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Argonne National Laboratory

PHYSICS DIVISION
SUMMARY REPORT

April—June 1967

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PHYSICS DIVISION SUMMARY REPORT

April—June 1967

Lowell M. Bollinger, Division Director

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Preceding Summary Reports:

ANL-7284, September-December 1966
ANL-7312, January-March 1967
ANL-7354, Annual Review

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-7354, which reports research in the year ending 31 March 1967.

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.

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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.

ARGONNE SIX-GAP BETA-RAY SPECTROMETER

G. T. Wood

Internal-conversion spectroscopy with the magnetic β -ray spectrometer has long been a basic tool in nuclear spectroscopy. Although the newer and simpler solid-state detectors with their good resolution and high efficiency as multichannel detectors have revolutionized γ -ray spectroscopy, they have not replaced magnetic β -ray spectrometers in conversion-electron spectroscopy. The superior resolution of the magnetic spectrometer and its freedom from source or target background (γ rays and charged particles) are often crucial properties. Moreover, the fact that the magnetic spectrometer can tolerate extremely intense radioactive sources or particle reaction rates will often offset its lower efficiency. To satisfy the need for a spectrometer to study the conversion electrons from radioactive decay and particle reactions, a six-gap magnetic beta-ray spectrometer (Figs. 1 and 2) of high transmission has been constructed. A fast spectrum-scanning system enhances the efficiency and reliability of data acquisition.

The basic elements—the iron yoke and pole pieces and the coils—were designed and constructed in Denmark. The spectrometer operates in the energy range from 10 keV to 5 MeV with transmissions up to 10% and a momentum resolution width in the 0.5–1.5% range.

Fig. 1. View of the Argonne six-gap ("orange") beta-ray spectrometer with the vacuum chamber opened.

Basic differences between gaps are equalized by coil shunts, and stray magnetic fields are compensated by trim coils. The welded-aluminum chamber is evacuated by a 4-in. diffusion pump. It is mounted on a stand with wheels and is equipped with ports to permit coupling to the Argonne Tandem accelerator. The source region and detector region may be separately closed off to allow access without breaking the vacuum in the main chamber.

The data are taken automatically by an electronic system which linearly sweeps the magnetic flux in the spectrometer gaps through a repetitive cycle (typically 100—500 sec per cycle) as shown in Fig. 3. An integrated signal from a "rate" coil placed in one of the spectrometer gaps is used to sense and control the magnetic field

Fig. 2. Paper model of toroidal magnet system of the spectrometer. Each of the six assemblies consists of two iron pole pieces, an iron yoke, and a coil. The source, which is mounted on the ring above the central lead shield, emits conversion electrons which the six gaps of the spectrometer focus on a common detector mounted directly beneath the source. The detector is visible beneath a lead shield interposed between it and the source.

Fig. 3. Spectrum of conversion electrons from 13-yr Eu^{152} decay, taken with one gap of the six-gap beta-ray spectrometer. The insert shows how the magnetic flux cycle is controlled by the magnetic-field sweep system.

relative to a zero-current state A. While the magnetic flux is being swept through the region of interest B, which is set by adjustable trip points a and b, a time-base generator is gated "on" in order to periodically advance the channel in a multichannel analyzer operating in the multiscaler mode. The detector pulses are collected and stored in this analyzer. This relatively fast scanning technique, which makes use of magnetic-field control and a multichannel analyzer, affords the advantages of rapid data collection, the ability to display the spectrum on a cathode-ray tube, linearity, stability, channeled data, and relative freedom from the effects of magnetic hysteresis and from corrections for the decay of the source.

Just above the source (either a radioactive sample or a target bombarded by particles from an accelerator) is a relatively open and magnetic-field-free region which is large enough to accommodate a NaI scintillation detector up to $4\frac{1}{2}$ in. in diameter or a Ge(Li) gamma-ray detector. The use of a γ -ray detector permits the simultaneous measurement of electrons and γ rays for the determination of internal-conversion coefficients or e^- - γ coincidence studies.

The electron detector is a plastic scintillator viewed by a photomultiplier tube, and is coupled to fast electronics capable of counting at rates in excess of a million per second. About 6 in. of lead shields it from direct radiations from the source (or target). The detector may also be set up as a double counter involving two photomultipliers which either view the same scintillator in coincidence (to reduce photomultiplier noise counts present when the energy bias is low) or view separate scintillators. With the latter configuration, an angular distribution of the electrons following particle excitation can be measured by individually counting the electrons from two gaps.

The six-gap beta-ray spectrometer is a powerful tool for nuclear-structure investigations. Although γ -ray techniques may be used to study transition energies, the detection of conversion electrons

may be less influenced by background. Moreover, the energy spacing of the K and L lines identifies the atomic number of the nucleus in which the transition takes place. When both γ -ray and electron intensities can be measured, multipolarities and mixing ratios may be deduced for the transitions. The angular distribution of conversion electrons from particle reactions, together with γ -ray angular-distributions, give additional information—including level spins and sublevel populations of states formed by the reaction. Conversion-electron spectroscopy is especially suited for heavy nuclei, for which internal conversion is high. The (p,n) , $(p,2n)$, and (heavy ion, xn) particle reactions, which are inaccessible to study by charged-particle detection, are interesting cases to study since the cross sections are high, and high-angular-momentum states may be excited.

CONVERSION OF THE ARGONNE TANDEM VAN DE GRAAFF

F. P. Mooring and J. R. Wallace

The EN-model tandem Van de Graaff accelerator at Argonne was shut down on 8 June 1967 after five years of intensive use in a program that has encompassed the entire range of nuclear experiments suitable for such a machine. After conversion into an FN-model tandem during the summer, it will be returned to service in the fall with increased voltage and current.

The Tandem and its associated experimental facilities were authorized in FY 60. The final acceptance tests were completed in February 1962, and the experimental program at the new machine was initiated early in March of that year. The accelerator has subsequently run about 29 000 hours in one of the most productive of the programs in nuclear physics.

Several special features combine to make the Argonne facility an exceptionally convenient and flexible accelerator laboratory. Its two large, separate, well-shielded target areas allow the beam to be switched from one experiment to another with a minimum of lost time and with little or no interference between experimental groups. An on-line computing system has greatly facilitated the accumulation and analysis of data. For low-level counting experiments, a special room was constructed of material with very little natural radioactivity. The operation-and-maintenance group frees the experimental scientists from responsibility for the machine and allows them to devote full time to their research.

A large part of the work at the Tandem has made use of one or more of the large pieces of experimental apparatus installed there. Among these are a 60-in. -diameter scattering chamber for measurements of angular correlations in three dimensions, an 18-in.

and a 30-in. scattering chamber, a broad-range magnetic spectrometer, and a large gamma-ray angular-correlation device. A Klystron bunching system provides a pulsed beam with pulses < 2 nsec long at a repetition rate of 3.75 Mc/sec.

Guided by their operating experience, the maintenance crew steadily worked to increase the reliability and general usefulness of the EN machine. After being fitted with freon-cooled baffles, the diffusion pumps could run for many months (instead of only a few weeks) before mercury had to be cleared from the cold traps and replaced in the pumps. The installation of inclined-field accelerator tubes allowed high terminal voltages to be attained without the exasperating delays previously required for tube conditioning. The stability of the ion beam injected into the tandem was improved by modifications in the power supply for the extraction voltage. The use of oxide-coated filaments stretched the useful life of the ion source by several orders of magnitude; and lengthening its adder canal and introducing an expansion cone made it much more efficient and easier to operate and made large ion currents routinely possible.

In response to the immediate high demand for accelerator time, the machine initially was run 112 hr/week (24 hr/day, 5 days/week—except for omission of the evening shift on Friday). As the demand increased, the weekly running time was lengthened—to 120 hr in January 1963, to 136 hr in October 1963, to 152 hr in January 1964, and to 168 hr (24 hr/day, 7 days/week) in September 1965.

The number of Tandem users increased very quickly; the log shows nine in the first scheduling period and 39 in the last. During the five years of its operation, the Tandem has been used by a total of 90 experimenters. Of these, 59 were from Argonne, 30 from nearby universities, and one from another national laboratory. Of the 59 from Argonne, 21 were permanent Physics Division employees, 21 held temporary appointments in Physics, 12 were from the Chemistry

TABLE I. Distribution of the scheduled time among different groups of users. The machine actually ran 82.1% of the scheduled time (28 897 hr out of 35 208 hr).

Year	Total time scheduled (hr)	Argonne users						Outside users	
		Physics		Other		Total		(hr)	(%)
		(hr)	(%)	(hr)	(%)	(hr)	(%)		
1962	3410	3058	89.7	352	10.3	3410	100	0	0.0
1963	7458	6166	82.7	1000	13.4	7166	96.1	292	3.9
1964	7036	5704	81.1	892	12.7	6596	93.7	440	6.3
1965	7344	5671	77.2	679	9.2	6350	86.5	994	13.5
1966 ^a	6396	4155	65.0	943	14.5	5098	80.0	1298	20.0
1967	3564	2126	59.7	416	11.7	2542	71.3	1022	28.7
Totals	35 208	26 880		4282		31 162		4046	

^aFor several months in 1966, operation was halted for 8 hr/day to allow an outside contractor to modify the building as required for the forthcoming conversion of the Tandem.

Division, and 5 were from other divisions. The 31 outside users included professors and students from nine universities. Table I shows how the scheduled time on the machine was divided among the different groups. The machine actually ran 28 897 hr (82.1% of the total scheduled time).

The nuclear physics and nuclear chemistry experiments at the Tandem extended over a wide range of problems; in many cases they have led the way in the discovery and interpretation of new phenomena. Among the highlights of this experimental program are: (a) the most careful and systematic studies of the inverse giant resonance—by means of the (p, γ) reaction, (b) provision of the experimental basis for the most searching DWBA analysis of a stripping reaction, (c) discovery of J-dependent effects in direct reactions, (d) supplying much of the reliable experimental basis for the existence of intermediate structure, (e) the first accurate and systematic study of energy levels in transuranic nuclei by use of nuclear reactions, and (f) a variety of experiments that exploited the discovery of isobaric analog states. In addition, (g) the most advanced on-line computing

system actually in use for nuclear experiments was developed for this accelerator.

Members of the Physics Division have published more than fifty journal articles on work done at the Tandem and have presented over a hundred talks at scientific meetings. A considerable number have also been published by other users. Many additional papers on more recent investigations are currently in press or in preparation.

COMPUTER OPERATION OF THE 60-in. SCATTERING CHAMBER.

J. L. Yntema

A computer now automatically operates the 60-in. -diameter scattering chamber at the Argonne tandem Van de Graaff accelerator—in accordance with the specific, but not detailed, instructions of the experimenter. This is believed to be the first system with the ability to search a region of energy or angle and to make statistical decisions on the basis of criteria specified for the particular experiment.

Very flexible and efficient operation of the precision chamber is provided by placing nine parameters under the control of the ASI-210 computer employed on-line in experiments at the Tandem. These parameters are the angles of four independently movable detector arms, the radial distance from the target to each detector, and the selection of the target out of the eight mounted on the changer. The chamber was designed to have the good geometrical precision required in many nuclear experiments and to offer great flexibility in the choice of experimental arrangement. Soon after the instrument was placed in operation, it became obvious that it could take data so rapidly that the output was limited mainly by the rate at which the experimenter could manipulate the controls. Computer control is faster and more systematic and is more nearly free of errors.

The initial experiments made use of four detectors, one on each arm. In order to use the same beam current without too high a counting rate at forward angles or too low a rate at backward angles, the solid angle subtended by the backward detector was made 80 times that of the forward one. The backward detector was located 100 mm from the center of scattering and the diameter of its defining aperture was 3.2 mm; the forward detector was 450 mm from the center and had a 1.6-mm defining aperture. The ratio of counting rates was approximately

1/50. If the counting ratio had turned out to be more unfavorable, the computer could have been instructed to adjust the radial distance of the forward detector to reduce the disparity in rates.

The initial experiment tried out two different modes of control. The target, the four detector angles, and the four radial distances were supplied to the computer in both modes; and in the first the total number of incident particles desired for each run was also fed in. In the second mode the computer determined the number of particles; the experimenter selected the transition of interest and instructed the computer to accumulate a specified total number of particles corresponding to that transition.

At the start of the experiment the computer is given the initial values of the nine scattering-chamber parameters. It next consults the experimenter's instructions and reads the positions required for the first run. It carries out the nine motions sequentially, clears the external memory, records the beam energy, and opens the shutter. After the required charge has been accumulated in the collector cup, the computer closes the shutter, records the total charge on magnetic tape, and records the contents of the four 512-channel spectra. It then clears the memory and proceeds to its next instruction.

An obvious advantage of computer operation is that all the relevant bookkeeping is done by the computer. Since the four detector arms are moved independently, it is possible and sometimes desirable to use different angular spacings of the data points in different sectors. Computer programming can prevent motion of a detector into space occupied by another detector or into fixed forbidden areas such as the beam collimator or the path of the transmitted beam. The rapid data sampling of the computer prevents unnecessarily long exposures or premature termination of a run. It also allows for rapid searches for maxima or minima in angular distributions. Partial analysis of

data while the run is still in process is sometimes helpful in the determination of the course which should be followed in a given experiment.

The primary objective of the initial experiment was to test the simultaneous operation of all components of the system—in particular, to test the correctness of the computer program (including a number of subroutines written in symbolic language), the proper operation of the interface connecting the computer and the scattering-chamber control system, the compatibility of the drive system with the time delay requirements of the computer, and the operation of the digiplex unit connecting the analog-to-digital converters with the appropriate sections of the external memory.

The experiment selected for this initial test was the measurement of the elastic scattering of 11-MeV protons by Mo^{92} , Mo^{95} , and Mo^{98} in 3° steps from 20° to 150° . As a convenient test of the reliability and usefulness of the system, this experiment offered the advantages of very rapid accumulation of information and a great difference between forward and backward cross sections. In addition, the parameters of the optical-model potentials for these nuclei were of value in DWBA calculations. The more than 120 data points, including a few points taken at 10.5 MeV, were acquired in about $2\frac{1}{2}$ hours.

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.

American Physical Society Meeting
Washington, D.C., 24-27 April 1967

LIFETIMES OF THE SECOND, THIRD, AND FOURTH EXCITED STATES IN Si^{29}

S. I. Baker* and R. E. Segel

Bull. Am. Phys. Soc. 12, 570 (April 1967)

The attenuated-Doppler-shift method has been used to investigate the lifetimes of the 2nd, 3rd, and 4th excited states in Si^{29} ; a similar measurement on the 1st excited state has been previously reported.¹ The lifetime of the $\frac{5}{2}^+$ 2nd excited state was found to be $(0.95^{+1.50}_{-0.50}) \times 10^{-13}$ sec. Since the 2nd excited state decays mainly to the $\frac{1}{2}^+$ ground state, this mode is a strongly enhanced E2 transition with $|M|^2 \approx 40$. Combining the lifetime with the branching and mixing ratios reported by others² yields $|M|^2 \approx 0.05$ for the primarily M1 transition to the $\frac{3}{2}^+$ 1st excited state. For the $\frac{3}{2}^+$ 3rd excited state, we find $\tau < 5 \times 10^{-14}$ sec, in agreement with the value 2×10^{-14} sec reported by Booth and Wright.³ For the $\frac{5}{2}^+$ 4th excited state, previously

* Present address: State University of Iowa, Iowa City, Iowa.

¹ S. I. Baker and R. E. Segel, Bull. Am. Phys. Soc. 12, 91 (1967).

² J. A. Becker, L. F. Chase, Jr., and R. E. McDonald (preprint).

³ E. C. Booth and K. A. Wright, Nucl. Phys. 35, 472 (1962).

unreported, we find $\tau < 6 \times 10^{-14}$ sec. Possible configurations for the low-lying states in Si^{29} will be discussed.

STUDIES OF MOLECULAR SYSTEMS BY ULTRAHIGH-RESOLUTION PHOTOIONIZATION MEASUREMENTS

J. Berkowitz

Invited paper listed by title only: Bull. Am. Phys. Soc. 12, 515 (April 1967)

COULOMB EXCITATION OF LOW-LYING EXCITED STATES IN Sc^{45}

A. E. Blaugrund,* R. E. Holland, and F. J. Lynch

Bull. Am. Phys. Soc. 12, 587 (April 1967)

Properties of the 1st excited state of Sc^{45} at 12.4 keV and the 2nd excited state at 376 keV have been measured. A limit on the admixture of E3 radiation in the predominantly M2 decay of the 1st excited state has been set by looking for E3 Coulomb excitation of this state with Cl^{35} ions. Our result is that $B(\text{E3}, \frac{7}{2}^- \rightarrow \frac{3}{2}^+) \leq 105 \text{ e}^2 \text{ fm}^6 = 2.7$ single-particle units. The mean lifetime has been remeasured as $\tau = 0.470 \pm 0.006$ sec. The K conversion coefficient has been measured as 580 ± 120 . The energy of the 2nd excited state was determined to be 375.5 ± 1.0 keV. It was found to decay primarily to the first excited state with a branching ratio of 10.8 ± 0.5 . The reduced matrix element for Coulomb excitation of the 2nd excited state was measured to be $B(\text{E2}, \frac{7}{2}^- \rightarrow \frac{3}{2}^-) = 60.5 \pm 10 \text{ e}^2 \text{ fm}^4$.

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

L. M. Bollinger

Invited paper listed by title only: Bull. Am. Phys. Soc.
12, 461 (April 1967)

ENERGY DEPENDENCE OF HIGH-ENERGY RADIATIVE TRANSITIONS

L. M. Bollinger and G. E. Thomas

Bull. Am. Phys. Soc. 12, 597-598 (April 1967)

The energy dependence of the widths of high-energy radiative transitions has been studied by measuring the average γ -ray spectrum produced by neutron capture in many resonances. The technique has been described previously.¹ For the $\text{Pt}^{195}(n, \gamma)\text{Pt}^{196}$ reaction, transitions from the initial band of states (just above the neutron binding energy at 7.9 MeV) to 8 low-energy states in the energy range 0—1610 keV were observed. All of these are thought to be E1 transitions from 1^- initial states to 0^+ or 2^+ final states. If the widths are assumed to depend on the γ -ray energy E_γ as E_γ^α , a preliminary treatment of the data gives $\alpha = 5 \pm 0.5$. This is a marked departure from the E_γ^3 dependence that results from phase-space considerations alone but is in excellent agreement with the E_γ^5 dependence² that is expected if one assumes that the Lorentzian shape of the dipole giant resonance may be extrapolated to energies in the 6—8-MeV range. Similar studies of $\text{W}^{183}(n, \gamma)\text{W}^{184}$ are in progress.

¹ L. M. Bollinger and G. E. Thomas, Bull. Am. Phys. Soc. 12, 105 (1967).

² P. Axel, Phys. Rev. 126, 671 (1962).

Hfs STUDIES OF LOW-LYING LEVELS IN Pt¹⁹⁵ BY ATOMIC-BEAM MAGNETIC RESONANCE

W. J. Childs and L. S. Goodman

Bull. Am. Phys. Soc. 12, 509 (April 1967)

An atomic beam of Pt was produced by electron bombardment of a graphite oven containing Pt metal. Measurements of hyperfine transition frequencies have been made for the three lowest atomic levels of Pt¹⁹⁵ at fields up to 1000 G. The values of the electronic g factors g_J and the magnetic-dipole hyperfine-interaction constants A_J deduced are given in Table II. In addition, the value of g_J for the 3P_2 level at 6567 cm^{-1} was obtained for the even isotopes.

TABLE II

Atomic state	Excitation energy (cm ⁻¹)	g_J	A_J (Mc/sec)
$5d^9 6s\ ^3D_3$	0.0	1.33393 ± 0.00002	5717 ± 21
$5d^9 6s\ ^3D_2$	775.9	1.06658 ± 0.00002	2608 ± 3
$5d^8 6s^2\ ^3F_4$	823.7	1.23948 ± 0.00002	849 ± 1
$5d^{10}\ ^1S_0$	6140.0	...	...
$5d^8 6s^2\ ^3P_2$	6567.5	1.11691 ± 0.00003^a	...

^a Measured in Pt^{194, 196}

HYPERFINE MUONIC SPECTRA OF SEPARATED ISOTOPES OF EUROPIUM

R. E. Coté, W. V. Prestwich, R. A. Carrigan, Jr.,* P. D. Gupta,* R. B. Sutton,* M. N. Suzuki,* A. Gaigalas,[†] and S. Raboy[†]

Bull. Am. Phys. Soc. 12, 581 (April 1967)

K and L x rays from muonic atoms of the separated isotopes of Eu¹⁵¹ and Eu¹⁵³ have been detected with a resolution of about 5 keV FWHM. The spectra for the two isotopes differ considerably, as expected in this region, because of the sudden onset of collective behavior, and show a large isotope shift. Analysis of the Eu¹⁵³ spectrum, using a procedure previously described,¹ shows that, as for Ho and Tb, most lines can be fitted with the assumption that the rotational model is applicable. The intrinsic quadrupole moment was determined to lie between 6.8 and 7.1 b. The spectrum of Eu¹⁵¹ does not have the appearance typical of a rotational nucleus. Analysis is complicated by the effects of the large magnetic moment. Parameters for this nucleus will be presented.

*Carnegie-Mellon University, Pittsburgh, Pennsylvania.

[†]State University of New York, Binghamton, New York.

¹R. E. Coté et al., Bull. Am. Phys. Soc. 12, 75 (1967).

THREE-BODY CORRELATIONS AND THE ENERGY EXPANSION IN NUCLEAR MATTER

B. D. Day

Invited paper listed by title only: Bull. Am. Phys. Soc. 12, 461 (April 1967)

The most important progress in nuclear-matter theory in the last two or three years has been Bethe's discovery¹ of the proper way to treat three-body correlations. This work has led to improved

¹H. A. Bethe, Phys. Rev. 138, B804 (1965).

agreement between theory and experiment, and it has also clarified the nature of the Brueckner-Goldstone expansion for the energy of nuclear matter. Here I will say nothing about the results of detailed calculations and their comparison with experiment. Instead I would like to review the important physical ideas which are brought out by Bethe's work. I will try to show in a simple way what was wrong with the old treatment of three-body correlations; and how the correct approach leads naturally to a rapidly converging expansion for the energy of nuclear matter.

Let us first review the nature of the problem. The concept of nuclear matter arises in a natural way in our attempt to understand the structure of nuclei in terms of realistic nucleon-nucleon forces. The basic assumption is that an adequate description of nuclei is furnished by the nonrelativistic Schrödinger equation for neutrons and protons interacting through a two-body potential. To investigate the consequences of this assumption, one must solve the many-body Schrödinger equation for the nucleus under consideration. If the two-body potential were sufficiently weak and sufficiently smooth, Hartree-Fock theory could be successfully applied. However, the two-body potential is not smooth and weak. Instead, it seems to contain a very strong short-range repulsion. This repulsion is often idealized to an infinitely repulsive core. Recently a repulsion of Yukawa shape has also been used—the so-called soft core. Whether a soft core or a hard core is used, the qualitative result is the same. Strong short-range correlations are introduced which make the Hartree-Fock method not valid. In fact this short-range repulsion complicates the problem to such an extent that it is really too hard for us at the present time.

It is therefore natural to study especially simple limiting cases, and the simplest of these is nuclear matter. In nuclear matter, we have equal numbers of neutrons and protons which fill all space at some uniform density. There is no surface region to worry about, and

of course the Coulomb forces must be neglected. The problem, then, is simply to calculate the energy per particle of the system in its ground state. This is to be done as a function of the density, and the equilibrium density is the one that minimizes the energy per particle. The empirical values of the equilibrium density and binding energy are obtained by extrapolation from observed nuclei. The equilibrium density of nuclear matter is about one particle in six cubic Fermis, and the energy per particle is -16 MeV.

So the problem is to calculate the ground-state energy of an interacting Fermi gas. Let us now see how to attack this problem. The basic tool for this investigation is the Brueckner-Goldstone expansion. This is a formally exact expansion for the ground-state energy of a many-body system.

The starting point of the Brueckner-Goldstone theory is the independent-particle picture. For a finite nucleus, this is the shell model; for nuclear matter it is a noninteracting Fermi gas. The nucleons are in plane-wave states of the lowest energy allowed by the exclusion principle. All states with momentum less than the Fermi momentum k_F are occupied, and all others are empty. The zero-order term in the energy is the kinetic energy of the Fermi sea, which is about 23 MeV per particle at normal density.

The interaction energy is given by the Brueckner-Goldstone expansion. The leading term in this expansion represents the interaction of each pair of particles in the Fermi sea. So let us consider the interaction of such a pair.

In first order, the interaction energy of the pair is equal to the diagonal matrix element of the potential. This can be calculated from the expressions

$$|\ell m\rangle \equiv \exp(i\vec{k}_\ell \cdot \vec{r}_1) \exp(i\vec{k}_m \cdot \vec{r}_2), \quad (1)$$

$$\langle \ell m | v | \ell m \rangle = \int \phi^*(\vec{r}) v(\vec{r}) \phi(\vec{r}) d^3r, \quad (2)$$

$$\phi(\vec{r}) = \exp(i\vec{k}_{\ell m} \cdot \vec{r}). \quad (3)$$

Equation (1) is notation—the state $|\ell\rangle$ means the product of two single-particle plane waves with momenta k_ℓ and k_m . The interaction energy is given by the matrix element in Eq. (2), which can be written as an integral over the relative coordinate $\vec{r}$ of the two particles. The unperturbed two-body wave function $\phi(\vec{r})$ is a plane wave with momentum $\vec{k}_{\ell m}$, which is the relative momentum of the two interacting particles.

Now, to be definite, let us assume that the short-range repulsion in the potential is represented by a hard core. Then the expression $\langle \ell m | v | \ell m \rangle$ for the interaction energy is infinite and therefore useless. The remedy for this difficulty is quite clear from the physical point of view. We must take account of the strong short-range correlations which prevent any pair of particles from coming closer together than the core radius.

This physical idea is incorporated into the theory by analogy with two-particle scattering in empty space. If one calculates the scattering amplitude to first order in v (that is, if one uses the Born approximation), then one obtains infinity because of the hard core. But if one calculates to all orders of v , which amounts to solving the two-body Schrödinger equation, then one of course obtains the correct result. Similarly, in nuclear matter, one calculates the interaction energy of the pair to all orders in v . This turns out to be equivalent to solving a Schrödinger equation that describes the interaction of two particles inside the nucleus. The formula obtained in this way for the interaction energy of the pair is

$$\left. \begin{array}{l} \text{Interaction energy} \\ \text{of pair } (\ell m) \end{array} \right\} = \langle \ell m | v | \psi_{\ell m} \rangle \equiv \langle \ell m | G | \ell m \rangle, \quad (4)$$

$$\left. \begin{array}{l} \text{Total energy due to} \\ \text{2-body correlations} \end{array} \right\} = \sum_{\ell < m < k_F} \langle \ell m | G | \ell m \rangle \quad (5)$$

≈ -35 MeV per particle.

The interaction energy is equal to the matrix element $\langle \ell m | v | \psi_{\ell m} \rangle$. In this expression, $\psi_{\ell m}$ is the correlated two-body wave function for the pair (ℓm) . It is obtained by solving the two-body Schrödinger equation inside the nucleus. In regions of space where v gets very large, ψ gets very small in such a way that v times ψ remains finite and physically meaningful.

The matrix element $\langle \ell m | v | \psi_{\ell m} \rangle$ is, by definition, a diagonal element in the unperturbed state $|\ell m\rangle$ of Brueckner's reaction matrix (G matrix), as shown in Eq. (4). The total two-body interaction energy is found by summation over all pairs of particles in the Fermi sea as shown in Eq. (5). This is the leading term in the Brueckner-Goldstone expansion, and it comes to about -35 MeV per particle.

The fundamental quantities of the theory are ψ and G . If one of these is known, the other can be calculated. I will not give the detailed formulas from which ψ and G are calculated. However, the two most important properties of ψ can be understood in a simple way. First, it is clear that ψ must vanish inside the hard core. Second, at large distances, ψ must approach the unperturbed plane wave ϕ . This can be made plausible by the following argument. Imagine the interaction of two particles in plane-wave states in the Fermi sea. If these particles were in empty space, they could scatter into two new plane-wave states with the same total energy. The scattering would be determined by the behavior of the scattered wave at large r , and the scattered wave is of course given by the difference between ϕ and ψ . But in nuclear

Fig. 4. Typical plots of ϕ and ψ in the relative S state.

matter there can be no scattering. The reason is that all two-body states that have the same total energy as the initial pair of plane waves are already occupied by the other nucleons in the Fermi sea. So there is no scattered wave at large r , which means that ψ approaches ϕ at large r . This phenomenon is called the healing of the two-body wave function. The repulsive core produces a wound in ψ at small r ; but at large r , ψ approaches ϕ and the wound is healed.

Figure 4 shows typical plots of ϕ and ψ in the relative S state. The S-wave component of the plane wave ϕ is a sine function whose wavelength depends on the initial relative momentum of the pair. The correlated wave function ψ is plotted for two different potentials. The curve labeled "pure hard core" is for a hard-core potential with no attractive force at all. You see that ψ vanishes inside the core and then rises rapidly and approaches ϕ . The curve labeled "core plus attraction" is for a hard core with a typical nuclear attractive force outside. Again ψ vanishes inside the core; then it rises steeply, overshoots ϕ , and finally approaches ϕ at larger distances.

These curves illustrate two important points. First, the healing is quite rapid. As soon as we get outside the hard core, ψ begins to approach ϕ . Second, the wave function for the pure hard core is not much different from the wave function for a core plus attraction. Both of these facts indicate that the attractive part of the nuclear force is rather weak. We will see later that this weakness of

the attractive force is essential for the convergence of the energy expansion.

We have now discussed two-body correlations in some detail. The interaction energy of a pair is given by the G matrix, and the G matrix is calculated from the correlated two-body wave function. Let us now consider terms in the energy expansion that involve correlations among three particles.

These terms are represented by linked diagrams, some of which are shown in Fig. 5. In these diagrams, upward-directed lines represent occupied states above the Fermi sea. Downward-directed lines represent empty states (holes) in the Fermi sea. The "bubbles" represent occupied states in the Fermi sea. The wiggly lines represent G -matrix interactions. The G matrix appears as an effective two-body interaction in every term of the expansion.

Diagram (a) represents the interaction of two particles in states l and m in the Fermi sea. This gives the two-body correlation energy, which we have already discussed. All the other diagrams involve three particles.

Consider diagram (b) for example. In the G -matrix interaction at the bottom of the diagram, two particles jump into states a and b above the Fermi sea, represented by the upgoing lines. This leaves two holes in states l and m in the Fermi sea, represented by the downgoing lines. In the middle G -matrix interaction, the particle in state b above the sea interacts with a third particle in state n in the Fermi sea. Finally, in the topmost interaction, the two original particles

Fig. 5. Linked diagrams representing 3-particle terms in the energy expansion.

fall back into the Fermi sea. This diagram clearly involves three particles and therefore describes a three-body correlation. The distinguishing feature of three-body diagrams is that they all have three lines labeled with states in the Fermi sea—in other words, three hole lines.

Diagrams (b), (c), and (d) are three-body diagrams. Each one contains three hole lines l , m , and n . Diagram (b) is of third order in G , (c) is of fourth order, and (d) shows how to construct a three-body diagram of arbitrarily high order in G . In the first two interactions at the bottom of diagram (d), three particles are excited above the Fermi sea, leaving holes in states l , m , n . While above the sea, these particles can interact with each other any number of times. Then in the last two interactions at the top of the diagram the three particles fall back into the sea. There are only three hole lines, and this means that only three particles from the Fermi sea participate in the many interactions that take place.

In the old calculations^{2,3} of 1962, the three-body correlations were calculated in the lowest order of perturbation theory. In other words, diagrams of third order in G were evaluated and higher-order diagrams were neglected. These calculations gave only about 4 MeV of binding instead of 16, and the equilibrium density was only two-thirds of the empirical value.

In searching for the reason for this discrepancy, Bethe¹ evaluated the 3-body diagrams which are of fourth order in G . There are four of these, and Bethe found that altogether they contribute about -30 MeV per particle. This enormous result for diagrams of fourth order in G suggests that the expansion in powers of G does not converge.

²M. Razavy, Phys. Rev. 130, 1091 (1963).

³K. A. Brueckner and K. S. Masterson, Phys. Rev. 128, 2267 (1962).

This is indeed the case; an argument to make this divergence plausible is as follows.

Figure 6 shows two three-body diagrams.

Diagram (b) is of fifth order in G and (a) is of fourth order. In order to see whether or not an

expansion in powers of G converges, we would like to compare the contribution of diagram (b) with that of diagram (a).

Relative to (a), the contribution of (b) has one additional matrix element of G and one additional energy denominator. Also, the upper part of diagram (b) is different from the upper part of diagram (a). In the upper part of (a) we have two lines labeled a and b . But in diagram (b) the corresponding lines are labeled c and d . To obtain a rough estimate we neglect this difference between the diagrams.

Then the ratio of (b) to (a) is given by the expression

$$\frac{(b)}{(a)} \approx \sum_{c,d > k_F} \frac{\langle cd | G | ab \rangle}{E_\ell + E_m + E_n - E_c - E_d - E_f} \quad (6)$$

$$= (\psi_{ab} - \phi_{ab})_{r=0} = -1.$$

The matrix element $\langle cd | G | ab \rangle$ comes from the interaction in which a and b scatter into c and d . We also have an energy denominator which is equal to the excitation energy of the system at the level of particles c and d . The excitation energy is the difference between the energies of the empty states ℓ, m, n in the Fermi sea and the energies of the occupied states c, d, f above the Fermi sea. Finally we must sum over the indices c and d which appear in (b) but not in (a).

Now, G is closely related to ψ , and it is easy to show that this entire expression (6) is exactly equal to $(\psi - \phi)$ evaluated at $r = 0$. At $r = 0$, ψ of course vanishes and $\phi = 1$ because ϕ is just a

Fig. 6. Three-body diagrams:
(a) a fourth-order diagram,
(b) a fifth-order diagram.

plane wave. So the final result is -1 . The conclusion is that among the three-body diagrams, diagrams of fifth order in G are just as large as diagrams of fourth order in G . Adding more and more interactions does not reduce the contribution of a diagram. It is clearly the hard core that is responsible for this result. The hard core causes ψ to vanish at short distances, and this leads to the ratio -1 .

This factor -1 does not mean that the three-body diagrams are on the borderline between convergence and divergence. Instead it implies a very strong divergence. The reason is that there are two diagrams of third order in G , four of fourth order, eight of fifth order, and so on. Thus perturbation theory (that is, an expansion in powers of G) is useless for computing the interaction energy of three nucleons. The same thing is true for the interaction of four particles, five particles, etc. The only exception is the two-body correlation energy, which involves only a single diagram and therefore presents no problem of convergence. This is where the old calculations went wrong. For the three-body energy, they took only the first term of a badly divergent series.

Since the three-body diagrams cannot be summed order by order, Bethe proposed that they be summed all at once by means of an integral equation. Using the ideas of Faddeev,⁴ Bethe¹ wrote down the appropriate integral equation. If this Bethe-Faddeev equation is expanded in powers of G , the diverging perturbation series is generated. But if the equation is solved correctly, one obtains a finite and meaningful result for the three-body correlation energy. To a good approximation, the result can be expressed in the simple form

$$\left. \begin{array}{l} \text{Total 3-body} \\ \text{correlation energy} \end{array} \right\} = \text{Diagram} \times f(r), \quad (7)$$

⁴L. D. Faddeev, Soviet Phys. — JETP 12, 1014 (1961); Soviet Phys. — Doklady 6, 384 (1962).

the middle interaction being

$$\langle bn|G|bn\rangle \rightarrow \langle bn|Gf(r)|bn\rangle. \quad (8)$$

This indicates that the correct total energy due to three-body correlations is given by a single diagram of third order in G , with one modification. The modification is that in the middle interaction we have a matrix element not of G but of G times a function $f(r)$. The function $f(r)$, which is found by solving the Bethe-Faddeev equations, is of the order of 1 or smaller. For our purposes there is no need to study the detailed behavior of $f(r)$. The important point is simply that the total three-body energy is no larger than the contribution from an individual three-body diagram. The same will undoubtedly be true for the energy due to correlations between more than three particles.

So we find that, because of the hard core, it is wrong to regard the Brueckner-Goldstone expansion as a perturbation series in the G matrix. Instead, all three-body diagrams must be lumped into a single term, and the same for four-body diagrams, five-body diagrams, etc. We then come to the question of the relative magnitude of the various terms. The answer is that the contribution to the energy rapidly decreases as the number of interacting particles in the cluster increases. Therefore we have a rapidly converging expansion for the interaction energy in which the first term comes from two-body correlations, the second from three-body correlations, and so on.

The rapid convergence of this expansion can be made plausible by an argument shown in Fig. 7. Diagram (a) is a typical 3-body diagram, and (b) is a four-body diagram. Diagram (b) is obtained from diagram (a) by allowing the particle in state b above the Fermi sea to interact

Fig. 7. Diagrams representing terms in the expansion for the interaction energy: (a) a typical 3-body diagram, (b) a 4-body diagram.

with a fourth particle in state n in the Fermi sea. Let us now compare the energy contributions from these two diagrams. Diagram (b) has an additional matrix element $\langle bn|G|bn\rangle$ and an additional energy denominator. Thus the ratio of (b) to (a) is given by

$$\begin{aligned} \frac{(b)}{(a)} &= \sum_{n < k_F} \frac{\langle bn|G|bn\rangle}{E_k + E_l + E_m - E_a - E_b - E_c} \\ &\approx \rho \int e^{-i\vec{k}_{bn} \cdot \vec{r}} \left(e^{i\vec{k}_{bn} \cdot \vec{r}} - \psi_{bn}^R(\vec{r}) \right) d^3r, \end{aligned} \quad (9)$$

in which the summation extends over all states n in the Fermi sea.

We must now evaluate this formula. Using the relationship between G and ψ , one finds that the matrix element of G divided by the energy denominator is equal to the integral shown in the last line of Eq. (9). The factor

$$e^{-i\vec{k}_{bn} \cdot \vec{r}}$$

comes from the final state $\langle bn|$ of the matrix element. And operating with G on the initial state and dividing by the energy denominator gives the difference between the unperturbed plane wave

$$e^{i\vec{k}_{bn} \cdot \vec{r}}$$

and the correlated wave function $\psi_{bn}(\vec{r})$. Finally the sum over states n in the Fermi sea to a good approximation simply gives a factor of ρ , the particle density.

The superscript R on ψ denotes the reference-spectrum approximation for ψ . The important properties of ψ^R are the same as those of the exact ψ ; ψ^R vanishes inside the core, and outside it approaches the unperturbed plane wave just as fast as ψ does.

Let us now examine this integral, which can be rewritten as

$$\rho \int e^{-i\vec{k}_{bn} \cdot \vec{r}} \left(e^{i\vec{k}_{bn} \cdot \vec{r}} - \psi_{bn}^R(\vec{r}) \right) d^3 r = \frac{\text{correlation vol.}}{\text{vol. per particle}} \quad (10)$$

$$\approx \frac{2 \times \frac{4\pi}{3} c^3}{\frac{4\pi}{3} r_0^3} \approx \frac{1}{10},$$

where $c = 0.4 F$ and $r_0 = 1.1 F$. The difference between the unperturbed plane wave and the correlated wave function is a measure of the strength of the two-body correlations at the point $\vec{r}$. Therefore each volume element $d^3 r$ is weighted by the strength of the two-body correlations at that point. For this reason I call the value of this integral the correlation volume. Inside the hard core, where the correlation is complete, ψ vanishes and the integrand is equal to one. So the weight factor for volume elements inside the core is unity. But volume elements far outside the core receive a very small weight because the difference between ψ and the unperturbed plane wave is very small there.

The correlation volume is multiplied by the density ρ , which is the reciprocal of the volume per particle. So the ratio of the four-body diagram to the three-body diagram is just the ratio of the correlation volume to the volume per particle, as shown in Eq. (10). This ratio is rather small. The correlation volume is roughly twice the volume of the hard core of radius c . And the volume per particle is the volume of a sphere of radius r_0 , where r_0 is about $1.1 F$. For a core radius of $0.4 F$, one finds the ratio of the four-body diagram to the three-body diagram to be about 0.1 .

This factor 0.1 is the ratio of an individual four-body diagram to an individual three-body diagram. However, the total three-body energy is comparable to that from a single three-body diagram, and the same is true for the four-body energy. Therefore the total four-body energy should be roughly one-tenth of the total three-body energy. In general, adding one more particle to a cluster should reduce the contribution to the energy by about the same factor.

All this is consistent with a very simple physical picture. Imagine that two particles are strongly correlated. Then the probability that a third particle is close enough to be correlated with the first two is just the ratio of the correlation volume to the volume per particle. So it is quite reasonable that the three-body energy should be smaller than the two-body energy by this same factor.

Detailed calculations of the two-and three-body terms support the claim of rapid convergence. The two-body contribution is about -35 MeV per particle, and the three-body contribution is very small—only about 1 MeV per particle. This very small three-body contribution is the result of cancellation between the attractive and repulsive parts of the force. The attractive and repulsive parts individually would contribute roughly 5 MeV per particle. In either case, the convergence is quite satisfactory.

Thus the energy expansion converges because the correlation volume is much less than the volume per particle. We may therefore ask what properties of the nucleon-nucleon interaction are responsible for this desirable state of affairs. One necessary condition is quite clear. Since the correlation volume is at least as large as the volume of the hard core, it is certainly necessary that the volume of the hard core be much smaller than the volume per particle.

But this is not enough. It is also essential that the attractive part of the potential be so weak that ψ rapidly approaches ϕ outside the hard core. This leads to a correlation volume which is comparable in magnitude to the core volume. If the attractive part of the potential had been sufficiently strong, then ψ would have differed appreciably from ϕ over the whole range of the force, which is about $1.4 F$. The correlation volume then would have been even larger than the volume per particle, and our expansion would have failed.

So the expansion works because the hard core is small enough and the attractive potential is weak enough to permit rapid healing of the two-body wave function.

These physical ideas are not new. They were clearly and explicitly stated in 1958 in a paper by Gomes, Walecka, and Weisskopf.⁵ What is relatively new is the realization that these same physical ideas emerge in a simple way from the rather complicated Brueckner-Goldstone many-body theory.

The necessary first step in this development was Bethe's recognition, in his study of three-body correlations, that perturbation theory in the G matrix does not converge. This leads in a natural way to an expansion in the number of interacting particles. One then finds that the expansion parameter is the correlation volume divided by the volume per particle. This parameter is small because the hard core is small and the attractive force is weak. Thus even though perturbation theory is useless, we still have a valid expansion that starts from the independent-particle picture.

To summarize, I would say that Bethe's work has brought the detailed many-body theory into complete agreement with our elementary physical ideas about why the independent-particle picture works. In my opinion this is very strong evidence that our present approach to the theory of nuclear matter is the correct one.

⁵ L. C. Gomes, J. D. Walecka, and V. F. Weisskopf, Ann. Phys. (N. Y.) 3, 241 (1958).

$\text{Si}^{30}(\text{d}, \text{t})\text{Si}^{29}$ AND $\text{Si}^{30}(\text{He}^3, \alpha)\text{Si}^{29}$ REACTIONS

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The $\text{Si}^{30}(\text{d}, \text{t})\text{Si}^{29}$ and the $\text{Si}^{30}(\text{He}^3, \alpha)\text{Si}^{29}$ reactions have been investigated with the 22.4-MeV deuteron beam and the 33-MeV He^3 beam of the ANL cyclotron. The target thickness was estimated

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by comparing the observed deuteron elastic scattering and cross sections predicted with the optical-model parameters used in the JULIE calculations. The energy levels to which transitions were observed and (in parentheses) the quantum numbers of the levels and the spectroscopic factors S were the ground state ($\ell = 0$, $S = 0.8$) and the levels at 1.28 MeV ($\ell = 2$, $\frac{3}{2}^+$, $S = 0.7$), 2.03 MeV ($\ell = 2$, $\frac{5}{2}^+$, $S = 1.7$), 2.43 MeV ($\ell = 2$, $\frac{3}{2}^+$, $S = 0.17$), 3.07 MeV ($\ell = 2$, $\frac{5}{2}^+$, $S = 0.1$), 3.62 MeV ($\ell = 3$, $\frac{7}{2}^-$, $S = 0.08$), 4.9 MeV ($\ell = 2$, $\frac{5}{2}^+$, $S = 1.0$), and 6.7 MeV ($\ell = 2$, $\frac{5}{2}^+$, $S = 0.3$). A state near 8.3 MeV could be observed only at angles larger than 20° in the deuteron experiment. This is probably the isobaric analog of the Al^{29} ground state and the spectroscopic factor is approximately 2. The relative spectroscopic factors of the (d,t) and (He^3 , α) experiments are in good agreement.

RESONANT STRUCTURE IN THE SCATTERING OF NEUTRONS BY Cr

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We have measured the polarization and differential cross sections of neutrons scattered by Cr at 5 angles from 0.35–0.965 MeV with a resolution width of 20 keV. A well-defined structure with an average width of 40–50 keV and a spacing of 70–80 keV is observed in the energy dependence of both the polarization and cross-section data at each angle. A phase-shift analysis is consistent with the existence of 5 approximately isolated resonant structures for energies below 0.75 MeV, each formed by s-wave neutrons, although some interference effects are evident in the energy-dependent behavior of the phase-shift

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parameters. In this energy region, total-cross-section measurements¹ performed with good resolution show a large number of fine-structure peaks, many of which should probably be associated with p- and d-wave neutron interactions. The observed s-wave structure can, therefore, probably be interpreted largely as individual resonances, the broader 40—50 keV widths arising from the effects of interference with a large s-wave background cross section.

¹C. D. Bowman, E. G. Bilpuch, and H. W. Newson, Ann. Phys. (N. Y.) 17, 319 (1962).

THEORY OF NUCLEAR LEVEL DENSITY—MODIFICATIONS OF THE PERIODIC SINGLE-PARTICLE SPECTRUM

P. B. Kahn* and N. Rosenzweig

Bull. Am. Phys. Soc. 12, 497 (April 1967)

Accurate results in closed form were recently obtained for the level density of a degenerate Fermi system with strictly periodic single-particle spectra.¹ Now the analysis has been extended to include nonperiodic modifications of the periodic level scheme. The modification may be a combination of positional shifts and additions and deletions of individual levels. If these alterations occur in the vicinity of the Fermi level, then the resulting formulas are still simple. Positional shifts lead to the usual additive corrections to the excitation energy in the standard formulas. However, the net creation or destruction of levels with respect to the periodic scheme leads, in addition, to a novel multiplicative energy-independent correction of the standard formulas.

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¹P. B. Kahn and N. Rosenzweig, Phys. Letters 22, 307 (1966).

For example, if a nonrecurring gap in the periodic level scheme occurs near the Fermi energy, the large diminution which it produces in the level density persists indefinitely with increasing excitation energy.

ANGULAR DISTRIBUTIONS FROM $\text{Na}^{23}(p, \gamma)\text{Mg}^{24}$

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Bull. Am. Phys. Soc. 12, 553 (April 1967)

Angular distributions of the gamma rays feeding the ground state (γ_0) and first excited state (γ_1) of Mg^{24} from the $\text{Na}^{23}(p, \gamma)\text{Mg}^{24}$ reaction were measured at 44 energies between 5.0 and 10.7 MeV (16.5—21.9 MeV excitation in Mg^{24}). This energy range includes the peak of the giant dipole resonance in Mg^{24} . The γ_0 yield is unusually low¹ and the compound nucleus appears to be a major contributor. There is a small asymmetry about 90° ; in contrast to any of the (p, γ) angular distributions previously reported, the yield is greater in the backward direction. The characteristic γ_0 angular distribution is $1 - 0.1 P_1 + 0.5 P_2$. The coefficient of P_2 , which is unaffected by interference between opposite-parity radiations, requires the capture to be from 40—100% p wave. As has been found in other cases, the γ_1 angular distribution is somewhat less constant; it is about $1 + 0.1 P_1 + 0.1 P_2$ at the lower energies and about $1 + 0.1 P_1 - 0.25 P_2$ at the upper end of the region covered. The variations in the angular distributions are not correlated with the fluctuations in the yield curve.

¹L. Meyer-Schützmeister, R. E. Segel, and R. C. Bearse, Bull. Am. Phys. Soc. 12, 72 (1967).

(d,p) REACTION IN THE 1p SHELL

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Bull. Am. Phys. Soc. 12, 501 (April 1967)

Angular distributions were obtained for the (d,p) reaction at 12 MeV. These data, obtained at the Argonne tandem Van de Graaff accelerator, were taken with a solid-state counter and (where necessary) also with a magnetic spectrograph. Absolute cross sections were determined to 10–15%. Results for all the reactions corresponding to 1p transitions from stable nuclei to bound final states were analyzed except for a few weak transitions to states of high excitation. Data for the $\text{Be}^9(\text{d,p})\text{Be}^{10}$ and $\text{B}^{10}(\text{d,p})\text{B}^{11}$ angular distributions were obtained from other experiments.^{1,2} Some of the experimental results are shown in Fig. 8, where they are compared with DWBA calculations made with zero range, with a lower cutoff radius of 4 F, and with a finite range (local-energy approximation). The latter does not appreciably improve the quality of fit. Average distorting optical-model parameters were used for all these calculations.

The spectroscopic factors for the various transitions were compared with those predicted in the shell-model calculations of Cohen and Kurath.³ As seen in Fig. 9, the level of agreement is surprisingly good. The biggest discrepancy seems to be in the $\text{C}^{12}(\text{d,p})\text{C}^{13}$ ground-state reaction. This may be associated with the fact that C^{12} is the most tightly bound of the nuclei studied and therefore resonances may still have an important effect. Angular distributions

* Present address: Yale University, New Haven, Connecticut.

¹ U. Schmidt-Rohr, R. Stock, and P. Turek, Nucl. Phys. 53, 77 (1964).

² R. Siemssen and L. L. Lee, Jr. (to be published).

³ S. G. Cohen and D. Kurath (to be published).

Fig. 8. Angular distributions for the (d,p) reactions on Li^6 , Li^7 , and Be^9 (Ref. 1) targets, together with DWBA calculations.

Fig. 9. Comparison of measured and calculated (Ref. 3) spectroscopic factors.

for transitions which Cohen and Kurath predict to be predominantly $\Delta J = \frac{1}{2}$ show sharp structure—usually a pronounced minimum at $\sim 90^\circ$; those with $\Delta J = \frac{3}{2}$ do not show such structure. Thus J-dependent effects, very similar to those observed in the 2p shell, do seem to be present.

EXCITATION FUNCTIONS OF (p,p) SCATTERING OVER THE "QUASIELASTIC" (p,n) THRESHOLD

J. A. Nolen, Jr., G. C. Morrison, J. P. Schiffer, and N. Williams

Bull. Am. Phys. Soc. 12, 526 (April 1967)

Moore *et al.*¹ showed that the coupling of the (d,p) and (d,n) channels leads to an anomaly in the (d,p) excitation function at the threshold of the (d,n) reaction to the analog state. Since the (p,p) and (p,n) channels are similarly coupled, the (p,p) excitation function may show an anomaly at the threshold of the "quasielastic" (p,n) reaction. We measured the (p,p) excitation functions at several angles for $\text{Zr}^{90,91,92,94}$ and Cu^{65} . All show structure; however, it seems uncorrelated with the quasielastic (p,n) threshold. For Zr^{91} we also measured the excitation function for the proton decay² of the analog state; the total cross section is very small even at 150 keV above threshold and is only ~ 1 mb at 200 keV above threshold. This fact, combined with the large (p,p) cross section may explain the absence of an observable effect in the (p,p) channel.

¹C. F. Moore, C. E. Watson, S. A. A. Zaidi, J. J. Kent, and J. G. Kulleck, Phys. Rev. Letters 17, 926 (1966).

²A. I. Yavin, R. A. Hoffswell, L. H. Jones, and T. M. Noweir, Phys. Rev. Letters 16, 1049 (1966).

DYNAMIC QUADRUPOLE EFFECTS IN MUONIC ATOMS OF EVEN NUCLEI

S. Raboy,^{*} A. K. Gaigalas,^{*} R. E. Côté, W. V. Prestwich,[†]
R. A. Carrigan, Jr.,[‡] R. B. Sutton,[‡] and C. C. Trail
Bull. Am. Phys. Soc. 12, 522 (April 1967)

K and L x rays from muonic atoms of the Th²³² and U²³⁸ 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 with the assumption that the nuclei had axially symmetric charge distributions given by a modified Fermi function. The information contained in the K and L data was sufficient to limit the range of values of the parameters in the Fermi function. The quality of the fit is discussed.

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ELASTIC SCATTERING OF ALPHA PARTICLES FROM Ca⁴⁴

P. P. Singh,^{*} J. J. Kroepfl,^{*} B. A. Watson,^{*} T. P. Marvin,^{*}
A. H. Sauter,^{*} D. W. Devins,^{*} A. J. Elwyn, and J. P. Schiffer
Bull. Am. Phys. Soc. 12, 586 (April 1967)

The elastic scattering of α particles from Ca⁴⁴ is being investigated using 75- $\mu\text{g}/\text{cm}^2$ -thick and 98.6% enriched targets. Measurements have been made in the alpha energy range 11.8–13.82 MeV in 40-keV intervals. At each energy, angular distributions of the elastically scattered α particles are obtained in the angular range

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25—165° in 5° steps. At all angles the differential cross section as a function of energy exhibits fluctuations about an average value which decreases monotonically with increasing energy. These fluctuations are only about 5% of the average cross section at the forwardmost angle but increase to about 30% at the backward angles. The average width of these fluctuations is about 40 keV, which is roughly equal to the experimental resolution width. The differential cross sections, at a given energy, decrease by a factor greater than 10^3 in going from 25° to 165°. At energies about 13 MeV and above, the angular distributions start to show marked maxima and minima. A phase-shift analysis and optical-model fits to the data are planned.

CONCERNING THE PARENT FERROMAGNESIAN SILICATE RESERVOIR
OF THE BRONZITE CHONDRITE METEORITES

E. L. Sprenkel-Segel and G. J. Perlow

Bull. Am. Phys. Soc. 12, 593 (April 1967)

The Mössbauer effect in Fe^{57} was used to investigate iron minerals in meteorites. The absorption spectra are composites of the 2-line patterns of olivine $(\text{Mg, Fe})_2\text{SiO}_4$ and pyroxene $(\text{Mg, Fe})\text{SiO}_3$ and the 6-line patterns of troilite (FeS) and kamacite (nickel-iron alloy with body-centered cubic structure). The ratio of olivine iron to pyroxene iron (calculated from the absorption intensities and the recoilless fractions) was found to be 1.5 ± 0.2 for the bronzite chondrites Collescipoli, Ochansk, and Oakley. The ratio of olivine iron to pyroxene iron may be combined with the electron-microprobe analyses¹ of iron and magnesium in the separated minerals to obtain the number of formula units of pyroxene relative to olivine in the unseparated sample.

¹K. Keil and K. Fredriksson, J. Geophys. Res. 69, 3487 (1964).

Previous measurements¹ have shown that 36 bronzite chondrites have olivines and pyroxenes of similar compositions and this report indicates that three of the same meteorites have similar proportions of olivine and pyroxene. Thus it appears that at least 3 (and perhaps all) of the equilibrated bronzite chondrites were derived from a common parent ferromagnesian silicate reservoir.

$\text{Mg}^{25}(\text{He}^3, \text{d})\text{Al}^{26}$ REACTION AT 12 MeV

A. Weidinger,* G. C. Morrison, R. H. Siemssen,[†] and B. Zeidman

Bull. Am. Phys. Soc. 12, 555 (April 1967)

The $\text{Mg}^{25}(\text{He}^3, \text{d})\text{Al}^{26}$ reaction was studied at $E(\text{He}^3) = 12$ MeV by use of the Argonne tandem Van de Graaff and a broad-range magnetic spectrograph. All known states up to 4.2 MeV were observed in this experiment; but the doublets at 2.07 MeV and 4.20 MeV have not been resolved. For the 15 strongest transitions, angular distributions between 5° and 35° were measured. They all have characteristic $\ell = 0$, $\ell = 2$, or $\ell = 0 + 2$ stripping patterns. The $\ell = 0$ admixtures in the angular distributions limit spins and parities to 2^+ or 3^+ for the states at 2.55, 2.92, 3.59, 3.68, and 3.75 MeV, for which no spins and parities were previously known. Spectroscopic factors have been extracted with the Oak Ridge DWBA code Julie. The results can be interpreted in the framework of the unified model.

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NUCLEON TRANSFER REACTIONS ON Mo ISOTOPES

J. L. Yntema and H. Ohnuma

Bull. Am. Phys. Soc. 12, 526 (April 1967)

The single-nucleon-transfer reactions (d,t) , (d,He^3) , and (He^3,d) have been studied on self-supporting, isotopically enriched targets of Mo with the deuteron and He^3 beams of the ANL cyclotron. Strong transitions were observed to the ground states and to levels at 0.74 and 1.26 MeV in Nb^{97} , levels at 0.24, 0.79, and 1.23 MeV in Nb^{95} , levels at 0.297, 0.69, and 1.29 MeV in Nb^{93} , levels at 0.675, 1.26, 2.20, 2.39, and 2.49 MeV in Mo^{97} , levels at 0.78 and 1.03 MeV in Mo^{95} , and levels at 0.94, 1.48, 2.42, 2.55, 2.97, 3.08, 3.22, and 3.46 MeV in Mo^{93} . Angular distributions have been obtained and compared with distorted-wave calculations. Several strongly excited states have been observed in Tc^{101} , Tc^{99} , Tc^{97} , and Tc^{95} .

14th Annual Conference on Mass Spectrometry and Allied Topics
Denver, Colorado, 14-19 May 1967

KINETIC ENERGY SPECTRUM AND ANGULAR DISTRIBUTION OF
PHOTOELECTRONS FROM SOME ATOMS AND MOLECULES

J. Berkowitz, H. Ehrhardt,* and T. Tekaat*

The photoelectron energy spectra produced by the impact of 584 Å photons on the gases Kr, H₂, N₂, O₂, CO, NO, N₂O, and several alkanes have been investigated. The angular distributions of photoelectrons corresponding to the simultaneous formation of specific electronic states of the ion have been measured in the range 30°—130°. A preference for electron ejection in the direction of light propagation is shown in the formation of the electronic ground states of NO⁺ and O₂⁺. Both involve the ejection of an electron from a π_g orbital. A tentative explanation for this behavior will be given.

The onset energies for the various electronic states have been obtained with a resolution of ca. 40 meV. The relative transition probabilities for formation of various electronic states in a given molecular ion, as well as the Franck-Condon factors within specific states, have been obtained.

Similar experiments with the alkanes (methane, ethane, propane, and n-butane) reveal directly the existence of widely separated electronic states (or groupings of states) in the ion, as well as the probability of forming these states. This energy distribution function, of vital importance to the study of the unimolecular decay of ions, can be compared with the derivative of the photoionization-efficiency curve for these molecules.

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LATTICE EFFECTS ON THE EMISSION OF SECONDARY PARTICLES
FROM METAL MONOCRYSTALS

Manfred Kaminsky

The total sputtering yield S and the total yield S_i of secondary positive ions has been measured for atomically clean surfaces of the (111) planes of aluminum, copper, and silver monocrystals bombarded by a 0.4—1.6-MeV mass-analyzed D^+ beam at angles of incidence of 0° and 45° . A portable mass spectrometer has been used to determine also the species of uncharged and positively charged sputtered particles. In addition, the total yield S_{s0} of neutral sputtered particles has been measured. From the experimentally determined values of S and S_{s0} , it was possible to determine the total yield $S_{s+} = S - S_{s0}$ of positive sputtered particles. Then with the aid of these values of S_{s+} and S_i , the yield $S_R = S_i - S_{s+}$ of backscattered primary ions could be determined.

These experimental results supplement previous observations^{1,2} made with the (110) and (100) planes of Ag and Cu. The crystallographic orientation and the target material show a systematic influence on the observed phenomena.

¹M. Kaminsky, Phys. Rev. 126, 1267 (1962).

²M. Kaminsky, Advances in Mass Spectrometry 3, 69 (1964).

Eighth Biennial Conference on Carbon, American Carbon Committee
Buffalo, New York, 19-23 June 1967

MÖSSBAUER STUDIES OF CESIUM-GRAPHITE COMPOUNDS

G. L. Montet,* G. J. Perlow, L. E. Campbell, G. R. Hennig,*
and A. J. F. Boyle†

The Mössbauer effect of the 81-keV gamma ray from Cs^{133} is being used to examine the chemical bonding in lamellar compounds of cesium and graphite. All experiments have been carried out at liquid helium temperature using techniques and information available from earlier work.¹ All samples were prepared by reacting ultra-pure cesium with pyrolytic or spectroscopically pure polycrystalline graphite in vacuo, using the well-known "two-bulb" system.²

Earlier measurements of electrical and magnetic properties of lamellar compounds of graphite demonstrate rather conclusively that most of these compounds are only incompletely ionized.² The measurements do not reveal whether the charge is shared equally by the intercalated atoms or is localized on one ion, with the rest of the reactant present in an atomic or molecular state. One of the objectives of the current study is to ascertain, if possible, the distribution of electric charge in the donor (cesium) of the lamellar compound.

The earliest specimen examined was the first-stage compound C_8Cs , made from pyrolytic graphite. A relatively broad line was observed; this could be evidence of either quadrupole broadening of the first excited nuclear state in Cs^{133} or of magnetic broadening

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† The University of Western Australia, Nedlands, Western Australia.

¹ A. J. F. Boyle and G. J. Perlow, Phys. Rev. 149, 165 (1966); 151, 211 (1966).

² G. R. Hennig, Prog. Inorg. Chem. 1, 125 (1959).

due to a long relaxation time in atomic cesium, if present. The relaxation time might be expected to increase in a more dilute cesium compound; hence a test was made by measuring the Mössbauer line from $C_{24}Cs$ (made from polycrystalline graphite), but no significant increase in the line broadening was found.

A further experiment was carried out by examining the Mössbauer emission from a specimen of cesium-graphite placed in a magnetic field. To this end a sample of C_8Cs made from polycrystalline graphite was placed in a 40-kG magnetic field in a superconducting solenoid. The purpose was to make use of the paramagnetic alignment of an unpaired spin in the presence of high fields at low temperatures. If atomic cesium with a 6s valence electron were present, a spectrum of many lines (due to the nuclear Zeeman effect in an internal field of about 10^6 G) should be observed. A modest additional broadening was observed, which was more nearly characteristic of the applied field of 40 kG than of the expected nuclear field of a megagauss.

Thus far we have found no evidence for the presence of atomic cesium in these compounds; it appears that the electric charge is shared among the donor atoms of the compound. Studies are continuing with additional samples made from pyrolytic graphite in order to explore the effects of crystallite alignment and to determine the source of the observed broadening in the absence of a magnetic field.

American Physical Society MeetingToronto, 21-23 June 1967ATOMIC-BEAM MAGNETIC-RESONANCE MEASUREMENTS OF Rh^{103}

Y. W. Chan* and L. S. Goodman

Bull. Am. Phys. Soc. 12, 653 (May 1967)

TABLE III

	$ A (\text{MH}_z)$	g_J
$^4\text{F}_{9/2}$	175.5738 (6)	1.332531 (14)
7/2	87.4164 (12)	1.231440 (35)
5/2	107.3853 (17)	1.108352 (28)
3/2	32.3769 (13)	0.473994 (15)
$^2\text{D}_{5/2}$	47.3338 (17)	1.118064 (96)
3/2	91.7178 (11)	0.744142 (39)
$^2\text{F}_{7/2}$	88.1979 (11)	1.147102 (38)
5/2	210.88 (32)	0.947652 (40)

Magnetic-dipole
hyperfine-interaction constants
A and electronic g factors g_J
have been measured by the atomic-
beam magnetic-resonance method
for the eight lowest-lying atomic
levels of Rh^{103} . The results
are listed in Table III.

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PROGRESS REPORT ON THE ARGONNE POLARIZED-ION SOURCE

D. C. Hess, C. W. Schmidt, and D. von Ehrenstein

Bull. Am. Phys. Soc. 12, 634-635 (May 1967)

The polarized-ion source under construction¹ for the
Argonne tandem is almost completed. The atomic hydrogen beam
has been satisfactorily focused by using two 6-pole magnets separated

¹ D. von Ehrenstein and D. C. Hess, Proceedings of the 2nd
International Symposium for Polarization Phenomena, Experientia
Supplementum 12 (Birkhäuser-Verlag, Basel, 1966), p. 88.

by a drift space. Polarization of positive ions was observed earlier with the $T(d, \alpha)n$ reaction. The latest major step forward was the successful testing of the charge-exchange unit which transforms positive ions to the negative ones needed for injection into the tandem. This charge-exchange unit had an efficiency of more than 10%. It was operated with NaK vapor, which is supposed to be less hazardous than the pure K used in similar experiments.² An incidental convenience is that NaK, the eutectic mixture of Na (22%) and K (78%), is liquid at room temperature. The ion source is currently being installed at its final location near the low-energy end of the tandem.

²B. L. Donnally and R. Becker, Bull. Am. Phys. Soc. 12, 29 (1967).

ANOMALOUS ENERGY LOSSES OF ENERGETIC PROTONS (0.75—1.75 MeV) IN COPPER MONOCRYSTALS OF VARIOUS CRYSTALLOGRAPHIC ORIENTATIONS

M. Kaminsky

Bull. Am. Phys. Soc. 12, 635 (May 1967)

The energy loss of protons penetrating through thin monocrystalline Cu foils of different but well-defined crystallographic orientations was measured for $E_p = 0.75 - 1.75$ MeV for various angles of incidence. Over twice the area struck by the beam, each foil thickness varied $\leq 5\%$. The angular spread of the incident proton beam was $< 0.01^\circ$ and the angle of incidence was defined to $< 0.1^\circ$. The emerging protons were collimated before being analyzed with a surface-barrier solid-state detector. For protons incident within 0.2° of the $[111]$, $[100]$, or $[110]$ direction, the emergent particle spectrum consisted of two well-separated peaks. The low-energy peak p_1 was characteristic for the normal energy loss expected for polycrystalline targets, while the high-energy peak p_2 is thought to be due to channeled protons;

and $\langle dE/dx \rangle_{av p_2}$ decreased in the order $[111] > [100] > [110]$. Determination of $f = \langle dE/dx \rangle_{av p_2} / \langle dE/dx \rangle_{av p_1}$, the ratio of the energy loss rates of channeled and unchanneled protons, showed that $f[111]$ is slightly greater than 0.5 while $f[100]$ and $f[110]$ are slightly less than 0.5; and f is practically independent of E_p . These results are in reasonable agreement with Lindhard's "equipartition rule."

ENERGY LEVELS OF Si^{30}

N. G. Puttaswamy, D. S. Gemmell, L. Meyer-Schützmeister, and H. Ohnuma

Bull. Am. Phys. Soc. 12, 665 (May 1967)

Angular-correlation studies of the $Si^{30}(\alpha, \alpha'\gamma)$ reaction at $E_\alpha = 13.000$ and 13.015 MeV have led to spin assignments for the energy levels of Si^{30} . Since their population depends strongly on the bombarding energy, targets about $200 \mu g/cm^2$ thick were used. They consist of SiO_2 (95% Si^{30}) evaporated on thin carbon backings. Detecting the scattered alphas by an annular silicon detector at 180° to the beam restricted the observation to natural-parity states. The gamma detector was a 25-cc Ge(Li) counter whose angle was varied from 30° to 90° . A two-parameter analysis of the coincidences between the gammas and the scattered alphas showed strong excitation of the Si^{30} states at 2.232 (2^+), 3.501 (2^+), 3.781, 4.807, 4.819, 5.276, and 5.954 MeV, the given values of J^π being previously known. The level energies quoted above (estimated to have an error of 5 keV) are computed from the data at all angles by taking the Doppler shift into account. Our results show $J^\pi = 2^+$ and 0^+ for the 4.819- and 3.781-MeV states, respectively; the value 0^+ was deduced by comparing our result with those of Broude et al.¹ The absence of the 3.767-MeV state in our experiment favors 1^+ , one possibility suggested by Broude et al.¹

¹C. Broude, P. J. M. Smulders, and T. K. Alexander, Nucl. Phys. A90, 321 (1967).

(d,p) STRIPPING REACTIONS ON THE BARIUM ISOTOPES

D. von Ehrenstein, G. C. Morrison, J. A. Nolen, Jr., and N. Williams

Bull. Am. Phys. Soc. 12, 714 (May 1967)

In order to supplement our study of isobaric analog resonances in the Ba isotopes,¹ we investigated the (d,p) reactions on all stable Ba isotopes with the 12-MeV deuteron beam of the Argonne tandem Van de Graaff. Protons were detected with a broad-range magnetic spectrograph. Angular distributions were obtained typically between 5° and 50° (Fig. 10). From the observed proton spectra, we

Fig. 10. Angular distributions of protons from the Ba(d,p) reaction. The solid lines are DWBA calculations for $l = 1$ and $l = 2$, as indicated. Similar data and curves for $l = 0$ and $l = 3$ were reported in the Physics Division Annual Review [Argonne National Laboratory Report ANL-7354, p. 58]. To reproduce the shapes of the experimental distributions in the calculation, a lower cutoff of $1.25 \times A^{1/3}$ had to be applied (equally for all l values).

¹N. Williams, G. C. Morrison, J. A. Nolen, Jr., and D. von Ehrenstein (succeeding abstract).

obtained the level schemes (in the first few MeV) of all the odd-A barium isotopes from Ba^{131} to Ba^{139} . Most of these levels were previously unknown. DWBA calculations were used to extract l values and absolute spectroscopic factors for levels in different isotopes; the systematic behavior of levels from isotope to isotope has been investigated. The (d,p) spectra of the odd-A target isotopes Ba^{135} and Ba^{137} show strong excitation of the neutron particle-hole states at excitation energies $\gtrsim 4$ MeV in Ba^{136} and Ba^{138} . The positions of these states can be compared with those observed strongly in the inelastic proton spectra at isobaric analog resonances.²

²G. C. Morrison, N. Williams, J. A. Nolen, Jr., and D. von Ehrenstein, Phys. Rev. Letters 19, 592 (1967).

ISOBARIC ANALOG STATES IN THE BARIUM ISOTOPES

N. Williams, G. C. Morrison, J. A. Nolen, Jr., and D. von Ehrenstein

Bull. Am. Phys. Soc. 12, 714 (May 1967)

Previously reported work¹ on the elastic and inelastic scattering of protons has been extended to include all the stable isotopes of barium. Previously observed isobaric-analog resonances corresponding to f- and p-wave proton capture in Ba^{138} , Ba^{136} , and Ba^{134} are seen in Ba^{132} and Ba^{130} . Both s- and d-wave resonances are observed in Ba^{136} , Ba^{134} , Ba^{132} , and Ba^{130} . Absolute Coulomb shifts for all the resonances have been obtained by use of the Q values found from the (d,p) reaction on the same target.² By means of a resonance-fitting

¹G. C. Morrison and Z. Vager, Proceedings of the Conference on Isobaric Spin in Nuclear Physics (Academic Press, New York, 1966), p. 320.

²D. von Ehrenstein, G. C. Morrison, J. A. Nolen, Jr., and N. Williams (preceding abstract).

program, the total widths Γ , partial widths Γ_p , and resonance energies E_R have been derived from the elastic scattering; inelastic partial widths Γ_p were obtained from the inelastic scattering. It has been observed that neutron particle-hole states based on a particular particle are strongly excited in inelastic scattering at the energy of the corresponding "particle" resonance. With Ba^{137} and Ba^{135} targets, the analogs of such states are observed as elastic-scattering resonances.

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III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATIONS

THE $\Lambda\Lambda$ -HYPERNUCLEUS ${}^6\text{He}_{\Lambda\Lambda}$

S. Ali* and A. R. Bodmer

Nuovo Cimento (1 August 1967)

The $\Lambda\Lambda$ -hypernucleus ${}^6\text{He}_{\Lambda\Lambda}$ has been studied in great detail by a three-body α - Λ - Λ model, using the results obtained from the α - α - Λ - Λ model of ${}^{10}\text{Be}_{\Lambda\Lambda}$. Apart from calculating the binding energy of ${}^6\text{He}_{\Lambda\Lambda}$, the shape dependence of various Λ - Λ potentials (including both hard-core and purely attractive types) on scattering length, effective range, etc., has also been investigated. Different Λ - Λ potentials having different shapes but the same intrinsic range are found to be very nearly equivalent for the $\Lambda\Lambda$ -hypernuclei. Our results suggest that the alternative interpretation of the event reported by Danysz *et al.* as ${}^{11}\text{Be}_{\Lambda\Lambda}$ (all the theoretical analyses of this event have so far been based on the ${}^{10}\text{Be}_{\Lambda\Lambda}$ interpretation) deserves serious consideration. The possible implications of our results about the range of the Λ -N interaction are also discussed.

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COULOMB EXCITATION OF LOW-LYING EXCITED STATES IN Sc^{45}

A. E. Blaugrund, R. E. Holland, and F. J. Lynch

Phys. Rev. (20 July 1967)

Properties of the first excited state of Sc^{45} at 12.4 keV and the second excited state at 376 keV have been measured. A limit on the admixture of E3 radiation in the predominantly M2 decay of the first excited state has been set by looking for E3 Coulomb excitation of this state with Cl^{35} ions. Our result is that $B(\text{E}3, \frac{7}{2}^- \rightarrow \frac{3}{2}^+) \leq 105 \text{ e}^2 \text{ fm}^6 = 2.7$ single-particle units. The mean lifetime has been remeasured as $\tau = 0.470 \pm 0.006$ sec. The K conversion coefficient has been measured as 580 ± 120 . The energy of the second excited state was determined to be 375.5 ± 1.0 keV. It was found to decay primarily to

the first excited state with a branching ratio of 10.8 ± 0.5 . The reduced matrix element for Coulomb excitation of the second excited state was measured to be $B(E2, \frac{7}{2}^- \rightarrow \frac{3}{2}^-) = 60.5 \pm 10 \text{ e}^2 \text{ F}^4$.

LIFETIME OF THE 1.042-MeV STATE IN ^{18}F

A. E. Blaugrund, D. H. Youngblood, G. C. Morrison, and
R. E. Segel

Phys. Rev. (20 June 1967)

The lifetime of the 1.042-MeV $T=1$ state in ^{18}F was measured by use of the attenuated-Doppler-shift method. Analysis of the measurements by use of the universal stopping cross section given by Lindhard, Scharff, and Schiott give a mean life $\tau = (0.4_{-0.2}^{+0.3}) \times 10^{-14}$ sec. The experimental lifetime agrees with the value calculated from the corresponding Gamow-Teller β transition according to a relation given by Kurath. The accuracy of the universal stopping cross section is discussed.

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

H. H. Bolotin and H. J. Fischbeck

Phys. Rev. (20 June 1967)

The 3.3-h positron decay of Cu^{61} has been investigated by use of Ge(Li) detectors and coincidence techniques. A total of nineteen γ -ray transitions have been observed ranging in energy from 67 to 2120 keV, of which only eight had been reported previously. The decay scheme based on these data incorporates all of these transitions and requires only those Ni^{61} levels that have been excited in nuclear reactions. The excitation energies of the levels observed to be populated in Ni^{61} from the decay of Cu^{61} 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.

LOW-LYING EXCITED STATES OF Ag^{108} AND Ag^{110} POPULATED IN THERMAL-NEUTRON-CAPTURE REACTIONS

H. H. Bolotin and A. I. Namenson

Phys. Rev. (20 May 1967)

The thermal-neutron-capture γ -ray spectra following the reactions $\text{Ag}^{107}(n, \gamma)\text{Ag}^{108}$ and $\text{Ag}^{109}(n, \gamma)\text{Ag}^{110}$ were studied with the aid of a Ge(Li) detector operated in the singles and pair-spectrometer modes. The use of isotopically enriched targets led to unambiguous assignments of 33 primary transitions in Ag^{108} and 46 transitions issuing from the capture state in Ag^{110} . In each nuclide, these transitions were used to define the low-lying states to an accuracy of $\sim \pm 1$ keV up to an excitation energy of ~ 1300 keV. The observed strengths of the primary transitions are examined to determine the possible presence of systematic regularities of the type reported in the rare-earth rotational region. These data are compared with previous (d, p) studies with a view toward establishment of the parity of the states populated in both reactions.

ENERGY LEVELS OF $_{68}\text{Er}^{166}$ AND $_{69}\text{Tm}^{166}$ (7.7 h) EXCITED IN THE DECAY OF $_{67}\text{Ho}^{166}$ (26.7 h), $\text{Ho}^{166\text{m}}$ (1.2×10^3 yr), AND $_{70}\text{Yb}^{166}$ (57 h)

S. B. Burson, P. F. A. Goudsmit,* and J. Konijn*

Phys. Rev. (20 June 1967)

The γ -ray spectra accompanying the decay of $_{67}\text{Ho}^{166}$ (26.7 h), $_{67}\text{Ho}^{166\text{m}}$ (1.2×10^3 yr), $_{70}\text{Yb}^{166}$ (57 h), and $_{69}\text{Tm}^{166}$ (7.7 h) have been examined with Ge(Li) detectors. Chemically purified sources of Yb^{166} revealed only the known 82.3-keV transition in Tm^{166} . Nine transitions observed in the 26.7-h Ho^{166} activity fit known excited levels in Er^{166} : 80.57 (2^+), 786.4 (2^+), the 1460.9-keV (0^+) β -vibrational state, and two higher levels at 1663.0 (1^+) and 1830.5 keV (1^-). Forty-two of the 63 transitions observed in the spectrum of 1.2×10^3 -yr $_{67}\text{Ho}^{166\text{m}}$ are assigned among 14 excited states in Er^{166} ; these states are at 80.57 (2^+), 265.0 (4^+), 545.4 (6^+), 911.2 (8^+), 859.9 (3^+), 956.4 (4^+), 1075.4 (5^+), 1216.3 (6^+), 1376.1 (7^+), 1556.1 (8^+), 1666.5 (5^-), 1693.0 (5^-), 1787.3 (6), and 1828.1 keV (5, 6). The first four levels are members of the $K=0$ ground-state rotational band. The next six states are members of the $K=2$ γ -vibrational band based on the 786.4-keV

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band head. Approximately ninety γ rays are resolved in the Ge(Li) spectrum of Tm^{166} . These, together with a summary of the results of internal-conversion measurements made previously by other investigators, are listed in a table containing 110 transitions believed to occur in the Tm^{166} decay. We have placed approximately eighty of these γ rays into twenty-three excited states in Er^{166} . The energies (keV) of these states are 80.57 (2^+), 265.0 (4^+), 545.4 (6^+), 786.4 (2^+), 859.9 (3^+), 956.4 (4^+), 1075.4 (5^+), 1375 (2^+), 1458.9 (3^-), 1514.5 (3^-), 1530.1 (2^+ or 3^+), 1572.4 (4^-), 1704 (3^+ or 4^+), 1918.6 (3^-), 1940, 2134.4 (3^+), 2161.2 (3^+), 2174.4 (3^+), 2243, 2274, 2292, 2679, and 2728. The 1530- and 1704-keV states may be the 2^+ and the 4^+ levels of the β -vibrational band based on the 1460.9-keV (0^+) band head. A study of the γ -ray spectrum in coincidence with annihilation radiation (in triple coincidence) indicates that the two reported positron branches of 1932 keV (1% per disintegration) and 1210 keV (0.3% per disintegration) decay to the 80.57- and to the 786.4-keV levels, respectively. Comparison of the relative γ -transition intensities between members of the γ -vibrational band and various members of the ground-state rotational band yield a value of the mixing parameter $z = 0.045 \pm 0.003$. The rotational E2 transition rates relative to the vibrational transition rates are calculated, yielding a mean value of 45.5 ± 3 for the ratio. The energy values of the members of the ground-state and γ -vibrational bands are compared with the usual expansion in $I(I+1)$. The third-order term $CI^3(I+1)^3$ is believed necessary to describe both bands.

CONTACT MAGNETIC-DIPOLE HYPERFINE STRUCTURE IN $3d^N 4s^2$ ATOMS

W. J. Childs

Phys. Rev. (5 August 1967)

The experimental value of $a(s)/\gamma$, where $a(s)$ is the contact part of the magnetic-dipole hyperfine interaction and $\gamma = \mu_I/I$, is considered as a function of the number N of 3d electrons present. The effects of intermediate coupling and configuration interaction (including core polarization) are allowed for wherever possible in the extraction of $a(s)$ from the available experimental data. The resulting curve, which should more accurately describe the variation of the contact hfs with N , is considerably smoother than when these refinements are omitted. New experimental results for Ni^{61} are included.

SPECTROSCOPIC FACTORS FOR THE 1p SHELL

S. Cohen and D. Kurath
Nucl. Phys. (1967)

Spectroscopic factors are given for single-nucleon-transfer reactions in the 1p shell. The calculations are based on effective interactions deduced previously. The strength for such reactions is found to lie in relatively few states of the adjacent nuclei. Sum rules indicate the degree of intermediate coupling of the representation.

SHELL MODEL OF THE NICKEL ISOTOPES

S. Cohen, R. D. Lawson, M. H. Macfarlane, S. P. Pandya,
and Michitoshi Soga
Phys. Rev. (20 August 1967)

The isotopes of nickel are described by a shell model within the identical-nucleon configurations $(2p_{3/2}, 1f_{5/2}, 2p_{1/2})^n$. A least-squares fit to observed level energies yields an effective interaction which satisfactorily reproduces the level structure of the Ni isotopes from Ni^{58} to Ni^{65} . This best-fit interaction is shown to indicate repulsive interactions between identical-nucleon shells and to conserve seniority to a useful degree of approximation. The interaction matrix elements are in fair agreement with those of an approximate reaction matrix computed by Kuo from Hamada and Johnston's free-nucleon interaction, this agreement being obtained only when core polarization is taken into account. Moments and transitions also show the strong influence of core excitation. Observed quadrupole moments and E2 transition rates are adequately reproduced with an effective neutron charge of between 1.5e and 2e; in particular, the observed inhibition of the crossover ground-state decay of the second $2^+(2_2^+)$ states of Ni^{60} and Ni^{62} is reproduced with 2_2^+ wave functions for which a 2-phonon vibrational description is clearly incorrect. It is shown that the original model cannot account for the large deviations of observed magnetic moments from the Schmidt values, nor for the observed spreading of stripping strength into a given orbit over several states of the residual nucleus. To account for these, it is necessary to introduce effective transition operators, strongly modified by the influence of neglected configurations.

ELEMENTS OF THE BRUECKNER-GOLDSTONE THEORY OF NUCLEAR MATTER

B. D. Day

Rev. Mod. Phys. (October 1967)

The basic ideas of the Brueckner-Goldstone theory of nuclear matter are presented in a simple way. The treatment is aimed at beginners and nonspecialists. It is supposed to provide the necessary background for a review article by Bethe and Rajaraman (which will follow this paper in the Reviews of Modern Physics). Therefore, the discussion is limited to a few important topics, and these are considered in some detail.

The Goldstone expansion is presented (but not derived) and the construction and evaluation of the Goldstone diagrams are explained. The reaction matrix and the correlated two-body wave function are defined, and their properties are discussed. The reference-spectrum method for calculating the reaction matrix is derived, and its use is illustrated. Finally, the related topics of convergence and the definition of single-particle energies are considered. The choice of the single-particle potential energy for occupied states is treated in detail. (Intermediate-state energies will be discussed by Bethe and Rajaraman.) The reason for the divergence of the perturbation series for the binding energy is exhibited; and this series is rearranged into a convergent expansion, for which the density plays the role of small parameter.

NEUTRON-PICKUP REACTIONS ON Mg^{26}

D. Dehnhard and J. L. Yntema

Phys. Rev. (20 August 1967)

The single-neutron pickup from Mg^{26} has been studied with both the (d,t) and the (He^3 , α) reaction. Absolute and differential cross sections were measured at forward angles with the 21.5-MeV deuteron beam and the 33.0-MeV He^3 beam of the Argonne 60-in. cyclotron. Spectroscopic factors from the two different reactions were generally found to be in very good agreement for the transitions to the low excited states. The experimental results are compared with predictions of the Nilsson model. It is found that band mixing due to the Coriolis force can explain the rather large absolute strength of the ground-state transition and the absence of strong transitions to two rotational bands based on Nilsson orbits Nos. 6 and 7.

NEUTRON-PICKUP REACTIONS ON Si^{30}

D. Dehnhard and J. L. Yntema

Phys. Rev. (20 November 1967)

The neutron-pickup reactions $\text{Si}^{30}(\text{d}, \text{t})\text{Si}^{29}$ and $\text{Si}^{30}(\text{He}^3, \alpha)\text{Si}^{29}$ have been studied. The results indicate that the neutron configuration of Si^{30} contains about equal components of $1\text{d}_{3/2}$ and $2\text{s}_{1/2}$ neutrons. A small f-wave neutron component in the ground-state wave function was also found. Strong transitions with $\ell = 2$, $J = \frac{5}{2}$ were observed to levels at 2.03, 4.89, 6.72, and 8.32 MeV. The latter is probably the isobaric analog of the ground state of Al^{29} . The level at 4.08 MeV was not excited. The results are compared with the neutron stripping reaction $\text{Si}^{28}(\text{d}, \text{p})\text{Si}^{29}$ and with experiments on the γ decay of the states of Si^{29} .

INELASTIC ALPHA SCATTERING AND ASSOCIATED GAMMA RADIATION. III

David R. Inglis

Phys. Rev. (20 May 1967)

In a 0-2-0 transition in a deformed nucleus excited by inelastic scattering of α particles, the pattern of γ radiation sometimes rotates rapidly backward as the α -particle scattering angle is increased. Previous papers employing a two-dimensional model have shown that this striking behavior may be attributed to the "beats" between incoming and outgoing waves at the edges of the nucleus. The most conspicuous effect there neglected was that of the "focus" of intensity of each of the distorted waves in the middle of its "shadow side" of the nucleus. Here it is shown that the influence of this effect modifies but need not destroy the reverse-rotation phenomenon, and that it provides an explanation for the failure of the reverse rotation to persist for small-angle scattering in most of the observations.

ACCURATE CALCULATION OF THE REACTION MATRIX IN LIGHT NUCLEI

A. Kallio and B. D. Day

Phys. Letters (7 August 1967)

An improved Eden-Emery method is developed to solve the Bethe-Goldstone equation virtually exactly. The equation is first written in the form of an integro-differential equation. The solution is constructed with the aid of a sequence of inhomogeneous differential equations of second order. The resulting t -matrix elements are then used to perform a self-consistent calculation of the binding energy of ^4He and ^{16}O . For ^4He a few of the lowest order Goldstone diagrams are also evaluated. The result differs by less than 0.5 MeV/A from the value obtained with variational calculations for the same interaction.

A FORMULATION OF NEWTON'S SECOND LAW

Amnon Katz

Am. J. Phys. (September 1967)

Newton's second law is presented in a form strong enough that it makes meaningful assertions about force and mass while defining them at the same time.

BOUNDARY CONDITIONS THAT ENFORCE MACH'S PRINCIPLE ON GENERAL RELATIVITY

Amnon Katz

Nuovo Cimento

It is argued that the boundary conditions that require the line element to degenerate to $ds^2 = c^2 dt^2$ at infinity in the spacial coordinates enforce Mach's principle in general relativity. Physically this leads to space closure at coordinate infinity.

LIFETIMES OF THE FIRST TWO LEVELS IN ^{30}P

E. F. Kennedy, D. H. Youngblood, and A. E. Blaugrund
 Phys. Rev. (20 June 1967)

The lifetimes of the first two levels in ^{30}P were measured by the attenuated-Doppler-shift technique. The measurements were analyzed by use of the universal stopping cross section given by Lindhard, Scharff, and Schiott, and a mean life $\tau = (1.55 \pm 0.30) \times 10^{-13}$ sec was obtained for the first level; for the second level only a lower limit ($\tau \geq 3.0 \times 10^{-12}$ sec) was obtained. The experimental result for the first level is compared with the value calculated from the corresponding Gamow-Teller β transition according to the relation given by Kurath. Slightly revised energies of 677.0 ± 1.0 and 709.0 ± 1.0 keV are assigned to these levels.

ENERGY LEVELS OF Fe^{59} FROM THE $\text{Fe}^{58}(\text{d},\text{p})\text{Fe}^{59}$ REACTION

E. D. Klema, L. L. Lee, Jr., and J. P. Schiffer
 Phys. Rev. (20 September 1967)

The angular distributions of the protons from the $\text{Fe}^{58}(\text{d},\text{p})\text{Fe}^{59}$ reaction leading to eight states of Fe^{59} have been measured with 10-MeV deuterons at the Argonne tandem accelerator. Data were taken from 15° to 165° . Absolute cross sections were obtained by comparing the 7-MeV deuterons elastically scattered at 20° with the ground-state protons from the (d,p) reaction at $E_d = 10$ MeV. Values of the orbital-angular-momentum transfer and spectroscopic factors were obtained by comparing the measured cross sections at the forward peaks with those calculated by means of the distorted-wave Born approximation. Spins were assigned by use of the empirical J-dependence rules. The assignments $E_{\text{exc}}(\ell, J, S)$ resulting from the present work are ground state $(1, \frac{3}{2}, 0.45)$; 0.287 MeV $(1, \frac{1}{2}, 0.22)$; 0.470 MeV $(3, \frac{5}{2}, 0.54)$; 0.728 MeV $(1, \frac{3}{2}, 0.20)$; 1.026 MeV $([3], [\frac{7}{2}], 0.08)$; 1.214 MeV $(1, \frac{1}{2}, 0.81)$; 1.572 MeV $(4, \frac{9}{2}, 1.07)$; and 1.749 MeV $(2, \frac{5}{2}, [\frac{3}{2}], 3.59/(2J+1))$.

M2 TRANSITIONS IN NUCLEI

Dieter Kurath and R. D. Lawson

Phys. Rev. (20 September 1967)

A survey of experimental data about M2 transitions between low-lying nuclear states shows that the great majority of transitions in nuclei with $A > 30$ is severely inhibited. For heavy nuclei with a permanent deformation, the inhibition can be ascribed either to K forbiddenness or to an asymptotic selection rule. Even when a permanent deformation is not present, the effect of this selection rule may persist, and it can lead to M2 transitions whose lifetimes are several hundred times the single-particle estimate. In light nuclei, some transitions are inhibited by an isobaric-spin effect. Theoretical values are obtained for comparison with some recently measured M2 lifetimes in the region around $A = 40$. Both quadrupole deformation and the isobaric-spin effect can contribute to inhibitions in this region. The isobaric-spin effect is sufficient to account for the lifetimes in K^{39} and Ca^{41} . For nuclei further removed from Ca^{40} , the effect of deformation is also necessary. In some simple examples we show that such a trend results from the nature of the particle-hole interaction.

SHELL-MODEL THEORY OF IDENTICAL NUCLEONS

M. H. Macfarlane

Lectures in Theoretical Physics, University of Colorado

I. Introduction. II. Shell-Model Formalism: description of the shell model—dimensions; treatment of the shell-model interaction; rotations and spherical tensor operators; coupling and recoupling of angular momenta—summary of notation; occupation-number formalism for identical-nucleon systems; commutators of pair operators; the shell-model Hamiltonian in the occupation-number formalism; commutators involving powers of pair operators. III. Seniority and Quasi-Spin for Systems of Identical Nucleons: quasi-spin and the seniority classification of states of j^n ; normalization of many-pair states—blocking effect; quasi-spin tensorial character of single-nucleon and pair operators; the Wigner-Eckart theorem in quasi-spin space and the dependence of shell-model matrix elements on particle number; reduction formulae for operators linear and bilinear in the single-nucleon operators; reduction formulae for energy-matrix elements; restrictions on the shell-model interaction within j^n implied by conservation of seniority; generalization to many-shell configurations—coupled quasi-spins; generalization to many-shell configurations—uncoupled quasi-spins;

importance of seniority conservation to shell-model calculations.

IV. Lowest Seniority Shell-Model Calculations and Quasi-Particle

Approximations: review of evidence concerning goodness of seniority; shell-model calculations for the isotopes of nickel; the lowest seniority approximation for states of Ni^{62} ; seniority truncation and its limited usefulness; projection of number-eigenstates from the wave functions of the BCS ground state and of two-quasi-particle excited states; number-conserving quasi-particle approximations for states of Ni^{62} ; concluding discussion.

STRUCTURE OF PARTICLE-HOLE STATES IN Ba^{138}

G. C. Morrison, N. Williams, J. A. Nolen, Jr., and D. von Ehrenstein

Phys. Rev. Letters (4 September 1967)

Neutron particle-hole states in Ba^{138} have been observed in three different reactions: from the decay of isobaric analog resonances formed by the reaction $Ba^{138} + p$, in the reaction $Ba^{137}(d,p)Ba^{138}$, and as isobaric analog states in proton scattering from Ba^{137} . It is thus possible to make reasonable assignments of spin and parity as well as to determine the shell-model configurations of many of these states.

THERMAL-NEUTRON-CAPTURE GAMMA-RAY STUDIES OF THE EXCITED STATES OF ODD-A HAFNIUM ISOTOPES

A. I. Namenson and H. H. Bolotin

Phys. Rev. (20 June 1967)

A lithium-drifted germanium detector was used to investigate the primary high-energy γ rays following thermal-neutron capture in the even-A isotopes Hf^{176} , Hf^{178} , and Hf^{180} . The energies, intensities, and isotopic assignments of many of these transitions were determined. The primary transitions from the capture state to the low-lying Nilsson states in Hf^{179} and Hf^{181} were found to exhibit regularities which appear inconsistent with a wholly statistical capture model. These results, together with similar findings of other investigators for the cases of W^{183} , W^{185} , and W^{187} , are discussed in terms of both the statistical

model and evidence suggestive of operational selection rules which appear to govern the radiative decay of the capture states. In addition, six previously unreported transitions have been observed and assigned to the reaction $\text{Hf}^{177}(n, \gamma)\text{Hf}^{178}$.

COULOMB DISPLACEMENT ENERGIES OF Ca-Sc ISOBARIC PAIRS

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

Phys. Rev. Letters (19 June 1967)

A new experimental technique was used to measure Coulomb displacement energies ΔE_c in the Ca-Sc isobaric pairs with $A = 44, 46, 48$, and 50 . The reaction $\text{Ca}^{46}(\text{He}^3, d)\text{Sc}^{47}$ was used to measure this quantity for $A = 47$. This permits analysis of ΔE_c for all the isobaric pairs from $A = 41$ to 50 , for the ground states and for several excited states, which yields a consistent picture.

RESONANCE NEUTRON CAPTURE IN THE EVEN-A ISOTOPES OF TUNGSTEN

W. V. Prestwich and R. E. Coté

Phys. Rev. (20 August 1967)

The γ -ray spectra following neutron capture in the 4.14 - and 21.2 -eV resonances of W^{182} and the 18.8 -eV resonance of W^{186} have been observed with a 6 -cc $\text{Ge}(\text{Li})$ detector. Transitions corresponding to the $\text{W}^{182}(n, \gamma)\text{W}^{183}$ reaction have also been observed in the 115 - and 250 -eV resonances. In a special experiment using a NaI detector, the absolute width of the ground-state transition for the 4.14 -eV resonance in W^{182} was determined relative to the ground-state transition for the 7.62 -eV resonance in W^{183} .

SPECTRUM OF HIGH-ENERGY GAMMA RAYS FOLLOWING THERMAL-NEUTRON CAPTURE BY Er^{166}

W. V. Prestwich and R. E. Côté
Phys. Rev. (20 October 1967)

The thermal-capture γ -ray spectrum of the $\text{Er}^{166}(n, \gamma)\text{Er}^{167}$ reaction in a sample enriched in Er^{166} (99.97%) has been studied with a Ge(Li) pulse-height spectrometer. Some of the transitions are interpreted as populating states having excitation energies in good agreement with those of known states, and several additional levels with excitation energies less than 2 MeV are tentatively assigned on the basis of the data. The distribution of the radiative strength over final states previously assigned to a specific nuclear motion is compared with that expected for an initial state consisting of an s-wave neutron weakly coupled to the deformed target nucleus.

PRECISION DETERMINATION OF THE C^{12} - C^{13} NEUTRON SEPARATION ENERGY

W. V. Prestwich, R. E. Côté, and G. E. Thomas
Phys. Rev. (20 September 1967)

The neutron separation energy for the $\text{C}^{12}(n, \gamma)\text{C}^{13}$ reaction has been determined by observing the γ -ray transitions with a Ge(Li) detector. The energy of each transition was determined relative to an appropriate precision standard. The value obtained, 4946.47 ± 0.17 keV, is in good agreement with previous values and represents a significant improvement in precision.

PRESENT STATUS OF EXPERIMENTS WITH Sb^{121}

S. L. Ruby

Mössbauer Effect Methodology (Plenum Press, 1967)

This talk reviewed the recent studies of Sb^{121} with the Mössbauer technique. The first results have been to measure the quadrupole moment of the excited state, and then the magnetic moment of the same state. Also isomeric shifts have been measured in a variety of chemical compounds. An interpretation of these made possible

the extraction of a value for $\delta(r^2)/r^2$, and (more importantly) established the scale for electron charge density at the nucleus—a parameter quite useful to physical chemists.

TOTAL NEUTRON CROSS SECTION OF LANTHANUM

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

Phys. Rev. (20 July 1967)

The total neutron cross section of lanthanum has been measured from 0.1 to 1000 eV with the Argonne fast chopper. In order to explain its variation over the entire range, it is necessary to assume contributions by bound states together with contributions by the measured resonances at positive energies. The data could be fitted by assuming a bound level whose resonance parameters are the resonance energy $E_0 = -37.5$ eV, the reduced neutron width $\Gamma_n^0 = 0.115$ eV, and the radiation width $\Gamma_\gamma = 0.0565$ eV. The parameters for the resonances at 0.734, 2.994, 20.5, 72.3, 618, and 1182 eV have been measured. The state of $\text{La}^{139} + n$ at the neutron energy of 72.3 eV has been identified to be $J^\pi = 3^+$ on the basis of the observed γ -ray spectrum. The potential-scattering radius is measured to be 5.2 ± 1.0 F. Resonances at energies up to about 11 keV have been detected. On the basis of the measured positive-energy resonances and the negative-energy bound level, the thermal capture cross section has been calculated to be 9.6 ± 0.7 b. The resonance-capture integral is 12.1 ± 1.0 b. The s-wave neutron strength function S_0 for La^{139} is $0.7^{+1.0}_{-0.3} \times 10^{-4}$.

ABSOLUTE SPECTROSCOPIC FACTORS FOR (d,p) REACTIONS ON HEAVY DEFORMED NUCLEI

R. H. Siemssen and J. R. Erskine

Phys. Rev. Letters (10 July 1967)

A reanalysis of a previously reported experiment on the reaction $\text{W}^{182}(d,p)\text{W}^{183}$ still shows a serious discrepancy in the absolute spectroscopic factors if we use distortion parameters that fit the elastic-scattering data. Similar deviations exist for (d,p) reactions on other rare-earth and actinide nuclei.

LIFETIMES OF THE FIRST AND THE THIRD EXCITED STATES OF Ca^{41}

P. P. Singh, R. E. Segel, R. H. Siemssen, S. Baker, and
A. E. Blaugrund

Phys. Rev. (20 June 1967)

The lifetimes of the $\frac{3}{2}^-$ first excited state of Ca^{41} at $E_x = 1.95$ MeV and the $\frac{3}{2}^-$ third excited state at $E_x = 2.47$ MeV have been measured by the attenuated-Doppler-shift method. The two states were populated through the $\text{K}^{41}(p,n)\text{Ca}^{41}$ reaction at bombarding energies only a little above threshold. The γ rays were detected with a lithium-drifted germanium detector. Measurements were made at 0° and 90° to the beam and with Ca^{41} ions recoiling into vacuum, carbon, KCl, and gold. Some attenuation of the Doppler shift results from the recoiling ion changing its direction on collision with a nucleus. At the low recoil velocities encountered, this effect is comparable to the attenuation due to the energy loss in electronic collisions and it was explicitly taken into account. The lifetime of the first excited state was found to be $4.7^{+2.5}_{-1.0} \times 10^{-13}$ sec; that of the third excited state is $\geq 7 \times 10^{-13}$ sec. The speed of the E2 transition from the first excited state to the ground state is thus about three times the Moszkowski single-particle estimate. In contrast, the speed of the E2 ground-state transition from the third excited state (which decays mainly to the first excited state) is less than 6×10^{-3} of the single-particle estimate. These results are compared with theoretical predictions.

ENERGY DEPENDENCE OF HIGH-ENERGY K CONVERSION COEFFICIENTS

R. K. Smither

Phys. Letters (August 1967)

The K conversion coefficients for the 1—9-MeV region of the $^{113}\text{Cd}(n,\gamma)^{114}\text{Cd}$ gamma-ray spectrum are obtained by combining the Ge-diode analysis of the (n,γ) spectrum with the conversion-electron intensities from the previously published work of von Egidy and Kaiser. The K conversion coefficient was found to depend on the γ -ray energy as $E_\gamma^{-1.96}$ for the E1 radiation and as $E_\gamma^{-2.18}$ for the M1. Contrary to the suggestion from extrapolating the theoretical calculation, the values of the E1 and M1 conversion coefficients do not cross at high energies; at 9 MeV they still differ in the ratio of 1.7:1.0.

SCATTERING OF 43-MeV ALPHA PARTICLES BY THE TITANIUM ISOTOPES

J. L. Yntema and G. R. Satchler^{*}

Phys. Rev. (20 September 1967)

The elastic and inelastic scattering of 43-MeV alpha particles on isotopically enriched Ti targets has been measured. The results are analyzed by use of the distorted-wave theory and the collective model. The effect of the choice of different optical-model-potential parameters on the value of the deformation parameter β is investigated and found to be small for reasonable values of the potential parameters. In the three even-A isotopes, a number of 3^- and 4^+ levels have been identified. The excitation mechanisms of the first 2^+ and 4^+ state are compared with the results of coupled-equation calculations and with the predictions of the shell model and the vibrational model.

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IV. PUBLICATIONS SINCE THE LAST REPORT

PAPERS AND BOOKS

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 24B(7), 343-346 (3 April 1967)

AVERAGE WIDTHS FOR HIGH-ENERGY RADIATIVE TRANSITIONS

L. M. Bollinger and G. E. Thomas

Phys. Rev. Letters 18, 1143-1147 (19 June 1967)

LOW-LYING EXCITED STATES OF Ag^{108} AND Ag^{110} POPULATED IN THERMAL-NEUTRON-CAPTURE REACTIONS

H. H. Bolotin and A. I. Namenson

Phys. Rev. 157, 1131-1136 (20 May 1967)

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. 35, No. 2, 1-53 (1966)

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

W. J. Childs and L. S. Goodman

Phys. Rev. 156, 64-70 (5 April 1967)

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

William J. Childs

Phys. Rev. 156, 71-82 (5 April 1967)

CURRENT ALGEBRAS AND CONFIGURATION MIXING

F. Coester

Phys. Rev. 155, 1647-1648 (25 March 1967)

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[†] Institute for Theoretical Physics, Copenhagen.

CURRENT ALGEBRAS AT INFINITE MOMENTUM

F. Coester and G. Roepstorff

Phys. Rev. 155, 1583-1590 (25 March 1967)THE $Mg^{25}(He^3, \alpha)$ REACTION AT $E(He^3) = 33.0$ MeV

D. Dehnhard and C. Mayer-Böricke

Nucl. Phys. A97(1), 164-176 (1967)

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

D. Dehnhard and J. L. Yntema

Phys. Rev. 155, 1261-1263 (20 March 1967)

BASIS FOR THE DEPARTURE FROM EXPONENTIAL DECAY

M. N. Hack

Nuovo Cimento 47, 301-302 (11 February 1967)

INDUCTANCE-VARIATION METHOD OF MEASURING CHARACTERISTICS OF ELECTROMAGNETIC LEVITATION SYSTEMS

Albert J. Hatch and W. E. Smith*

J. Appl. Phys. 38, 742-745 (February 1967)

INELASTIC ALPHA SCATTERING AND ASSOCIATED GAMMA RADIATION. III

David R. Inglis

Phys. Rev. 157, 873-878 (20 May 1967)

ATOMNYE I IONNYE STOLKNOVENIYA NA POVERKHNOSTI METALLA

M. Kaminskii

Publishing House "Mir," Moscow, 1967 [Russian translation of ATOMIC AND IONIC IMPACT PHENOMENA ON METAL SURFACES by Dr. Manfred Kaminsky (Springer-Verlag, Berlin, 1965), edited by Academician L. A. Artsimovich]

EVAPORATIVE DATA ON INTERMEDIATE RESONANCES IN NUCLEAR REACTIONS

Donald W. Lang

Nucl. Phys. A96(2), 273-278 (April 1967)

COULOMB DISPLACEMENT ENERGIES OF Ca-Sc ISOBARIC PAIRS

J. A. Nolen, Jr., J. P. Schiffer, N. Williams, and

D. von Ehrenstein

Phys. Rev. Letters 18, 1140-1143 (19 June 1967)

*The University of New South Wales, Sydney, Australia.

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

A. R. Poletti,^{*} E. K. Warburton,^{*} and Dieter Kurath
Phys. Rev. 155, 1096-1104 (20 March 1967)

GAMMA-RAY SPECTRA OF Co⁶⁰ AND Mn⁵⁶ FOLLOWING RESONANCE-NEUTRON CAPTURE IN Co⁵⁹ AND Mn⁵⁵

W. V. Prestwich and R. E. Coté
Phys. Rev. 155, 1223-1229 (20 March 1967)

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

Carl E. Rosenkilde
Astrophys. J. 148, 825-832 (June 1967)

MAGNETIC HYPERFINE INTERACTION IN Sb¹²¹ USING THE MÖSSBAUER EFFECT

S. L. Ruby and G. M. Kalvius (Solid State Science Division)
Phys. Rev. 155, 353-355 (10 March 1967)

LEVEL STRUCTURE AND DECAY SCHEME OF Sc⁴³

J. J. Schwartz,[†] W. P. Alford,[†] T. H. Braid, and L. Meyer-Schützmeister
Phys. Rev. 155, 1191-1194 (20 March 1967)

RADIATIVE CAPTURE BY ¹⁹F: THE GIANT DIPOLE RESONANCES IN ²⁰Ne

R. E. Segel, Z. Vager, L. Meyer-Schützmeister, P. P. Singh, and R. G. Allas
Nucl. Phys. A93(1), 31-48 (1967)

ELASTIC SCATTERING OF 6-12-MEV DEUTERONS BY ⁴⁸Ti

R. H. Siemssen and C. Mayer-Böricke
Nucl. Phys. A96(3), 505-512 (1967)

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REPORTS AT MEETINGS

Symposium on the Use of Computers in Analysis of Experimental Data and the Control of Nuclear Facilities, Argonne National Laboratory, Argonne, Illinois, 4—6 May 1966

CONTRIBUTIONS TO PANEL PRESENTATION: FUTURE TRENDS IN DATA ANALYSIS, AUTOMATIC CONTROL, DISPLAY, AND PATTERN RECOGNITION

D. S. Gemmell

Use of Computers in Analysis of Experimental Data and the Control of Nuclear Facilities, Proceedings of a Symposium, No. 10 in the AEC Symposium Series, edited by Bernard I. Spinrad. Available as CONF-660527 from Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia 22151, pp. 270-272, 278-279

American Physical Society, 8th Annual Meeting of the Division of Plasma Physics, Boston, Massachusetts, 2—5 November 1966

SLAB-MODEL THEORY OF ADMITTANCE OF HIGH-FREQUENCY PLASMOIDS

M. Hasan, Albert J. Hatch, and J. Taillet*

Bull. Am. Phys. Soc. 12, 769 (May 1967)

APPARATUS FOR STUDYING PLASMA CONFINEMENT IN HIGH-FREQUENCY FIELDS

Albert J. Hatch

Bull. Am. Phys. Soc. 12, 759 (May 1967)

Annual Meeting of the Meteoritical Society, Smithsonian Institution, Washington, D.C., 3—5 November 1966

MÖSSBAUER DETERMINATION OF THE RATIO OF OLIVINE IRON TO PYROXENE IRON IN THE HIGH-IRON AND LOW-IRON GROUPS OF STONE METEORITES

E. L. Sprenkel-Segel and G. J. Perlow

Meteoritics 3, 126-127 (April 1967)

* Centre d'Etudes Nucleaires, Saclay, France.

American Physical Society Meeting, Washington, D. C., 24—27 April 1967

LIFETIMES OF THE SECOND, THIRD, AND FOURTH EXCITED STATES IN Si^{29}

S. I. Baker and R. E. Segel

Bull. Am. Phys. Soc. 12, 570 (April 1967)

COULOMB EXCITATION OF LOW-LYING EXCITED STATES IN Sc^{45}

A. E. Blaugrund, R. E. Holland, and F. J. Lynch

Bull. Am. Phys. Soc. 12, 587 (April 1967)

ENERGY DEPENDENCE OF HIGH-ENERGY RADIATIVE TRANSITIONS

L. M. Bollinger and G. E. Thomas

Bull. Am. Phys. Soc. 12, 597-598 (April 1967)

HFS STUDIES OF LOW-LYING LEVELS IN Pt^{195} BY ATOMIC-BEAM MAGNETIC RESONANCE

W. J. Childs and L. S. Goodman

Bull. Am. Phys. Soc. 12, 509 (April 1967)

HYPERFINE MUONIC SPECTRA OF SEPARATED ISOTOPES OF EUROPIUM

R. E. Coté, W. V. Prestwich, R. A. Carrigan, Jr., *

P. D. Gupta, * R. B. Sutton, * M. N. Suzuki, *

A. Gaigalas,† and S. Raboy†

Bull. Am. Phys. Soc. 12, 581 (April 1967)

$\text{Si}^{30}(\text{d}, \text{t})\text{Si}^{29}$ AND $\text{Si}^{30}(\text{He}^3, \alpha)\text{Si}^{29}$ REACTIONS

D. Dehnhard and J. L. Yntema

Bull. Am. Phys. Soc. 12, 571 (April 1967)

POSSIBLE INTERMEDIATE RESONANCE STRUCTURE IN THE SCATTERING OF NEUTRONS BY Cr

A. J. Elwyn, J. E. Monahan, R. O. Lane, A.

Langsdorf, Jr., and F. P. Mooring

Bull. Am. Phys. Soc. 12, 473 (April 1967)

THEORY OF NUCLEAR LEVEL DENSITY—MODIFICATIONS OF THE PERIODIC SINGLE-PARTICLE SPECTRUM

P. B. Kahn and N. Rosenzweig

Bull. Am. Phys. Soc. 12, 497 (April 1967)

* Carnegie Institute of Technology.

† State University of New York at Binghamton.

APS, Washington, D.C. (cont'd.)

ANGULAR DISTRIBUTIONS FROM $\text{Na}^{23}(\text{p}, \gamma)\text{Mg}^{24}$

L. Meyer-Schützmeister, R. C. Bearse, and R. E. Segel
Bull. Am. Phys. Soc. 12, 553 (April 1967)

(d,p) REACTION IN THE 1p SHELL

G. C. Morrison, J. P. Schiffer, R. H. Siemssen,
and B. Zeidman
Bull. Am. Phys. Soc. 12, 501 (April 1967)

EXCITATION FUNCTIONS OF (p,p) SCATTERING OVER THE
"QUASIELASTIC" (p,n) THRESHOLD

J. A. Nolen, Jr., G. C. Morrison, J. P. Schiffer,
and N. Williams
Bull. Am. Phys. Soc. 12, 526 (April 1967)

DYNAMIC QUADRUPOLE EFFECTS IN MUONIC ATOMS OF
EVEN NUCLEI

S. Raboy,* A. K. Gaigalas,* R. E. Coté, W. V. Prestwich,
R. A. Carrigan, Jr.,† R. B. Sutton,† and C. C. Trail‡
Bull. Am. Phys. Soc. 12, 522 (April 1967)

ELASTIC SCATTERING OF ALPHA PARTICLES FROM
CALCIUM-44

P. P. Singh, | J. J. Kroepfl, | B. A. Watson, |
T. P. Marvin, | A. H. Sauter, | D. W. Devins, |
A. J. Elwyn, and J. P. Schiffer
Bull. Am. Phys. Soc. 12, 586 (April 1967)

CONCERNING THE PARENT FERROMAGNESIAN SILICATE
RESERVOIR OF THE BRONZITE CHONDRITE METEORITES

E. L. Sprenkel-Segel and G. J. Perlow
Bull. Am. Phys. Soc. 12, 593 (April 1967)

$\text{Mg}^{25}(\text{He}^3, \text{d})\text{Al}^{26}$ REACTION AT 12 MEV

A. Weidinger, § G. C. Morrison, R. H. Siemssen, and
B. Zeidman
Bull. Am. Phys. Soc. 12, 555 (April 1967)

* State University of New York at Binghamton.

† Carnegie Institute of Technology.

‡ Brooklyn College.

| Indiana University.

§ Yale University.

APS, Washington, D.C. (cont'd.)

NUCLEON TRANSFER REACTIONS ON Mo ISOTOPES

J. L. Yntema and H. Ohnuma

Bull. Am. Phys. Soc. 12, 526 (April 1967)

American Physical Society Meeting, Toronto, 21—23 June 1967

ATOMIC-BEAM MAGNETIC-RESONANCE MEASUREMENTS
OF Rh^{103}

Y. W. Chan and L. S. Goodman

Bull. Am. Phys. Soc. 12, 653 (May 1967)

PROGRESS REPORT ON THE ARGONNE POLARIZED ION
SOURCE

D. C. Hess, C. W. Schmidt, and D. von Ehrenstein

Bull. Am. Phys. Soc. 12, 634-635 (May 1967)

ANOMALOUS ENERGY LOSSES OF ENERGETIC PROTONS
(0.75—1.75 MEV) IN COPPER MONOCRYSTALS OF VARIOUS
CRYSTALLOGRAPHIC ORIENTATIONS

M. Kaminsky

Bull. Am. Phys. Soc. 12, 635 (May 1967)

ENERGY LEVELS OF Si^{30}

N. G. Puttaswamy, D. S. Gemmell, L. Meyer-Schützmeister,
and H. Ohnuma

Bull. Am. Phys. Soc. 12, 665 (May 1967)

(d,p) STRIPPING REACTIONS ON THE BARIUM ISOTOPES

D. von Ehrenstein, G. C. Morrison, J. A. Nolen, Jr.,
and N. Williams

Bull. Am. Phys. Soc. 12, 714 (May 1967)

ISOBARIC ANALOG STATES IN THE BARIUM ISOTOPES

N. Williams, G. C. Morrison, J. A. Nolen, Jr.,
and D. von Ehrenstein

Bull. Am. Phys. Soc. 12, 714 (May 1967)

LECTURE SERIES

SHELL MODEL THEORY OF IDENTICAL NUCLEONS

M. H. Macfarlane

in Lectures in Theoretical Physics (University of
Colorado Press, Boulder, 1966), Vol. VIII-C, pp. 583-677

PHYSICS DIVISION INFORMAL REPORT

MEASUREMENT OF THE POLARIZATION OF THERMAL NEUTRONS
BY USE OF DEPOLARIZING STEEL SHEETS

M. T. Burgy and G. R. Ringo

Physics Division Informal Report PHY-1967B (January 1967)

STUDENT REPORTS

LIFETIME MEASUREMENTS IN Ca^{41} AND Si^{29}

Samuel I. Baker

Ph.D. Thesis, Illinois Institute of Technology, Chicago
(June 1967)

 $(^3\text{He}, \alpha)$ REACTIONS ON INTERMEDIATE-MASS NUCLEI

David D. Borlin

Ph.D. Thesis, Washington University, St. Louis,
Missouri (June 1967)

HIGH-FREQUENCY DISCHARGE PLASMAS AT LOW PRESSURES

Charles W. Cranfill

CSUI-ANL student report to Claremont Men's College,
California (Spring 1967)

USE OF A SUPERCONDUCTING BETA SPECTROMETER FOR INTERNAL
CONVERSION COEFFICIENT MEASUREMENTS

Stephen M. Curry

CSUI-ANL student report to Southern Methodist
University, Dallas, Texas (May 1967)

TOTAL CROSS SECTIONS FOR 14-MEV NEUTRONS

Jack Haugsnes

Ph.D. Thesis, Northwestern University, Evanston,
Illinois (June 1967)

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V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

NEW MEMBERS OF THE DIVISION

Visiting Scientists (Summer)

Dr. Harry J. Lipkin, Weizmann Institute of Science, Rehovoth, Israel.
Symmetries and quark models of elementary particles.
Returned to Argonne on 7 June 1967.

Dr. Madan Lal Mehta. Theory of random matrices. Came to Argonne
on 20 June 1967.

Research Associate (Summer)

Dr. Hiroyuki Yoshida, Rutgers, The State University, New Brunswick,
New Jersey. Study of xenon dibromide by Mössbauer
spectroscopy. Came to Argonne on 26 June 1967.

Postdoctoral

Dr. Theodore A. Walter. Photoionization studies with mass analysis.
Came to Argonne on 17 April 1967.

Resident Associate

Dr. Duane N. Olson, St. Olaf College, Northfield, Minnesota.

Mössbauer studies of Ir^{191} . (ACM-ANL supervisor under the sponsorship of the Office of College and University Cooperation.) Came to Argonne on 15 June 1967.

Resident Associate (Summer)

Dr. Ram P. Chaturvedi, State University of New York at Cortland.

Decay of Te^{124} . (OCUC affiliate; Faculty Summer Research Participation Program.) Returned to Argonne on 7 June 1967.

Resident Student Associates (Thesis.)

Mr. David L. Auton, graduate student, University of Chicago. Working with J. P. Schiffer on (He^3, d) stripping reactions on p-shell nuclei. (OCUC affiliate.) Came to Argonne on 5 June 1967.

Mr. Richard A. Morrison, graduate student, University of Chicago.

Working with J. P. Schiffer on (He^3, d) reactions on even-Z targets of the sd shell. (OCUC affiliate.) Came to Argonne on 5 June 1967.

Mr. Poh-Kun Tseng, graduate student, University of Michigan. Working with S. L. Ruby on studies of the Mössbauer effect by use of the reactor CP-5. (OCUC affiliate.) Came to Argonne on 20 April 1967.

AMU-ANL Predoctoral Fellowship

Mr. Donald A. McClure, graduate student, University of Missouri at Rolla. Working with H. H. Bolotin on experimental (n, γ) studies of low-energy nuclear states. Came to Argonne on 15 June 1967.

Co-op Technician

Mr. Dennis J. Ulicny, University of Detroit, Michigan. Working with M. Kaminsky on penetration of charged particles through metal monocrystals. Came to ANL on 8 May 1967.

Student Aides (Summer)

Mr. Norman Derby, Loyola University, Chicago. Working with J. R. Wallace on disassembly of the EN tandem Van de Graaff and assembly of the FN tandem. Came to ANL on 8 June 1967.

Mr. Marc Kastner, University of Chicago. Working with J. R. Erskine on study of nuclear energy levels (Sc^{50} , Pb^{208} , and deformed nuclei). Returned to ANL on 13 June 1967.

Mr. James A. Morman, St. Procopius College, Lisle, Illinois. Working with J. R. Wallace on disassembly of the EN tandem Van de Graaff and assembly of the FN tandem. Came to ANL on 6 June 1967.

Summer Student Training Program

Mr. Daniel Bunce, Otterbein College. Working with F. J. Lynch on pulse-shape discrimination between neutrons and gamma rays. Came to ANL on 12 June 1967.

Mr. Tommy Dickey, Ohio University. Working with A. J. Hatch on high-frequency discharges and plasmas. Came to ANL on 12 June 1967.

Mr. LaVester McGill, Arkansas State A. M. & N. College. Working with R. E. Segel on gamma-ray data analysis. Came to ANL on 12 June 1967.

Miss Jean O'Brien, St. Francis College. Working with J. P. Marion on analysis of neutron-capture γ -ray data. Came to ANL on 12 June 1967.

Mr. Raymond Ring, St. Benedict's College. Working with R. Smither on neutron-capture gamma-ray studies. Came to ANL on 12 June 1967.

Mr. Charles Stirrat, Wisconsin State University. Working with G. T. Wood on conversion-electron spectroscopy. Came to ANL on 12 June 1967.

Mr. John Torgerson, Wisconsin State College, River Falls. Working with J. L. Yntema on angular distributions from nucleon-transfer reactions. Came to ANL on 12 June 1967.

Scientific Assistant

Mr. James N. Worthington joined the Physics Division on 12 June 1967 to work with D. S. Gemmell.

Technicians

Mr. Donald R. Geboo joined the Physics Division on 15 May 1967 to work with J. R. Wallace.

Mr. Robert D. Pope joined the Physics Division on 22 May 1967 to work with J. R. Wallace.

Clerk

Miss Julie Ann Carroll joined the Physics Division on 5 June 1967 as receptionist.

PROMOTIONS

Dr. William A. Chupka was promoted to Senior Physicist on 1 July 1967.

Dr. Murray Peshkin was promoted to Senior Physicist on 1 July 1967.

LEAVES OF ABSENCE

Dr. Donald S. Gemmell left ANL on 16 June 1967 to go to the Max Planck Institute, Heidelberg, Germany, where he will be engaged in nuclear research with the MP tandem accelerator. He expects to return to Argonne on 1 October 1968.

Dr. Robert D. Lawson left ANL on 18 June 1967. After a month at A. E. R. E. , Harwell, England, he will go to the Weizmann Institute of Science, Rehovoth, Israel, where he will work on the theory of nuclear structure in collaboration with A. de Shalit and I. Talmi. He expects to return to Argonne on 1 September 1968.

DEPARTURES

Dr. Erhard Bieber, postdoctoral appointment from Technische Hochschule München, Germany, has been at Argonne since 1 November 1965. He has worked on decay of polarized neutrons and

the level scheme of Sm^{153} . He terminated at ANL on 12 May 1967 to go to Carl Zeiss, Inc., 444 Fifth Avenue, New York, New York.

Mr. David D. Borlin, AMU-ANL predoctoral fellow from Washington University has been at Argonne since 18 October 1965. He has worked on ($^3\text{He}, \alpha$) reactions on intermediate-mass nuclei; elastic scattering from heavy elements. He terminated at ANL on 15 May 1967 to return to Department of Physics, Washington University, St. Louis, Missouri.

Mr. Thomas Campana, technician, has been at Argonne since 4 April 1966. He terminated at ANL on 18 June 1967.

Mrs. Judith Hins, secretary, has been at Argonne since 15 June 1961. She terminated at ANL on 2 June 1967.

Dr. Karl K. Ilgen, resident associate (OCUC affiliate) from Technical University, Stuttgart, Germany, has been at Argonne since 2 February 1967. He has worked on small-angle neutron scattering. He terminated at ANL on 5 May 1967 to return to Inst. für Strahlenphysik, TH-Stuttgart, 7 Stuttgart-N, Seestr. 71, Germany.

Mr. Edward J. Leech, technician, has been at Argonne since 13 August 1963. He terminated at ANL on 4 June 1967.

Mr. L. Thomas Seeman, technician, has been at Argonne since 25 April 1961. He terminated at ANL on 28 April 1967.

Transfers

Mr. Victor J. Malasauskas, technician in Physics since 4 January 1966, transferred to High-Energy Physics on 1 May 1967.

Mr. James Pasteris, technician in Physics since 22 July 1963, transferred to Metallurgy on 24 April 1967.