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Argonne National Laboratory

PHYSICS DIVISION SUMMARY REPORT

January—March 1970

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ANL-7699
Physics

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

PHYSICS DIVISION SUMMARY REPORT

January—March 1970

Lowell M. Bollinger, Division Director

Preceding Summary Reports

ANL-7620, Annual Review
ANL-7641, April-September 1969
ANL-7698, October-December 1969

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-7620, which reports research in the year ending 31 March 1969.

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.

THRESHOLD PHOTONEUTRON FACILITY

H. E. Jackson and G. S. Mavrogenes*

Photoneutron experiments in which photoneutron spectra at threshold are observed with high resolution are a recent development in the study of individual highly excited nuclear states. They complement traditional (n, γ) measurements and in many cases extend experimentation to previously inaccessible classes of nuclei. A new experimental high-resolution photoneutron facility is now in operation at Argonne. The recently-constructed experimental area adjoins a new high-intensity electron linear accelerator which is used as a source of bremsstrahlen. In initial measurements, the performance of the installation has been found to be superior by at least an order of magnitude to that typical of previously reported experiments.

In threshold photoneutron experiments, nuclear states of interest are excited by gamma-ray absorption and then observed through their decay by neutron emission. The key to the technique is the use of intense pulsed bremsstrahlung beams of very precisely determined maximum energy, made possible by the recent advances in the design and performance of traveling-wave electron linacs. With this energy definition, excitation can be limited to a small band of

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*Chemistry Division.

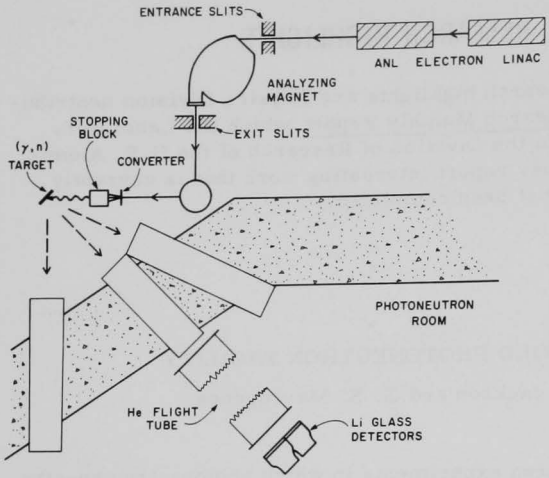

Fig. 1. Threshold photoneutron facility. The ANL electron linac is located in a vault separated from the photoneutron room by a shielding wall 7 ft thick. Both are below ground level.

excited levels just above the neutron binding energy. Established neutron time-of-flight techniques can then be employed to determine the neutron energy which, in turn, determines the energy of the photon absorbed. Because $E_\gamma / E_n \approx 100$, measuring neutron energy with a resolution width of 1% measures the incident-photon energy with 0.01% resolution. Consequently, previously undetected fine structure near the threshold in the (γ, n) cross section can be studied in detail. Both the (γ, n) and the (n, γ) reactions excite states just above the neutron binding energy, and in several cases they are identically the same states. But because the photoneutron experiments involve the inverse reaction, a new set of physical parameters is available for study.

Although the idea was demonstrated in the early sixties, only recent advances in accelerator design, together with the availability of large samples of separated isotopes, have made the technique practical for a broad class of target nuclei. The recently completed Argonne threshold photoneutron facility (Fig. 1) is housed below grade in an experimental room whose area is $\sim$900 ft^2 and which is separated from the linac pit by a shielding wall 7 ft thick.

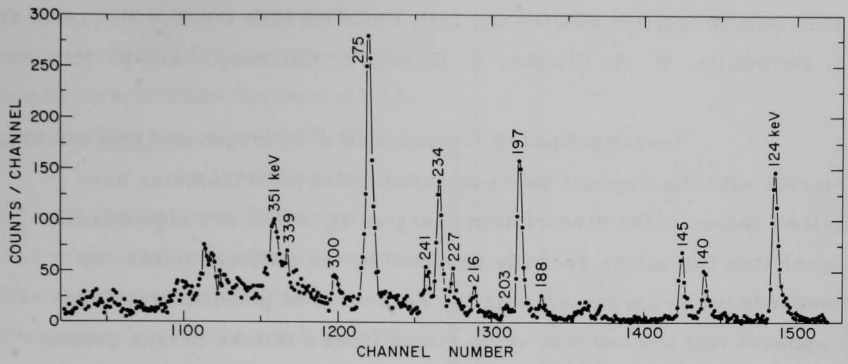

Fig. 2. Photoneutron spectrum for lead. The maximum bremsstrahlung energy (7.4 MeV) was chosen to permit excitation only of states in ^{207}Pb. Use of a thin target ($\frac{1}{8}$ in.) eliminated effects due to neutron scattering in the target material. The spectrum can be obtained in 5 h.

In the present experiments, the pulsed beam of electrons from the linac passes through a 90° analyzing magnet and emerges with an energy spread less than 300 keV. The beam is then focused, restored to its original direction by a second 90° magnet, and allowed to strike a thin radiator (the converter in Fig. 1). The resulting bremsstrahlung passes through a block of aluminum (which stops the electrons) and irradiates the target in which the (γ,n) reaction occurs. The photoneutrons enter the experimental area through three helium-filled flight tubes placed at 90°, 135°, and 155° to the direction of the bremsstrahlung beam. There they are detected in banks of neutron detectors, one bank at the end of each flight tube, and their energies are determined by their drift times.

In the experiments to date, the electron beam has had a 5-nsec pulse duration, a repetition rate of 720 sec^{-1}, and an intensity corresponding to an average current in excess of 20 μA. In initial measurements of photoneutrons from the Pb isotopes, the spectra (Fig. 2) were at least ten times as intense as those previously available—in spite of more stringent limitations on photon energy and sample thickness.

PHOTOIONIZATION STUDY OF THE PROPERTIES OF F_2, HF, AND DF

J. Berkowitz, W. A. Chupka, P. Guyon, J. Holloway,* and R. N. Spohr

Investigations of fluorine and of hydrogen and deuterium fluoride with the Argonne photoionization mass-spectrometer have yielded values of the dissociation energies D_0 which are significantly higher than the values recently reported by the National Bureau of Standards but in agreement with the consensus of previous results. It appears that the low NBS value stems from a failure to take proper account of the contribution from pair formation. An accurate knowledge of the thermochemical stability of F_2 and HF is important because the thermochemistry of other fluorine compounds is based on these values. The work may also have important implications for certain molecular properties. If the autoionization peaks observed in the ionization efficiency curves of HF and DF are correctly attributed to a Rydberg series converging to the $^2\Sigma$ first excited state of HF^+, the results can resolve the discrepancy between earlier photoelectron spectroscopic measurements and could lead to a dissociation energy for each of the Rydberg states.

A study of the photoionization efficiency of F_2 and HF was recently reported from the National Bureau of Standards.[1] With F_2, the individual processes forming F_2^+, $F^+ + F^-$, and $F^+ + F^0$ were separately investigated. From the threshold for the latter process, those authors deduced a value $D_0 = 1.34 \pm 0.03$ eV for the dissociation energy of F_2. This was a rather surprising value, much lower than other types of measurement had previously deduced. Furthermore, the direction of deviation was such as to lend credence to the new value, since the expected sources of error in this type of measurement (such

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*Chemistry Division.

[1] V. H. Dibeler, J. A. Walker, and K. E. McCulloh, J. Chem. Phys. 50, 4592 (1969); 51, 4230 (1969).

as low probability at threshold or excess kinetic energy at threshold due to an activation barrier) would give too large a value for $D_0(F_2)$.

An investigation of F_2 with the Argonne photoionization mass-spectrometry apparatus was undertaken approximately concurrently with the work at NBS. In the Argonne experiments, it was observed that the intensity of the F^- ion, which has a large resonance peak near the threshold for ion-pair formation (F^+, F^-), does not drop to zero at higher photon energy but has a number of smaller maxima that continue toward quite high energy. One of the larger of such subsidiary maxima appears in the vicinity of the threshold for dissociative ionization ($F^+ + F^0$), as seen in Fig. 3. If an investigator observing the high-energy onset for F^+ formation were unaware of the contribution of ion-pair formation in this region, he could be misled into placing this threshold at too low an energy. In the Argonne experiments, the F^- ionization efficiency curve was subtracted from the F^+ ionization efficiency curve, the curves being normalized at the resonant-pair-formation region. The residual curve could then be attributed solely to dissociative ionization.

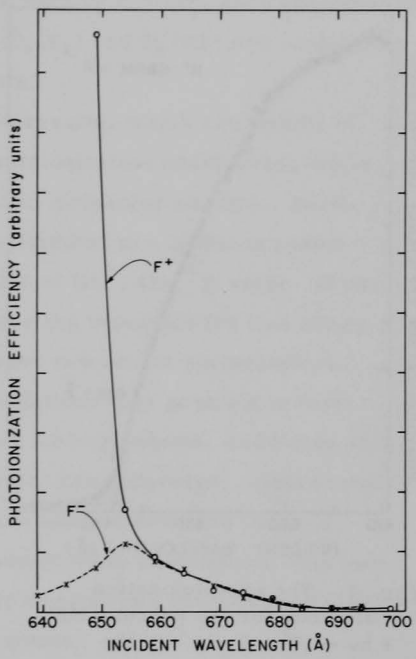

Fig. 3. The photoionization efficiency of F^+ and of F^- for the process $F_2 + h\nu$ in the vicinity of the dissociative ionization threshold. Upon subtracting the F^- curve from the F^+, the extrapolated threshold for dissociative ionization is shifted to 652.5 Å, instead of the previously reported 661 Å.

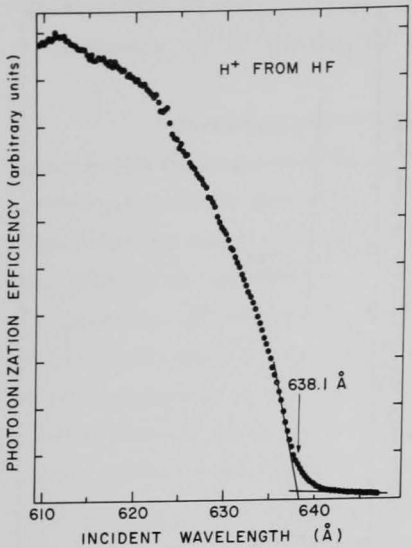

Fig. 4. The photoionization efficiency for the process HF + $h\nu \rightarrow H^+ + F + e^-$ in the threshold region.

The threshold for dissociative ionization, when corrected for a small contribution of internal thermal energy, was 19.01 eV. Combining this value with the well-established ionization potential of atomic fluorine yields $D_0(F_2) = 1.59 \pm 0.01$ eV. This result, which is significantly different from the NBS value, is supported by some recent sophisticated ab initio calculations of F_2, performed by A. C. Wahl and collaborators at Argonne. These calculations yield $D_0(F_2) = 1.54 \pm 0.1$ eV, remarkably close to the current value in view of the difficulty of such calculations.

The NBS group found further support for its value from a study of the photoionization efficiency of HF. Here again, both a prominent ion-pair process ($H^+ + F^-$) and a dissociative-ionization process ($H^+ + F^0$) appear. The thresholds for both processes were interpreted by the NBS investigators to yield $D_0(HF) = 5.74 \pm 0.03$ eV. Their values for $D_0(F_2)$ and $D_0(HF)$ could be combined in a thermochemical cycle to deduce the heat of formation $\Delta H_f(HF) = 65$ kcal/mole, a rather well established value obtained independently by accurate thermochemical techniques.

We have also studied HF at Argonne, and have verified our results by examining DF. The Argonne data (Fig. 4) are interpreted to yield $D_0(HF) = 5.85 \pm 0.01$ eV, again in significant disagreement

with the NBS results but in agreement with an earlier, spectroscopically deduced value. When our values for $D_0(F_2)$ and $D_0(HF)$ are combined, they also yield $\Delta H_f(HF) = 65$ kcal/mole.

In addition to the above results, which are mainly of chemical significance, a number of autoionization peaks observed in the HF-DF studies may be of interest in molecular physics. Most of these peaks have been tentatively attributed to a Rydberg series that converges to the first excited state of HF^+, the $^2\Sigma$ state. If our identification is correct, we can deduce the threshold for this state, thereby resolving a discrepancy between two recent photoelectron spectroscopic studies of HF.[2,3] In addition, it is possible to infer a dissociation energy for each of these Rydberg states, and hence also (approximately) for the $^2\Sigma$ state to which they converge. Concurrent ab initio theoretical studies of HF^+ are being undertaken by A. C. Wahl and collaborators. A comparison of these calculations with our experimental observations should help to establish the validity of the identifications made for the Rydberg states.

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[2] D. C. Frost, C. A. McDowell, and D. A. Vroom, J. Chem. Phys. 46, 4255 (1967).

[3] H. J. Lempka, T. R. Passmore, and W. C. Price, Proc. Roy. Soc. (London) A304, 53 (1968); H. J. Lempka and W. C. Price, J. Chem. Phys. 48, 1875 (1968).

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.

The Argonne (He^3,t) Symposium
Chicago, Illinois, 25 January 1970

THE $^{48}Ca(^3He,t)^{48}Sc$ REACTION AT 23 MeV

A. Richter,* J. R. Comfort, and J. P. Schiffer

ANL Physics Division Informal Report PHY-1970A, pp. 91-97

We want to report very recent and preliminary results on the structure of some levels in the nucleus ^{48}Sc. We have studied this nucleus via the $^{48}Ca(^3He,t)$ reaction at $E_{^3He}$ = 23 MeV, employing the Enge split-pole spectrograph at the Argonne tandem Van de Graaff accelerator.

The $(f_{7/2})^2$ spectrum in ^{48}Sc is reasonably well understood,[1-3] and we want to make only two points concerning its interpretation. Firstly, the Saclay experiment[2] has assigned the spins to the close 2^+-7^+ doublet in contradiction to the high-resolution experiment by Ohnuma et al.,[1] and the present experiment having a higher bombarding

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*On leave of absence from the Max-Planck-Institut für Kernphysik, Heidelberg, Germany.

[1] H. Ohnuma, J. R. Erskine, J. P. Schiffer, J. A. Nolen, Jr., and Norman Williams, contribution 4.74, International Conference on Nuclear Structure, Tokyo (1967); Phys. Rev. C1, 496 (1970).

[2] G. Bruge, A. Bussiere, H. Faraggi, P. Kossany-Demay, J. M. Loiseaux, P. Roussel, and L. Valentin, Nucl. Phys. A129, 417 (1969).

[3] J. J. Schwartz and B. A. Watson, Phys. Letters 29B, 567 (1969).

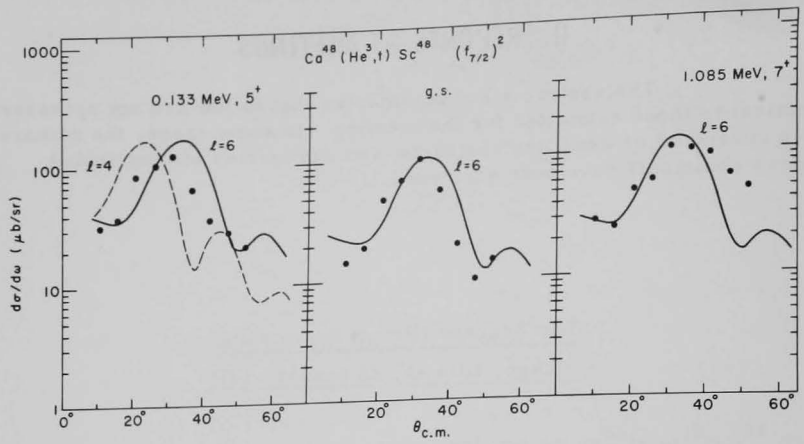

Fig. 5. Angular distributions from the $^{48}Ca(^{3}He,t)^{48}Sc$ reactions leading to the ground state (6^+), and the 0.133 MeV (5^+) and 1.085 (7^+) states belonging to the $(f_{7/2})^2$ configuration, together with DWBA calculations.

energy than the experiment of Ref. 1 still confirms the latter assignment. Secondly, we feel that the preliminary DWBA calculations assuming a pure central force (the curves shown in Fig. 5) fit the shapes of the angular distributions rather well for the even-J final states. It has been noted in a number of experiments (such as those reported in Refs. 2 and 4, for example) that the angular distributions leading to odd-J isospin $T_<$ states in the (^{3}He,t) reaction were described better by orbital angular-momentum transfers $\ell = J + 1$ rather than by $\ell = J - 1$. This effect seems to emerge from the DWBA calculation when a tensor force is added; in the present experiment the odd-J, $T_<$ states are also explained reasonably well by orbital angular momenta $\ell = J + 1$.

Since both the characteristic shapes of the angular distributions of transitions to the particle-hole states and also the simple

[4] S. I. Hayakawa, J. K. Kraushaar, P. D. Kunz, and E. Rost, Phys. Letters 29B, 327 (1969).

DWBA calculations seem to differentiate rather well between different angular-momentum transfers ℓ, we tried to understand the structure of a group of other states in ^{48}Sc by using information on the known $(f_{7/2})^2$ multiplet states. There exist some fairly strongly excited states lying above the states identified as belonging to the $(f_{7/2})^2$ configuration at about 3 MeV excitation and higher. Since all the possible $(f_{7/2})^2$ multiplet components are identified, a cross-shell (^{3}He,t) reaction may be expected in which an $s_{1/2}$ or $d_{3/2}$ neutron is replaced by an $f_{7/2}$ proton exciting odd-parity multiplets. On the other hand, replacing an $f_{7/2}$ neutron with a $p_{3/2}$ or $f_{5/2}$ proton should lead to even-parity multiplets in the same region of excitation. Furthermore, inspecting the relevant single-hole neutron and single-particle proton spectra of ^{47}Ca and ^{49}Sc, respectively, suggests that the odd-parity states in ^{48}Sc lie somewhat lower in excitation than the even-parity states.

Preliminary DWBA calculations for the angular distributions of odd ℓ seem to reveal clearly several candidates for odd-parity states. Even-parity states are also present, as is seen in Fig. 6. States which we assigned to 3^+ and 4^- are mixtures of two ℓ values. Such mixed-ℓ transitions were found in the ^{88}Sr(^{3}He,t)^{88}Y reaction[5] also in cross-shell transitions—a clear-cut violation of the empirical rule mentioned earlier that the non-natural-parity states are described better by $\ell = J + 1$. This rule seems to hold only for identical orbits. One would expect four odd-parity states from the $(\nu d_{3/2}{}^{-1})(\pi f_{7/2})$ and two from the $(\nu s_{1/2}{}^{-1})(\pi f_{7/2})$ configuration as well as four even-parity states from $(\nu f_{7/2}{}^{-1})(\pi p_{3/2})$ in the region between about 2.5 and 4 MeV, and we have identified those multiplets by utilizing ten strong transitions.

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[5] R. C. Bearse, J. R. Comfort, J. P. Schiffer, M. M. Stautberg, and J. C. Stoltzfus, Bull. Am. Phys. Soc. 15, 574 (1970).

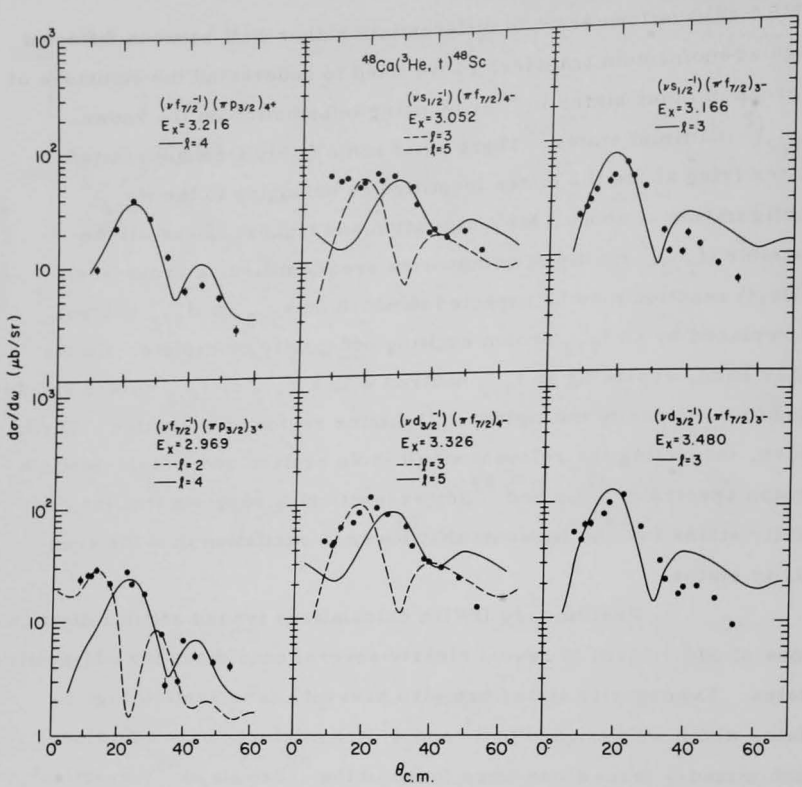

Fig. 6. Angular distributions from the ^{48}Ca(^{3}He,t)^{48}Sc reactions leading to some of the expected high-lying multiplet states in ^{48}Sc together with DWBA calculations. Excitation energies and possible configurations are given in the figure.

THE (He^3,t) REACTION IN THE A ≈ 90 REGION

J. P. Schiffer

ANL Physics Division Informal Report PHY-1970A, pp. 55-71

American Physical Society

Chicago, 26—29 January 1970

NUCLEAR SPECTROSCOPY WITH AVERAGE GAMMA-RAY SPECTRA FROM NEUTRON RESONANCE CAPTURE

Lowell Bollinger

Invited paper listed by title only: Bull. Am. Phys. Soc. 15, 21 (January 1970)

HYPERFINE AND ZEEMAN STUDIES OF THE $4f^{10}6s^2$ ^5I GROUND TERM OF $Dy^{161-164}$

W. J. Childs and L. S. Goodman

Bull. Am. Phys. Soc. 15, 46 (January 1970)

The atomic-beam magnetic-resonance technique is being used to make further hyperfine and Zeeman measurements[1—3] in the $4f^{10}6s^2$ ^5I ground term of Dy. In $Dy^{162-164}$ we find $g_J(^5I_8) = 1.24161(10)$, $g_J(^5I_7) = 1.17345(10)$, and $g_J(^5I_6) = 1.07155(10)$. In Dy^{161}, the hyperfine-interaction constants and g_J value of the $^5I_8$ ground state are $A = -116.231(1)$ MHz, $B = 1091.591(22)$ MHz, and $g_J = 1.24156(3)$. The corresponding quantities for Dy^{163} are $A = 162.749(2)$ MHz, $B = 1152.819(45)$ MHz, and $g_J = 1.24158(3)$.

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[1] A. Cabezas, I. Lindgren, E. Lipworth, R. Marrus, and M. Rubinstein, Nucl. Phys. 20, 509 (1960).

[2] K. F. Smith and I. J. Spalding, Proc. Roy. Soc. (London) 265A, 133 (1961).

[3] W. Ebenhoh, V. J. Ehlers, and J. Ferch, Z. Physik 200, 84 (1967).

T = 1 STATES IN THE MASS-12 SYSTEM

H. T. Fortune, J. E. Monahan, C. M. Vincent, and R. E. Segel

Bull. Am. Phys. Soc. 15, 35 (January 1970)

By comparing the level structures in ^{12}B and ^{12}C, the analogs of the first seven ^{12}B states can be identified. The excitation energies all agree to within 100 keV, except for the ^{12}C states at 16.56 MeV (2^-) and 17.26 MeV (1^-), for which large Thomas-Ehrman shifts can be expected. Spectroscopic factors for decomposing analog states into $^{11}B + p$ are from the proton widths[1]; neutron spectroscopic factors for forming ^{12}B are from the $^{11}B(d,p)$ data.[2] Consistent optical-model potentials were used in making the two calculations. For the second, fifth, and sixth analog states the $^{11}B + p$ spectroscopic factors were about 15% less than those from $^{11}B(d,p)$; but both the third and fourth analog states show significantly greater spectroscopic factors in $^{11}B + p$. We will discuss possible reasons for the discrepancies in the analysis of these s states and the accuracy with which spectroscopic factors can be obtained from nucleon-transfer reactions.

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[1] R. E. Segel et al., Phys. Rev. 139, B818 (1965).

[2] J. P. Schiffer et al., Phys. Rev. 164, 1274 (1967).

ISOMER SHIFTS OF ROTATIONAL STATES OF THE $K=\frac{1}{2}^-$, [521] BAND IN ^{171}Yb

W. Henning, G. M. Kalvius,* and G. K. Shenoy*

Bull. Am. Phys. Soc. 15, 107 (January 1970)

The isomer shifts of the 76-keV and 67-keV Mössbauer resonances in ^{171}Yb have been measured for divalent, trivalent, and metallic compounds. The ratio of changes of the mean-square charge radii of the $I=\frac{5}{2}$ and $I=\frac{3}{2}$ excited states relative to the ground state is

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*Solid State Science Division.

independent of electron-density calculations and $\Delta\langle r^2\rangle_{5/2}/\Delta\langle r^2\rangle_{3/2} = +0.38 \pm 0.16$. The decrease of $\Delta\langle r^2\rangle$ with increasing I contradicts the simple picture of centrifugal stretching as the sole core contribution to $\Delta\langle r^2\rangle$. Blocking effects of the unpaired neutron and Coriolis mixing of higher Nilsson states have to be considered too. The magnetic moment of the $\frac{5}{2}^-$ state was redetermined and the previous value[1] confirmed. A combination of all known magnetic properties of the rotational band yield $g^0_{s,\,eff} = (0.71 \pm 0.03)g_{s,\,0}$ and $g^1_{s,\,eff} = (0.82 \pm 0.03)g_{s,\,0}$ for the effective spin g factors of the unpaired neutron, in disagreement with theoretical calculations.[2]

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[1] W. Henning et al., Z. Physik 199, 207 (1967).

[2] Z. Bochnacki and S. Ogaza, in Hyperfine Structure and Nuclear Radiations (1968), p. 106.

SCATTERING OF ^{14}N AND ^{15}N FROM ^{16}O

R. Malmin,* P. P. Singh,* and R. H. Siemssen

Bull. Am. Phys. Soc. 15, 36 (January 1970)

The elastic scattering of ^{14}N and ^{15}N from ^{16}O was measured by use of the Argonne FN tandem. Excitation functions were obtained over laboratory energies from approximately 30 to 50 MeV in 0.5-MeV steps at center-of-mass angles from 40° to 100° in 10° intervals. Particles were identified by the associated-particle method, in which kinematic coincidence is required between the scattered ion and the recoiling target nucleus. Because of the very low cross sections involved in these reactions, large-area (10 × 50 cm) Nuclear Diode surface-barrier detectors were employed to maximize the solid angle covered, while detector slits with elliptically curved apertures ensured an angular resolution of $\frac{1}{2}$° for ^{15}N and 1° for ^{14}N.

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*Indiana University, Bloomington, Indiana.

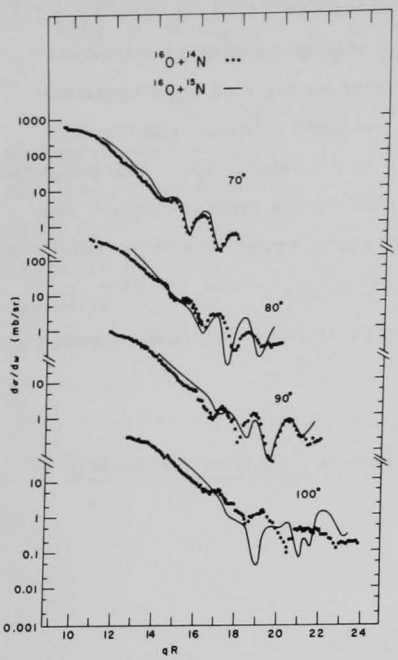

Fig. 7. Excitation-function data. None of the data have been shifted or rescaled.

Angular distributions at E = 35, 40, 45, and 50 MeV have been measured for both systems. Absolute cross sections were obtained by normalizing the ^{15}N data to Coulomb scattering and the ^{14}N data to the lower energy measurements of Jacobson[1] ($E_{lab} < 30$ MeV).

The data on excitation structure are shown in Fig. 7. The abscissa is qR, where $q = 2k \sin \frac{1}{2}\theta$ is the momentum transfer and $R = 1.0(A_1^{1/3} + A_2^{1/3})$. The gross structure shows a regular and pronounced diffraction-like behavior with the average cross section decreasing exponentially with energy, strikingly similar to that found in $^{18}O + ^{16}O$.[2]

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[1] L. A. Jacobson, Phys. Rev. 188, 1509 (1969).

[2] H. T. Fortune, A. Richter, R. H. Siemssen, and J. W. Tippie, International Conference on Nuclear Reactions Induced by Heavy Ions, Heidelberg, 15-18 July 1969 (North-Holland Publishing Co., Amsterdam, in press).

AN INTRASHELL COLLECTIVE STATE ABOVE THE PAIRING GAP IN ^{136}Ba

R. A. Meyer,* G. C. Morrison, and R. D. Griffioen†

Bull. Am. Phys. Soc. 15, 74-75 (January 1970)

An exhaustive study of the decay properties of ^{136}La and ^{136}Cs has been combined with reaction spectroscopy results to delineate the level structure of ^{136}Ba just above the pairing gap. We can characterize the wave functions of the odd-J levels as belonging predominantly to a single two-quasiparticle configuration. However, the lowest energy $J^{\pi} = 2^{+}$ and 4^{+} levels above the pairing gap cannot be characterized by a single configuration. On the contrary, their properties are more consistent with a description which includes several two-neutron quasiparticle states constructed from shell-model orbitals within the $g_{7/2}$-$d_{3/2}$ neutron shell.

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THE RELATIVE GAMMA-RAY STRENGTH FUNCTIONS OF ^{199}Au AND Ta

W. V. Prestwich and L. M. Bollinger

Bull. Am. Phys. Soc. 15, 87 (January 1970)

The spectra of gamma rays following the capture of reactor neutrons transmitted through a ^{10}Bo filter have been observed for samples of Au, Ta, and a Au-Ta mixture, using a Ge(Li)-NaI pair spectrometer. Defining the average γ-ray strength function for the process as $S_{\gamma} = \langle \Gamma_{\gamma_{ij}} / E_{\gamma}^{5} D_i \rangle$, where $\Gamma_{\gamma_{ij}}$ is the partial radiative width for radiation from an initial resonance i to a final state j, E_{γ} is the gamma-ray energy, and D_i the average level spacing at the initial state, the data indicate $S_{\gamma}(\mathrm{Au})/S_{\gamma}(\mathrm{Ta}) = 1.3 \pm 0.2$. This value is consistent with the predicted ratio 1.26 based upon an $A^{8/3}$ mass dependence.

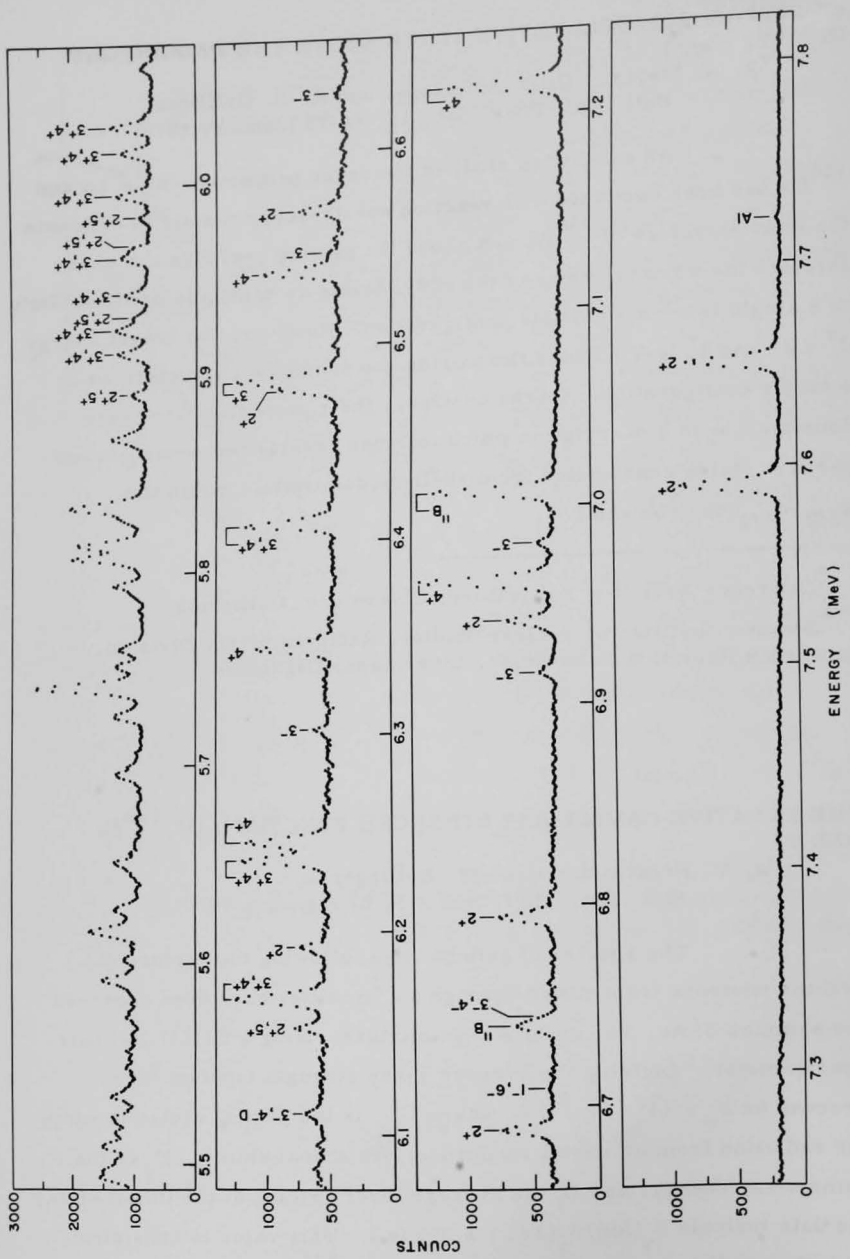
COUNTS
ENERGY (MeV)
Al

Fig. 8. The average-resonance-neutron-capture γ-ray spectrum obtained with a Sm metal capturing sample. The peaks identified with the $^{147}Sm(n,\gamma)^{148}Sm$ and $^{149}Sm(n,\gamma)^{150}Sm$ reactions are labeled with their most likely J^{π} values as determined from this work and all previously published work. In some cases two spin assignments are possible.

RADIATIVE CAPTURE THROUGH THE ^{38}Ar GIANT DIPOLE RESONANCE

R. E. Segel, L. Meyer-Schützmeister, D. S. Gemmell, R. C. Bearse, N. G. Puttaswamy, H. T. Fortune, J. V. Maher, and E. L. Sprenkel-Segel

Bull. Am. Phys. Soc. 15, 47 (January 1970)

The $^{37}Cl(p,\gamma)$ reaction has been studied over the range $E_p = 4-14$ MeV. Gamma rays are observed to the ground state and first excited state in ^{38}Ar, the latter transition being on the average ~3 times as strong as the former. A yield curve taken in 20-keV steps shows the γ_0 yield to be less concentrated than in the even-even, self-conjugate nuclei that have been extensively studied. After averaging over a wealth of fine and perhaps intermediate structure, the γ_0 yield appears to be divided between a 3-MeV-broad resonance centered at 11 MeV ($^{38}Ar^* = 21.0$ MeV) and a resonance about 6 MeV broad centered at 6 MeV ($^{38}Ar^* = 16.1$ MeV). The two broad structures may be attributed to a splitting of the ^{38}Ar giant dipole resonance into T=1 and T=2 components. The yield integrated to $E_p = 14$ MeV and converted to the inverse reaction by detailed balance amounts to 14% of the classical dipole sum for γ_0 and about 10% for γ_1.

ENERGY LEVELS IN ^{148}Sm AND ^{150}Sm

R. K. Smither and D. J. Buss

Bull. Am. Phys. Soc. 15, 86 (January 1970)

The average-resonance-capture spectrum of $^{147}Sm(n,\gamma)^{148}Sm$ and $^{149}Sm(n,\gamma)^{150}Sm$ are used to develop and extend the level schemes of ^{148}Sm and ^{150}Sm. The high quality of the data obtainable with the Argonne in-pile facility is illustrated in Fig. 8. The good separation of the gamma

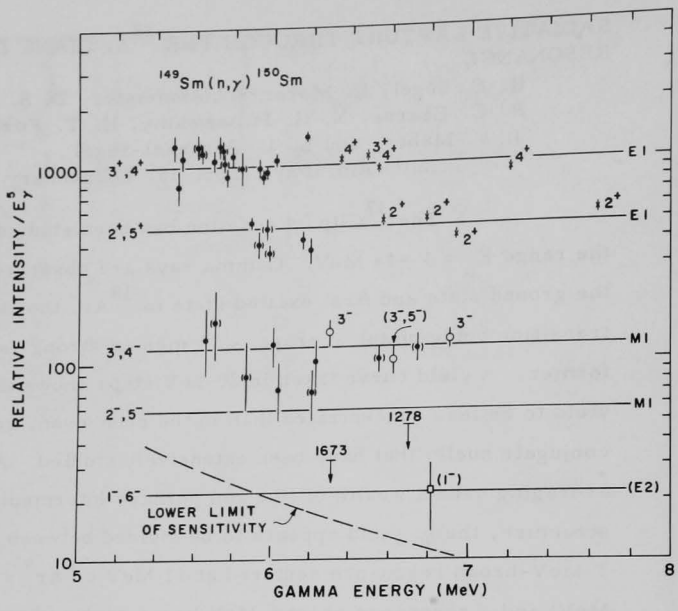

Fig. 9. The relative gamma intensities from average resonance neutron capture divided by E_γ^5, plotted as a function of the γ-ray energy E_γ for the ^{149}Sm(n, γ)^{150}Sm reaction. The x's indicate previously established E1 transitions while the open circles indicate previously established M1 transitions. The bars with arrows pointing down are upper limits. Some previously established J^π values are indicated for some of the well established levels. The numbers labeling some of the points are the energies (keV) of the corresponding final states. The J^π values to the left of the horizontal lines are the possible spin and parity assignments for each group.

intensities into different groups according to their spin and parity (as can be seen in Fig. 9) allows one to make unique spin and parity assignments for levels for which the previously published data suggested conflicting or ambiguous J^π values. The proposed energy (in keV) and J^π of the levels in ^{148}Sm are: g.s., 0^+; 550, 2^+; 1164, 3^-; 1180, 4^+; 1433, (2^-); 1454, 2^+; 1465, (1^-); 1594, 3^-; 1663, 2^+; 1733, 4^+; 1894, 3^+;

1903, 3^+ or 4^+; 1905, 6^+; 2031, 4^-; 2085, 3^+, 4^+; 2096, 6^+; 2111, 4^+; 2146, 4^+; 2194, 6^+; 2213, 5^+; 2228, 4^+; 2314, 2^+; 2328, (2^+ or 3^- or 5^-); 2389, 3^+ or 4^+; 2490, 3^+ or 4^+; 2525, 4^+; 2539, 2^+; 2568, 5^+; 2633, 4^+. The values in ^{150}Sm are: g.s., 0^+, 334, 2^+; 740, 0^+; 773, 4^+; 1046, 2^+; 1071, 3^-; 1165, (close doublet of 1^- and 1^+); 1194, 2^+; 1256, 0^+; 1278, (6^+); 1357 (3^-); 1417, 2^+; 1449, 4^+; 1504, 3^+; 1642, 4^+; 1684, 3^-; 1759, (2^- or 3^-); 1794, 2^+; 1819, 4^+; 1833, 2^+ or 5^+; 1948, (3^- or 5^-); 1970, 4^+; 1979, 3^- or 4^-; 2024, 4^+; 2043, 3^+ or 4^+; 2062, (3^+); 2095, 5^+; 2108, (3^- or 5^-); 2121, (3^-); 2194, 4^+; 2223, 4^+; 2260, 3^+ or 4^+; 2280, 3^-; 2290, 3 or 4^+; 2328, 3^- or 4^-; 2360, 3^+ or 4^+; 2370, 3^+; and 2453, 3^+.

Symposium on Reactions of Organic Ions in a Mass Spectrometer,
American Chemical Society
Houston, Texas, 22—27 February 1970

STUDIES OF ION-MOLECULE REACTIONS BY PHOTOIONIZATION TECHNIQUES

W. A. Chupka, J. Berkowitz, and M. E. Russell

Abstracts of Papers, PETR-105

Photoionization can be used in the study of ion-molecule reactions in order to exercise control over the internal energy distribution of the reactant ion. Diatomic and small polyatomic ions can often be prepared in specific vibrational (and sometimes rotational) states or known mixtures of states. Larger polyatomic ions can often be prepared with a known distribution of internal energies. The method of preparation takes advantage of the characteristics of the photoionization efficiency curve for each particular molecule. The control over internal energy permits the investigation of the manner in which the internal energy of the reactant ion affects its reactivity. In the case of exothermic reactions the effect of internal energy is usually small but gives valuable information regarding the mechanism of the reaction. In the case of reactions that are endothermic for unexcited reactants, the effects of internal energy can be very large even for reactions occurring at high kinetic energy of the reactant ion.

American Physical Society
Dallas, 23—26 March 1970

HYPERFINE MAGNETIC FIELDS IN USb FROM MÖSSBAUER SPECTROSCOPY

S. L. Ruby, G. K. Shenoy,* B. D. Dunlap,* G. M. Kalvius,* Moshe Kuznietz,* and F. P. Campos†

Bull. Am. Phys. Soc. 15, 261 (March 1970)

The Mössbauer effect of ^{121}Sb and ^{238}U in USb were investigated at 4.2°K. USb is a NaCl-type metallic antiferromagnet with $T_N \sim 217$°K. A saturation hf magnetic field of 160 ± 5 kOe was detected at the Sb nucleus. The presence of a unique hf field at all the nonmagnetic anions is consistent with the type-I antiferromagnetic structure, determined by neutron diffraction.[1] The hf field is large compared with 27.3 kOe found by NMR[2] at the ^{31}P nucleus in metallic UP. Since both USb and UP have the same crystal and magnetic structures, the difference in anion hf field can only partially be due to difference in ordered U moments μ_a (2.85 and 2.0 μ_B, respectively). While in UP RKKY-type interactions[2] dominate the hf field, larger covalency effects in USb cause the larger hf field there. The hf field at the U nucleus in USb is ~3.5 MOe, and when compared to that in UO_2,[3] it does not scale linearly with μ_a.

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*Solid State Science Division.

†Materials Science Division.

[1] M. Kuznietz *et al.*, J. Phys. Chem. Solids 30, 1642 (1969).

[2] S. L. Carr *et al.*, Phys. Rev. Letters 23, 786 (1969).

[3] S. L. Ruby *et al.*, Phys. Rev. 184, 374 (1969).

III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATION

DIRECT REACTIONS ON ^{10}Be

D. L. Auton

Nucl. Phys.

A ^{10}Be target has been prepared from neutron-irradiated beryllium by the AREMIS isotope separator. Angular distributions from the (d,p), (d,t), (p,p'), and (d,d) reactions on ^{10}Be were obtained with this target. Protons leading to the ground state and first excited state of ^{11}Be at 12.0 MeV incident deuteron energy indicate spin and parity assignments of $\frac{1}{2}^+$ and $\frac{1}{2}^-$, respectively. At an incident deuteron energy of 15.0 MeV, tritons could be detected up to an excitation of 5.5 MeV in ^{9}Be. No evidence was seen for an $\ell=1$ transition to known states at less than 3.0 MeV excitation in ^{9}Be, other than that to the ground state. Spectroscopic factors for observed states in the (d,p) and (d,t) reactions were obtained in DWBA analyses with reasonable parameters. Elastic and inelastic scattering of protons on ^{10}Be were observed at several incident energies from 12.0 MeV to 16.0 MeV. The elastic scattering was compared with optical-model calculations, and a B(E2) value for the 3.37-MeV ($2^+ \leftarrow 0^+$) transition was obtained by comparison of measured inelastic angular distributions with DWBA predictions. Spectroscopic information concerning transitions within the 1p shell is in good agreement with the values obtained in the shell-model calculations of Cohen and Kurath.

SIMPLE TECHNIQUE FOR PRECISE DETERMINATIONS OF COUNTING LOSSES IN NUCLEAR PULSE-PROCESSING SYSTEMS

H. H. Bolotin, M. G. Strauss (Electronics), and D. A. McClure

Nucl. Instr. Methods

A new technique has been developed to determine precisely the fraction of all counting losses suffered in counting and pulse-height-analysis systems. Of particular significance is the applicability of this method to time-dependent counting rates. The method is based on a technique in which the rate at which radiation is incident upon the detector is sampled continually. Upon the detection of a preset number of counts, a pulser signal is injected into the preamplifier. At the end of the experiment, the total number of injected pulses is compared with the number of these pulses that are

recorded in the multichannel analyzer or scaler. Since the pulser peak suffers the same fractional losses as the spectral components of the detected nuclear events, such a comparison provides an accurate representation of the counting losses due to all loss-producing effects. These include losses incurred in ADCs, computers, pileup rejectors, pulse-shape discriminators, etc. Losses suffered in the last two mentioned components are often not negligible compared with those due to the ADC and memory of fast multichannel analyzers. The application of this technique to constant average counting rates and to fluctuating counting rates encountered in charged-particle-induced reactions and in radioactive-decay studies are treated in detail.

HYPERFINE STRUCTURE OF MANY ATOMIC LEVELS OF Tb^{159}, AND THE Tb^{159} NUCLEAR ELECTRIC-QUADRUPOLE MOMENT

W. J. Childs

Phys. Rev.

The hyperfine structure and g_J values of the 17 lowest-lying atomic levels of Tb^{159} have been measured by the atomic-beam magnetic-resonance technique. Two of the three levels studied in the $4f^96s^2$ configuration had not been seen before, and the present work in $4f^85d6s^2$ provides the first hyperfine-structure information obtained for 11 of the 14 levels studied. The results are analyzed in detail by use of the best eigenvectors available and the effective-operator formalism. After making suitable corrections for hfs and Zeeman interactions with neighboring atomic states, values for a number of radial integrals are deduced by treating them as adjustable parameters. The value obtained for the electric-quadrupole moment of the Tb^{159} nuclear ground state is $Q(Tb^{159}) = +1.34 \pm 0.11$ b, in good agreement with earlier results. This value of Q has been corrected for Sternheimer shielding effects in both the 4f and 5d electron shells; it results from least-squares fits to the quadrupole hfs measurements in all 17 atomic states studied in both configurations.

ELECTRON g FACTORS OF LOW-LYING LEVELS OF Ce I

W. J. Childs and L. S. Goodman

Phys. Rev. (5 May 1970)

Electron g factors have been measured for 33 low-lying states of Ce I with the atomic-beam magnetic-resonance technique.

MEASUREMENT OF ANGULAR CORRELATIONS IN THE DECAY OF POLARIZED NEUTRONS

C. J. Christensen, V. E. Krohn, and G. R. Ringo

Phys. Rev. (April 1970)

The electron-momentum—neutron-spin correlation coefficient was found to be $A = -0.115 \pm 0.008$ and the antineutrino-momentum—neutron-spin correlation coefficient was found to be $B = 1.00 \pm 0.05$. The value of A leads to $|G_A/G_V| = 1.26 \pm 0.02$ for the ratio of Gamow-Teller to Fermi coupling constants in beta decay and B is consistent with zero scalar or tensor interaction.

MESON THEORY OF NUCLEAR FORCES

F. Coester

Quanta: Essays in Theoretical Physics Dedicated to Gregor Wentzel (1970)

Elimination of the meson degrees of freedom from the nuclear Hamiltonian requires a knowledge of the meson structure of the physical one-nucleon states. Conventional relativistic one-meson exchange potentials obtain if the one-nucleon states are calculated in first-order perturbation theory. If the meson-nucleon system is treated as a relativistic particle system without fields, then the physical one-nucleon state can be obtained exactly. Some of the features of local field theories can be recaptured in such models. The static limit of the nucleon-nucleon potential is local but otherwise largely arbitrary. The velocity-dependent terms are then unambiguously determined.

TWO-NUCLEON TRANSFER IN THE 1p SHELL

S. Cohen and D. Kurath

Nucl. Phys. (1970)

Two-nucleon coefficients of fractional parentage are given for the 1p shell, based on an earlier effective-interaction calculation. Magnitudes are also given which indicate the strength expected for two-nucleon transfer reactions.

THE RECOIL-FREE FRACTION FOR ^{182}W IN A SODIUM TUNGSTEN BRONZE

L. E. Conroy and G. J. Perlow

Phys. Letters (1970)

The recoil-free fraction f_a of the 100.1-keV line of ^{182}W was measured with the Mössbauer effect in an absorber of a tungsten bronze $Na_{0.8}WO_3$ at 4.2°K by the variation of line width with thickness. The result is $f_a = 0.18 \pm 0.01$ corresponding to $\theta_M = 298°K$ and rms zero-point motional amplitude R = 0.044 Å. The amplitude is almost as small as that in tungsten itself and considerably smaller than the amplitudes in beryllium or diamond.

MÖSSBAUER EFFECT OF THE 93-keV TRANSITION IN Zn^{67}

H. de Waard and G. J. Perlow

Phys. Rev. Letters (16 March 1970)

Mössbauer spectra obtained with carefully annealed sources consisting of Ga^{67} in $Zn^{66}O$ and with $Zn^{67}O$ absorbers show a well-resolved hyperfine structure that can be attributed to equal quadrupole splittings in source and absorber, with coupling constants $e^2qQ = 2.47 \pm 0.03$ MHz. The resonant absorption for the strongest line of the spectrum ranges from about 0.15 to 0.55% and its linewidth from 2.7 to 5 times the natural width $2\Gamma_0$. A pressure of about 40 kbar applied to the source gives rise to about an 8% reduction in its quadrupole coupling constant.

AN AUTOMATIC NUCLEAR-EMULSION SCANNER

John R. Erskine and R. H. Vonderohe (Applied Mathematics Division)

Nucl. Instr. Methods

A scanning machine has been built to process nuclear track plates exposed in a broad-range magnetic spectrograph. The scanner, which has been in use for almost two years, uses a PDP-9 digital computer to do pattern recognition and to control the scanning head. A high-resolution image-dissector tube scans the emulsion with a resolution width of about 5 μ. Many technical problems were solved to obtain good, stable signals of high resolution from typical

tracks in nuclear emulsions. The computer identifies objects as tracks if they have the proper length, width, and orientation. The machine scans 30—40 times faster than the typical human scanner. Counting accuracy is found to be influenced by brightness of tracks, length of tracks, number of tracks in a given area, fog level in the emulsion, and dirt. For the majority of plates exposed in the magnetic spectrograph, good counting accuracy is achieved except in regions of high track density. The high speed and large capacity of the machine make it a valuable addition to our facilities.

ASSIGNMENT OF $J^{\pi} = \frac{3}{2}^{-}$ FOR THE 8.11-MeV LEVEL OF ^{11}C

H. T. Fortune, J. R. Comfort, J. V. Maher, and B. Zeidman

Phys. Rev.

A study of the $^{10}B(^{3}He,d)^{11}C$ and $^{12}C(^{3}He,\alpha)^{11}C$ reactions leading to the 8.11-MeV state in ^{11}C yields an unambiguous assignment of $J^{\pi} = \frac{3}{2}^{-}$ for that state.

SHELL MODEL WITH REALISTIC FORCES: SPECTRA AND THE EFFECTS OF CORRELATIONS IN A = 6 NUCLEI

R. D. Lawson

Nucl. Phys. (1970)

Correlated wave functions that describe the motion of two nucleons outside an inert core are found by solving the coupled integro-differential equations describing the shell-model problem. The eigenvalues that emerge from the solution of this problem give the two-particle interaction energies relative to the closed shell, and the eigenfunctions contain all possible two-particle correlations that arise from exciting valence nucleons to states outside the Fermi sea. The theory is applied to ^{6}Li, and reasonable agreement with experiment is found when the Hamada-Johnston potential is used for the residual two-body force. The quantities compared with experiment are level scheme, E2 transition rates, M1 transition rates, and (in ^{6}Be) the Coulomb energy of the two valence nucleons. It is argued that better agreement with experiment would emerge if the tensor component of the Hamada-Johnston potential were weakened. The variation of the effective-interaction matrix elements with both the single-particle level scheme and the oscillator constant $\hbar\omega$ is examined.

This approach is shown to be equivalent to a reformulation of the Bloch-Horowitz theory in which not only the "model-space" states but also all other states allowed by the exclusion principle are treated on an equal footing.

LIFETIMES OF LOW-ENERGY LEVELS IN ^{45}Ti

F. J. Lynch, K.-E. Nystén, R. E. Holland, and R. D. Lawson

Phys. Letters

The mean lives of the first and second excited states of ^{45}Ti have been measured as 4.5 ± 0.5 μsec and 17.2 ± 1.0 nsec, respectively. These results are compared with the theoretical predictions made by use of the rotational model and the shell model. It is shown that the pure $f_{7/2}$ shell-model estimates for the lifetimes are fairly insensitive to large changes in the $f_{7/2}{}^2$ interaction energies in the T=0 states.

K_L AND K_S AS SHELL-MODEL EIGENSTATES

K. W. McVoy and W. J. Romo

Ann. Phys. (N.Y.)

The reaction formalism of Feshbach and MacDonald is used to rederive the results of the Wigner-Weisskopf treatment for the neutral K-meson system. The derivation of the Bell-Steinberger sum rule is particularly transparent in this approach.

ANALYSIS OF THE DISTRIBUTION OF THE SPACINGS BETWEEN NUCLEAR ENERGY LEVELS

James E. Monahan and Norbert Rosenzweig

Phys. Rev.

An empirical spacing distribution is always based on a finite, and usually small, number of observed levels. Thus, even if the spacing of levels were described exactly by the random-matrix model, the observed distribution would necessarily fluctuate about

the theoretical mean—the Gaudin-Mehta distribution. A statistic $\Lambda(n)$ is defined to enable one to judge whether the magnitude of the observed fluctuations about the Gaudin-Mehta distribution is compatible with the random-matrix model. It is found that the correlations between the spacings implied by the model tend to reduce the expected fluctuations significantly. The statistical properties of $\Lambda(n)$ are studied by means of a Monte Carlo calculation with matrices of order 100 sampled from the Gaussian orthogonal ensemble. An illustrative analysis of the published neutron resonances observed in U^{239} by Garg et al. reveals no obvious discrepancy between theory and experiment up to neutron kinetic energies of about 2 keV.

OBSERVATION OF NONLOCAL EFFECTS IN NUCLEAR SCATTERING

J. E. Monahan and R. M. Thaler*

Phys. Rev. (June 1970)

The question of how nonlocal effects might be observed in elastic scattering is investigated under the assumption that the interaction is describable by a Hamiltonian. The energy dependence of the real part of the forward-scattering amplitude is related to a dynamic quantity with dimensions of length, which we refer to as the nonlocal distance. Possible off-energy-shell effects can be discussed in terms of this nonlocal distance.

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*Case-Western Reserve University, Cleveland, Ohio.

A STUDY OF NUCLEI WITH MASSES NEAR 32 WITH THE (^{3}He,d) REACTION

R. A. Morrison

Nucl. Phys.

The (^{3}He,d) reaction has been studied on targets of ^{30}Si, ^{31}P, ^{32}S, and ^{34}S. Excitation energies were determined for new states in ^{35}Cl. Angular distributions were measured and absolute cross sections were deduced. Elastic-scattering angular distributions at E(^{3}He) = 15 MeV on ^{31}P and ^{30}Si were measured. The elastic scattering on ^{30}Si was used to determine optical-model parameters for use in the entrance channel of a distorted-wave Born-approximation (DWBA) calculation. Spectroscopic factors and values of the transferred

angular momentum were determined by comparing experimental angular distributions with the results of the DWBA calculation. The extracted spectroscopic factors were compared with those from other experiments and with shell-model calculations.

TIME-MODE OPERATION OF A MÖSSBAUER SPECTROMETER WITHOUT PRECISION CONTROL OF THE DRIVE WAVEFORM

Richard S. Preston and William P. McDowell (Electronics)

Nucl. Instr. Methods

A new method has been developed for storing a Mössbauer spectrum in a multichannel analyzer. The method combines the high counting-rate capability of conventional time-mode operation with the undistorted velocity scale characteristic of operation in the pulse-height mode. Nonlinearity and instability of the drive waveform can be tolerated because a normalization spectrum for eliminating vertical distortions can be obtained concurrently with the Mössbauer spectrum. This normalization spectrum costs practically nothing in counting time or counting statistics, but storage space must be available for it in the analyzer. The necessity for a normalization spectrum can be eliminated by a simple modification of the method, but at the cost of a slight nonlinearity of the velocity scale.

AN APPROXIMATION SCHEME FOR CONTINUUM SHELL-MODEL CALCULATIONS

William Romo

Nucl. Phys. (1970)

In an earlier article we proposed a generalization of the MacDonald projected T-matrix theory as a basis for nuclear-scattering calculations. In this paper our old formalism is slightly modified and it is shown that a calculational scheme based on the modified formalism gives substantially better results than one based on the unmodified formalism.

REACTION-MATRIX CALCULATION OF THE Λ-PARTICLE BINDING IN NUCLEAR MATTER

D. M. Rote* and A. R. Bodmer

Nucl. Phys. (1970)

The two principal procedures for obtaining the phenomenological Λ well depth D from the experimental separation energies B_Λ are discussed. A value $D \approx 30 \pm 2$ MeV, with an upper limit $D \lesssim 35$ MeV, is consistent with the results obtained from both procedures. A reaction-matrix calculation of D is made for central ΛN potentials. This is exact in the g-matrix approximation which gives the term proportional to the density ρ in an expansion in powers of ρ. To calculate the g matrix, the reference-spectrum method is used in the Kallio-Day form. The free kinetic energies are used for the unoccupied states. The difference between the single-particle energies of the bound and excited states of the Λ involves a gap which is identified with the well depth. This leads to a self-consistency condition for the determination of D. The nucleon-spectrum parameters are taken from the calculations of Sprung et al. The angle-average approximation for the exclusion-principle operator, appropriate to a Λ in nuclear matter, is examined and found to be excellent. For hard-core potentials, a perturbation expansion in the strength of the attractive tail is in general inadequate and, especially for potentials of short range, it is necessary to obtain the g matrix exactly for the complete potentials. For given low-energy scattering parameters, the presence of a sizable hard core very substantially reduces D. The p-state contribution to D can be quite large, especially for the phenomenological potentials with hard cores and with larger intrinsic ranges. Thus for Herndon and Tang's potentials which fit the binding energies of the A=3 and 4 hypernuclei as well as the Λp scattering data and which have rather large hard cores, one can get close to the phenomenological value of D by assuming zero p-state interaction. With some p-state interaction—about half of that for the s-state—reasonable suppression of the ΛN-ΣN coupling in nuclear matter can give agreement with the phenomenological depth. The well depth is found to depend fairly linearly on ρ over a large range and the Λ effective mass can be as small as $0.65\ M_\Lambda$.

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*University of Illinois at Chicago Circle, Chicago, Illinois.

MÖSSBAUER MEASUREMENTS OF TIN-ANTIMONY SOLID SOLUTIONS

S. L. Ruby, H. Montgomery (Metallurgy), and C. W. Kimball (Metallurgy)

Phys. Rev.

The isomer shifts for both Sb^{121} and Sn^{119} nuclei have been measured in primary solid solutions of the Sb+Sn system. The experimental results show that the variation of isomer shift with concentration is much weaker than that from one insulating compound to another. This indicates that an increase in the number of electrons per atom hardly changes the number of 5s electrons.

EIGENVALUES OF A MICROWAVE CAVITY FILLED WITH A PLASMA OF VARIABLE RADIAL DENSITY

J. L. Shohet and Albert J. Hatch

J. Appl. Phys. (May 1970)

A solution to the eigenvalue problem of a cylindrical plasma of variable radial density placed coaxially within a cylindrical cavity has been obtained. The solution is based on a model constructed by dividing the plasma into a series of concentric shells, in each of which the plasma density is assumed to be constant but not necessarily equal to that of any other shell. Maxwell's equations are solved exactly for the electromagnetic fields in each shell. The boundary relations at the inner and outer surface of each shell and at the cavity walls result in a set of simultaneous equations which may be solved numerically for the eigenfrequencies if the cavity dimensions, number of shells, and density in each shell are specified. For a given density profile, which may be obtained from experiments, the frequency shift of the system for a given mode may be determined as a function of the density of the central shell. A 10-shell model has been used to solve for the frequencies of the first 10 modes of the cylindrical cavity.

STUDY OF THE (d,p) REACTION ON THE EVEN-A BARIUM ISOTOPES 130—138

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

Phys. Rev. (July 1970)

The (d,p) reactions on $Ba^{130,132,134,136,138}$ have been investigated with 12.0-MeV deuterons from the Argonne tandem Van de Graaff accelerator. Proton spectra were recorded in a broad-range magnetic spectrograph. Many new levels were observed. The ground-state Q values (in MeV) for the (d,p) reactions (including the odd-A targets) are found to be 5.269 for A = 130, 4.977 for A = 132, 4.746 for A = 134, 6.886 for A = 135, 4.680 for A = 136, 6.398 for A = 137, and 2.493 for A = 138. Proton angular distributions were measured for states up to an excitation energy of about 3 MeV. The observed angular-momentum transfers were ℓ_n = 0, 1, 2, 3, and 5, which correspond to the population of states of the $3s_{1/2}$ and $2d_{3/2}$ configurations below the closed neutron shell at N = 82 and the $2f_{7/2}$, $3p_{3/2}$, $3p_{1/2}$, $1h_{9/2}$, and $2f_{5/2}$ configurations above it. From the observed ℓ values, it was possible to assign spins in some isotopes from a knowledge of the spin in other isotopes by taking account of systematic shifts in the Q values of levels and also from shell-model expectations. Distorted-wave Born-approximation calculations were used to extract absolute spectroscopic factors. The problems and uncertainties arising in such calculations were studied in some detail. They derive in part from the need to use a sharp radial cutoff to fit the experimental angular distributions; calculations with nonlocal potentials and finite-range approximations did not yield satisfactory fits. Another source of uncertainty is the dependence of the spectroscopic factors upon the geometric parameters of the bound-state potential well. The results are interpreted with the help of pairing theory; centers of gravity and single-particle energies are deduced.

IV. PUBLICATIONS SINCE THE LAST REPORT

JOURNAL ARTICLES AND BOOK CHAPTERS

(d,p) AND (d,t) REACTION STUDIES OF THE ACTINIDE ELEMENTS. I. U^{235}
T. H. Braid, R. R. Chasman (Chemistry), J. R. Erskine, and A. M. Friedman (Chemistry)
Phys. Rev. C1, 275-289 (January 1970)

TWO-NUCLEON TRANSFER IN THE 1p SHELL
S. Cohen and D. Kurath
Nucl. Phys. A141(1), 145-157 (1970)

FOUR-HOLE-LINE DIAGRAMS IN NUCLEAR MATTER
B. D. Day
Phys. Rev. 187, 1269-1302 (20 November 1969)

THEORY OF NUCLEAR LEVEL DENSITY FOR PERIODIC INDEPENDENT-PARTICLE ENERGY-LEVEL SCHEMES
Peter B. Kahn* and Norbert Rosenzweig
Phys. Rev. 187, 1193-1200 (20 November 1969)

POLARIZATION AND DIFFERENTIAL CROSS SECTION FOR NEUTRONS SCATTERED FROM ^{12}C
R. O. Lane, R. D. Koshel,† and J. E. Monahan
Phys. Rev. 188, 1618-1625 (20 December 1969)

LIFETIME OF THE 11-keV LEVEL IN Cs^{134}
F. J. Lynch and L. E. Glendenin (Chemistry)
Phys. Rev. 186, 1250-1252 (20 October 1969)

ANALOGS AND THE RESONANCE RENAISSANCE
M. H. Macfarlane and J. P. Schiffer
Comments on Nuclear and Particle Physics 3(5), 141-146 (September-October 1969)

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*State University of New York, Stony Brook, New York.

†Ohio University, Athens, Ohio.

STUDY OF THE $Al^{27}(He^3,p)Si^{29}$ AND $Al^{27}(He^3,p\gamma)Si^{29}$ REACTIONS
L. Meyer-Schützmeister, D. S. Gemmell, R. E. Holland, F. T. Kuchnir, H. Ohnuma, and N. G. Puttaswamy
Phys. Rev. 187, 1210-1219 (20 November 1969)

COULOMB ENERGIES
J. A. Nolen, Jr.,* and J. P. Schiffer
Ann. Rev. Nucl. Sci. 19, 471-526 (1969)

HYPERFINE ANOMALY IN ^{193}Ir BY THE MÖSSBAUER EFFECT, AND ITS APPLICATION TO DETERMINATION OF THE ORBITAL PART OF HYPERFINE FIELDS
G. J. Perlow, W. Henning, D. Olson, and G. L. Goodman (Chemistry)
Phys. Rev. Letters 23, 680-682 (29 September 1969)

AN APPROXIMATION SCHEME FOR CONTINUUM SHELL-MODEL CALCULATIONS
William Romo
Nucl. Phys. A142, 300-320 (1970)

CHANGE IN NUCLEAR RADIUS UPON EXCITATION FOR ^{119}Sn, ^{121}Sb, ^{125}Te, $^{127,129}I$, and ^{129}Xe FROM MÖSSBAUER ISOMER SHIFTS
S. L. Ruby and G. K. Shenoy (Solid State Science)
Phys. Rev. 186, 326-331 (10 October 1969)

LEVEL SCHEME OF ^{153}Sm BASED ON (n,γ), (n,e^-), and β-DECAY EXPERIMENTS
R. K. Smither, E. Bieber, T. von Egidy,† W. Kaiser,† and K. Wien‡
Phys. Rev. 187, 1632-1671 (20 November 1969)

INELASTIC SCATTERING OF PROTONS FROM B^{10} BETWEEN 5 AND 16.5 MeV
B. A. Watson, R. E. Segel, J. J. Kroepfl,§ and P. P. Singh§
Phys. Rev. 187, 1351-1364 (20 November 1969)

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*University of Maryland, College Park, Maryland.

†Physik-Department der Technischen Hochschule München, Germany.

‡Institut für Technische Kernphysik der Technischen Hochschule Darmstadt, Germany.

§Indiana University, Bloomington, Indiana.

ABSENCE OF RECOIL DOPPLER BROADENING OF THE 3367-keV TRANSITION FOLLOWING THE REACTION $^{9}Be(n_{th}, \gamma)^{10}Be$

K. J. Wetzel

Phys. Rev. 186, 1292-1293 (20 October 1969)

(d,t) AND (d,He^3) REACTIONS ON THE CALCIUM ISOTOPES

J. L. Yntema

Phys. Rev. 186, 1144-1160 (20 October 1969)

REPORTS AT MEETINGS

Conference on Computational Physics, Culham Laboratory, Abingdon, Berkshire, England, 28 July-1 August 1969

A SYSTEMS APPROACH TO THE NUCLEAR SHELL MODEL

S. Cohen

Computational Physics, Vol. 1: Invited Papers (UKAEA Culham Laboratory, Abingdon, Berkshire, England, 1969), Report No. CLM-CP (1969), Session VII, pp. H1-H17

Physics and Chemistry of Fission, Proceedings of the Second IAEA Symposium, Vienna, 28 July-1 August 1969 (International Atomic Energy Agency, Vienna, 1969)

SHORT-LIVED SPONTANEOUSLY FISSIONING ISOMERS IN NEUTRON-INDUCED FISSION

A. J. Elwyn and A. T. G. Ferguson*

pp. 457-460

Neutron Capture Gamma-Ray Spectroscopy, Proceedings of the International Symposium, Studsvik, Sweden, 11-15 August 1969 (International Atomic Energy Agency, Vienna, 1969)

THERMAL-NEUTRON CAPTURE GAMMA-GAMMA COINCIDENCE STUDIES AND TECHNIQUES

H. H. Bolotin

pp. 15-34

LEVEL STRUCTURE OF LOW-LYING EXCITED STATES OF ^{187}W

H. H. Bolotin and D. A. McClure

pp. 389-402

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*A. E. R. E., Harwell, Berks., England.

Neutron Capture Gamma-Ray Spectroscopy (cont'd.)

USE OF AVERAGE-RESONANCE-CAPTURE MEASUREMENTS FOR NUCLEAR SPECTROSCOPY
R. K. Smither and L. M. Bollinger
pp. 601-605

RECENT IMPROVEMENTS IN THE ARGONNE 7.7-m BENT-CRYSTAL SPECTROMETER
R. K. Smither and D. J. Buss
pp. 55-63

LOW-LYING ROTATIONAL BANDS IN ^{153}Sm
R. K. Smither and T. von Egidy*
pp. 355-358

American Physical Society, Chicago, 26-29 January 1970

HYPERFINE AND ZEEMAN STUDIES OF THE $4f^{10}6s^2$ ^{5}I GROUND TERM OF $Dy^{161-164}$
W. J. Childs and L. S. Goodman
Bull. Am. Phys. Soc. 15, 46 (January 1970)

T=1 STATES IN THE MASS-12 SYSTEM
H. T. Fortune, J. E. Monahan, C. M. Vincent, and R. E. Segel
Bull. Am. Phys. Soc. 15, 35 (January 1970)

ISOMER SHIFTS OF ROTATIONAL STATES OF THE $K=\frac{1}{2}^-$, [521] BAND IN ^{171}Yb
W. Henning, G. M. Kalvius (Solid State Science), and G. K. Shenoy (Solid State Science)
Bull. Am. Phys. Soc. 15, 107 (January 1970)

SCATTERING OF N FROM ^{16}O
R. Malmin,† P. P. Singh,† and R. H. Siemssen
Bull. Am. Phys. Soc. 15, 36 (January 1970)

AN INTRASHELL COLLECTIVE STATE ABOVE THE PAIRING GAP IN ^{136}Ba
R. A. Meyer,‡ G. C. Morrison, and R. D. Griffioen‡
Bull. Am. Phys. Soc. 15, 74-75 (January 1970)

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*Physikdepartment der Technischen Hochschule, München, Germany.

†Indiana University, Bloomington, Indiana.

‡Lawrence Radiation Laboratory, Livermore, California.

APS, Chicago (cont'd.)

THE RELATIVE GAMMA-RAY STRENGTH FUNCTIONS OF ^{199}Au AND Ta

W. V. Prestwich and L. M. Bollinger

Bull. Am. Phys. Soc. 15, 87 (January 1970)

RADIATIVE CAPTURE THROUGH THE ^{38}Ar GIANT DIPOLE RESONANCE

R. E. Segel, L. Meyer-Schützmeister, D. S. Gemmell, R. C. Bearse, N. G. Puttaswamy, H. T. Fortune, J. V. Maher, and E. L. Sprenkel-Segel

Bull. Am. Phys. Soc. 15, 47 (January 1970)

ENERGY LEVELS IN ^{148}Sm AND ^{150}Sm

R. K. Smither and D. J. Buss

Bull. Am. Phys. Soc. 15, 86 (January 1970)

Symposium on Reactions of Organic Ions in a Mass Spectrometer, American Chemical Society, Houston, Texas, 22-27 February 1970

STUDIES OF ION-MOLECULE REACTIONS BY PHOTOIONIZATION TECHNIQUES

W. A. Chupka, J. Berkowitz, and M. E. Russell

Abstracts of Papers, PETR-105

American Physical Society, Dallas, 23-26 March 1970

HYPERFINE MAGNETIC FIELDS IN USb FROM MÖSSBAUER SPECTROSCOPY

S. L. Ruby, G. K. Shenoy (Solid State Science), B. D. Dunlap (Solid State Science), G. M. Kalvius (Solid State Science), Moshe Kuznietz (Solid State Science), and F. P. Campos (Materials Science)

Bull. Am. Phys. Soc. 15, 261 (March 1970)

V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

NEW MEMBERS OF THE DIVISION

Resident Student Associate

Mr. Hsiang Fan, graduate student, University of Chicago, Chicago, Illinois. Working with J. P. Schiffer on data analysis, programming, and computer operation for charged-particle experiments at the tandem. Came to Argonne on 12 January 1970.

AUA-ANL Predoctoral Fellowship

Mr. Ronald E. Malmin, graduate student, Indiana University, Bloomington. Working with R. H. Siemssen on scattering of ^{14}N and ^{15}N from ^{16}O. Returned to Argonne on 1 February 1970.

Guest Fellow (Thesis)

Mr. Peter Chien, graduate student, University of Illinois, Chicago Circle Campus. Working with A. R. Bodmer on topics in hypernuclear structure. (CEA affiliate, National Science Foundation.) Came to Argonne on 23 March 1970.

Student Associate (Thesis)

Mr. Robert S. Hamilton, undergraduate student, Illinois Institute of Technology. Working with R. E. Segel on study of the giant dipole resonance in ^{36}Ar and ^{38}Ar by radiative capture of protons. (CEA affiliate, Senior Thesis Program.) Came to Argonne on 26 February 1970.

Mr. Robert T. Knight, undergraduate student, Illinois Institute of Technology. Working with R. S. Preston on Mössbauer effect in biological materials. (CEA affiliate, Senior Thesis Program.) Came to Argonne on 2 February 1970.

Student Aides (ACM)

Mr. Thomas E. Main, Knox College, Galesburg, Illinois. Working with S. B. Burson on beta-ray spectrometry. Came to ANL on 16 March 1970.

Mr. Larry R. Zobel, St. Olaf College, Northfield, Minnesota. Working with W. A. Chupka on the study of appearance potentials; ionization of molecules by irradiation with uv, etc. Came to ANL on 16 March 1970.

CSUI-ANL Honor Students

Mr. John W. Bellatti, Illinois College, Jacksonville, Illinois. Working with H. H. Bolotin on determination of functions to be folded with a Gaussian to fit γ spectra from Ge(Li) detectors; computer programming to analyze γ-γ coincidence tapes. Came to ANL on 2 February 1970.

Mr. George G. Campbell, Thiel College, Greenville, Pennsylvania. Working with T. H. Braid on multi-wire proportional counters. Came to ANL on 2 February 1970.

Mr. James W. Connelley, University of Pittsburgh, Pittsburgh, Pennsylvania. Working with G. C. Morrison on a study of certain deuteron reactions on nuclei around A = 90. Came to ANL on 2 February 1970.

Mr. Richard W. Nopper, Jr., John Carroll University, Cleveland, Ohio. Working with A. J. Hatch on rf plasma impedance measurements. Came to ANL on 2 February 1970.

Mr. Russell L. Tobias, Temple University, Philadelphia, Pennsylvania. Working with R. H. Siemssen on theoretical analysis of heavy-ion scattering data in terms of the optical model and of strong absorption models. Came to ANL on 2 February 1970.

Computer Operator

Mr. Donald R. Cyborski transferred from the Applied Mathematics Division to the Physics Division on 2 January 1970 to work with D. S. Gemmell.

Technician

Mr. Bozydar H. Orszula joined the Physics Division on 12 January 1970 to work with J. R. Wallace.

PROMOTIONS

The following were promoted to Senior Scientists, effective 18 March 1970: Dr. Manfred Kaminsky
Dr. James E. Monahan
Dr. Ralph E. Segel.

DEPARTURES

Miss Jeanette M. Ebl, scientific assistant, has been in the Physics Division since 7 October 1968. She terminated at ANL on 19 February 1970.

Mr. Anthony C. Jackson, scientific technician, has been in the Physics Division since 7 July 1969. He terminated at ANL on 31 March 1970.

Dr. Joseph C. Stoltzfus, visiting scientist from Beloit College (ACM-ANL supervisor 1968—1969), has been in the Physics Division since 26 August 1968. He developed the position-sensitive detector system for the split-pole magnetic spectrograph, and has studied (^{3}He,t) reactions and the isospin-violating (d,α) reactions on ^{12}C and ^{28}Si. He terminated at ANL on 2 January 1970 to return to Beloit College, Beloit, Wisconsin.

Miss Rosemary Sutter, scientific assistant, has been in the Physics Division since 23 May 1966. She terminated at ANL on 27 March 1970.

Transfer

Mr. Garfield Jenkins, scientific technician in Physics since 2 July 1956, transferred to Information Services on 1 January 1970.

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