January 1967)

K and L x rays from muonic atoms of Ho and Tb were detected by a Ge(Li) system which had a full width at half-maximum of 6.2 keV at 5.1 MeV. The data were analyzed under the assumption that the nuclei had an axially symmetric charge shape with a radial distribution given by the Fermi distribution. The information contained in the K and L data was sufficient to limit the half-radius of Ho and Tb to 1.14 to $1.17 \times A^{1/3}$ F. The intrinsic quadrupole moment for Ho was determined to be between 7.8 and 7.9 b and for Tb limited from 7.30 to 7.44 b.

* Brooklyn College.

† Carnegie Institute of Technology.

‡ State University of New York at Binghamton.

(α, t) REACTION ON 1p-SHELL NUCLEI AT 43 MEV

D. Dehnhard and R. H. Siemssen

Bull. Am. Phys. Soc. 12, 17 (January 1967)

(α, t) reactions on Li^6 , Be^9 , B^{10} , B^{11} , C^{12} , and N^{14} have been studied at an incident energy of $E_\alpha = 43$ MeV. Differential cross sections for c.m. angles from approx. 10° to 50° have been obtained for all ground-state transitions, as well as for the tritons leading to the 1st excited states in Be^7 (0.431 MeV) and C^{12} (4.433 MeV) and to 5 excited states in B^{10} . The data were found to be consistent with the interpretation in which single-proton transfer is the dominant reaction mode in the (α, t) reaction at forward angles, even for very light nuclei as targets. Previously observed¹ discrepancies between the spectra from the (α, t) reaction and those from the (d, n) and the (He^3, d) reactions most probably arise from a strong J and Q dependence of the (α, t) reaction, the strong Q dependence being a consequence of the large momentum mismatch in the (α, t) reaction. Distorted-wave Born-approximation calculations performed with the computer code JULIE also showed a strong J and Q dependence; however, these calculations so far failed to reproduce the experimental angular distributions.

¹N. A. Vlasov, S. P. Kalinin, A. A. Ogloblin, and V. I. Chuev, Soviet Phys. — JETP 12, 1129 (1961).

DECAY OF Cu^{61} AND ENERGY LEVELS IN Ni^{61}

H. J. Fischbeck and H. H. Bolotin

Bull. Am. Phys. Soc. 12, 112 (January 1967)

The 3.3-h positron decay of Cu^{61} has been investigated using Ge(Li) detectors and coincidence techniques. The Cu^{61} activity was produced from the $\text{Co}^{59}(\alpha, 2n)\text{Cu}^{61}$ reaction. Sources were

obtained by chemical separation and from the Argonne Isotope Separator. A total of 19 γ lines ranging from 67 to 2120 keV has been measured where only 8 had been previously identified. All observed γ transitions have been incorporated into a decay scheme which requires only those levels in Ni^{61} which are excited in nuclear reactions. The levels in Ni^{61} found to be populated from the Cu^{61} decay are 67.3, 282.8, 655.7, 908.8, 1100.2, 1132.4, 1185.5, 1446.9, 1611.8, 1730.2, and 2119.8 keV. Previously no levels above 1186 keV had been recognized as being populated in the Cu^{61} decay.

HYPERFINE-INTERACTION CONSTANTS AND THE NUCLEAR ELECTRIC QUADRUPOLE MOMENT OF Ni^{61}

L. S. Goodman and W. J. Childs

Bull. Am. Phys. Soc. 12, 112 (January 1967)

Hyperfine-interaction constants of Ni^{61} have been determined by the atomic-beam magnetic-resonance method in the $^3\text{F}_4$ and $^3\text{D}_3$ atomic states. The nuclear electric quadrupole moment calculated from these data is $Q = 0.134(25)\text{b}$. The calculation and the agreement of this value with nuclear theory will be discussed.

RECENT STUDIES OF PARTIAL RADIATION WIDTHS IN ^{196}Pt

H. E. Jackson

Invited paper listed by title only: Bull. Am. Phys. Soc. 12, 27 (January 1967)

TEMPERATURE DEPENDENCE OF THE HYPERFINE FIELD IN NpAl_2 BY THE MÖSSBAUER EFFECT IN Np^{237}

M. Kalvius,* B. Dunlap,* S. Ruby, and M. Brodsky†

Bull. Am. Phys. Soc. 12, 25 (January 1967)

Recent observations¹ of the Mössbauer effect of Np^{237} in the Laves-phase compound NpAl_2 have shown the existence of a magnetic hyperfine spectrum at 4.2°K . Using a source obtained from the α decay of Am^{241} present as a solid solution ($\sim 5\%$) in Th metal, we have investigated the temperature dependence of the hyperfine field in a NpAl_2 absorber. A magnetic transition is observed at 57°K . At higher temperatures, a single line is observed which, while being about 15 times natural linewidth, is substantially narrower than previously reported.¹

* Solid State Science Division.

† Metallurgy Division.

¹J. A. Stone and W. L. Pillinger, Bull. Am. Phys. Soc. 11, 474 (1966).

POLARIZATION AND DIFFERENTIAL CROSS SECTION FOR NEUTRONS SCATTERED FROM ^{10}B AND ^{11}B

R. O. Lane, A. J. Elwyn, F. P. Mooring, and A. Langsdorf, Jr.

Bull. Am. Phys. Soc. 12, 87 (January 1967)

Measurements of polarization $P(\theta)$ and differential cross section $\sigma(\theta)$ for neutrons scattered from ^{10}B and ^{11}B were obtained at 5—9 angles at each of 70 neutron energies from 0.075 to 2.25 MeV. The reaction $^7\text{Li}(p,n)^7\text{Be}$ provided the partially polarized beam of neutrons and a spin-precession magnet was employed to obtain the asymmetry. For $^{10}\text{B} + n$, $P(\theta)$ is nearly constant for $0.5 \text{ MeV} \leq E_n \leq 2.25 \text{ MeV}$ and shows no appreciable effect of the

resonance in σ_T at $E_n = 1.9$ MeV. The shape of the differential cross section changes as the energy increases across this resonance, but $\sigma(\theta)$ integrated over solid angle varies only slightly at resonance. Most of the width of this state seems to be in the α channel. For $^{11}\text{B} + n$, large polarizations are observed from the resonance at 1.28 MeV up to 2.25 MeV. Over nearly all this region, $P(\theta)$ at the backward angles is approximately 40—50%, so that this nucleus is a useful analyzer. Resonance behavior of the interference terms in $\sigma(\theta)$ indicate that the parity of the state at $E_{\text{ex}} = 5.0$ MeV is opposite to that of the one at $E_{\text{ex}} = 4.5$ MeV. Calculations for $^{11}\text{B} + n$ in terms of states in ^{12}B (including bound states) are in progress.

GIANT DIPOLE RESONANCE IN ^{24}Mg STUDIED BY PROTON CAPTURE IN ^{23}Na

L. Meyer-Schützmeister, R. E. Segel, and R. C. Bearse
Bull. Am. Phys. Soc. 12, 72 (January 1967)

Yield curves of the γ rays leading to the ground state and to the 1st excited state in ^{24}Mg from the reaction $^{23}\text{Na}(p, \gamma)^{24}\text{Mg}$ were measured at 90° over the range from 4.0—12.0 MeV in 25- or 30-keV steps. The strong structure exhibited indicates the existence of many resonances with widths of the order of 100 keV or less. The yield curve of the ground-state transition indicates that a significant portion of the reaction proceeds through the compound nucleus. The integrated (p, γ_0) cross section is unusually small, while the (p, γ_1) reaction is of normal strength. Comparing the present results with measurements of the $^{24}\text{Mg}(\gamma, p_{\text{all}})$ reaction,¹ it appears that, in the total proton decay of the giant dipole resonance

¹S. A. E. Johansen, Phys. Rev. 97, 1186 (1955).

in ^{24}Mg , the ground state of ^{23}Na is populated only 10% of the time. On the assumption that the giant dipole resonance consists largely of 1p-1h configurations, the present results indicate that the $\frac{3}{2}^+$ ground state of ^{23}Na contains only a small amount of 1h configuration. Angular distributions of the γ rays have been taken over a part of the yield curve, and these show the usual constancy.

STRUCTURE OF THE BARIUM ISOTOPES VIA ISOBARIC ANALOG STATES*

G. C. Morrison

Invited paper listed by title only: Bull. Am. Phys. Soc. 12, 8 (January 1967)

Introduction

Since the discovery of isobaric analog states in heavy nuclei by Anderson and Wong,¹ the investigation of these states has become a very active field in many different branches of nuclear physics. Perhaps the most fruitful field of investigation has followed from their observation in proton-induced reactions² in which unbound analog states are excited as states in the compound nucleus and show up as resonances in the various reactions. The information which I wish to present on the structure of the Ba isotopes comes from such studies of isobaric analog states. By way of introduction, I would like to discuss first some general features of isobaric analog resonances.

*The research reported here was done in collaboration with N. Williams, J. Nolen, Jr., and D. von Ehrenstein.

¹J. D. Anderson and C. Wong, Phys. Rev. Letters 7, 250 (1961).

²J. D. Fox, C. F. Moore, and D. Robson, Phys. Rev. Letters 12, 198 (1964).

Fig. 7. Schematic diagram illustrating the relation between isobaric analog states in the nuclei $A + p$ and $A + n$.

Figure 7 is a schematic diagram showing excitation of isobaric analog states in the compound nucleus. These states are formed by adding a proton to the target nucleus A and are the analogs, having the same isobaric spin, of the low-lying states in the nucleus formed by adding a neutron to the target [e.g., in a (d, p) reaction]. That

they are observed as sharp resonances, not completely spread out into the continuum of background states of lower T , is due to two reasons: (1) neutron decay of these states is T -forbidden, involving a change of isobaric spin $\Delta T = \frac{3}{2}$, as can be seen from the figure, and (2) states of similar configuration but lower T with which mixing might occur are much lower in energy for heavy nuclei.

It was soon realized that the study of resonances in elastic proton scattering should give information similar to that from a (d, p) stripping reaction. The ℓ value of the resonance can be obtained from the shape of the resonance at different angles, just as the ℓ value in a stripping reaction can be obtained from the shape of the angular distribution; the elastic proton width Γ_p is proportional to, and can be quantitatively related to, the reduced width or spectroscopic factor S of a level excited in the (d, p) reaction. Such a correspondence has now been demonstrated in many experiments.³ An important extension of the study of resonant elastic scattering has followed from the realization that a measurement of the polarization of the elastically scattered proton can determine the J value of the resonance.⁴

³ For example, P. Richard, C. F. Moore, J. A. Becker, and J. D. Fox, Phys. Rev. 145B, 971 (1966).

⁴ G. Terrell and C. F. Moore, Phys. Rev. Letters 16, 804 (1966).

Most recent work has dealt mainly with resonant inelastic scattering⁵ from which information can be obtained that is unique to such studies. This is illustrated in Fig. 8. Two types of information can be obtained. Inelastic proton scattering at a particular resonance gives information similar to that from a neutron pickup experiment. For the case of proton scattering at the lowest resonance, illustrated here, the

Fig. 8. Schematic diagram showing elastic and inelastic scattering at isobaric-analog-state resonances.

information is equivalent to that from the pickup reaction on the ground state of the nucleus $A + n$. However, for inelastic scattering from other than the ground-state analog, the information is equivalent to that which would be obtained from a pickup reaction on an excited state. We can also observe the decay of the various resonances to a particular state or states, as illustrated here for the case of decay to the second excited state. In this way we obtain information on the expansion of states in the $A + n$ nucleus in terms of the excited states of the target nucleus. Such information is obviously equivalent to that which would be obtained from a stripping reaction on an excited state.

Level Systematics in the Ba Isotopes

After this brief introduction, we now turn to the subject of this review, namely, the structure of the Ba isotopes via isobaric

⁵For example, D. L. Allan, G. A. Jones, G. C. Morrison, R. B. Taylor, and R. B. Weinberg, Phys. Letters 17, 56 (1965); S. A. A. Zaidi, P. v. Brentano, D. Riek, and J. P. Wurm, Phys. Letters 19, 46 (1965).

Fig. 9. Single-particle states predicted around the closed shell at $N = 82$ and low-lying excited states in Ba^{137} and Ba^{139} .

analog states. This work is being carried out at Argonne National Laboratory. It has involved various collaborators: Z. Vager (in the earlier stages), N. Williams, and (recently) J. Nolen and D. von Ehrenstein. Instead of parading our results on all the Ba isotopes, I have chosen to present some recent results on the structure of a very specific set of states, namely neutron particle-hole states, which are seen most prominently in the isotope Ba^{138} . These results have been chosen for presentation since they provide the best example of the unique information that can be obtained from the study of resonances associated with isobaric analog states.

As an orientation to the level configurations expected in the Ba isotopes, Fig. 9 shows the single-particle levels predicted by the shell model around the closed shell $N = 82$. It can be noted that the levels are similar to those predicted around $N = 20$. Ba^{138} has 82 neutrons and the first few excited states of Ba^{139} and Ba^{137} can be related to the corresponding neutron single-particle levels above and below $N = 82$, as shown. However, such states are not necessarily pure single-particle states. The neutron particle-hole states in Ba^{138} will have configurations for which the particles are from levels above $N = 82$ and the holes from levels below $N = 82$. The $1h$ levels are not expected to be observed in this work because of the high l values involved in transitions to or from such states. Of importance in fixing the location of the particle-hole states in Ba^{138} is the difference between the binding energy of the last neutron in Ba^{139} and that in Ba^{138} . Since this is about 3.8 MeV, as calculated from nuclear mass

tables,⁶ the centroid energy of the $f_{7/2}(d_{3/2})^{-1}$ particle-hole states is expected at about this excitation energy in Ba^{138} . The difference from the gap energy of 2 MeV shown here can be accounted for by the pairing energy of the $(d_{3/2})^2$ configuration.

Figure 10 presents the excitation function of protons elastically scattered on Ba^{138} . It shows three prominent resonances corresponding to the La^{139}

analogs of the first three states in Ba^{139} whose relative positions are shown by arrows at the top of the figure. We will not be concerned here with higher resonances. The first resonance corresponds to the $f_{7/2}$ ground state of Ba^{139} , the second to the $p_{3/2}$ first excited state of Ba^{139} . [The latter resonance is p-wave and the angular distribution of the inelastic protons to the first excited state in Ba^{138} (2^+) is anisotropic.] The third resonance is also p-wave (either $p_{3/2}$ or $p_{1/2}$ since the angular distribution of protons to the 2^+ state is isotropic), $p_{3/2}$ being favored both on the basis of level systematics and from a detailed analysis of the elastic scattering at different angles.⁷

Conclusive evidence for the spin of the third resonance is shown in Fig. 11, for which data I am indebted to L. Veaser of

Fig. 10. Excitation function of protons scattered elastically on Ba^{138} at 170° . Positions of levels in Ba^{139} to which the resonances correspond are shown above.

⁶J. H. E. Mattauch, W. Thiele, and A. H. Wapstra, Nucl. Phys. 67, 1 (1965).

⁷J. P. Wurm, P. v. Brentano, E. Grosse, H. Seitz, and S. A. A. Zaidi, Recent Progress in Nuclear Physics with Tandems (Proceedings of the Conference at Heidelberg, Germany, 18-21 July 1966), edited by W. Hering (Max Planck Institute for Nuclear Physics, Heidelberg, 1966), Contributed Papers, p. 49.

Fig. 11. Polarization of protons scattered elastically on Ba^{138} at 80° , 110° , and 145° . The smooth lines are the predicted polarizations at each angle. The positions, spins, and parities of the resonances are shown for the 145° case.

Fig. 12. Schematic representation of the analog of a single-particle neutron state.

Wisconsin University who has carried out the polarization measurements.⁸ The smooth lines are the theoretically predicted polarization at the angles shown; the calculations make use of the proton widths derived from the analysis of the elastic-scattering resonances. The two curves shown for a choice of $p_{3/2}$ and $p_{1/2}$ clearly fix the third resonance as $p_{1/2}$.

To see why the excitation of neutron particle-hole states should be a preferred mode of decay of an isobaric analog state, let us consider the composition of the analog of a single-particle neutron state (Fig. 12). The right side of the figure is a symbolic representation of the components of the analog-state wave function. A proper normalization would multiply its amplitude by the factor $1/\sqrt{2T+1}$. We can see that in addition to that part of the wave function denoted by "entrance channel" (the "proton + target" channel in a resonance

⁸L. Veaser, Bull. Am. Phys. Soc. 12, 86 (1967).

experiment) the total wave function contains the sum of all states obtained by conversion of the excess neutrons in the target in turn to protons. When such protons are unbound, their emission leads to the excitation of neutron particle-hole states in the residual (target) nucleus. As previously pointed out, such states are the same as would be excited in a neutron pickup

reaction on the parent analog nucleus. However, as stressed earlier, analog-state reactions offer the possibility of examining the particle-hole states based on excited states of the analog nucleus by observing them at the corresponding excited analog-state resonances.

In the case of protons incident on Ba^{138} , the situation is as shown schematically in Fig. 13. We can examine the particle-hole states in Ba^{138} at successive resonances for which the "particle" has the configuration shown. The lowest particle-hole states in Ba^{138} will have a $d_{3/2}$ or $s_{1/2}$ neutron "hole" configuration and will result from the emission at the resonance of $d_{3/2}$ or $s_{1/2}$ protons.

Table II shows the possible spins and parities of the lowest neutron particle-hole states expected in Ba^{138} on the basis of these three resonances. We see that in some instances the same spins can arise from several different configurations. The centroid energies that are expected for these sets of states are also shown. The lowest energy is derived from the difference in neutron binding energies as described earlier; the extension to higher energies follows from the known excitation energies of the levels in Ba^{137} and Ba^{139} in an obvious manner.

Fig. 13. Schematic diagram showing population of particle-hole states in Ba^{138} at successive analog-state resonances in La^{139} .

TABLE II. Particle-hole states in Ba¹³⁸.

Configuration	J ^π				Centroid energy
$f_{7/2}(d_{3/2})^{-1}$	2 ⁻	3 ⁻	4 ⁻	5 ⁻	3.83
$f_{7/2}(s_{1/2})^{-1}$		3 ⁻	4 ⁻		4.11
$p_{3/2}(d_{3/2})^{-1}$	0 ⁻	1 ⁻	2 ⁻	3 ⁻	4.48
$p_{3/2}(s_{1/2})^{-1}$		1 ⁻	2 ⁻		4.76
$p_{1/2}(d_{3/2})^{-1}$		1 ⁻	2 ⁻		4.93
$p_{1/2}(s_{1/2})^{-1}$	0 ⁻	1 ⁻			5.21

Resonant Inelastic Proton Scattering on Ba¹³⁸

We come to the experimental results. Figure 14 shows the spectra of protons scattered from Ba¹³⁸ at an angle of 145° at three different energies, two at resonance energies and one off resonance. We can see from these spectra that a group of states at

Fig. 14. Spectra of protons scattered from Ba¹³⁸ at 145°, the upper and lower spectra at resonance energies and the middle spectrum at an energy between resonances. Peaks due to elastic scattering from impurities (C¹², C¹³, N¹⁴, and O¹⁶) are labeled.

about 4 MeV appear strongly and selectively at the two different isobaric-analog resonances. The protons are detected in cooled Ortec silicon surface-barrier detectors, and excitation functions normally are taken simultaneously in detectors fixed at four angles. These measurements were taken with a resolution width of ~ 30 keV. The background associated with protons elastically scattered from C^{12} in the upper spectra is $\sim 1/2000$ of the height of the elastic peak.

Figure 15 shows excitation functions for two of the peaks shown in Fig. 14, that to the 4.16-MeV state being associated with the $f_{7/2}$ resonance and that to the 4.44-MeV state with the $p_{3/2}$ resonance. One can see that they resonate strongly and off resonance tend to zero.

Figure 16 shows the angular distributions of the inelastic proton groups associated with the $f_{7/2}$ resonance. The angular distributions appear to be symmetric about 90° . If the corresponding particle-hole states were pure unmixed states, then the shapes of the distributions would be of the form $1 + A_2 P_2(\cos \theta)$ for each state formed by the emission of a $d_{3/2}$ proton, the coefficients A_2 being unique for each possible final spin 2^- to 5^- ; and the distributions would be isotropic for both

Fig. 15. Excitation function of protons inelastically scattered to states at 4.16 and 4.44 MeV in Ba^{138} .

Fig. 16. Differential cross sections of inelastic proton groups associated with the $f_{7/2}$ resonance in elastic proton scattering on Ba^{138} .

states formed by the emission of an $s_{1/2}$ proton. Since no purely isotropic angular distribution is observed, we can remark immediately that there is mixing of the particle-hole states. However, the curves are all of the expected $1 + A_2 P_2(\cos \theta)$ form, and well describe the observed shapes in each case. This shows that only the emission of protons of these j values is involved. Only in one case is the angular distribution that expected for a particular final spin value. The distribution of protons leading to the 3.86-MeV state has the form predicted for a 5^- final state. It is gratifying that this is the only state that has no other with which to mix. In this connection, it should be remarked that because of the increased penetrability for emission of s -wave protons, only a small $(s_{1/2})^{-1}$ hole component in the wave function of the final particle-hole state can appreciably modify the expected pure d -wave angular distribution for that particular spin value.

In the case of the third resonance, to which the polarization work ascribes $\frac{1}{2}^-$, we indeed find that the angular distribution of the more prominent inelastic proton groups leading to the particle-hole states are isotropic, as is required for this spin assignment. Background problems at this resonance make it difficult to measure reliable angular distributions for the weaker groups.

Ba¹³⁷(d,p)Ba¹³⁸ Reaction

I would like now to leave the excitation of the neutron particle-hole states in Ba¹³⁸ by inelastic scattering and come to their observation in another reaction. This is possible for such states in Ba¹³⁸, but incidentally not in other $N=82$ nuclei, since Ba¹³⁷ is stable. Thus, we can supplement our (p,p') study of these states with the study of the Ba¹³⁷(d,p) reaction. The ground state of Ba¹³⁷ is believed to be almost a pure $(d_{3/2})^{-1}$ neutron configuration,

Fig. 17. Proton spectrum from the $\text{Ba}^{137}(\text{d},\text{p})\text{Ba}^{138}$ reaction at 50° , as detected with a magnetic spectrograph.

so we expect neutron particle-hole states based on $(\text{d}_{3/2})^{-1}$ to be strongly excited in this reaction but not those based on $(\text{s}_{1/2})^{-1}$. Thus the results of the two experiments may do much to elucidate the structure of particular states.

The spectrum of protons from the (d,p) reaction on Ba^{137} at 50° is shown in Fig. 17. The protons were analyzed with a magnetic spectrograph. The labeled states in the plot are due to impurities or to the states of Ba^{139} resulting from a small fraction of Ba^{138} in the Ba^{137} target. The states from the (d,p) reaction in Ba^{137} are all the others! I show this complete spectrum before discussing the particle-hole states because it is somewhat unusual in its lack of any strongly excited states (apart from the ground state) below the region of excitation at which the particle-hole states occur. In addition, the Ba^{139} impurity groups serve to show that the Q values of the particle-hole states in Ba^{138} are similar to those of the particle states on which they are based.

Fig. 18. Angular distributions of proton groups from the $\text{Ba}^{137}(\text{d},\text{p})$ reaction to particle-hole states in Ba^{138} .

Figure 18 shows the angular distributions of some of the proton groups from the (d,p) reaction to the particle-hole states in Ba^{138} . That they indeed have the appropriate shapes for $\ell = 3$ and 1 at this deuteron energy and Q value can be seen from comparison with the angular distributions of the $\text{Ba}^{138}(\text{d},\text{p})$ reaction to the ground state ($\ell = 3$) and first excited state ($\ell = 1$) of Ba^{139} , which are also shown. The smooth lines are not DWBA fits. However, DWBA analysis has been used to extract relative spectroscopic factors.

Comparison of the $\text{Ba}^{138}(\text{p},\text{p}')$ and $\text{Ba}^{137}(\text{d},\text{p})$ Reactions

Figure 19 summarizes and compares the information on the neutron particle-hole states in Ba^{138} obtained from the (p,p') and (d,p) reactions. The upper portion shows the inelastic cross sections (integrated over angle) for states excited on each resonance as a function of excitation energy in Ba^{138} . One can see how the excitation energies of the particle-hole states derived from each resonance increase with increasing resonance energy, as is expected from the description of these states. However, apart from the particle-hole states based on the $f_{7/2}$ resonance, it can be seen that there are more states observed than would be expected on the basis of spin values alone. In addition, states sometimes are observed at more than one resonance. These observations again show that the particle-hole states are not pure but the strength of an individual state is spread out over several states.

The lower portion of Fig. 19 shows the relative spectroscopic factors for the particle-hole states observed in the (d,p) reaction. We can see that the excitation energies are in good agreement with those of states observed in the (p,p') reaction—except that some states are unresolved in the (p,p') reaction. [Recent (p,p') measurements with the magnetic spectrograph have confirmed and extended the agreement shown here.] We can also note that states appearing at both $f_{7/2}$ and $p_{3/2}$ resonances show evidence for $\ell = 3$ and 1 admixtures in the (d,p) measurements. The (d,p) reaction does not separate the states observed at the $p_{3/2}$ and $p_{1/2}$ resonances.

Perhaps most importantly it should be noted that some states that are strongly excited on the $f_{7/2}$ resonance are only weakly excited in the (d,p) reaction, as for example the states at 3.92 and 4.16 MeV excitation. Since the ground state of Ba^{137} is predominantly a $(d_{3/2})^{-1}$ neutron configuration, such states are expected to have mainly a $(f_{7/2})(s_{1/2})^{-1}$ neutron configuration. In addition, the state at 3.92 MeV is also observed in the decay of the $p_{3/2}$ resonance whereas that at 4.16 MeV is not. Since a particle-hole state based on a $p_{3/2}$ particle can give rise to only one (3^-) of the two possible spins

Fig. 19. Location of particle-hole states in Ba^{138} from the $\text{Ba}^{138}(\text{p}, \text{p}')$ and $\text{Ba}^{137}(\text{d}, \text{p})$ reactions.

TABLE III. Strength of particle-hole excitations in Ba¹³⁸ from (p, p') and (d, p) reactions.

Resonance	(p, p')			(d, p)		
	(E _R) _{c.m.} (MeV)	(E _{p'}) _{c.m.} (MeV)	∑Γ _{p'} (keV)	ℓ	∑ $\frac{2J+1}{2J_0+1}$ S (Relative ^a)	(2J+1)S for Ba ¹³⁸ (d, p)
f _{7/2}	9.94	~6.0	12.8	3	6.0	6.0
p _{3/2}	10.56	~6.2	13.7	1	2.6	2.0
p _{1/2}	11.02	~6.3	12.2	1		0.8

^aNormalization: $\frac{2J+1}{2J_0+1} S = 1$ for Ba¹³⁷(d, p)Ba¹³⁸ (g. s.).

(3⁻ and 4⁻) from the f_{7/2}(s_{1/2})⁻¹ configuration, it can be inferred that the 3.92- and 4.16-MeV states have spins of 3⁻ and 4⁻, respectively. Of course, the wave function of the 3.92-MeV state must have, in addition, a strong (p_{3/2})(d_{3/2})⁻¹ component. The states at 3.56 and 3.64 MeV, which are observed strongly in both reactions, are most probably of spins 3⁻ and 4⁻ or vice versa and arise from a dominant f_{7/2}(d_{3/2})⁻¹ configuration. Similar arguments permit us to infer or restrict the J value of other particle-hole states.

In addition to the partial cross sections and relative spectroscopic factors presented above, we can also calculate the summed strength of these states observed in the inelastic scattering at each resonance and in the (d, p) reaction. The results are shown in Table III.

The left-hand side of the table shows the sum of the inelastic widths for each of the three resonances. These have been calculated on the basis of the resonance parameters Γ and Γ_p derived from the analysis of the corresponding elastic proton resonances. Also shown are the mean energies of inelastic protons for each of the three resonances; it can be seen that they are closely the same at each resonance. Thus the sum of the widths is

approximately independent of any variations in outgoing proton penetrabilities at each resonance and their near equality must reflect the nature of the reaction leading to these states.

We have earlier emphasized that the preferred population of particle-hole states in the decay of isobaric-analog states follows naturally from the composite nature of the analog state. Now at each resonance the decay to the particle-hole states involves the emission of the same d and s protons. The only change is in the neutron orbit outside the core of excess neutrons. On this basis, we would expect the reduced widths to be equal; and since the penetrabilities are approximately the same, the sum of the partial widths should thus be closely the same. That this result is indeed observed therefore provides a very effective demonstration of the composite nature of an isobaric-analog state.

The near equality of the sum of the partial widths can similarly be understood in terms of the equivalent neutron pickup reaction on the parent analog nucleus. For each particle state in Ba^{139} , the particle-hole states would be formed by pickup of the same d and s neutrons from the $N=82$ core and the sum of the spectroscopic factors would be expected to be the same in each case. In accord with this explanation, it can be remarked that we have also observed particle-hole states in Ba^{136} in the (p, p') reaction at the same particle analog resonances as in Ba^{138} . We find them more weakly excited. This result is in accord with the above discussion since on the pure shell model a total of only four d and s neutrons are now available for pickup from the core as against the six d and s neutrons in the case of Ba^{138} .

The right-hand side of Table III shows the sum of the relative strengths of the $\ell=3$ and 1 transitions to the particle-hole states formed in the (d, p) reaction. The relative strengths result from a normalization which makes the reasonable assumption that

the ground state of Ba^{137} is pure $(d_{3/2})^{-1}$ and that the $\ell=2$ (d,p) reaction to the ground state of Ba^{138} takes up the entire $d_{3/2}$ strength. With this normalization, we can see that the total strength for the $\ell=3$ and 1 transitions to the particle-hole states are in very good agreement with the absolute strengths observed in the Ba^{138} (d,p) reaction to the corresponding individual particle states. Such a result is again to be expected from our description of these particle-hole states.

Resonant Proton Scattering on Ba^{137}

To complete our discussion of the reactions that lead to the particle-hole states in Ba^{138} , we can consider the observation of their analog states as shown schematically in Fig. 20. Indeed, we first observed them⁹ as resonances in the elastic scattering of protons on Ba^{137} and were led from the results to a description of the resonances as such. However, their observation as elastic-

Fig. 20. Schematic diagram showing excitation of the La^{138} states which are the analogs of particle-hole states in Ba^{138} .

scattering resonances in the $\text{Ba}^{137} + p$ reaction can only give results similar to those we have obtained with more assurance from the Ba^{137} (d,p) reaction. But their observation as resonances leads to the possibility of observing their decay to the $(s_{1/2})^{-1}$ hole state in Ba^{137} . Thus we can hope to elucidate further the structure of the

⁹ G. C. Morrison and Z. Vager, in Proceedings of the Conference on Isobaric Spin in Nuclear Physics, Florida State University, Tallahassee, Florida, 17-19 March 1966, edited by J. D. Fox and D. Robson (Academic Press, New York, 1966), p. 320.

particle-hole states in Ba^{138} in so far as only those states with an $(s_{1/2})^{-1}$ hole component in the wave function would be expected to decay to the first excited state of Ba^{137} .

Figure 21 shows the excitation functions of elastic and inelastic proton scattering on Ba^{137} for a range of incident proton energies corresponding to those particle-hole states based mainly on the $f_{7/2}$ particle. One can see that the positions of the various resonances in elastic proton scattering (upper curve) agree remarkably well with the corresponding positions of the particle-hole states in the parent analog nucleus Ba^{138} (as indicated by the arrows along the top of the figure).

Of more importance is the fact that the inelastic scattering (lower curve) indeed resonates selectively at only a few of the elastic-scattering resonances. On this basis we can make further inferences on the structure of these states. For example, the analog of the particle-hole state at 4.16 MeV in Ba^{138} is seen to decay weakly to the $(s_{1/2})^{-1}$ first excited state in Ba^{137} . This result is in keeping with our previous interpretation of this level as a 4^- state of dominant $(f_{7/2})(s_{1/2})^{-1}$ configuration. The cross section for inelastic scattering to the $(s_{1/2})^{-1}$ hole state involves the product of two terms—that for forming the resonance and that for decay of the resonance. Thus the analog of the 4.16-MeV state decays only weakly by inelastic proton emission since, despite the large probability for decay, there is only a small probability for formation which depends on the amplitude

Fig. 21. Excitation functions of protons scattered elastically and inelastically on Ba^{137} at 170° . Positions of levels in Ba^{138} to which elastic scattering resonances correspond are shown above.

of the $(f_{7/2})(d_{3/2})^{-1}$ component in the wave function. (There is little evidence for the resonance in elastic proton scattering at this energy.) It has been suggested previously that the spin of the state at either 3.56 or 3.64 MeV in Ba^{138} is 4^- . The wave function of the 4^- level will be orthogonal to that of the 4.16-MeV level having a dominant $(f_{7/2})(d_{3/2})^{-1}$ configuration. Hence, we expect that inelastic scattering to the $(s_{1/2})^{-1}$ hole states will again be weak since the amplitude of the $(f_{7/2})(s_{1/2})^{-1}$ component, which determines the decay of the state, is now small. Insofar as the analog of the state at 3.64 MeV appears to decay weakly to the $(s_{1/2})^{-1}$ hole state in Ba^{137} and with comparable intensity to the analog of the 4.16-MeV state, the result suggests that the 3.64-MeV level in Ba^{138} is the one with spin 4^- .

It has previously been suggested that the level at 3.92 MeV in Ba^{138} is a 3^- state with both $(f_{7/2})(s_{1/2})^{-1}$ and $(p_{3/2})(d_{3/2})^{-1}$ components in the wave function. In this case, the analog of the 3.92-MeV state not only has a large probability for inelastic decay to the $(s_{1/2})^{-1}$ hole state in Ba^{137} via the $(f_{7/2})(s_{1/2})^{-1}$ component but also has a large probability for formation through the $(p_{3/2})(d_{3/2})^{-1}$ component; a strong p-wave resonance is observed in elastic scattering. On the basis of this description, strong inelastic scattering is expected at the resonance corresponding to the 3.92-MeV state in Ba^{138} —as is borne out experimentally. Similar arguments allow us to infer or restrict the structure of other particle-hole states in Ba^{138} .

Conclusions

In summary, then, we have observed the same neutron particle-hole states in Ba^{138} in three different reactions: from the decay of isobaric analog resonances, in the (d,p) reaction, and as isobaric-analog states. From the totality of information, I have

shown that it is possible to identify and characterize most of these states. Our conclusions with regard to those states that are based on the $f_{7/2}$ particle are given in Table IV. Although these are highly excited states in Ba^{138} , it has been possible not only to make spin assignments but also to infer the principal configurations of their wave functions. This points up the extent to which the study of isobaric-analog states indeed gives access to unique information.

TABLE IV. Summary of particle-hole states in Ba^{138} , based on $2f_{7/2}$ particle.

Energy in Ba^{138} (MeV)	J^π	Configuration
3.56	3^-	$fd^{-1} + (fs^{-1})$
3.64	4^-	$fd^{-1} + (fs^{-1})$
3.86	5^-	fd^{-1}
3.92	3^-	$fs^{-1} + pd^{-1} + (fd^{-1})$
4.08	(2^-)	$fd^{-1} + pd^{-1}$
4.16	4^-	$fs^{-1} + (fd^{-1})$

MEASUREMENT OF ISOBARIC ANALOG STATES WITH (He^3, p) REACTIONS

J. A. Nolen, Jr., J. P. Schiffer, D. von Ehrenstein, and N. Williams

Bull. Am. Phys. Soc. 12, 92 (January 1967)

The (He^3, p) reaction on even-even targets should proceed with large cross section, in analogy to the (t, p) reaction, to states that are the analogs of 0^+ ground states. This effect has been observed for a series of even Ca isotopes bombarded with the 12-MeV He^3 beam of the Argonne tandem Van de Graaff accelerator. The protons were detected with a broad-range magnetic spectrograph. The Ca-Sc Coulomb-energy differences were measured to be 7.230, 7.208, and 7.012 ± 10 keV for the isobaric pairs with $A = 44, 46$, and

50, respectively. With these results, 8 Ca-Sc Coulomb energy differences have now been accurately determined. They are being analyzed with Wood-Saxon wavefunctions¹ and seem to be consistent with the parameters for charge radii and optical wells that have been observed in other work.

¹K. W. Jones, J. P. Schiffer, L. L. Lee, Jr., and J. L. Lerner, Phys. Rev. 145, B894 (1966); F. G. Perey and J. P. Schiffer, Phys. Rev. Letters 17, 324 (1966).

INVESTIGATION OF THE $\text{Ca}^{48}(\text{He}^3, p)\text{Sc}^{50}$ REACTION

H. Ohnuma, J. R. Erskine, J. A. Nolen, Jr., and J. P. Schiffer
Bull. Am. Phys. Soc. 12, 110 (January 1967)

The $\text{Ca}^{48}(\text{He}^3, p)\text{Sc}^{50}$ reaction was studied at $E(\text{He}^3) = 12$ MeV by use of the Argonne tandem Van de Graaff and a broad-range

Fig. 22. Observed levels of Sc^{50} and comparison with previous measurements.

magnetic spectrograph. It was found that $Q_0 = 7.965 \pm 0.015$ MeV and that there are excited states at 259, 331, 761, 1857, 2227, 2334, 3087, 3262, and 3289 ± 5 keV. The energies of the first and the second excited states agree very well with the results (Fig. 22) of a study of the β decay of Ca^{50} by Shida et al.¹ But their assignment $J^\pi = 1^+$ to the 330-keV state is difficult to reconcile with the fact that in the present work only four states are observed near the ground

¹Y. Shida, M. Ishihara, K. Miyano, H. Morinaga, and Ren Chiba, Phys. Letters 13, 59 (1964).

state, as expected from the $(f_{7/2})_p(p_{3/2})_n$ configuration.² Our Q_β value, taken with that recently measured³ for $\text{Ca}^{48}(t,p)\text{Ca}^{50}$, yields $Q_\beta = 4.966 \pm 0.020$ MeV for the ground-state decay. If we assume that the β decay of Ca^{50} feeds some level around 2 MeV instead of the 330-keV state, its log ft value would be about 3.9.

²H. Ohnuma and K. Sasaki, Phys. Letters 17, 126 (1965); J. Vervier, Nucl. Phys. 78, 497 (1966).

³S. Hinds, J. H. Bjerregaard, Ole Hansen, and O. Nathan, Phys. Letters 21, 328 (1966); D. C. Williams, J. D. Knight, and W. T. Leland, Phys. Letters 22, 162 (1966).

DECAY OF THE THIRD EXCITED STATE IN Ca^{41}

R. E. Segel, E. F. Kennedy, L. L. Lee, Jr., and J. P. Schiffer

Bull. Am. Phys. Soc. 12, 92 (January 1967)

The $\frac{3}{2}^-$ 3rd excited state of Ca^{41} at 2.47 MeV contains a good fraction ($\sim 30\%$) of the $2p_{3/2}$ single-particle strength as observed in the $\text{Ca}^{40}(d,p)\text{Ca}^{41}$ reaction. The E2 decay of this state to the $\frac{7}{2}^-$ ground state of Ca^{41} may therefore be expected to proceed with approximately single-particle strength, but such a transition was not observed in earlier work.¹ We have sought this transition by observing (p, γ) coincidences from the $\text{Ca}^{40}(d,p)$ reaction. In the γ spectrum, filtered by 1 cm of Pb and observed by a 25×20 -cm NaI(Tl) crystal placed 45 cm from the target, the 1.95-MeV line from the 0.52–1.95-MeV cascade appeared strongly in the spectrum but $< 1\%$ of the decays went by the 2.47-MeV crossover. From the limit on the lifetime of this state² we get $\tau > 7 \times 10^{-11}$ sec for the crossover or $|M|^2 < 0.006$ single-particle units.

¹L. L. Lee, Jr., J. P. Schiffer, and D. S. Gemmell, Phys. Rev. Letters 10, 496 (1963).

²P. P. Singh, R. E. Segel, R. H. Siemssen, S. I. Baker, and A. E. Blaugrund, Phys. Rev. (to be published).

STUDY OF THE $^{63}\text{Cu}(n, \gamma)^{64}\text{Cu}$ AND $^{65}\text{Cu}(n, \gamma)^{66}\text{Cu}$ REACTIONS

E. B. Shera,* H. H. Bolotin, and H. J. Fischbeck

Bull. Am. Phys. Soc. 12, 128 (January 1967)

Gamma-ray spectra from the thermal neutron-capture reactions on separated targets of both stable isotopes of Cu have been studied using a Ge(Li) spectrometer. The high-energy capture spectrum from the ^{63}Cu target was studied in the energy interval 6–8 MeV, corresponding to transitions from the capture state at 7914 ± 3 keV to low-lying states with excitation energies in the range 0–2 MeV. Nine excited levels were found to be populated by prominent direct transitions. Preliminary analysis indicates levels at 160, 277, 346, 612, 664, 739, 879, and 928 keV in ^{64}Cu . Similar measurements on ^{65}Cu yield preliminary energies of 185, 274, 384, 463, and 822 keV for states below 1 MeV in ^{66}Cu . The low-energy transitions (up to 1 MeV) of both isotopes have been studied with a Ge(Li) detector surrounded by a large NaI anticoincidence annulus. Coincidence data using Ge and NaI detectors have been obtained for both isotopes and have been used in developing the low-lying level schemes of these isotopes.

* Los Alamos Scientific Laboratory.

TOTAL NEUTRON CROSS SECTION OF LANTHANUM

Hla Shwe, R. E. Coté, and W. V. Prestwich

Bull. Am. Phys. Soc. 12, 106 (January 1967)

With high-purity La_2O_3 samples with thicknesses of $0.0748\text{--}12.18\text{ g/cm}^2$ of La, σ_t was measured from 0.1 to 1000 eV with the Argonne fast chopper (Fig. 23). Above a few eV, σ_t is found to be several b lower than the values in BNL-325. Its

Fig. 23. The observed total neutron cross section of lanthanum.

The solid curve is computed by using the well-known Breit-Wigner shape for the resonances, the measured parameters for the six positive-energy resonances, and a bound level at the energy $E_0 = -37.5$ eV, with reduced neutron width $\Gamma_n^0 = 0.115$ eV and radiation width $\Gamma_\gamma = 0.0565$ eV. The error bars represent standard statistical errors. Where errors are not shown, they are the size of the dots or smaller. The experimental points shown are composites of the total measurements made. Many points have been omitted for clarity.

variation over the entire range can be explained by a bound level at $E_0 = -37.5$ eV with $\Gamma_n^0 = 0.115$ eV and $\Gamma_\gamma = 0.0565$ eV and the known positive-energy resonances. A new resonance at 618 eV was assigned to ^{139}La . The γ spectrum from capture at the 72.3-eV resonance of ^{139}La shows that the capturing state is $J^\pi = 3^+$. The interference between resonance and potential scattering near the 72.3-eV resonance shows that $R'/R = 0.74$. This value is the lowest measured in this mass region, but is consistent with predictions of the optical model. The values of the radiation widths of the resonances at 0.734 and 72.3 eV (identified as p- and s-wave resonances in ^{139}La) are found to be more nearly the same than earlier results¹ had indicated.

¹ J. A. Harvey, R. C. Block, and G. G. Slaughter, Bull. Am. Phys. Soc. 4, 385 (1959).

POSSIBLE TWO-PHONON QUADRUPOLE-OCTUPOLE AND THREE-PHONON QUADRUPOLE VIBRATIONAL STATES IN Cd^{114}

R. K. Smither

Bull. Am. Phys. Soc. 12, 18 (January 1967)

Fig. 24. The level scheme of Cd^{114} , based on (n, γ) and (d, p) experiments. The energies, spins, and parities of the lower energy levels are given at the left. The width of the arrows representing the gamma transitions reflects their intensity. The arrows at the right-hand side of the level scheme indicate the presence of high-energy transitions to these levels from the neutron-capture state. The l_n values obtained for the levels from the (d, p) angular distributions are given at the far right.

Recent (n, γ) and (d, p) experiments were used to further develop the level scheme of Cd^{114} . Special emphasis was placed on defining the properties of new levels with excitation energies in the 1—3 MeV range. The main features of this level scheme appear in Fig. 24. [Above 3 MeV the average level spacings become so small (~ 15 keV) that the detailed interpretation of individual levels in terms of special nuclear models is no longer practical.] Of special interest were levels which exhibited collective properties, i. e., enhanced E2 transitions to lower collective levels and special selection rules in their γ -decay modes. Four states in the 1—3 MeV region fit the theoretical description of corresponding members of the 3-phonon quadrupole vibrational quintet (0^+ , 2^+ , 3^+ , 4^+ , 6^+). Their energies (in keV), spins, and parities are 1731.80 (4^+), 1783.19 (3^+), 1841.46 (2^+), and 1863.64 (0^+). A fifth state at 2024.30 keV may be interpreted as the 6^+ member of the quintet. Many of the details of the γ decay of these levels to lower-lying collective levels are shown in Fig. 24. Their energies and energy spacings are consistent with second-order perturbation theory. In Fig. 25 the theoretically predicted energy levels are compared with the experimentally observed levels. All necessary

Fig. 25. Comparison between experiment and second-order perturbation theory for the 3-phonon quadrupole vibrational states in Cd^{114} . Theoretical predictions are given on the left. The necessary parameters are obtained from the energies of the 1-phonon and 2-phonon ($N_2 = 2$) states.

Fig. 26. Comparison of the negative-parity levels found in the level scheme of Cd^{114} with the predictions of fourth-order perturbation theory for the energies and energy separations of the 1-quadrupole + 1-octupole vibrational quintet. N_2 is the number of quadrupole phonons in the state and N_3 is the number of octupole phonons in the state.

parameters are determined from the energies of the one-phonon and two-phonon states. The enhancement of the E2 transitions to the 2-phonon states (1134 keV, 1209 keV, and 1283 keV) relative to those to the 1-phonon state (558 keV) and ground state is predicted by the model and therefore supports these associations.

Three negative-parity states with excitation energies (in keV), spins, and parities of 1757.77 (2^-), 1933.04 (3^-), and 1957.70 (2^- or 1^-) appear to be good candidates for members of the 2-phonon quadrupole-octupole vibrational quintet (1^- , 2^- , 3^- , 4^- , 5^-). The level at 2024.30 keV mentioned above can also be interpreted as the 4^- or 5^- member of this negative-parity quintet. The details of the γ decay of these levels to the lower collective levels is shown in Fig. 26. Their energies and energy spacings are consistent with fourth-order perturbation theory and with the value of the $B(E2)$ for the 3^- one-phonon octupole state. The theoretical predictions for the energies of these levels are shown at the right in the level scheme.

DECAY OF Xe^{125}

G. T. Wood, H. J. Sathoff, and D. Parks

Bull. Am. Phys. Soc. 12, 20 (January 1967)

We are reporting work on the decay of 18-h Xe^{125} based on γ -ray, internal-conversion electron, positron, and γ - γ coincidence studies. Ge(Li) and NaI(Tl) detectors, and a six-gap magnetic beta-ray spectrometer (Copenhagen type) were employed in the work.

The sources were prepared by irradiating quartz-encapsulated xenon gas (enriched to 5% Xe^{124}) with neutrons in the Argonne CP-5 reactor. Radioactive Xe^{125} was separated and embedded in $100 \mu\text{g}/\text{cm}^2$ nickel foils in the Argonne electromagnetic isotope separator.

The best γ -ray singles data were obtained in a cylindrical 3.5-cm³ Ge(Li) detector (coupled to a FET preamplifier) with an energy resolution width of about 3 keV at 400 keV. However, the FET detector was used only in the range from 70 to 900 keV whereas a rectangular 3.2-cm³ Ge(Li) detector (without an FET) was employed over the entire region from 50 to 1700 keV.

The Ge(Li) detectors were energy calibrated by use of standard sources and a mercury pulser which converts a dc voltage measured with a digital voltmeter to a standard reference pulse. The full-energy peak efficiency was also calibrated by use of standard sources and Monte Carlo calculations.

The spectra were automatically analyzed for energy and intensity in one step by computer (CDC 3600). The calculation involved a peak-energy versus peak-position calibration, a peak-energy width versus peak-energy calibration, a photoefficiency versus energy calibration, a peak search, and a least-squares fit to individual peaks (in which a Gaussian shape and straight-line background were used both with a calibrated width and with an unconstrained width). Close-lying peaks are reanalyzed as multiplets and broad peaks as doublets. Finally the spectrum is plotted, and an energy scale and peak and Compton-edge labels are supplied in order to aid in further evaluation of the computations. Although most peaks were satisfactorily analyzed automatically, a few peaks such as those resting on a back-scatter peak or a Compton edge were rerun with a polynomial background and calibrated fixed width. The gamma-ray energies and intensities obtained from these measurements are given in Table V.

The table also summarizes the results from the Ge(Li)-NaI(Tl) coincidence studies, in which the two detectors were placed 180° apart and a Pb antiscatter shield was used. Digital gates were set on the prominent peaks (55, 188, 243, and 453 keV) in the NaI spectrum, and the coincidence spectra were studied in Ge(Li) as seen

TABLE V. Gamma rays and K conversion electrons from decay of Xe^{125} .

Gamma energy (keV)	Relative γ -ray intensities				K-conversion-electron intensities	Electron-conversion coefficients			
	Ge(Li) singles	Ge(Li) coincidences with NaI at				Measured a_K	Theory (Rose)		
		55 keV	188 keV	243 keV			453 keV	$a_K^{(M1)}$	$a_K^{(E2)}$
55	11.5								
75 x									
85 x									
113.8	0.75	1.1(2) e							
187.6	100	100 n							
210.1	0.12(1) e		0.11(2) e	0.13(2) e					
216.3 u	0.24(1)								
243.0	51.0				3.4 g	0.066	0.057	0.066	
258.7 u	0.025(7)								
270.7 u	0.10(1)								
289 u			0.079(2) b						
372.0	0.26(1)		0.10(3)	0.08(2)					
428.9 c	0.049(2)								
453.8	7.8(1)				0.078	0.0100	0.113	0.094	
511.3 a									
554.6	0.057(6)			0.08(3) e	0.00043	0.0076	0.0059	0.0055	
637.0	0.41(1)			0.41(5) n	0.0024	0.0059	0.0050	0.0037	
719.0 u	0.022(7)								
728.8	0.11(1)			0.31(4)	0.00069	0.0062	0.0036	0.0027	
821.1	0.051(2)								
848.7	1.89(2)	1.3(4)	2.0(2)	1.89(16) n	0.0053	0.0028	0.0026	0.0019	
903.7	0.98(2)		0.98(10) n		0.0026	0.0027	0.0022	0.00017	
940.0	0.29(5)			0.23(7)	0.00075	0.0026	0.0020	0.0015	
996.3	1.5(2)				0.00048	0.0032	0.0018	0.0013	
1009.2	0.28(4)				0.00048	0.0017	0.0017	0.0013	
1075.7 u	0.20(5)								
1093	0.12(2)								
1140.4 u	0.58(2)				0.00074	0.0013	0.0013	0.0010	
1183.0 c	1.5(3)				0.0016	0.0011	0.0012	0.00090	

a Annihilation radiation.

b The intensity given assumes that the 289-keV γ ray feeds the 188-keV level directly.

c Complex.

e The errors quoted are statistical only.

g The normalization assumes that the 243-keV transition is pure E2 (Ref. 1).

n Normalized to singles intensity.

u Unassigned.

x Pb x rays.

in the table. On the basis of the proposed decay scheme, and with neglect of angular-correlation effects, relative intensities were determined for the peaks appearing in each coincidence spectrum. The coincidence results agree satisfactorily with the singles results in all cases except for the 372-keV gamma ray which appears with about triple intensity in the singles spectrum. Thus it is suggested that this peak has a noncoincident component and is complex (even though not broadened).

Fig. 27. A partial decay scheme of Xe^{125} . The circles indicate coincidence relations established from γ - γ coincidence measurements. The energies followed by an asterisk were determined by Geiger from conversion-electron spectroscopy in a high-resolution spectrometer.

Figure 27 is a decay scheme of the levels most firmly established in this work. The energies and spin-parity assignments of the low-lying levels are due to J. S. Geiger¹ who performed high-resolution conversion-electron spectroscopy and angular correlations on the more intense transitions. The coincidence relations revealed by our coincidence studies are indicated by the circles. Except for the 615.9-keV level, the levels we propose are also proposed by Geiger. The level energies and transition intensities agree with those of Geiger within the uncertainties of our work (~ 3 keV in energy and 20% in intensities). The level at 372 keV, proposed by Geiger, is not inconsistent with our work since the 372-keV transition appears predominantly noncoincident with the 243-keV transition in our coincidence studies.

¹J. S. Geiger (private communication).

The K-conversion-electron data for transitions with energies of 243 keV and above are also given in Table V. Our relative electron intensities were normalized to the γ -ray intensity scale on the assumption that the 243-keV transition is pure E2 (as determined by Geiger¹) so that $\alpha_K^{243} = 0.066$. From a comparison with the theoretical values obtained by Rose,² it is found that most of the measured values of α_K fall in the M1-E2 range and that all of the measured high-energy transitions are probably M1 and/or E2.

Measurement of the positron spectrum yielded a branching ratio $I(\text{K capture})/I(\text{positron emission}) = 200$, in near agreement with the theory of Feenberg and Trigg.³

We are indebted to J. L. Lerner for performing the isotope separations, to H. H. Bolotin for the use of his Ge(Li) detectors, to H. Fischbeck, P. J. Daly, and K. J. Hofstetter for use of their peak-efficiency measurements, and to W. Snow for Monte-Carlo calculations of peak efficiency.

² M. E. Rose, Internal Conversion Coefficients (North-Holland Publishing Co., Amsterdam, 1958).

³ E. Feenberg and G. Trigg, *Rev. Mod. Phys.* 22, 399 (1950).

PROTON STATES IN 1f2p-SHELL NUCLEI*

Ben Zeidman

Invited paper listed by title only: *Bull. Am. Phys. Soc.* 12, 8 (January 1967)

Nuclei in the 1f2p shell have been studied in proton-transfer reactions—proton pickup via (d, He^3) reactions and proton stripping via (He^3, d) reactions—at the Argonne cyclotron and tandem.

* The research reported here was done in collaboration with T. H. Braid, J. A. Nolen, Jr., G. C. Morrison, and R. H. Siemssen.

NUCLEON NUMBER	ELEMENTS
50 <u>1g_{9/2}</u>	Sn
40 <u>2p_{1/2}</u> <u>1f_{5/2}</u> <u>2p_{3/2}</u>	Zr
28 <u>1f_{7/2}</u>	Ni
20 <u>1d_{3/2}</u> <u>2s_{1/2}</u> <u>1d_{5/2}</u>	Ca
8	O

Fig. 28. Single-particle levels according to the shell model. Major shells close at 20 and 50; subshells close at 28 and 40.

Van de Graaff accelerators. These studies show systematic trends in the excitation energies of proton-hole and particle states, which are interpreted in terms of the interactions between nucleons in shell-model orbits. The single-particle shell-model levels are shown in Fig. 28. Nuclei in the 1f_{2p} shell nominally are considered to have a filled core of 20 neutrons and 20 protons, which corresponds to Ca⁴⁰. The 1f_{7/2}-shell nuclei are defined as those beyond Ca⁴⁰ with Z and N both ≤ 28 . On this basis, therefore, proton pickup from 1f_{7/2}-shell nuclei should involve particles both from the 1f_{7/2} shell and from the 2s1d shell of the core, both of which are occupied. In addition, small admixtures

of 2p and 1f_{5/2} particles may be seen. In the stripping reactions on targets in the 1f_{7/2} shell, however, levels corresponding to addition of protons in the unfilled shells will be seen strongly, while transitions to filled orbitals will be inhibited. It is therefore seen that except for the levels that correspond to addition of protons to partially filled orbits, the spectra observed in transitions leading to the same final nucleus will appear vastly different in pickup and stripping reactions.

The orbital-angular-momentum transfer ℓ is identified by comparison of the expected angular distributions with those calculated by use of the DWBA code JULIE. It has previously been shown that the angular distributions for a given ℓ are independent of j ($j = \ell \pm \frac{1}{2}$) for (d, He³) reactions or the inverse reaction. Since the range of d and He³ energies are similar in the two transfer reactions, a single set of potentials was used for both reactions in the DWBA calculations.

These potentials are basically characterized by a real well depth $V = 170$ MeV for He^3 and 105 MeV for d. The well depth and other parameters were chosen to give good agreement with the elastic scattering of He^3 and d in the mass range $A = 40-70$. The calculated angular distributions were obtained from the DWBA program in which the potentials and geometric parameters mentioned above are used in the zero-range formalism with a spin-orbit term in the potentials. The spectroscopic factor S , the basic information sought in nuclear-structure studies, is a measure of the overlap wave function of the target and the final nucleus plus or minus one nucleon. S is related to the data by

$$\frac{d\sigma(\theta)}{d\omega} = NC^2 S \frac{d\sigma}{d\omega}(\text{DWBA}) \quad \text{for } (d, \text{He}^3)$$

and by

$$\frac{d\sigma(\theta)}{d\omega} = \frac{(2J_f + 1)}{(2J_i + 1)} \frac{3}{2} NC^2 S \frac{d\sigma}{d\omega}(\text{DWBA}) \quad \text{for } (\text{He}^3, d).$$

The factor N involves the overlap of the d and He^3 wave functions; the value $N = 2.93$ for zero-range DWBA calculations has been used in accordance with the paper by Bassel¹ and other experimental results. The isospin coupling coefficient C^2 is 1 for (d, He^3) reactions. J_f and J_i are the spins of the final and initial states, respectively. In other reactions, it is found that the calculated cross section varies if a cutoff radius is used. For the potentials used in the present DWBA calculation, however, the calculated cross sections vary by less than 10%, independent of cutoff radius until an unrealistically large cutoff is used. Accordingly, all calculations have been performed with no cutoff. It is therefore seen that there are no free parameters in the extraction of spectroscopic factors or in the DWBA calculations.

¹R. H. Bassel, Phys. Rev. 149, 791 (1966).

(d, He³) Reactions

A typical spectrum for the (d, He³) reaction on an N=28 nucleus is shown in Fig. 29. The strong transitions are those to the ground state ($\ell = 3$) and to states at about 2.5 MeV excitation

Fig. 29. The $\text{Fe}^{54}(\text{d}, \text{He}^3)\text{Mn}^{53}$ spectrum, a typical one for N=28 nuclei. The strong states are the ground state ($\ell = 3$) and the states at 2.71 MeV ($\ell = 0$) and 3.05 MeV ($\ell = 2$).

($\ell = 0$ and $\ell = 2$). There are also other weak transitions.

The quality of the fits to the angular distributions is shown in Fig. 30, where it is seen that the strong transitions are well fitted by the calculated curves and even the weak transitions are moderately well fitted. The presence of weak $\ell=1$ and $1f_{5/2}$ transitions indicates that the shell closure is not exact and some configurations from the higher orbitals are observed.

The results of the (d, He³) reactions are

summarized in Fig. 31(a, b), where a "strength" $S/(2j + 1)$ is presented for transitions to various excitation energies. The sum of the strengths for a given (ℓ, j) is the fraction of the total possible occupancy of the shell, which would be unity for a full shell. The strong similarity of the distribution of strength in all N=28 nuclei is seen in Fig. 31(a), where the $^{48}_{20}\text{Ca}(d, \text{He})^{47}_{19}\text{K}$ results have been displaced to match the observed $2s_{1/2}$ and $1d_{3/2}$ levels in the other N=28 nuclei. The most striking feature of this comparison is the near degeneracy of the $2s_{1/2}$ and $1d_{3/2}$ strength at N = 28. The results for N=26 nuclei are shown in Fig. 31(b), where it is seen that the degeneracy is

removed and the $1f_{7/2}$, $1d_{3/2}$, and $2s_{1/2}$ are roughly equally spaced.

The similarity of the strength distribution for an equivalent number of neutrons, independent of proton number, is further illustrated in Fig. 32.

Here the mean excitation energy for the $1f_{7/2}$, $1d_{3/2}$, and $2s_{1/2}$ strength is shown for Sc and V nuclei. [The strength for V^{47} has been inferred from the $Ti^{46}(He^3, d)V^{47}$ reaction.] The

near degeneracy of the $1f_{7/2}$ and $1d_{3/2}$ strength for $N = 24$, the wide splitting for all orbitals at $N = 26$, and the near

degeneracy of the $1d_{3/2}$ and $2s_{1/2}$ orbitals at $N = 28$ are

predicted by a model which treats the monopole interaction between orbitals.² The basis of this model is to consider Ca^{40} as the core for the $1f_{7/2}$ -shell nuclei and then treat the interaction between the hole (either $1d_{3/2}$ or $2s_{1/2}$) and the $1f_{7/2}$ -shell nucleons in terms of two parameters—one dependent upon the number of particles, the other upon the isotopic spin. The excitation energies of the s and d states are determined with respect to the ground states of the residual nuclei and an s-d splitting of 2.53 MeV in $Ca^{40}(d, He^3)K^{39}$ is also used. The quality of agreement between the data and the calculation is quite good, especially since a very simple model is used and the presence of $2p$ and $1f_{5/2}$ strength is ignored.

Fig. 30. Angular distributions from the $Fe^{54}(d, He^3)Mn^{53}$ reaction. The quality of fits for the various l values is similar to those for other reactions studied and is representative of all l values observed in the $1f_{7/2}$ shell.

²R. K. Bansal and J. B. French, Phys. Letters 10, 145 (1964).

(a)

(b)

Fig. 31. Strengths from (d, He^3) reactions: (a) N=28 reactions, (b) N=26 reactions. The abscissae are $S/(2J+1)$, where J is the spin of the final state. For even-even targets, the spin of the final state is equivalent to the total angular-momentum transfer j.

Fig. 32. Hole states in Sc and V isotopes. The experimental and calculated excitation energies of hole states in Sc and V isotopes produced by proton pickup reactions on Ti and Cr isotopes, respectively, are compared.

It is interesting to see how much of the observed trends result simply from a change in the nuclear well because of increased numbers of particles, both protons and neutrons. Accordingly, a calculation was performed by use of the code ABACUS II, in which the depth of the well was adjusted to give the correct binding energy of the $1d_{3/2}$ proton. This well was then used to calculate the binding energy of the $2s_{1/2}$ and $1f_{7/2}$ protons. Figure 33 is a summary of

Fig. 33. Differences between the binding energies of $1d_{3/2}$ protons and protons in the $2s_{1/2}$ orbit or $1f_{7/2}$ orbit. The ordinate is the algebraic difference between the mean binding energies for each orbital. The dots are experimental values; the arrows indicate that the associated points should be raised, but the exact

amounts are not yet known. The curve is the calculated value of the difference for the $2s_{1/2}$ state, but has arbitrarily been moved to approximate the data for the $1f_{7/2}$ state.

known differences in binding energy between the $1d_{3/2}$ and $1f_{7/2}$ and $2s_{1/2}$ protons, together with curves showing the calculated values of these differences. By choosing the well to match the $1d_{3/2}$ binding energy, some of the residual nuclear interactions have already been included; but it is seen that although the general trend of binding energy differences is in agreement with the data, the changes in well depth and size are not sufficient to completely account for the variation in binding energy.

(He^3, d) Reactions

In the (He^3, d) reaction, protons are added to the target to form the states of the final nucleus. These protons interact with the protons and neutrons in the target; the forms of these interactions determine the observed spectrum. If the interaction is weak or restricted (e.g., when completely open or closed neutron shells are present), then one expects a comparatively simple spectrum—modified by the protons in the target. For partially filled proton and neutron shells, however, the strong interaction between particles in the same angular-momentum state results in fragmentation of strength and probably in a marked dependence upon neutron number for the strength and excitation energy for various transitions.

The spectra from (He^3, d) reactions on the even-A Ti isotopes is shown in Fig. 34, where the ℓ values for the levels are indicated above the peaks. The $1f_{7/2}$ strength is at or near the ground state and the $\ell=1$ strength is concentrated between 2.0 and 2.5 MeV. The spectroscopic factors and excitation energies for a number of $1f_{7/2}$ -shell nuclei are summarized in Fig. 35. For the reactions leading to V, Mn^{53} , and Co^{55} , both the protons and neutrons are basically in the $1f_{7/2}$ shell, which ends at N or Z = 28. For all of these nuclei, the p strength is concentrated in the vicinity of 2.3

Fig. 34. The spectrum observed for (He^3, d) reactions on Ti isotopes. The l value associated with each transition is indicated above the peak.

Fig. 35. Spectroscopic factors for (He^3, d) reactions in the $1f_{7/2}$ shell. In the (d, He^3) results on the right of the figure, the strong hole-state ($1f_{7/2} 2s_{1/2}, 1d_{3/2}$) contributions have been suppressed to accentuate the weak transitions.

MeV excitation. This constancy is quite surprising, although such a result would not be totally unexpected for the isotopes of one element. However, beyond $N = 28$ (the $1f_{7/2}$ -shell closure), namely in the $\text{Fe}^{56}(\text{He}^3, d)\text{Co}^{57}$ reaction, the p strength drops to 1.5 MeV. This drop is about 700 keV! Since Fe^{56} has 30 neutrons, to a large extent the 2 neutrons outside the $N=28$ shell are in the $2p$ shell. The interactions between these neutrons and the $2p$ protons added to the target is such as to depress the excitation energy of the $2p$ proton states about 700 keV. From a comparison of the (d, He^3) reactions on Fe^{54} and Fe^{56} , at the right of the figure, it is seen that there is more $l=1$ strength in the $\text{Fe}^{56}(d, \text{He}^3)\text{Mn}^{55}$ reaction than in the $\text{Fe}^{54}(d, \text{He}^3)\text{Mn}^{53}$ and that this increase primarily involves the transitions to the state at 1.5 MeV. From this it is inferred that

Fig. 36. $\text{Zn}(\text{He}^3, \text{d})$ spectra.

the $\text{Cr}^{54}(\text{He}^3, \text{d})\text{Mn}^{55}$ reaction similarly would show enhanced $\ell=1$ transitions to states near 1.5 MeV excitation. The conclusion is then that when neutrons are added to a closed shell, the proton levels in the same single-particle state are depressed.

The spectra from the $\text{Zn}(\text{He}, \text{d})\text{Ga}$ reactions are shown in Fig. 36. There are a number of states observed at low excitation which involve $\ell=1$ and $\ell=3$ transitions, and in $\text{Ga}^{65, 67, 69}$ a strong $\ell=4$ state is observed at 2 MeV excitation. For the reaction $\text{Zn}^{70}(\text{He}^3, \text{d})\text{Ga}^{71}$, however, only four strong states are seen and the $\ell=4$ state is at 1.49 MeV excitation. The data are summarized in Fig. 37 in the form of excitation energies and spectroscopic factors. The very low-lying state in Ga^{65} is a doublet with about 50 keV separation. The upper member of this doublet rises slowly with increasing neutron number and then, between $N = 38$ and $N = 40$, abruptly jumps to 1.1 MeV excitation. The three strong states in Ga^{71} at 0, 0.49, and 1.1 MeV excitation are believed to correspond to $2p_{3/2}$, $1f_{5/2}$, and $2p_{1/2}$ transitions, respectively. The $\ell=4$ transition in Ga^{71} is about 500 keV lower than in the lighter Ga isotopes. From the earlier discussion, it is inferred that there

Fig. 37. Spectroscopic factors for $\text{Zn}(\text{He}^3, d)\text{Ga}$ reactions. The legend indicates the ℓ value for each transition. In extracting spectroscopic factors, all $\ell=1$ transitions are assumed to be $j=\frac{3}{2}$ transitions. Since some of the $\ell=1$ transitions are, in fact, $j=\frac{1}{2}$ transitions, the spectroscopic factors for these states should be multiplied by 2 when the spins are determined.

is a strong neutron-proton interaction in all the Ga isotopes for the $\ell=1$ and $\ell=3$ states, but this interaction suddenly becomes apparent for the $1g_{9/2}$ transition at $N = 40$ (Zn^{70}). This is analogous to the effect observed at $N = 30$ for the p protons. The implication is, therefore, that in the addition of a pair of neutrons between $N = 38$ and $N = 40$, a substantial fraction of the added pair is in the $1g_{9/2}$ state. From the analogy to the situation at $N = 28$, an apparent shell exists for $1g_{9/2}$ neutrons at $N = 38$, but this is a selective shell which does not exist for the p and f neutrons.

In fact, in the absolute sense, there are no closed shells. Whenever pickup reactions are performed in "closed-shell" nuclei, some admixture from nominally unfilled shells is always observed. In an experiment performed by D. Borlin,³ direct examination of the Zn isotopes by means of the (He^3, α) pickup reaction indicates the presence of $\ell=4$ neutrons in all the Zn isotopes. For Zn^{70} , however, the $\ell=4$ transition is more than twice as strong as in the lighter Zn isotopes. There appears to be a minimum level below which the presence of a configuration and its interactions with the other nucleons does not affect the gross properties of the energy spectrum.

³D. Borlin (private communication).

Summary

Both in the (d, He^3) and in the (He^3, d) reactions, the gross features of the observed spectra were not affected by the presence of small admixtures of other, nominally absent, configurations. In the (d, He^3) investigations, the marked dependence upon neutron number and weak dependence upon proton number was adequately explained by a model which neglected the presence of the observed p and $1f_{5/2}$ admixtures. In the (He^3, d) reaction, the effect of small admixtures of p neutrons and protons in the $f_{7/2}$ shell and $1g_{9/2}$ neutrons in the Zn isotopes seems to be small until a threshold is reached. This insensitivity to small admixtures suggests that closed shells should be considered in an operational sense, wherein a shell may exist for selected orbitals rather than all orbitals. This may provide an empirical basis for restricting the number of configurations to be treated in shell-model calculations, in which the complexity increases rapidly as the number of treated configurations increases slowly. This operational approach also may be useful for estimating the reliability of assumptions used in restricting the scope of shell-model calculations and as a measure of the degree to which restricted calculations may be expected to agree with experimental results.

1967 National Particle Accelerator Conference
Washington, D. C., 1—3 March 1967

SIMPLE IMPROVEMENTS IN SMALL HIGH-VOLTAGE DC POWER SUPPLIES

Alexander Langsdorf, Jr.

The performance of transformer-rectifier power supplies for high dc voltages and small currents can be improved by using simple design features which reduce difficulties ascribable to capacitive and reactive properties of the transformer secondary windings. For example, (1) in a doubler circuit, the output voltage may have a line-frequency ripple (independent of load current) as a result of capacitive current circulating between secondary and core. If the core is properly insulated from the primary and from ground, it and one secondary terminal can be connected to the dc midpoint of the doubler circuit; then this circulating current causes no external ripple voltage. (2) Similar ripple may be caused by capacitive coupling between the secondary and the output wiring. Careful layout reduces this ripple and proper shielding eliminates it. (3) The relatively large volume of insulation between primary and secondary in these transformers leads to a large secondary leakage reactance which causes poor voltage regulation under varying load current. Provided the secondary can carry some additional current, a (rather small) capacitor can be connected across the secondary terminals; it will improve regulation and reduce the generation of rf interference.

American Physical Society MeetingChicago, 27—30 March 1967PHOTOIONIZATION SPECTRUM OF H_2 WITH 0.04-Å RESOLUTION.
REACTIONS OF H_2^+ IN SELECTED STATES

W. A. Chupka

Invited paper listed by title only: Bull. Am. Phys.
Soc. 12, 273 (March 1967)EFFECT OF INCIDENT-BEAM COMPOSITION ON THE MEAN
RESIDENCE TIME OF ALKALI IONS ON POLYCRYSTALLINE
TUNGSTEN SURFACES

Manfred Kaminsky

Bull. Am. Phys. Soc. 12, 379-380 (March 1967)

Modulated beams of alkali metal atoms were incident on atomically clean surfaces of polycrystalline tungsten, and the mean residence times τ_i of alkali ions were measured with a phase-sensitive mass spectrometer.¹ The dependence of τ_i

Desorbing ion	Beam composition	τ_i^0 (10^{-13} sec)	E_i (eV)
Na^+	Atomic sodium	0.85 ± 0.15	2.69 ± 0.03
	45% Na, 24% NaCl, 31% Na_2Cl	2.00 ± 0.50	2.55 ± 0.03
K^+	Atomic potassium	0.59 ± 0.10	2.41 ± 0.03
	70% K, 11% KCl, 15% K_2Cl	6.20 ± 1.00	2.30 ± 0.03
Rb^+	Atomic rubidium	0.47 ± 0.10	2.12 ± 0.02
	85% Rb, 5% RbCl, 10% Rb_2Cl	15.5 ± 0.80	2.05 ± 0.02

¹M. Kaminsky, Advances in Energy Conversion 3, 255 (1963).

on the surface temperature T is given by Frenkel's equation

$\tau_i = \tau_i^0 \exp(E_i/kT)$, where E_i is the desorption energy. The values were determined from measurements over different temperature ranges falling between 1100 and 1700°K with an incident beam flux of approximately 3×10^{11} particles $\text{cm}^{-2} \text{sec}^{-1}$. For comparison, the table also shows the earlier values² for incident beams from alkali chloride sources.

² M. Kaminsky, *Advances in Mass Spectrometry* 3, 295 (1964); *Ann. Physik* 18, 53 (1966).

MAGNETIC MOMENT IN Sb^{121} FROM MÖSSBAUER MEASUREMENTS

S. L. Ruby and G. M. Kalvius*

Bull. Am. Phys. Soc. 12, 418 (March 1967)

In order to determine the previously unknown magnetic moment $\mu(\frac{7}{2}^+)$ of the first excited state in Sb^{121} , we have utilized NMR results¹ on MnSb ($H_i = 328.6$ kOe, $e^2 qQ/h = 93$ MHz, $\eta = 0$, 90° between H and the electric-field gradient), an atomic beam result² [$\mu(\frac{5}{2}^+) = 3.359$ nm], and Mössbauer measurements. The only unknown parameters for predicting our experimental spectra are $R = g(\frac{7}{2})/g(\frac{5}{2})$ and the isomer shifts S_I . We get $\mu(\frac{7}{2}) = 2.35 \pm 0.03$ nm.

* Solid State Science Division.

¹ A. Tsujimura, T. Hihara, and Y. Koi, *J. Phys. Soc. Japan* 17, 1078 (1962).

² W. G. Proctor and F. C. Yu, *Phys. Rev.* 8, 21 (1951).

III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATION

THE $\Lambda\Lambda$ HYPERNUCLEI ${}^6_{\Lambda\Lambda}\text{He}$ AND ${}^{10}_{\Lambda\Lambda}\text{Be}$ AND THE Λ - Λ AND Λ -N INTERACTIONS

Shamsher Ali* and A. R. Bodmer
Phys. Letters (3 April 1967)

The $\Lambda\Lambda$ hypernuclei ${}^6_{\Lambda\Lambda}\text{He}$ and ${}^{10}_{\Lambda\Lambda}\text{Be}$ are analyzed with various Λ - Λ potentials and with two different ranges for the Λ -N potential. Values of coupling constants are obtained from the Λ - Λ potentials; in particular, values of $g_{\Lambda\Lambda\sigma}^2$ are obtained which are compatible with the values of $g_{NN\sigma}^2$ obtained from the N-N data.

* International Centre for Theoretical Physics, Trieste, Italy.

A STUDY OF ENERGY LEVELS IN ODD-MASS YTTERBIUM ISOTOPES BY MEANS OF (d,p) AND (d,t) REACTIONS

D. G. Burke,* B. Zeidman, B. Elbek,* B. Herskind,* and M. Olesen*

Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. (1966)

The results of an experimental study of (d,p) and (d,t) reactions with 12-MeV deuterons on targets of Yb^{168} , Yb^{170} , Yb^{172} , Yb^{174} , and Yb^{176} are reported. A magnetic spectrograph was used to analyze the reaction products with an over-all energy resolution of $\sim 0.1\%$. The observed populations of the low-lying states in the final odd nuclei are in general agreement with predictions based on the stripping theory for deformed nuclei, made by the use of the Nilsson wave functions and single-particle cross sections obtained from a distorted-wave Born-approximation calculation.

The relative populations of the various members of a rotational band based on an intrinsic state are highly characteristic of the state, and change only slightly from one nucleus to another. This property permits the unambiguous assignment of all the low-lying

* Institute for Theoretical Physics, Copenhagen.

orbitals, except those with very weak cross sections, without the necessity of measuring angular distributions.

Many previously unknown levels have been found in the present work, and approximately fifty of them have been classified in terms of the Nilsson model. In addition, some speculations concerning vibrational states have been made. The use of the complementary reactions is shown to be a useful technique for determining the hole or particle character of the states. The filling of the orbitals as a function of mass number is in good agreement with pairing-theory predictions, and indicates that the pairing-energy parameter Δ is 0.80 ± 0.15 MeV.

HYPERFINE STRUCTURE OF NINE LEVELS IN TWO CONFIGURATIONS OF V^{51} . I. EXPERIMENTAL

W. J. Childs and L. S. Goodman

Phys. Rev. (5 April 1967)

The hyperfine structure of the $3d^3 4s^2 \ ^4F_{3/2, 5/2, 7/2, 9/2}$ and $3d^4 ({}^5D)4s \ ^6D_{1/2, 3/2, 5/2, 7/2, 9/2}$ levels in V^{51} has been studied in detail by the atomic-beam magnetic-resonance technique. Evidence of substantial J mixing within each multiplet is found. This paper discusses the experiment itself; the following paper discusses the theoretical considerations, corrections to the raw data, and the final results.

HYPERFINE STRUCTURE OF NINE LEVELS IN TWO CONFIGURATIONS OF V^{51} . II. THEORETICAL

William J. Childs

Phys. Rev. (5 April 1967)

The experimental data of the preceding paper on the hfs of nine low levels in two configurations of V^{51} are analyzed and compared with the theory. The effects of intermediate coupling, configuration interaction, and relativity are considered. Corrections for J mixing within each multiplet are made. The measured J dependence of the hyperfine-interaction constants and electronic

g factors of the nine levels is in rather good agreement with the theory. The ground-state nuclear electric-quadrupole moment is evaluated independently in each of the two configurations. Since the two values are the same to within 3%, the differential Sternheimer effect is apparently small. Although the new value of the quadrupole moment is now in good agreement with the theoretical prediction, the absolute value of any Sternheimer shielding is still unknown.

CURRENT ALGEBRAS AND CONFIGURATION MIXING

F. Coester

Phys. Rev. (25 March 1967)

Assigning mixed configurations to hadron states implies an auxiliary space of "one-particle states" that contains more states than does the space of observable particles and resonances. An approximate model Hamiltonian that has all these states as one-particle eigenstates implies a corresponding modification of the unitary representations of the Lorentz transformations. This in turn requires a modification of the weak-interaction current operators if their tensor transformation properties are to be maintained. This paper describes the formal construction of such models and examines the relations between the exact and the approximate quantities.

CURRENT ALGEBRAS AT INFINITE MOMENTUM

F. Coester and G. Roepstorff

Phys. Rev. (25 March 1967)

We examine the mathematical properties of the "infinite momentum limit" of current-density operators. Free-field currents are examined for heuristic purposes. For physical particles we consider the restrictions of the current-density operators to the one-particle subspace. The existence of an operator limit is demonstrated for scalars, vectors, and antisymmetric tensors. The limit vanishes for scalars and, except in special cases, diverges for higher tensors. The kernels of the limit operators are obtained explicitly as functions of the same invariant form factors that determine the kernels of the original current densities. Commutation relations for the integrated

currents are dynamical hypotheses. "Local" commutation relations for the densities at infinite momentum are incompatible with the assumption that the spins are bounded in the one-particle subspace.

THE $\text{Mg}^{25}(\text{He}^3, \alpha)$ REACTION AT $E(\text{He}^3) = 33.0$ MEV

D. Dehnhard and C. Mayer-Böricke

Nucl. Phys. (1967)

Angular distributions of the (He^3, α) neutron pickup reaction on Mg^{25} ($J^\pi = \frac{5}{2}^+$) leaving the final nucleus Mg^{24} in its ground-state rotational band ($K = 0$; $J^\pi = 0^+, 2^+, 4^+$) have been measured at an incident energy $E(\text{He}^3) = 33.0$ MeV. The striking similarity between the shapes of the three observed angular distributions suggests a pure $\ell=2$, $j=\frac{5}{2}$ transition to the two excited states, as for the ground state. Relative spectroscopic factors have been extracted by DWBA calculations. The results were compared with previous experiments in which the neutron pickup from Mg^{25} was investigated by means of the (p, d) and (d, t) reactions and with values calculated from the rotational model.

EVIDENCE FOR TARGET-EXCITATION EFFECTS IN A SINGLE-PARTICLE-TRANSFER REACTION

D. Dehnhard and J. L. Yntema

Phys. Rev. (20 March 1967)

The transitions to the $\frac{7}{2}^+$ and $\frac{9}{2}^+$ states in Mg^{25} have been measured with both the $\text{Mg}^{26}(\text{He}^3, \alpha)\text{Mg}^{25}$ and $\text{Mg}^{26}(d, t)\text{Mg}^{25}$ reactions. The only angular distribution that is fitted reasonably well by DWBA calculations is the $\text{Mg}^{26}(\text{He}^3, \alpha)\text{Mg}^{25}$ transition to the $\frac{7}{2}^+$ state. The larger cross section for the $\frac{7}{2}^+$ transition in the (He^3, α) reaction and the differences between the shapes of the angular distributions of the transitions to the $\frac{7}{2}^+$ and $\frac{9}{2}^+$ states suggest strongly that the former is excited primarily by a multiple-excitation process, while interference effects between the simple single-nucleon transfer and multiple excitation may be more important in the latter.

BASIS FOR THE DEPARTURE FROM EXPONENTIAL DECAY

M. N. Hack

Nuovo Cimento (11 February 1967)

The derivation of the exponential-decay law in damping theory has always suggested to us a close connection to the corresponding problem of the temporal behavior of the approach to equilibrium in statistical mechanics. In each case one starts from the underlying fundamental dynamical law and determines a regime in which the time evolution of the decay (of an excited state or of a nonequilibrium state, respectively) satisfies approximately an equation of the Pauli or master type. In both cases it is well known that one does not get, from the Schroedinger or Liouville equation, a law of exactly exponential type, but that there are deviations very early and very late in the decay. Arguments have been developed that elucidate the physical reason for the appearance of the deviations from pure exponential decay.

EVAPORATIVE DATA ON INTERMEDIATE RESONANCES IN NUCLEAR REACTIONS

Donald W. Lang

Nucl. Phys. (April 1967)

The data on high-energy tails of evaporative spectra are interpreted in terms of "intermediate resonances" and the widths and spacings of these resonances are estimated. The estimated widths are close to the limits of present techniques of observation. It appears that the levels should overlap strongly. Cross correlations and other properties that help in identification are discussed.

SPIN ASSIGNMENTS IN THE 2p SHELL FROM J DEPENDENCE IN (d,p) ANGULAR DISTRIBUTIONS

L. L. Lee, Jr., and J. P. Schiffer

Phys. Rev. (20 February 1967)

The empirically established J dependence in (d,p) angular distributions is used to assign spin values to energy levels in the nuclei Ti^{47} , Ti^{49} , Ti^{51} , Cr^{51} , Fe^{59} , and Ni^{65} —most of

which are populated by $l=1$ (d,p) transitions with large cross sections. The results are in general agreement with available nuclear-structure calculations.

RELATIVE PHASES OF E2 AND M1 MATRIX ELEMENTS IN 1p-SHELL NUCLEI

A. R. Poletti,* E. K. Warburton,* and Dieter Kurath
Phys. Rev. (20 March 1967)

The predictions of the independent-particle model for seven mixed E2-M1 gamma-ray transitions in the 1p-shell nuclei are compared with experiment. Agreement is excellent both for the M1 widths and for the E2/M1 mixing ratios if, in the latter case, collective enhancement of E2 transitions is included. This collective enhancement is discussed first in terms of effective charges, then in terms of perturbation theory in a Nilsson model. The seven transitions considered are ones for which the experimental results are especially reliable, and the theoretical results are relatively insensitive to details of the model. The main motive of this work was to compare the measured phases of the E2/M1 mixing ratios with theory. The agreement both for the absolute phases and the magnitudes was good enough to establish these seven transitions as standards for later consideration of the phases of E2/M1 mixing ratios for less well-understood transitions. Some general relationships between $E(L+1)/M_L$ and $M(L+1)/E_L$ mixing ratios of corresponding transitions in conjugate nuclei are discussed.

*Brookhaven National Laboratory.

GAMMA-RAY SPECTRA OF Co^{60} AND Mn^{56} FOLLOWING RESONANCE-NEUTRON CAPTURE IN Co^{59} AND Mn^{55}

W. V. Prestwich and R. E. Coté
Phys. Rev. (20 March 1967)

The gamma-ray spectra resulting from neutron capture at energies corresponding to the resonance at 132-eV in Co^{59} and to those at 336, 1098, and 2355 eV in Mn^{55} have been observed with

a Ge(Li) spectrometer at the Argonne fast-chopper time-of-flight system. The spectra are compared with the thermal-capture spectra and with the proton spectra observed in deuteron stripping. The reduced gamma-ray width for transitions in Co^{60} exhibit a dependence on the l_n value of the associated final state. The thermal and two higher energy resonance spectra in Mn^{56} display significant correlation with the corresponding stripping strengths. No such correlation was observed for the 132-eV resonance in Co^{59} or the 336-eV resonance in Mn^{55} .

THRESHOLD BEHAVIOR OF PARTIAL-WAVE AMPLITUDES IN QUANTUM FIELD THEORY

Gert Roepstorff and J. L. Uretsky*

Phys. Rev. (23 December 1966)

We show within the framework of Wightman field theory and the Haag-Ruelle scattering theory that the inelastic partial-wave amplitude for a scattering with two particles in the initial or final state has the classic threshold behavior $T \sim j^l$ and under additional assumptions the phase shifts for elastic scattering obey $\sin \delta_l \sim k^{2l+1}$ in the low-energy limit.

* High-Energy Physics Division.

THE TENSOR VIRIAL-THEOREM INCLUDING VISCOUS STRESS AND THE OSCILLATIONS OF A MACLAURIN SPHEROID

Carl E. Rosenkilde

Astrophys. J. (June 1967)

The tensor virial-theorem is extended to include viscous stress. By using the virial method it is verified that a slightly viscous Maclaurin spheroid is unstable (with respect to second-harmonic deformations of the toroidal type) beyond the classical point of bifurcation (where the eccentricity of a meridional section exceeds 0.8127). The corresponding criteria operative in the case of a rotating, charged, liquid drop (of interest in nuclear fission theory) are discussed in an Appendix.

MAGNETIC HYPERFINE INTERACTION IN Sb^{121} USING THE MÖSSBAUER EFFECT

S. L. Ruby and G. M. Kalvius*

Phys. Rev. (10 March 1967)

The Mössbauer resonance in ferromagnetic MnSb was observed at 4.2°K. Using the ground-state interaction as given by NMR, we obtained the value $g_{7/2}/g_{5/2} = 0.498 \pm 0.005$. Substituting +3.359 nm as the $\frac{5}{2}$ moment gives $+2.35 \pm 0.03$ nm for the $\frac{7}{2}$ state.

* Solid State Science Division.

INTERPRETATION OF MÖSSBAUER MEASUREMENTS IN TIN AND ANTIMONY

S. L. Ruby, G. M. Kalvius,* G. B. Beard,[†] and R. E. Snyder[†]
Phys. Rev.

Using the Mössbauer effect in Sb^{121} , measurements of the isomeric shift and quadrupole splitting have been made in a variety of antimony compounds. These data, along with similar results in Sn^{119} by earlier authors, have been interpreted using Hartree-Fock self-consistent-field atomic wave functions. The new values for Sn^{119} are: $\delta r/r = (1.3 \pm 0.4) \times 10^{-4}$, $Q = (-0.06 \pm 0.02)$ barns. Those for Sb^{121} are: $\delta r/r = (-8.1 \pm 3.0) \times 10^{-4}$, $Q(\frac{5}{2}^+)$ = (-0.26 ± 0.1) barns. The interpretation for Sn extends the work of Shpinel, Boyle, and Flinn; the result that $\delta r/r > 0$ for Sn^{119} is opposite to a conclusion recently reached by Goldanski. The value of $\delta r/r$ for Sb^{121} is much larger than that anticipated by a simple nuclear model.

* Solid State Science Division.

[†] Wayne State University, Detroit, Michigan.

LEVEL STRUCTURE AND DECAY SCHEME OF Sc^{43}

J. J. Schwartz,* W. P. Alford,* T. H. Braid, and L.
Meyer-Schützmeister

Phys. Rev. (20 March 1967)

The $\text{Ca}^{40}(\alpha, p)\text{Sc}^{43}$ and $\text{Ca}^{40}(\alpha, p\gamma)\text{Sc}^{43}$ reactions have been used to study the level structure and decay scheme of Sc^{43} from the ground state through 1.95 MeV in excitation. Previously unreported doublets are observed with energies of (1.418, 1.426) MeV and (1.810, 1.826) MeV. There is some indication that a third doublet may lie at (0.846, 0.855) MeV. On the basis of the decay scheme, it is suggested that the levels at 1.810 and 0.475 MeV have spin $\frac{3}{2}$.

*University of Rochester, New York.

ELASTIC SCATTERING OF 6—12-MEV DEUTERONS BY ^{48}Ti

R. H. Siemssen and C. Mayer-Böricke

Nucl. Phys. (1967)

Angular distributions of deuterons elastically scattered from ^{48}Ti have been measured in 1-MeV steps from 6 to 12 MeV; and the data have been analyzed with the nuclear optical model. The optical-model parameters were found to vary smoothly with energy. Good fits have been obtained with an average set of parameters. No anomalous energy dependence of the optical-model parameters V and W was found.

IV. PUBLICATIONS SINCE THE LAST REPORT

PAPERS AND BOOKS

EVIDENCE FOR A SINGLE DOMINANT STATE FOR THE E1 GIANT RESONANCE

R. G. Allas, S. S. Hanna, L. Meyer-Schützmeister, R. E. Segel,
P. P. Singh, and Z. Vager

Selected Papers in Physics 151: Direct Process in
Nuclear Reaction III (Physical Society of Japan, Tokyo,
1966), pp. 187-190

[Reprinted from Phys. Rev. Letters 13,
628-631 (23 November 1964).]

EQUILIBRIUM COMPOSITION OF SELENIUM VAPOR; THE THERMO-
DYNAMICS OF THE VAPORIZATION OF HgSe, CdSe, AND SrSe

J. Berkowitz and W. A. Chupka

J. Chem. Phys. 45, 4289-4302 (1 December 1966)

NOTES ON DOPPLER-SHIFT LIFETIME MEASUREMENTS

A. E. Blaugrund

Nucl. Phys. 88, 501-512 (1966)

AUTOMATED NUCLEAR SHELL-MODEL CALCULATIONS

S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga*

Methods in Computational Physics: Vol. 6, Nuclear Physics,
edited by B. Alder (Academic Press, New York, 1966),
pp. 235-252

PRESYMMETRY

H. Ekstein

Phys. Rev. 153, 1397-1402 (25 January 1967)

AN ON-LINE COMPUTER SYSTEM IN USE WITH LOW-ENERGY
NUCLEAR PHYSICS EXPERIMENTS

D. S. Gemmell

Nucl. Instr. Methods 46, 1-15 (January 1967)

*Tokyo Institute of Technology, Japan.

SPIN ASSIGNMENTS IN THE 2p SHELL FROM J DEPENDENCE IN
(d,p) ANGULAR DISTRIBUTIONS

L. L. Lee, Jr., and J. P. Schiffer

Phys. Rev. 154, 1097-1100 (20 February 1967)

ANALYSIS OF INTERMEDIATE STRUCTURE IN TERMS OF LEVEL-
PARAMETER STATISTICS

J. E. Monahan and A. J. Elwyn

Nucl. Phys. A93(3), 683-688 (March 1967)

ANALYSIS OF THE INTERMEDIATE STRUCTURE OBSERVED IN THE
NEUTRON CROSS SECTION OF ^{19}F

J. E. Monahan and A. J. Elwyn

Phys. Rev. 153, 1148-1151 (20 January 1967)

ON THE SCALING OF x-RAY PHOTOGRAPHS

J. E. Monahan, M. Schiffer (Biological & Medical Research
Division), and J. P. Schiffer

Acta Cryst. 22, 322 (February 1967)

THRESHOLD BEHAVIOR OF PARTIAL WAVE AMPLITUDES IN
QUANTUM FIELD THEORY

Gert Roepstorff and J. L. Uretsky (High Energy Physics)

Phys. Rev. 152, 1213-1218 (23 December 1966)

$\text{Ca}^{46}(\text{He}^3, \text{d})\text{Sc}^{47}$ REACTION

J. J. Schwartz,* W. Parker Alford,* and A. Marinov

Phys. Rev. 153, 1248-1252 (20 January 1967)

USE OF CRYSTAL DIFFRACTION WITH A Ge-DIODE DETECTOR
FOR HIGH-RESOLUTION GAMMA-RAY SPECTROSCOPY

R. K. Smither and A. I. Namenson

Rev. Sci. Instr. 38, 52-65 (January 1967)

MÖSSBAUER ANALYSIS OF METEORITIC IRON MINERALS

E. L. Sprenkel-Segel and S. S. Hanna†

in Mössbauer Effect Methodology, ‡ edited by I. J.
Gruverman (Plenum Press, New York, 1966), Vol. 2,
pp. 113-126

* University of Rochester.

† Stanford University.

‡ Proceedings of the 2nd Symposium, New York, 25 January 1966.

REPORTS AT MEETINGS

Zeeman Centennial Conference, Amsterdam, 6—11 September 1965

THE ZEEMAN SPLITTING OF THE HYPERFINE LEVELS OF
THE ^5D GROUND MULTIPLET OF Fe^{57}

L. S. Goodman and W. J. Childs

Physica 33(1), 283-284 (1967)

Isobaric Spin in Nuclear Physics (Proceedings of the Conference on
Isobaric Spin in Nuclear Physics, Tallahassee, Florida, 17—19 March
1966), edited by John D. Fox and Donald Robson (Academic Press
Inc., New York, 1966)

EXCITATION OF ISOBARIC ANALOG STATES IN MEDIUM-
WEIGHT NUCLEI BY THE (He^3, α) REACTION

T. H. Braid, L. Meyer-Schützmeister, and D. D. Borlin
pp. 605-609 + discussion on pp. 610-611

THE ISOBARIC-SPIN SPLITTING OF NUCLEAR EXCITATIONS

Malcolm H. Macfarlane

pp. 383-410

A STUDY OF ISOBARIC SPIN PURITY OF ANALOG STATES
IN Cu^{59}

G. C. Morrison and J. P. Schiffer

pp. 748-756

STUDY OF ISOBARIC-ANALOG STATES BY PROTON
SCATTERING ON Ba ISOTOPES

G. C. Morrison and Z. Vager

pp. 320-326 + discussion on pp. 327-332

ISOBARIC-SPIN PURITY IN THE GIANT RESONANCE

R. E. Segel

pp. 194-207 + discussion on pp. 208-218

EVIDENCE FOR A DEPENDENCE OF SINGLE-PROTON TRANSFER
REACTIONS ON ISOBARIC SPIN

R. H. Siemssen, G. C. Morrison, B. Zeidman, and
H. Fuchs*

pp. 523-528 + discussion on p. 529

* Hahn-Meitner Institut, Berlin.

Isobaric Spin in Nuclear Physics (cont'd.)

ISOTOPIC SPIN EFFECTS IN $B^{10} + p$

P. P. Singh, R. E. Segel, S. S. Hanna, and M. A. Grace

pp. 357-365

American Physical Society meeting, New York, 30 January—2 February 1967

LIFETIME OF THE FIRST EXCITED STATE IN Si^{29}

S. I. Baker and R. E. Segel

Bull. Am. Phys. Soc. 12, 91 (January 1967)

GROUND-STATE DECAY OF THE THIRD EXCITED STATE IN ^{41}Sc

R. C. Bearse, R. E. Segel, and D. H. Youngblood

Bull. Am. Phys. Soc. 12, 92-93 (January 1967)

POLARIZATION MEASUREMENTS ON SLOW NEUTRONS BY MEANS OF A STERN-GERLACH MAGNET

E. Bieber, V. E. Krohn, and G. R. Ringo

Bull. Am. Phys. Soc. 12, 87 (January 1967)

GAMMA-RAY TRANSITIONS IN F^{20}

D. E. Blatchley and G. E. Thomas

Bull. Am. Phys. Soc. 12, 53 (January 1967)

AVERAGE WIDTHS OF HIGH-ENERGY RADIATIVE TRANSITIONS PRODUCED BY NEUTRON CAPTURE

L. M. Bollinger and G. E. Thomas

Bull. Am. Phys. Soc. 12, 105 (January 1967)

(He^3, α) REACTION ON Ca^{40} AND EVEN-A Ti ISOTOPES

D. Berlin and T. H. Braid

Bull. Am. Phys. Soc. 12, 92 (January 1967)

BRANCHING RATIOS OF STATES IN Mg^{25}

R. T. Carpenter* and D. E. Blatchley

Bull. Am. Phys. Soc. 12, 72 (January 1967)

*University of Iowa.

APS, New York (cont'd.)

DYNAMIC QUADRUPOLE EFFECTS IN MUONIC ATOMS OF
Ho AND Tb

R. E. Coté, W. V. Prestwich, C. C. Trail,^{*} R. A.
Carrigan, Jr.,[†] A. Gaigalas,[‡] R. B. Sutton,[‡] and
S. Raboy[‡]

Bull. Am. Phys. Soc. 12, 75 (January 1967)

(α ,t) REACTION ON 1p-SHELL NUCLEI AT 43 MEV

D. Dehnhard and R. H. Siemssen

Bull. Am. Phys. Soc. 12, 17 (January 1967)

DECAY OF Cu^{61} AND ENERGY LEVELS IN Ni^{61}

H. J. Fischbeck and H. H. Bolotin

Bull. Am. Phys. Soc. 12, 112 (January 1967)

HYPERFINE-INTERACTION CONSTANTS AND THE NUCLEAR
ELECTRIC QUADRUPOLE MOMENT OF Ni^{61}

L. S. Goodman and W. J. Childs

Bull. Am. Phys. Soc. 12, 112 (January 1967)

TEMPERATURE DEPENDENCE OF THE HYPERFINE FIELD
IN NpAl_2 BY THE MÖSSBAUER EFFECT IN Np^{237}

M. Kalvius (Solid State Science), B. Dunlap (Solid State
Science), S. Ruby, and M. Brodsky (Metallurgy)

Bull. Am. Phys. Soc. 12, 25 (January 1967)

POLARIZATION AND DIFFERENTIAL CROSS SECTION FOR
NEUTRONS SCATTERED FROM ^{10}B AND ^{11}B

R. O. Lane, A. J. Elwyn, F. P. Mooring, and A.
Langsdorf, Jr.

Bull. Am. Phys. Soc. 12, 87 (January 1967)

GIANT DIPOLE RESONANCE IN ^{24}Mg STUDIED BY PROTON
CAPTURE IN ^{23}Na

L. Meyer-Schützmeister, R. E. Segel, and R. C. Bearse

Bull. Am. Phys. Soc. 12, 72 (January 1967)

^{*} Brooklyn College.

[†] Carnegie Institute of Technology.

[‡] State University of New York at Binghamton.

APS, New York (cont'd.)

MEASUREMENT OF ISOBARIC ANALOG STATES WITH (He^3, p) REACTIONS

J. A. Nolen, Jr., J. P. Schiffer, D. von Ehrenstein,
and N. Williams

Bull. Am. Phys. Soc. 12, 92 (January 1967)

INVESTIGATION OF THE $\text{Ca}^{48}(\text{He}^3, p)\text{Sc}^{50}$ REACTION

H. Ohnuma, J. R. Erskine, J. A. Nolen, Jr., and
J. P. Schiffer

Bull. Am. Phys. Soc. 12, 110 (January 1967)

DECAY OF THE THIRD EXCITED STATE IN Ca^{41}

R. E. Segel, E. F. Kennedy, L. L. Lee, Jr., and
J. P. Schiffer

Bull. Am. Phys. Soc. 12, 92 (January 1967)

STUDY OF THE $^{63}\text{Cu}(n, \gamma)^{64}\text{Cu}$ AND $^{65}\text{Cu}(n, \gamma)^{66}\text{Cu}$ REACTIONS

E. B. Shera,* H. H. Bolotin, and H. J. Fischbeck

Bull. Am. Phys. Soc. 12, 128 (January 1967)

TOTAL NEUTRON CROSS SECTION OF LANTHANUM

Hla Shwe, R. E. Coté, and W. V. Prestwich

Bull. Am. Phys. Soc. 12, 106 (January 1967)

POSSIBLE TWO-PHONON QUADRUPOLE-OCTUPOLE AND
THREE-PHONON QUADRUPOLE VIBRATIONAL STATES IN
 Cd^{114}

R. K. Smither

Bull. Am. Phys. Soc. 12, 18 (January 1967)

DECAY OF Xe^{125}

G. T. Wood, H. J. Sathoff, and D. Parks

Bull. Am. Phys. Soc. 12, 20 (January 1967)

American Physical Society meeting, Chicago, 27—30 March 1967

EFFECT OF INCIDENT-BEAM COMPOSITION ON THE MEAN
RESIDENCE TIME OF ALKALI IONS ON POLYCRYSTALLINE
TUNGSTEN SURFACES

Manfred Kaminsky

Bull. Am. Phys. Soc. 12, 379-380 (March 1967)

* Los Alamos Scientific Laboratory.

APS, Chicago (cont'd.)

MAGNETIC MOMENT IN Sb^{121} FROM MÖSSBAUER MEASUREMENTS

S. L. Ruby and G. M. Kalvius (Solid State Science)
Bull. Am. Phys. Soc. 12, 418 (March 1967)

ANL TOPICAL REPORT

ENERGY-ANALYZING SYSTEM FOR THE ARGONNE 60-INCH CYCLOTRON

W. J. Ramler (Chemistry), J. J. Livingood, G. W. Parker (Chemistry), J. Aron (Chemistry), and M. C. Oselka (Chemistry)
Argonne National Laboratory Topical Report ANL-7251
(October 1966)

PHYSICS DIVISION INFORMAL REPORT

NOTES ON PROGRAMMING THE ASI COMPUTERS FOR DATA HANDLING

R. E. Holland
Physics Division Informal Report PHY-1967A (February 1967)

STUDENT REPORT

DETERMINATION OF TRANSITION MULTIPOLARITIES WITH A SUPERCONDUCTING CONVERSION-ELECTRON SPECTROMETER

David B. Johnson
ACM student report to Ripon College (December 1966)

V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

NEW MEMBERS OF THE DIVISION

Resident Associates

Dr. David L. Bushnell, Northern Illinois University. Gamma-ray spectroscopy with the 7.7-m bent-crystal spectrometer; Te^{124} structure. (OCUC affiliate, CSUI-ANL.) Came to Argonne on 1 February 1967.

Dr. Karl K. Ilgen, Technical University, Stuttgart, Germany. Neutron experiments with the 4-MeV Van de Graaff. (OCUC affiliate.) Came to Argonne on 2 February 1967.

University Users of the ANL Tandem

Mr. Thomas H. Hall, Indiana University. Scattering of particles on light and medium-weight nuclei. First came to use the machine on 10 March 1967.

AMU-ANL Predoctoral Fellowship

Mr. Bruce A. Watson, graduate student, Indiana University. Working with R. E. Segel on $\text{B}^{10}(\text{p}, \text{p})\text{B}^{10}$. Came to Argonne on 1 March 1967.

Student Aides (ACM)

Mr. Joseph L. Cecchi, Knox College. Working with W. A. Chupka on ion collision processes. Came to ANL on 20 March 1967.

Mr. Lynn Knutson, St. Olaf College, Northfield, Minnesota. Working with S. B. Burson on internal conversion. Came to ANL on 6 February 1967.

Mr. Norman C. Sandstrom, St. Olaf College, Northfield, Minnesota. Working with G. J. Perlow on experiments with the Mössbauer effect. Came to ANL on 6 February 1967.

Co-op Technician

Mr. Dennis Budd, Antioch College, Yellow Springs, Ohio. Working with L. S. Goodman on design of a rf field exciter for atomic-beam research. Came to ANL on 9 January 1967.

CSUI-ANL Honor Students

Mr. Charles W. Cranfill, Claremont Men's College, California. Working with A. J. Hatch on low-density, very-high-frequency plasmas; ionization phenomena in air. Came to ANL on 7 February 1967.

Mr. Stephen M. Curry, Southern Methodist University, Dallas, Texas. Working with S. B. Burson on use of a superconducting magnet in measuring internal-conversion coefficients. Came to ANL on 7 February 1967.

Mr. Charles M. Hathaway, Northeastern State College, Oklahoma. Working with R. E. Côté on determination of the weak, short-range, spin- and velocity-independent interaction between the neutron and the electron by measuring variations in the transmission of liquid bismuth. Came to ANL on 7 February 1967.

Miss Barbara Okray, College of St. Teresa, Winona, Minnesota. Working with L. S. Goodman on an integrated-circuit assembly which will be used to program a rf synthesizer. Came to ANL on 7 February 1967.

Mr. James A. Rice, Northern Illinois University, DeKalb, Illinois. Working with G. T. Wood on determination of nuclear energy levels by studying conversion electrons by use of a beta spectrometer. Came to ANL on 7 February 1967.

Technician

Mr. Stuart O. Goldman joined the Physics Division on 30 January 1967 to work with J. P. Schiffer.

PROMOTION

Miss Rosemary Sutter was promoted to Scientific Assistant on
20 March 1967.

DEPARTURES

Mr. Samuel I. Baker, AMU-ANL Predoctoral Fellow from Illinois Institute of Technology, has been at Argonne since 1 March 1965. He has worked on lifetimes of the first and third excited states in Ca^{41} by the attenuated-Doppler-shift method; lifetime measurements of low-lying states in Si^{29} . He terminated at ANL on 3 March 1967 to go to State University of Iowa, Iowa City.

Mr. Kenneth Ball, Technician, has been at Argonne since 20 June 1966. He terminated on 24 February 1967.

Mr. Richard H. Davis, Technician, has been at Argonne since 14 November 1962. He terminated on 3 January 1967.

Mr. Edwin Sinars, Technician, has been at Argonne since 8 March 1966. He terminated on 24 February 1967.