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Argonne National Laboratory

PHYSICS DIVISION SUMMARY REPORT

June—August 1966

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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ANL-7247
Physics
AEC Research and
Development Report

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ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

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PHYSICS DIVISION SUMMARY REPORT

June — August 1966

Lowell M. Bollinger, Division Director

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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FOREWORD

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

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

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

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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.

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

J. E. Monahan and A. J. Elwyn

The concept that compound-nucleus resonance states are formed through a sequence of successively more complex excitations (configurations) is based on the assumption that the residual nucleon-nucleus interaction can be described in terms of two-body potentials. There is considerable interest in the possibility that these intermediate configurations may be observable as structure of intermediate width in a cross section measured as a function of incident-particle energy. The observation of such structure would provide an immediate qualitative understanding of the mechanism of nuclear reactions. Of at least equal interest would be the spectroscopic information that could be obtained from a study of the simplest ("doorway state") configuration. An intermediate structure of the kind expected for doorway states has been observed in the scattering of neutrons from ^{19}F at energies between 0.2 and 2.2 MeV. Both the angular distributions and the polarizations of neutrons were measured. An analysis of these data shows that they are consistent with the interpretation of the observed intermediate structure in terms of doorway states and leads to an assignment of the spins and parities of these states.

Fig. 1. The total neutron cross section of ^{19}F . The lowest curve shows the observed results, measured with energy spreads of 15–20 keV in the neutron beam. The other curves show the result of averaging the observed data over successively larger averaging intervals ΔE . The points on the curve $\Delta E \approx 125$ keV indicate the values of the integrated scattering cross sections obtained in the measurement of the differential cross section and polarization with a beam-energy spread of about 125 keV.

Evidence of intermediate structure in the neutron total cross section of ^{19}F is shown in Fig. 1. The lowest curve in this figure is the cross section measured with an energy spread of 15–20 keV in the neutron beam. The remaining curves are the same data numerically averaged over successively larger averaging intervals ΔE , the values of which are noted in the figure. As shown, the observed fine structure (having characteristic widths of 15–20 keV) is almost completely "averaged out" for $\Delta E \gtrsim 60$ keV. But an intermediate structure, having characteristic widths of 100–150 keV, is relatively insensitive to the averaging for $\Delta E < 190$ keV. Thus the 100–150-keV width of this structure seems to be an intrinsic property of the compound system ^{20}F and is not simply a reflection of the energy spread in the incoming neutron beam.

The angular distributions and polarizations were measured¹ with neutron beams having an energy spread of 125–150 keV.

¹A. J. Elwyn, J. E. Monahan, R. O. Lane, and A. Langsdorf, Jr., Nucl. Phys. 59, 113 (1964).

These data can be used in a phase-shift analysis to test for several general properties of doorway states. For example, a doorway state will have many of the properties of a stationary state; in particular, the spin and parity of a doorway state are good quantum numbers. Further, in the neighborhood of an isolated doorway state, the scattering matrix (when averaged over an energy interval considerably larger than the widths and spacings of compound-nucleus states but smaller than the width of the doorway states) can be written in the form

$$\langle S(E) \rangle = S_{\phi} \left[1 - i \frac{\Gamma_d^{\uparrow}}{E - E_d + \frac{1}{2} i \Gamma_d} \right]. \quad (1)$$

Here $\langle S(E) \rangle$ is the energy-averaged scattering matrix element for elastic scattering in the channel with total spin J , channel spin s , and relative orbital angular momentum ℓ ; $\Gamma_d^{\uparrow}$ is the width of the doorway state for decay into this channel; Γ_d is the total width of the state; E_d is the apparent resonant energy; and S_{ϕ} is the matrix element for potential scattering.

Figure 2 shows the phase shifts obtained from the ^{19}F data. The energy dependences of the resonance values of $\eta_{J\ell s}$ and $\delta_{J\ell s}$ are reasonably well described by the doorway-state formalism, while the corresponding nonresonance values of the parameters are virtually independent of energy—also as expected for doorway states. Further, as shown in Fig. 3, the differential cross sections $\sigma(\theta)$ and the polarization cross sections $\sigma_p(\theta) = \sigma(\theta)P(\theta)$ calculated with these "phase shifts" are in good agreement with the measured values. Thus, these measurements are consistent with the interpretation of the observed intermediate structure as doorway states. In this connection, it is important to note that the parameters $\eta_{J\ell s}(E)$ and $\delta_{J\ell s}(E)$ were calculated from the data independently at each energy E and were not constrained to any predetermined energy dependence. A reasonably

Fig. 2. A phase-shift analysis of the differential cross section and polarization for neutrons scattered from ^{19}F . The top curve shows the energy dependence of the parameters $\delta(E)$ (in radians) and $\eta(E)$ (as described in the text) for those states that show the clearest resonance behavior. The phase shifts were calculated modulo π . However, in order to exhibit their energy dependence continuously in the neighborhood of a resonance, values are plotted in the interval $-\pi/4$ to π . The bottom curve shows the more constant energy dependence of the parameters for the other channels involved in the analysis. The arrows indicate the positions of the various resonances.

Fig. 3. Comparison of measured and calculated values of the differential cross section $\sigma(\theta)$ and the polarization cross section $\sigma_p(\theta)$. The calculations employed the "phase-shift" parameters shown in Fig. 2.

PARITY MIXING IN Hf^{180}

R. D. Lawson and R. E. Segel

In the past few years a great deal of effort has been expended to determine whether or not nuclear states have well defined parity. According to the "conserved vector current" theory, a state may have an abnormal parity component which can be as large as one part in 10^{13} . In this note¹ it is shown that nuclear systematics in deformed nuclei can sometimes be used to set an upper limit on the possible parity mixing; in fact, in the example discussed the systematics provide a more reliable estimate of the mixing than does the existing experiment.

The case in point is the decay of the 5.5-hour metastable 8^- state in Hf^{180} (Fig. 4). The 57.6-keV electric-dipole transition

Fig. 4. The low-lying states of Hf^{180} . The metastable 8^- level has a lifetime of 5.5 hours and decays 86% of the time to the 8^+ state via the emission of 57.6-keV radiation. The cross-over transition to the 6^+ state (501-keV transition) is a 14% branch. The 0^+ , 2^+ , 4^+ , 6^+ , and 8^+ levels form a $K=0$ rotational band which is referred to as the ground-state rotational band.

between this state and the 1085-keV 8^+ level is inhibited by a factor of about 10^{16} . Thus even if the probability of mixing an 8^+ contaminant into the 8^- state is only 10^{-13} , the emission of magnetic-dipole radiation should form an appreciable component of the 57.6-keV radiation provided it too is not inhibited. The L internal-conversion coefficient²

¹ R. D. Lawson and R. E. Segel, Phys. Rev. Letters 16, 1006 (1966).

² G. Scharff-Goldhaber and M. McKeown, International Conference on Weak Interactions, Argonne National Laboratory Report ANL-7130.

unique assignment $J^\pi = 1^-$ can be made for states at $E_d = 0.32, 0.82, 1.15$, and 1.51 MeV and $J^\pi = 0^-$ for states at $E_d = 0.45$ and 1.93 MeV. There is also an indication of a 2^- state at $E_d \approx 1.84$ MeV.

From the resonance values of η and δ (Fig. 2) we obtain the values $\Gamma_{d(Jls)}^\uparrow / \Gamma_{d(Jls)} = 0.60, 0.45, 0.50, 0.65, 0.76$, and 0.35 for the states at $E_d = 0.32, 0.45, 0.82, 1.15, 1.51$, and 1.93 MeV, respectively. Here $\Gamma_d^\uparrow$ is the width of the doorway state for decay into the entrance channel and Γ_d is the total width of the state. In the doorway-state interpretation, values of Γ_d considerably larger than $\Gamma_d^\uparrow$ indicate an appreciable damping of the doorway states into the more complex compound-nucleus states. Although there is some uncertainty associated with these values, there is good reason to conclude that a nonzero damping width can be assigned to at least the levels at $E_d = 1.15$ and 1.93 MeV. If so, the fine-structure peaks shown in the lowest curve in Fig. 1 can be interpreted as members of the next most complicated excitation in the hierarchy leading to the compound-nucleus states in ^{20}F .

for this transition has been measured. If one neglects penetration effects, the measurements are consistent with theory only if the transition has mixed parity (90.5% E1 + 9.5% M1).

The relevant part of the wave function for the 8^- state can be written

$$\psi_{8^-} = \psi_{K=8}^{8^-} + i g \phi_K^{8^+},$$

where g^2 is the probability that admixed into the 8^- level is an 8^+ state which can undergo M1 decay. Assuming that the admixed state is part of the ground-state rotational band and that the M1 transition proceeds at single-particle speed, one arrives at the conclusion that $g^2 = 3.5 \times 10^{-16}$. On the other hand, one can obtain a much smaller upper limit on g^2 from a knowledge of the properties of the 501-keV cross-over transition between the 8^- and 6^+ states. Angular-correlation studies³ show that this gamma ray is 3.6% quadrupole. If this value is taken as an upper limit on the electric-quadrupole component of this radiation, it may be used in conjunction with the measured gamma-ray lifetimes within the ground-state band to give $g^2 \leq 1 \times 10^{-17}$ —only a thirty-fifth of the value obtained from direct experiment. Even if the admixed 8^+ state is not part of the ground-state rotational band, the same arguments can be carried out—except that now the systematics of interband M1 and E2 transitions in this region have to be used. In each case one is led to an estimate of g^2 which is at least an order of magnitude smaller than that obtained from the conversion-coefficient experiment.

Thus nuclear systematics can be extremely useful in predicting the allowable parity-violating component in a nuclear wave function of a state that can decay by the emission of radiation of given multipolarity. It should be stressed, however, that neither experiment

³ E. Bodenstein, H. J. Körner, E. Gerdau, J. Radloff, C. Günther, and G. Strube, Z. Physik 165, 57 (1961).

nor the estimate based on systematics gives a direct measure of the probability of parity violation alone. Rather, what is measured is the product of the fraction of parity-violating component and the probability that the nuclear state has a part which can decay by the emission of radiation of given multipolarity. These two factors must, of course, be separately estimated before comparison with the predictions of the conserved vector current can be made.

PHOTOIONIZATION MASS SPECTROMETRY

J. Berkowitz, W. A. Chupka, and W. Jivry

The new mass spectrometer for photoionization studies is now in routine use on a variety of problems. As described in an earlier report,¹ the apparatus consists of a commercial vacuum ultraviolet monochromator attached to a mass spectrometer with high transmission and sensitivity. The photon sources include the many-line spectrum of hydrogen and the continua of argon and helium. These give usable photon intensities over the entire wavelength region from the visible down to about 550 Å, the latter corresponding to a photon energy of about 22.5 eV.

The abrupt thresholds of photoionization phenomena and the high resolution associated with the sharp photon energies available make photoionization techniques very advantageous in the measurement of many quantities of interest in chemical physics. The problems of getting sufficiently intense continuous sources in the vacuum ultraviolet, of using windowless sources at photon energies above about 11 eV, and of obtaining sufficiently intense ion beams have been largely overcome in this instrument. Its sensitivity has proved to be about 100 times that of previous ones of its type. Its versatility and effectiveness are illustrated by the following examples of work done in the past few months.

Stable Gases. The ionization efficiency curves for parent ions and all important fragment ions have been measured for alkanes (methane, ethane, propane, and n-butane) and for alcohols (methanol, ethanol, propanol, and n- and iso-butanol). Thresholds for various fragmentation processes have been obtained with improved accuracy. The data have been used to construct breakdown curves (Fig. 5), which are plots of the probability for production of the various fragments as a

¹ Physics Division Summary Report, April—December 1965, ANL-7108, p. 57.

Fig. 5. Breakdown curves for the propane ion. The ordinate is the probability of forming the indicated ion; the abscissa is the sum of the internal energy of the propane ion and its ionization potential. As seen from the curves, the most important fragmentation processes are dissociation of $C_3H_8^+$ into $C_3H_7^+ + H$, $C_2H_4^+ + CH_4$, and $C_2H_5^+ + CH_3$.

The dissociations become energetically possible in this order. But since the second involves rearrangement of the hydrogens whereas the third is a simple bond-breaking process, the latter becomes the dominant process almost as soon as it becomes energetically possible.

function of the internal energy content of the parent molecular ion.

These have been compared with predicted curves based on the statistical theory of mass spectra. Fair to good quantitative agreement was found. Similar measurements on the gases H_2O , H_2O_2 , H_2S , CF_4 , and C_2F_2 gave improved values of the ionization potential and dissociation energy of the OH radical and a first measured value (2.51 eV) of the electron affinity of the SH radical.

Free Radicals. The photoionization efficiency curve for the CF_3 radical was measured for the first time. The adiabatic ionization potential was found to be 9.25 eV. The shape of the curve shows clearly that the geometrical structures of the radical and its ion are greatly different and hence the "vertical" ionization potential is very much higher (~ 11.0 eV) than the adiabatic. This finding clears up long-standing discrepancies in earlier work.

The photoionization of the CH_3 radical shows some interesting structure, possibly due to auto-ionization. A precise measurement of the threshold for formation of CH_2^+ from CH_3 yields the first precise value (87.8 kcal/mole) for the heat of formation of the methylene radical CH_2 .

High-Temperature Vapors. Photoionization of vapors of NaI, MgI_2 , TlI, and Te have yielded accurate values of ionization potentials of various molecular species and heats of formation of several ionic fragments. Very accurate dissociation energies were obtained for the molecules TlI (2.77 eV) and Te_2 (2.64 eV). This technique should be applicable to a large number of such high-temperature molecules and should yield data with much higher precision than those conventionally determined by electron-impact or thermodynamic methods.

Ion-Molecule Reactions. In this study, the reactant ions were produced in different vibrational and electronic states by photons with various wavelengths and were accelerated to energies ranging from thermal to 400 eV. The various endoergic and exoergic reactions investigated included those of O_2^+ with H_2 and with He and of H_2^+ with He and with H_2 . Very large variations in reaction cross section as a function of internal excitation were observed. In most cases, as expected from simple theoretical considerations, the cross sections for endoergic reactions increase with increasing internal energy while the opposite is true for exoergic reactions. However, several exceptions and other unpredictable behavior have been observed. The observations also lead to new and more accurate experimental values for the energies of formation of the important H_3^+ and HeH^+ ions. Formation of H_3^+ by the reaction of excited H atoms with H_2 molecules was also observed for the first time.

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 Minneapolis, 20—22 June 1966

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

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

Bull. Am. Phys. Soc. 11, 477 (June 1966)

The Doppler-shift technique was used to measure the lifetime of the $\frac{3}{2}^-$ third excited state at $E_x = 2.468$ MeV in Ca^{41} . This state was formed by the $\text{K}^{41}(p,n)\text{Ca}^{41}$ reaction through a resonance, 55 keV above threshold, at $E_p = 3.815$ MeV. The preponderant¹ 519-keV gamma ray to the 1.949-MeV first excited state was observed at 0° and at 90° with a Ge(Li) detector. Background (especially the troublesome 511-keV annihilation radiation) was reduced by requiring coincidence with the 1.949-MeV gamma [detected by a large NaI(Tl) crystal]. The recoils were stopped in KCl backed by carbon (or, in some 90° observations, by lead). The observation that the shift was $\lesssim 1/5$ of the full shift implies $\tau \gtrsim 7.0 \times 10^{-13}$ sec. Combining this with the recent measurement² of a 1% upper limit for the ground-state branch yields $|M|^2 \lesssim 0.02$

*Indiana University.

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

²L. L. Lee, Jr., R. E. Segel, E. F. Kennedy, and J. P. Schiffer, private communication.

for the ratio of the transition probability to the single-particle estimate for this $E2 \frac{3}{2}^- \rightarrow \frac{7}{2}^-$ transition. The third excited state thus differs from the first (also $\frac{3}{2}^-$), for which a similar measurement³ gave about a quarter of the full shift. This yields a mean life of $(4.5 \pm 1.0) \times 10^{-13}$ sec and consequently $|M|^2 = 7$.

³P. P. Singh, R. H. Siemssen, R. E. Segel, and S. I. Baker, Bull. Am. Phys. Soc. 10, 1115 (1965).

INTERMEDIATE STRUCTURE OBSERVED IN NEUTRON CROSS SECTIONS

J. E. Monahan

Invited paper listed by title only: Bull. Am. Phys. Soc. 11, 451 (June 1966)

Many cross sections, when measured as functions of incident-particle energy, show a resonance-like structure. Some of these resonances are observed to have widths that are larger than the widths usually associated with states of the compound nucleus but are considerably smaller than the widths expected for single-particle resonances. The following is a description of some experimental and theoretical investigations of this intermediate structure by the author in collaboration with A. J. Elwyn, R. O. Lane, A. Langsdorf, Jr., and F. P. Mooring.

It has been suggested by Block and Feshbach¹ and by Kerman, Rodberg, and Young² that such intermediate structure might be associated with some particularly simple mode of excitation of the nucleus and that these simple excitations act as doorways to the more

¹B. Block and H. Feshbach, Ann. Phys. (N.Y.) 23, 47 (1963).

²A. K. Kerman, L. A. Rodberg, and J. E. Young, Phys. Rev. Letters 11, 422 (1963).

complex compound-nuclear states. In its simplest form this idea is based on two assumptions. First, that the initial state of the target nucleus can be described by a simple shell-model configuration and second, that the residual interaction that couples the entrance channel to excitations of the compound system can be represented as a sum of two-body forces. For such a system only simple configurations—namely those made up of at most $2p-1h$ excitations relative to the initial state of the target—are directly coupled to the incident channel. These simple configurations thus act as doorways through which the system must pass in the formation of compound-nuclear states. If the doorway states are sufficiently separated in energy relative to the strength of their coupling to the more complex excitations, such states should be observable as structure in the corresponding cross section.

It is, of course, possible to generalize this definition of a doorway state by the choice of other models for the description of the target nucleus. However, in the present context, the question of models is of more than academic interest only if doorway states can be isolated and their properties measured. The question we wish to consider, therefore, is whether observed intermediate structure can be interpreted as doorway states. As far as possible, we avoid the introduction of any particular nuclear model.

One of the more obvious consequences of the doorway concept is that the width of the doorway state should be intermediate between the width of a single-particle state and that of the actual states of the compound nucleus. Shortly after this idea was proposed, a considerable amount of neutron data, which seemed to show intermediate structure, was interpreted as evidence for the observability of doorway states. On closer examination, however, most of this structure was shown to be caused by poor counting statistics and other experimental instabilities. At present, it seems reasonably clear³ that doorway

³A. D. Carlson and H. H. Barschall, Proceedings of the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, 1965, paper [101].

Fig. 6. The total cross section σ_T , the capture cross section σ_c , and the square root of the second moment of the cross section for molybdenum.

states are not observed in neutron scattering from most heavy nuclei—at least for neutron energies such that several partial waves contribute significantly to the scattering. Further, it is clear that a somewhat detailed analysis of the scattering data is necessary to distinguish possible doorway-state structure from similar structure caused by ordinary statistical fluctuations in the widths and spacings of the compound-nuclear levels.

Two types of neutron scattering measurements made at Argonne exhibit the type of correlated structure that is expected for doorway states. The first of these is a so-called self-indication measurement that gives the first and second moments of a cross section with respect to the energy spectrum of the beam of incident neutrons.

Self-Indication Measurements

Figure 6 shows data on the scattering of neutrons from Mo (of natural isotopic composition) over a range of neutron energies from 200 to ~300 keV. This type of experiment gives a measure of the cross section averaged over the energy spectrum of incoming neutrons, namely

$$\sigma_T \equiv \langle \sigma_T \rangle = \frac{1}{\Delta} \int_{\Delta} dE \sigma(E), \quad (1)$$

where Δ is the energy spread of the neutron beam (~ 10 keV in these measurements). The self-indication measurement simultaneously gives a measure of the corresponding variance or second moment of the cross section within the resolution width Δ , i. e.,

$$\langle \delta^2 \rangle = \text{var } \sigma_T = \frac{1}{\Delta} \int_{\Delta} dE [\sigma_T(E) - \langle \sigma_T \rangle]^2. \quad (2)$$

As indicated in Fig. 6, $\langle \delta^2 \rangle \approx 4 \text{ b}^2$ for Mo over the interval from 200 to 300 keV. The fine structure in $\sigma_T(E)$ that contributes to $\langle \delta^2 \rangle$ is undoubtedly composed of resonances having widths much smaller than the 10-keV spread Δ .

In addition to this fine structure, there exists a resonance-like structure in the average cross section $\langle \sigma_T \rangle$. As shown in Fig. 6, this structure has an average amplitude of about 0.5 b above background and an average width of about 30 keV. This structure in the average cross section will be called "intermediate structure" in the discussion that follows.

First consider the possibility that this intermediate structure can be explained in terms of expected statistical fluctuations in the parameters that describe compound-nuclear levels. Let $\langle \sigma_T \rangle_i$ denote a single measured value of the average cross section, Eq. (1), at a mean neutron energy E_i and let $\mathcal{E}\{\langle \sigma_T \rangle_i\}$ be the average of a sequence of such values for energies $E_1, E_2, \dots, E_N$ where $E_{i+1} - E_i = \Delta$. The sum of the individual beam-energy spreads Δ thus covers the entire energy interval being considered. A measure of the intermediate structure in the average cross section that is expected from various assumed statistical distributions for the widths and spacings of levels of the compound nucleus is given by the relation⁴

⁴A. Agodi and G. Pappalardo, Nucl. Phys. 47, 129 (1963). In the present work the results obtained in this paper are generalized to consider fluctuations in level widths as well as in level spacings.

$$\mathcal{E}\{[\langle\sigma_T\rangle_i - \mathcal{E}\{\langle\sigma_T\rangle_i\}]^2\} \approx K(\pi\lambda^2)^2 \sum_i f_i^2 \sum_{J_i} g_{J_i}^2 \left[\sum_{\ell s} T_{\ell s}^{J_i} \right]^2 D_{J_i} / \Delta, \quad (3)$$

where f_i is the relative abundance of the i th isotope of the target, g_J is the usual spin factor, D_{J_i} is the average spacing of levels of given spin and parity, and Δ is the energy spread that is associated with the measured values $\langle\sigma_T\rangle_i$ in Eq. (1). The transmission coefficients are defined in terms of the corresponding elements of the scattering matrix by the relation

$$T_{\ell s}^{J_i} = 1 - |\langle \mathcal{S}_{\ell s}^{J_i} \rangle|^2. \quad (4)$$

Finally K is a constant whose value depends on the particular distributions that are assigned to the widths and spacings of the levels of the compound nucleus. For distributions that are believed reasonable it can be shown that

$$1 < K \leq 3. \quad (5)$$

A formula for $\text{var } \sigma_T$, as defined in Eq. (2), has been derived by Thomas.⁵ This is

$$\text{var } \sigma_T \approx 2(\pi\lambda^2)^2 \sum_i f_i^2 \sum_{J_i} g_{J_i}^2 \sum_{\ell s} T_{\ell s}^{J_i}. \quad (6)$$

Equation (6) follows immediately from the results given by Thomas if the additional assumption of random signs is made for the reduced-width amplitudes of the compound-nuclear states.

These relations (3) and (6) have been used as follows to analyze the scattering data for Mo (Fig. 6). The transmission coefficients $T_{\ell s}^J$ were calculated by use of an optical-model potential that was obtained by fitting previously measured⁶ angular distributions

⁵R. G. Thomas, in Statistical Theories of Spectra: Fluctuations, edited by C. E. Porter (Academic Press, Inc., New York, 1965), p. 563.

⁶A. J. Elwyn, R. O. Lane, A. Langsdorf, Jr., and J. E. Monahan, Phys. Rev. **133**, B80 (1964).

and polarizations of neutrons scattered from Mo at slightly higher energies. For these T_{ls}^J , Eq. (6) gives $\text{var } \sigma_T \approx 3.7 \text{ b}^2$. This is in reasonably good agreement with the measured values which average about 4 b^2 .

Using these transmission coefficients together with the measured values $\langle \sigma_T \rangle_i$, we obtain from Eq. (3) a value for the maximum number of levels in isotope i of given spin and parity—namely Δ/D_{Ji} —that can exist in the interval Δ and still give rise to the observed intermediate structure. For Mo at these energies we find that the average spacing in each isotope must be at least 150 eV if the observed structure is to be explained in terms of statistical fluctuations. The average level spacing in Mo for neutron energies below 10 MeV has been measured to be 21 eV by the group at Columbia University.⁷ Since there are seven isotopes of Mo for which $f_i \gtrsim 0.1$, this measured value is consistent with spacings of 100–140 eV in each isotope. Thus the amplitude of the fluctuations in $\langle \sigma_T \rangle$ can be explained in terms of statistical fluctuations in level parameters.

Still it is difficult to explain the widths of 15–20 keV observed in the measurements of $\langle \sigma_T \rangle$. To make this more quantitative we have considered the ordered sequence of signs obtained by taking differences of successive values of the measured cross section $\langle \sigma_T \rangle_i$, i.e., $\{\text{sgn}[\langle \sigma_T \rangle_i - \langle \sigma_T \rangle_{i+1}] \mid i = 1, \dots, n\}$. This can be shown to be a random sequence if the assumptions leading to Eq. (3) are valid. We have been able to show that on the basis of these assumptions the sequence actually obtained from the Mo measurements should be observed with a probability of ~ 0.1 . Almost identical results are obtained from an analysis of measured values of $\langle \sigma_T \rangle_i$ for tin targets over the range of neutron energies from 300 to 500 keV. Thus these measurements indicate a significant correlation that is not expected from the simple

⁷J. Rainwater, S. Winchank, W. W. Havens, Jr., and J. B. Garg, International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, 1965.

Fig. 7. The total cross section σ_{tz} , the capture cross section σ_{az} , and the square root of the second moment of the cross section for silver.

statistical considerations leading to Eq. (3). On the other hand, this is the type of correlation associated with doorway states.

Figure 7 shows the same type of self-indication measurements for neutrons scattered from Ag. Here there is no evidence of any structure other than the fine-structure fluctuations that contribute to the value of $\text{var } \sigma_T$. In Figs. 6 and 7 the lines through the data points are drawn merely as a reference and have no theoretical significance. Also shown in Figs. 6 and 7 are measured values of the capture cross section. These have no relevance to the present discussion.

Angular Distributions and Polarizations

We now consider a different kind of experiment, namely the measurement of angular distributions and polarizations of neutrons scattered from various target nuclei. Some of these data clearly exhibit an intermediate structure. These data and the analysis that has been made in an attempt to identify this structure are described below.

Figure 8 shows the neutron scattering cross sections⁸ (integrated over angle) as functions of energy for five target nuclides with mass number ranging from 19 to 31. The observed resonance peaks

⁸A. J. Elwyn, J. E. Monahan, R. O. Lane, and A. Langsdorf, Jr., Nucl. Phys. 59, 113 (1964).

Fig. 8. The neutron scattering cross sections (integrated over angle) vs energy for F, Na, Mg, Al, and P.

have widths of about 150 keV and are spaced about 300—400 keV apart. The corresponding angular distributions and polarizations of neutrons scattered from these

targets show definite correlations that are qualitatively of the type that would be expected if these levels are actually doorway states.

The 150-keV average width of this structure is nearly equal to the energy spread in the beam of incident neutrons used in these measurements. In order to determine whether this structure—or more specifically, whether the observed width of these peaks—is simply a reflection of the spread in beam energy, the total cross sections of Al and F were remeasured with neutron beams having an energy spread of about 20 keV. The Al results are shown in Fig. 9.

Fig. 9. The total cross section σ_t for aluminum. The lowest curve is the cross section measured with a resolution width of 15—20 keV. The curves above it are numerical averages of these data, taken over successively larger averaging intervals ΔE as noted.

Fig. 10. The total cross section σ_t for fluorine. The description is the same as for Fig. 9.

scattering system and is not simply a reflection of the energy spread in the incoming neutron beam.

Figure 10 shows the cross section of F, also measured with an energy resolution width of 15—20 keV. These results are similar to those obtained for Al and the same conclusions can be drawn.

It should be noted that the widths of the fine-structure peaks shown in the lowermost curves in Figs. 9 and 10 are also of the same order of magnitude as the corresponding resolution widths ΔE . Thus even the "good-resolution" measurements give only an upper limit for the width of the fine structure. From these data, however, it is obvious that there are several levels having widths $\lesssim 20$ keV in the immediate neighborhood of each of the intermediate-structure peaks.

The lowermost curve in Fig. 9 shows the cross section of Al measured with an energy resolution width of 15—20 keV. The remaining curves are numerical averages of these data taken over successively larger averaging intervals ΔE , the values of which are noted. As shown, the observed fine structure is almost completely "averaged out" for $\Delta E \approx 60$ keV while the intermediate structure observed in the original angular distribution and polarization measurements (Fig. 8) is relatively insensitive to the averaging for $\Delta E \lesssim 200$ keV. Thus the 100—150 keV width of this structure seems to be an intrinsic property of the

The angular distribution and polarization data can be used to test for general properties that distinguish doorway states from statistical fluctuations. For example, a doorway state will have many of the properties of a stationary state; in particular, the spin and parity of a doorway state should be good quantum numbers. Further, in the neighborhood of an isolated doorway state, the scattering matrix (when averaged over an energy interval large compared with the widths and spacings of the compound nuclear states but small compared with the width of the doorway state) takes the simple form

$$\langle S(E) \rangle = S_{\phi} \left[1 - i \frac{\Gamma_d^{\uparrow}}{E - E_d + \frac{1}{2} i \Gamma_d} \right]. \quad (7)$$

Here $\langle S(E) \rangle$ is the energy-averaged scattering matrix element (for a given channel $J\ell S$), $\Gamma_d^{\uparrow}$ is the width of the corresponding doorway state for decay into the continuum, Γ_d is the total width of the state, and S_{ϕ} is the matrix element for potential scattering. More specifically, S_{ϕ} describes the scattering from the single-particle potential obtained by taking the expectation value of the total Hamiltonian with respect to the ground state of the target nucleus. Thus, in practice, S_{ϕ} is somewhat model dependent. In the calculations described below, we set S_{ϕ} equal to $e^{-2i\phi_{J\ell}}$, where $\phi_{J\ell}$ is the phase shift for scattering from a hard sphere of radius $a_{J\ell}$. The values of $a_{J\ell}$ were determined by fitting the measured angular distributions and polarizations of energies at which the intermediate structure is a minimum.

Figure 2 (p. 4) shows the results of a phase-shift analysis of the F data in terms of real parameters $\eta(E)$ and $\delta(E)$ defined by the relation

$$\langle S(E) \rangle = \eta(E) e^{-2i\delta(E)}, \quad (8a)$$

or equivalently,

$$2(\delta - \phi) = \tan^{-1} \left\{ \frac{(E - E_d) \Gamma_d^\uparrow}{(E - E_d)^2 + \frac{1}{4} \Gamma_d (\Gamma_d - 2\Gamma_d^\uparrow)} \right\}, \quad (8b)$$

and

$$\eta = \left[\frac{(E - E_d)^2 + \frac{1}{4} (\Gamma_d - 2\Gamma_d^\uparrow)^2}{(E - E_d)^2 + \frac{1}{4} \Gamma_d^2} \right]^{1/2}. \quad (8c)$$

In principle, this analysis should give estimates for the widths $\Gamma_d^\uparrow$ and Γ_d associated with each doorway state d . Also we should be able to determine the spin and parity of each doorway state—provided, of course, that the angular distributions and polarizations observed in the neighborhood of these intermediate resonances behave as predicted by Eqs. (8).

The lowermost curve in Fig. 2 is the measured total cross section for F . This is simply a duplication of the corresponding curve in Fig. 8 and is repeated here so that $\eta(E)$ and $\delta(E)$ can be easily compared with the structure in the measured cross section. The arrows indicate the positions E_d of possible resonance structure. In Fig. 2, these arrows are duplicated on the center curves, which show the behavior of the damping parameter $\eta_{J\ell S}(E)$ for the various values of spin, parity, and channel spin indicated at the top of the figure. The arrows are duplicated again in the upper curves which show the behavior of the corresponding phase shifts $\delta_{J\ell S}(E)$. Thus, for example, in the neighborhood of $E = 1.15$ MeV, $\eta_{110}(E)$ goes through a minimum at about the same energy as the corresponding phase shift $\delta_{110}(E)$ reaches $\pi/2$.

In general the energy dependence of the resonant $\eta_{J\ell S}$ and $\delta_{J\ell S}$ is reasonably well described by Eqs. (8a) and (8b) and the nonresonant parameters are virtually constant with energy. Thus, the measured angular distributions and polarizations are consistent

with the interpretation of this intermediate structure as doorway states. In this connection, it is important to note that the parameters $\eta_{J\ell S}(E)$ and $\delta_{J\ell S}(E)$ were calculated from the data independently at each energy E and were not constrained to any predetermined energy dependence. A reasonably unique assignment of spin and parity 1^- can be made for the states at $E_d = 0.32, 0.80, 1.15$, and 1.52 MeV and 0^- for the state at $E_d = 1.95$ MeV.

Associated with almost every phase-shift analysis there is a list of qualifications and reservations, and this is no exception. Our starting assumption was that only s and p waves contribute to the scattering over the entire energy interval covered by these data. Also, the calculations were biased to the extent that our search of parameter space was confined mostly to regions in which only one or two of the phase shifts are near their resonant values. Within these limitations, however, we feel reasonably confident that no other spin and parity assignments fit the data nearly as well as those given above. Also, we believe that the qualitative behavior obtained for the resonant phase shifts is correct.

Any quantitative results, however, are more suspect. From the values of $\eta_{J\ell S}(E)$ shown in Fig. 2, we obtain a value for the ratio $[\Gamma_{d(J\ell S)}^\uparrow / \Gamma_{d(J\ell S)}]$ that is only slightly larger than 0.5 for most of the levels. This would indicate an appreciable damping of the doorway states into the more complex compound-nuclear states. Unfortunately, in the case of F there is another contribution to the total width Γ_d , namely that associated with inelastic neutron scattering. This, of course, obscures any estimate of the damping width. However, the inelastic scattering decreases sharply for neutron energies above ~ 0.5 MeV so there is some indication of a nonzero damping width, at least for the levels at $E_d = 1.15$ and 1.52 MeV. If this argument is accepted, it is possible to interpret the fine-structure levels shown in Fig. 10 as members of the next hierarchy of excitation—for example, $3p-2h$ states in the simple shell-model picture described earlier.

In an evaluation of average cross sections in terms of energy-averaged scattering amplitudes, it is necessary to consider the so-called "fluctuation cross section" σ^{fl} , where

$$\sigma^{\text{fl}} \propto \langle |S|^2 \rangle - |\langle S \rangle|^2. \quad (9)$$

This cross section represents the contribution to the measured scattering that is not taken into account when S is simply replaced by $\langle S \rangle$ in the expression for the scattering cross section. An inequality satisfied by σ^{fl} is

$$0 < \sigma^{\text{fl}} < \sigma_c, \quad (10)$$

where σ_c is the usual optical-model compound-nucleus-formation cross section. Since a nonzero value for σ^{fl} arises solely from the averaging, it is obvious that $\sigma^{\text{fl}} \rightarrow 0$ as the averaging interval approaches zero.

In the analysis of the F data, we consistently (i.e., at all values of neutron energy) obtain a better fit to the data for values of σ^{fl} near zero. In fact, for values of σ^{fl} large enough to produce noticeable differences in the values of the phase shifts, significantly poorer fits to the observed angular distributions and polarizations are obtained.

Figure 3 (p. 4) shows a comparison between the measured angular distributions and polarizations and the values calculated from the phase shifts shown in Fig. 2. The relatively poor agreement for the polarized cross section $\sigma_p(\theta)$ at back angles for neutron energies above 1 MeV is probably caused by our neglect of d waves in the analysis.

The same type of angular distribution and polarization measurements has been made for neutrons scattered from Fe and Cr. Here again we observe an intermediate structure characterized by an average width that is considerably larger than the energy spread ΔE of the neutron beam. The results for Cr are shown in Fig. 11.

A phase-shift analysis is being made for these data. Thus far we have obtained preliminary results for the first few levels

of Cr. These levels can be assigned spin and parity $\frac{1}{2}^+$. Since these are zero-spin targets and the data cover a range of energies at which there is no inelastic scattering, we hope here to avoid some of the ambiguities that remain in the analysis of the F data.

One aim of this work has been an attempt to isolate those regions of mass

number and excitation energy in which intermediate structure is observed. There is little doubt, we believe, that such structure is observed. Further, the present results indicate (1) that this structure shows correlations that are not explained by statistical arguments, and (2) that the angular distributions and polarizations measured near an intermediate-structure peak are consistent with the doorway-state interpretation of this structure.

As mentioned above, we have avoided the specification of a nuclear model in this analysis. Ultimately, however, the validity of the doorway-state concept—and certainly its practical value in the study of nuclear structure—depends on detailed calculations based on such models. If quantum numbers and widths can be established for this structure, the value of such calculations becomes apparent.

Fig. 11. The differential cross section and polarization cross section of chromium at $\theta = 22^\circ$. The description is the same as for Fig. 9.

International Symposium on Organic Scintillators
Argonne National Laboratory, 20-22 June 1966

NEW LIQUID SCINTILLATORS WITH FASTER RESPONSE AND HIGHER EFFICIENCY

Frank J. Lynch

The variation of light intensity with the time following excitation by gamma rays has been measured for a quaterphenyl compound whose solubility was enhanced by substitution of alkyl groups. The decay curves, measured by use of a probability-sampling technique, were analyzed to yield preliminary estimates of the time constants τ_1 related to energy transfer from solvent to solute, τ_2 related to the rapidly decaying component from the singlet state, and τ_3 related to the slower component which is probably due to excimers. A solution (~ 65 g/liter, $\gamma = 1.12 \times 10^{-2}$) of 1,4-bis (2-butyloctyloxy)-p-quaterphenyl (QP-G12) in toluene shows $\tau_1 \approx 0.05$ nsec, $\tau_2 \approx 1.4$ nsec, and $\tau_3 \approx 11.4$ nsec (Fig. 12). The intensity of the slow component (mean life τ_3) is

Fig. 12. Measured intensity of light from QP-G12 in toluene ($\gamma = 1.12 \times 10^{-2}$). The curve on the left shows data points with the background subtracted and the theoretical slow curve super-

imposed. The curve on the right shows the data points after subtraction of the slow component. The theoretical curve was fitted by visual inspection.

about 20% of that of the fast component (mean life τ_2). This is about a third of the slow/fast ratio measured for 2,5-diphenyloxazone (PPO) in toluene at the same mole fraction. This indicates that QP-G12 does not form excimers as readily as PPO does. For both solutes, measurement shows that τ_1 varies about as the reciprocal of the concentration, as

TABLE I. The time constants τ_1 , τ_2 , and τ_3 for the three components of the scintillation and the ratio of the intensities of the slow (τ_3) and fast (τ_1 and τ_2) components for different concentrations γ of the two solutes.

Solute	γ	τ_1 (nsec)	τ_2 (nsec)	τ_3 (nsec)	Slow/fast
PPO	9.5×10^{-4}	1.65	1.6	7.1	0.09
	5.3×10^{-3}	0.2	1.6	7.1	0.31
	2.5×10^{-2}	0.1	1.6	7.9	1.01
	5.6×10^{-2}	0.1	2.4	9.2	1.4
QP-G12	7.1×10^{-4}	1.1	1.4	11.4	0.05
	1.12×10^{-2}	0.05	1.4	11.4	0.2

expected. For the same mole fractions, moreover, the fact that the value of τ_1 for QP-G12 is only about half that for PPO indicates that the rate of transfer from solvent molecule to solute is higher for QP-G12 than for PPO. The results of the measurements on QP-G12 and PPO are shown in Table I. The QP-G12 has a higher light output and shorter τ_1 and τ_2 than the plastic Naton 136 which is commonly used for delayed-coincidence measurements. Preliminary attempts to exploit this advantage led to improved time resolution; for 511-keV gamma rays, the full width at half-maximum was about 0.25 nsec and the slope of the decay curve was $T_{1/2} \approx 0.037$ nsec.

American Physical Society MeetingMexico City, 29—31 August 1966SU₃ MODEL IN LIGHT NUCLEI

Akito Arima

Invited paper listed by title only: Bull. Am. Phys. Soc.
11, 765 (July 1966)

PLOTING THE CURRENT-VOLTAGE RELATION FOR CORONA

Alexander Langsdorf, Jr.

Bull. Am. Phys. Soc. 11, 746 (July 1966)

Equations relating current i to voltage V for the approximately steady dc flow of space-charge-limited homopolar corona were derived by Townsend¹ and later by many others,² always with simplifying assumptions such as that the coordinate variables are separable. For such equations one may demonstrate that as i increases, a plot of $\sqrt{i}$ vs V should approach linearity for a variety of plausibly achievable conditions. A large amount of data, old and new, thus plotted conforms to this expectation surprisingly well for either polarity, and for a wide range of electrode sizes, shapes, and spacings and of gas compositions and pressures, etc. —even when the conditions may not accord with the assumptions made in deriving the relation.

In 1913, Langmuir³ studied the similar space-charge limiting of electron current in a high vacuum and demonstrated that the maximum current flow should vary as the three-halves power of the voltage, regardless of the shapes of the electrodes. J. E. Monahan⁴

¹ J. S. Townsend, Phil. Mag. 28, 83 (1914).

² For example, N. N. Tikodeev, Zhur. Tekhn. Fiz. 25, 1449 (1955).

³ I. Langmuir, Phys. Rev. 2, 450 (1913).

⁴ J. E. Monahan (private communication).

has shown that, similarly, the voltage dependence of the square root of the maximum corona current should be linear for any electrode configuration, if several reasonable conditions are fulfilled. These conditions include the following: (1) The thin ion-producing zone surrounding one electrode does not change in area. (2) The other electrode is inert, i. e. , no ions or electrons are emitted from it, nor produced near it. (3) The potential drop across the ion-producing zone is (nearly) independent of the current. (4) There exists an ion mobility which is independent of electric field strength. (5) There is sufficient space charge so that the electric field strength at the surface of the ion-producing zone is of no importance. (6) In the region occupied by space charge, there is a great preponderance of ions of one sign only. This implies that there must be very little if any photoionization in the bulk of the gas, and but little emission of ions or electrons from the inert electrode.

Plots of $\sqrt{i}$ vs V are convenient displays which make deviations from the usual linearity most conspicuous. This is an aid to disclosing and explaining the occasional unusual and complex behavior of corona systems—either because any of the above six conditions fail to apply or for some other reasons. Further work will be required before one can satisfactorily explain why the relation between $\sqrt{i}$ and V is so often found to be linear. This linearity is especially surprising for corona discharges from negative wires; though often visibly inhomogeneous and unstable, these discharges conform fairly well to the linear relation.

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III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATION

MOLECULAR COMPOSITION OF SULFUR VAPOR

J. Berkowitz

in Elemental Sulfur (Interscience Publishers, 1965)

The discussion is divided into the following sections.

- I. Historical Background. II. The Mass-Spectrometric Method.
- III. Current Experiments—A. General considerations. B. Highest temperature: CaS, SrS, FeS, and the dissociation energy of S_2 .
- C. Intermediate Temperatures: ZnS, CdS, HgS, and the progressive complexity of the vapor. D. Low temperatures: extrapolation of HgS equilibria to pure sulfur. E. Free energies of formation.
- IV. Interpretation of Results. V. Kinetic Aspects of Sulfur Vaporization.
- VI. Evaporation Coefficients of S_6 and S_7 from Orthorhombic Sulfur.
- VII. Molecular Configuration of Sulfur Vapor Species. VIII. The Formation of Mixed Sulfur-Selenium Molecules. The discussion is supplemented with 12 tables, 8 figures, and a bibliography of 42 references.

PHOTOIONIZATION OF HIGH-TEMPERATURE VAPORS. I. THE IODIDES OF SODIUM, MAGNESIUM, AND THALLIUM

J. Berkowitz and W. A. Chupka

J. Chem. Phys. (15 August 1966)

A vacuum ultraviolet monochromator, a mass spectrometer, and a molecular-beam source of high-temperature vapors have been combined to obtain photoionization efficiency curves of high-temperature species. In the TII system, the ions Tl^+ , I^- , and TII^+ were observed. Two independent threshold processes yield 2.77₀ eV and 2.76₉ eV for $D_0(TII)$. The ions Na^+ , NaI^+ , Na_2I^+ , $Na_2I_2^+$, and $Na_3I_2^+$ were detected in NaI vapor. The threshold for Na^+ yields 3.00 eV for $D_0(NaI)$. No negative ions were observed in NaI vapor. The ions MgI_2^+ and MgI^+ were measured in MgI_2 vapor, the latter providing a basis for estimates of the energies for successive removal of I atoms from MgI_2 . The ionization potentials of TII, NaI, Na_2I_2 , and MgI_2 are found to be 8.46₉, 7.64, 7.64, and 9.57 eV.

ANGULAR DISTRIBUTION OF VALENCE-SHELL PHOTOELECTRONS

J. Berkowitz and H. Ehrhardt*

Phys. Letters (15 June 1966)

It has been known for many years that the angular distribution of photoelectrons (relative to the direction of the incident photons) depends upon the quantum numbers n and l of the shell from which the electrons are ejected. However, experimental work has been confined to the x-ray range, where K- and L-shell electrons are ejected; and the theoretical treatments have considered only systems with central fields (i. e. , atoms—not molecules) and have ignored autoionization. To examine the behavior of outer-shell electrons experimentally, a collimated beam of He resonance light (584 Å) was passed perpendicularly through a molecular beam. The photoelectron detector was a simple retarding field, followed by an electron lens and multiplier. Among the rare gases studied, the angular variation is most rapid for Xe, intermediate for Kr, and least for Ar—although a p electron is ejected in each case. Each has its maximum at 90° with respect to the incident light, with possibly a small asymmetry in the distribution favoring the backward direction. Preliminary measurements in N_2O indicate an angular distribution that is either isotropic or has a shallow minimum at 90° .

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NOTES ON DOPPLER-SHIFT LIFETIME MEASUREMENTS

A. E. Blaugrund

Nucl. Phys.

By use of the universal scattering cross section derived by Lindhard et al., the velocity of an ion in a scattering medium is calculated as a function of time. The effect of both electronic and atomic collisions is included. In addition, the average scattering angle (in the laboratory system) resulting from multiple atomic collisions is derived. It is shown that in most cases the attenuation of the Doppler shift as a result of the changed direction of the scattered nucleus is more important than the effect of slowing down due to atomic collisions. In fact, at low velocities and for heavy scatterers the change in the direction of motion is the dominating factor. The results are given in a form amenable to numerical analysis. In the limiting

cases of (1) very short lifetimes and (2) predominantly electronic scattering, the average Doppler shifts are given in an analytical form.

DEBYE-WALLER FACTOR FOR THE CESIUM ION IN THE CESIUM HALIDES BY MEASUREMENT OF THE MÖSSBAUER EFFECT IN Cs^{133}

A. J. F. Boyle and G. J. Perlow

Phys. Rev. (4 November 1966)

The cesium halides have been studied in further Mössbauer measurements employing the 81-keV transition in Cs^{133} at 4.2°K. The values obtained for the recoilless fraction f_a are $100 f_a = 1.59 \pm 0.06$ for CsF, 1.45 ± 0.07 for CsCl, 1.35 ± 0.07 for CsBr, and 0.94 ± 0.08 for CsI. The characteristic temperature Θ_M defined by $f_a = \exp(-3E_r/2k\Theta_M)$ has the value (in °K) 109 ± 1 for CsF, 106 ± 1 for CsCl, 104 ± 1 for CsBr, and 96 ± 2 for CsI. These results are qualitatively discussed in terms of the dispersion and polarization of the lattice modes. Both for CsF which has the NaCl structure and for CsI which can be regarded as monatomic, values of the Debye temperature are deduced from the Mössbauer results and compared with available data.

OBSERVATIONS OF THE MÖSSBAUER EFFECT IN Cs^{133}

A. J. F. Boyle and G. J. Perlow

Phys. Rev. (9 September 1966)

In an extension of measurements on the Mössbauer effect of the 81-keV transition in Cs^{133} we have measured the isomer shifts of a variety of cesium chemicals, including the halides and the metal. The measurements were done in transmission at 4.2°K using a source whose nominal composition was $\text{Ba}^{133}\text{Al}_4$. The isomer shifts of the halides are shown to correlate linearly with the chemical shifts of their nmr frequencies. A fractional effect of $(1.86 \pm 0.26) \times 10^{-4}$ was observed for the cesium metal, and the isomer shift with respect to BaAl_4 was -0.158 ± 0.057 mm/sec. When the latter is combined with the halogen shifts (which lead to an isomer shift of ~ 0.3 mm/sec for Cs^+), it is found that the cesium decay product of Ba^{133} in BaAl_4 has the electron configuration $6s^2$. The existence of this species

is supported by a plausibility argument in terms of the band structure of aluminum. The observed line width of the resonance in metallic cesium is 0.75 ± 0.18 mm/sec. In view of the source contribution, this is consistent with the natural line width. A spin-density-wave (SDW) ground state for Cs would lead to a hyperfine structure that was not observed.

HYPERFINE INTERACTIONS AND THE MAGNETIC FIELDS DUE TO CORE POLARIZATION IN Fe^{57}

W. J. Childs and L. S. Goodman
Phys. Rev. (5 August 1966)

Magnetic-dipole hyperfine-interaction constants have been measured for the $^5\text{D}_{4,3,2,1}$ states of the ground term of Fe^{57} in an atomic-beam magnetic-resonance experiment. The values are $a_J = 38.0795(10)$, $26.351(2)$, $18.762(2)$, and $14.077(5)$ Mc/sec for $J = 4, 3, 2$, and 1 , respectively. The deviations of the ratios of these factors from theoretical predictions are ascribed to core polarization and the implications of this assumption are discussed.

EXPERIMENTAL SEARCH FOR STABLE, FRACTIONALLY CHARGED PARTICLES

W. A. Chupka, J. P. Schiffer, and C. M. Stevens (Chemistry Division)
Phys. Rev. Letters (4 July 1966)

Various samples of matter were examined to search for stable quarks, particles of charge $\frac{1}{3}e$ or $\frac{2}{3}e$. Evaporation through electric fields was used to enhance the concentration of these particles. The three materials examined were iron meteorites, air, and sea water; the concentrations were less than 10^{-17} , 5×10^{-27} , and 3×10^{-29} per nucleon. With some assumptions, the limit for sea water is thought to be the most stringent and corresponds to a calculated concentration of cosmic-ray-induced quarks of mass $\sim 50 \text{ BeV}/c^2$. Some negatively charged ions observed below these limits showed one of the properties expected from fractionally charged atoms; these latter results are inconclusive and not consistently reproducible.

INTERNAL SYMMETRIES IN A COUPLED-CHANNEL SOLUBLE MODEL WITH INELASTICITY

James T. Cushing

Phys. Rev. (29 July 1966)

The conjecture that an internal symmetry group may be selected by a bootstrap mechanism is studied within the framework of a closed, exactly soluble model. In order to have two-body unitarity and crossing without necessarily identically zero amplitudes, two types of particles of different mass (each possessing internal quantum numbers corresponding to an unspecified internal symmetry group and each assigned to irreducible representations of this group) are allowed to scatter in a two-dimensional world. The symmetry group makes its appearance explicitly only through the crossing matrix characterized by a parameter which is to be determined self-consistently. All two-body channels, both elastic and inelastic, are treated exactly. Unitary, crossing-symmetric, analytic scattering amplitudes corresponding to the various processes are constructed for continuous ranges of the parameter of the crossing matrix. Even with the additional constraint of a self-consistency requirement in the form of Levinson's theorem, an internal symmetry group is not selected by the bootstrap mechanism in this model. Also, a technique is developed for converting a coupled set of singular, linear Cauchy integral equations into an equivalent uncoupled Fredholm set.

SPIN-2⁺ MESON DECAYS IN THE QUARK MODEL

M. Elitzur,* H. R. Rubinstein,* H. Stern,* and H. J. Lipkin

Phys. Rev. Letters (15 August 1966)

The spin-2 nonet is described by SU(6) 405 wave functions that are eigenstates of the number of strange quarks. The decay branching ratios are obtained by a rearrangement of the quarks and antiquarks into two quark-antiquark pairs without change of quantum numbers, after an appropriate spin recoupling.

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ENERGY LEVEL STRUCTURE OF Ca^{40} AS OBSERVED WITH THE $\text{K}^{39}(\text{He}^3, \text{d})\text{Ca}^{40}$ REACTION

John R. Erskine

Phys. Rev. (19 August 1966)

The $\text{K}^{39}(\text{He}^3, \text{d})\text{Ca}^{40}$ reaction was studied at a bombarding energy of 12 MeV with a broad-range magnetic spectrograph. Angular-distribution data were obtained for 15 levels which were observed in Ca^{40} between 3.5 and 8.6 MeV excitation. Spectroscopic factors were extracted with a DWBA analysis of the data. The major components of the $(d_{3/2}^{-1} f_{7/2})_{T=0}$, $(d_{3/2}^{-1} p_{3/2})_{T=0}$, and $(d_{3/2}^{-1} f_{7/2})_{T=1}$ configurations in Ca^{40} were identified. The remarkably close agreement of the spacings and spectroscopic factors of the $T=1$ states with their analogues in K^{40} is hard to reconcile with the large Coulomb-mixing effects in the hole-particle calculations of Gillet and Sanderson.

LEVEL STRUCTURE IN Cr^{52} POPULATED IN 5.7-DAY Mn^{52} DECAY

M. S. Freedman,* F. Wagner, Jr.,* F. T. Porter,* and
H. H. Bolotin

Phys. Rev. (17 June 1966)

The energy-level structure in Cr^{52} populated in the decay of 5.7-day Mn^{52} has been studied with a toroidal-field electron spectrometer and Ge(Li) detector. The decay is found to populate only the states at (MeV, J_{π} , ν = dominant seniority) (3.6177, 5^+ , 4), (3.1146, 6^+ , 2), (2.7688, 4^+ , 2), (2.3703, 4^+ , 4), and (1.4345, 2^+ , 2). Low upper limits set on the intensity of gamma rays of 2.65, 1.73, 1.465, 1.214, 1.18, 1.07, and 0.61 MeV previously reported in Mn^{52} remove all evidence for the population by Mn^{52} of states at 3.832, 3.161, and 2.648 MeV (the latter two known from nuclear reactions). All 9 possible transitions of multipolarity E2 or lower between known levels have been seen, including new weak gammas of 0.504 and 0.398 MeV. Conversion coefficients indicate strong M1 mixing only in the transition of 1.2474 MeV from the 3.6177- to the 2.7686-MeV state, for which $\Delta\nu = 0$, in agreement with seniority selection rule for half-filled shells; and E2 dominance in the 1.4345-, 1.3343-, 0.9358-, 0.8498-, 0.7443-, and 0.3460-MeV transitions. Seniority mixing coefficients in the two 4^+ states deduced from gamma intensities agree with those derived from previously reported nuclear-reaction data. The ratio of electron capture to positron emission for decay to the 6^+ state is 2.04, in good agreement with theory.

* Chemistry Division.

MEASUREMENT OF THE ELECTRON-NEUTRON INTERACTION BY THE ASYMMETRICAL SCATTERING OF THERMAL NEUTRONS BY NOBLE GASES

V. E. Krohn and G. R. Ringo

Phys. Rev. (26 August 1966)

The electron-neutron interaction has been obtained from measurements of thermal neutron scattering by argon, krypton, and xenon. In terms of the slope of the electric structure factor of the neutron at zero momentum transfer, the values obtained were $0.0196 \pm 0.0013 F^2$ from Ar, $0.0197 \pm 0.0007 F^2$ from Kr, and $0.0190 \pm 0.0005 F^2$ from Xe. The final result is $0.0193 \pm 0.0004 F^2$, which corresponds to an electron-neutron scattering length of $-1.34 \pm 0.03 \times 10^{-16}$ cm and an effective potential of -3720 ± 90 eV.

During the course of the experiment, the neutron absorption cross sections of krypton and xenon (at 2200 m/sec) were measured by transmission and found to be 25.0 ± 0.8 b and 25.1 ± 1.0 b, respectively. Also, some free-atom thermal-neutron scattering cross sections were measured. The results were 2.415 ± 0.010 b for neon, 0.647 ± 0.003 b for argon, 7.61 ± 0.04 b for krypton, 4.30 ± 0.02 b for xenon, 73.7 ± 0.4 b for ^{36}Ar , 1.705 ± 0.009 b for ^{22}Ne , and 5.1 ± 0.3 b for ^{21}Ne .

THE REACTION MATRIX AND EFFECTIVE SHELL-MODEL INTERACTIONS FOR THE Ni ISOTOPES

R. D. Lawson, M. H. Macfarlane, and T. T. S. Kuo*

Phys. Letters (1 August 1966)

Shell-model calculations are performed for the nickel isotopes with an approximate reaction matrix, corrected in various ways for core polarization, as interaction. The resulting energy levels are compared with experiment and with the predictions of phenomenological shell-model interactions.

*Palmer Physical Laboratory, Princeton University.

ANOMALOUS ISOTOPE SHIFT OF THE NUCLEAR CHARGE RADIUS

F. G. Perey* and J. P. Schiffer

Phys. Rev. Letters (8 August 1966)

It is shown that the isobaric-spin dependence of the shell-model potential gives rise to the experimentally observed "anomalous" isotopic shift of nuclear charge radii. The charge radii calculated from a Woods-Saxon potential, which is consistent with recent optical-model analyses and reproduces the last-particle binding energies, are in qualitative agreement with experimental determinations from electron scattering and from muonic x rays.

* Oak Ridge National Laboratory.

MÖSSBAUER EFFECT IN COMPOUNDS OF ^{127}I

G. J. Perlow and M. R. Perlow

J. Chem. Phys. (5 September 1966)

The Mössbauer effect of the 57.6-keV transition to the ground state of ^{127}I , which follows the β decay of $^{127\text{m}}\text{Te}$, is used to measure the isomer shifts of a variety of compounds at 4.2°K. A comparison of the shifts with the quadrupole couplings in KICl_2 , KICl_4 , ICl , and I_2 indicates no detectable contribution from iodine s orbitals to the bonds. A shift of 0.56 mm/sec is observed per p electron removed from the closed-shell I^- configuration. With the aid of a shielding constant derived by Hafemeister, DeWaard, and DePasquali, one finds a shift of -2.8 mm/sec per s electron removed. With this, the orbital populations on iodine in IO_4^- and IO_6^- are determined from their shifts. It is found that localized sp^3d^2 hybrids for the latter lead to an unreasonable charge on the iodine while a delocalized description does not demand iodine 6d orbitals and can be made to give a reasonable result. For the tetrahedrally bonded IO_4^- , either description suffices and gives an acceptable answer. It is shown that frozen aqueous hydriodic acid is highly ionic while the condensed anhydrous substance is mainly covalently bonded. The substance produced when the Te in $\text{Te}(\text{OH})_6$ undergoes beta decay and subsequently emits the γ ray of interest is found to be mainly IO_6^{5-} as shown by their relative shift. The large recoilless fractions found for telluric acid and the paraperiodate ion are attributed to the large ionic charge in a simple analysis.

CRYSTAL STRUCTURES OF V-Fe ALLOYS AS DETERMINED BY THE MÖSSBAUER EFFECT IN Fe^{57}

R. S. Preston, D. J. Lam,* M. V. Nevitt,* D. O. Van Ostenburg,* and C. W. Kimball†

Phys. Rev. (16 September 1966)

We have measured Mössbauer absorption by Fe^{57} in vanadium-rich V-Fe alloys in the composition range from 0—50 at. % Fe and have interpreted our results in terms of structural features. The literature on the V-Fe system does not suggest the existence of ordering in samples quenched from high temperatures, and x-ray diffraction patterns for our own V-Fe samples include only the lines characteristic of a disordered (bcc) lattice. However, the Mössbauer results can be understood only if a CsCl-like ordering exists over the range of compositions from about 15 to 50 at. % Fe.

*Metallurgy Division.

†Solid State Science Division.

QUADRUPOLE INTERACTION IN Sb^{121} BY MÖSSBAUER TECHNIQUES

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

Phys. Rev. (5 August 1966)

Mössbauer techniques have been used to study the quadrupole resonance of Sb^{121} in cubic Sb_2O_3 (senarmontite). The interaction constant was measured to be $e^2qQ = -557 \pm 20$ MHz; except for the sign, this had earlier been determined more accurately by electric-quadrupole-resonance measurements. The sign, which implies a positive electric field gradient, is consistent with a partially covalent bonding of the 5p electrons to the three nearly coplanar oxygen atoms surrounding each antimony atom. The previously unknown quadrupole moment of the first excited ($\frac{7}{2}^+$) state is found by measuring $R = Q(\frac{7}{2}^+)/Q(\frac{5}{2}^+)$; its value is found to be 1.38 ± 0.02 . Then, using $Q(\frac{5}{2}^+) = -(0.54 \pm 0.07)$ b from optical spectroscopy gives $Q(\frac{7}{2}^+) = -(0.75 \pm 0.09)$ b.

*Solid State Science Division.

†Wayne State University.

ANALYSIS OF γ - γ CASCADES BY POLARIZATION AND DIRECTIONAL CORRELATION: DECAY OF Rh^{101}g

G. T. Wood, S. Koički,* and A. Koički*

Phys. Rev. (23 September 1966)

A procedure is given for analyzing γ - γ cascades with the results of polarization-direction correlation and directional-correlation measurements in cases in which both transitions may be of mixed multipole order. A method is also presented for obtaining polarization-direction correlation coefficients from the measured rates via a Monte Carlo program based on Compton-scattering theory. The methods were applied to the 198—127-keV γ - γ cascade in Ru^{101} populated by the decay of Rh^{101}g . It was determined that the spin of the 127-keV state is $\frac{3}{2}^+$ and the spin of the 325-keV state is $\frac{1}{2}^+$. The E2/M1 mixing ratio is 0.17 ± 0.04 for the 127-keV transition and -0.12 ± 0.03 for the 198-keV one. Relative γ -ray intensities of 94, 100, and 21, respectively, were found for the 127-, 198-, and 325-keV transitions. In a triple-coincidence scintillation-counter measurement, the K internal-conversion coefficient of the 127-keV transition was found to be 0.16 ± 0.02 .

* University of Pennsylvania.

LOWEST $T=\frac{3}{2}$ STATE IN P^{29}

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

Phys. Letters (30 August 1966)

The residual activity between bursts of a mechanically chopped beam has been used to measure the $\text{Si}^{28}(\text{p}, \gamma)\text{P}^{29}$ yield near the lowest $T=\frac{3}{2}$ state. This resonance was found at $E_p = 5.833 \pm 0.010$ MeV and has $\Gamma_{\text{total}} < 2.5$ keV and $\Gamma_\gamma = 0.8 \pm 0.3$ eV.

IV. PUBLICATIONS SINCE THE LAST REPORT

PAPERS AND BOOKS

PHENOMENOLOGICAL α - α POTENTIALS

S. Ali* and A. R. Bodmer

Nucl. Phys. 80, 99 (1966)

MOLECULAR COMPOSITION OF SULFUR VAPOR

J. Berkowitz

in Elemental Sulfur, edited by Beat Meyer (Interscience Publishers, New York, 1965), pp. 125-159

ANGULAR DISTRIBUTION OF VALENCE-SHELL PHOTOELECTRONS

J. Berkowitz and H. Ehrhardt†

Phys. Letters 21, 531-532 (15 June 1966)HYPERFINE INTERACTIONS AND THE MAGNETIC FIELDS DUE TO CORE POLARIZATION IN Fe^{57}

W. J. Childs and L. S. Goodman

Phys. Rev. 148, 74-78 (5 August 1966)

EXPERIMENTAL SEARCH FOR STABLE, FRACTIONALLY CHARGED PARTICLES

W. A. Chupka, J. P. Schiffer, and C. M. Stevens (Chemistry Division)

Phys. Rev. Letters 17, 60-65 (4 July 1966)

CONCEALED CONFIGURATION MIXING AND THE SPECTROSCOPY OF THE PSEUDONIUM NUCLEI

S. Cohen, R. D. Lawson, and J. M. Soper†

Phys. Letters 21, 306-309 (15 May 1966)

*The University, Manchester, England.

†Physikalisches Institut der Universität, Freiburg/Br., Germany.

‡Atomic Energy Research Establishment, Harwell, England.

SPIN- 2^+ MESON DECAYS IN THE QUARK MODEL

M. Elitzur,* H. R. Rubinstein,* H. Stern,* and H. J. Lipkin
Phys. Rev. Letters 17, 420-422 (15 August 1966)

LEVEL STRUCTURE IN Cr^{52} POPULATED IN 5.7-DAY Mn^{52} DECAY

M. S. Freedman (Chemistry Division), F. Wagner, Jr.
(Chemistry Division), F. T. Porter (Chemistry Division),
and H. H. Bolotin
Phys. Rev. 146, 791-798 (17 June 1966)

MEASUREMENT OF THE SPINS OF SOME STATES IN Fe^{55}

D. S. Gemmell, L. L. Lee, Jr., A. Marinov, and J. P. Schiffer
Erratum: Phys. Rev. 148, 1246 (19 August 1966)

SYSTEM FOR SUPPRESSING LARGE, NONSTATISTICAL NOISE
BURSTS IN DIGITAL AVERAGING

L. S. Goodman and F. O. Salter (Applied Mathematics Division)
Rev. Sci. Instr. 37, 769-771 (June 1966)

SUPPRESSION OF MULTIPACTING IN PARTICLE ACCELERATORS

Albert J. Hatch
Nucl. Instr. Methods 41, 261-271 (May 1966)

MAGNETIC HYPERFINE INTERACTIONS AND ELECTRIC QUADRUPOLEAR
COUPLING IN ALLOYS OF IRON WITH THE ALPHA-MANGANESE
STRUCTURE

C. W. Kimball (Solid State Science Division), Walter C.
Phillips (Solid State Science Division), M. V. Nevitt (Metallurgy
Division), and R. S. Preston
Phys. Rev. 146, 375-378 (10 June 1966)

J DEPENDENCE IN THE (He^3, α) REACTION

L. L. Lee, Jr., C. Mayer-Böricke, and R. H. Siemssen
Phys. Rev. 147, 797-799 (22 July 1966)

ENERGY LEVELS OF Ca^{48} AND Ca^{40} AS OBSERVED WITH INELASTIC
SCATTERING OF 11.5-MEV PROTONS

A. Marinov and J. R. Erskine
Phys. Rev. 147, 826-828 (22 July 1966)

* Weizmann Institute of Science, Rehovoth, Israel.

ISOSPIN SELECTION RULE IN THE $C^{12}(d,\alpha)B^{10}$ REACTION

L. Meyer-Schützmeister, D. von Ehrenstein, and R. G. Allas
Phys. Rev. 147, 743-752 (22 July 1966)

HIGH-ENERGY γ SPECTRA RESULTING FROM NEUTRON CAPTURE IN HAFNIUM ISOTOPES

A. Namenson, H. E. Jackson, and R. K. Smither
Phys. Rev. 146, 844-852 (17 June 1966)

ANOMALOUS ISOTOPE SHIFT OF THE NUCLEAR CHARGE RADIUS

F. G. Perey* and J. P. Schiffer
Phys. Rev. Letters 17, 324-328 (8 August 1966)

SHELL STRUCTURE EFFECTS IN THE LEVEL DENSITY OF A FERMI SYSTEM

N. Rosenzweig
Nuovo Cimento 43, 227-235 (11 June 1966)

QUADRUPOLE INTERACTION IN Sb^{121} BY MÖSSBAUER TECHNIQUES

S. L. Ruby, G. M. Kalvius (Solid State Science Division),
R. E. Snyder,[†] and G. B. Beard[†]
Phys. Rev. 148, 176-180 (5 August 1966)

MÖSSBAUER STUDY OF Kr^{83} IN THE COMPOUND KrF_2

S. Ruby and H. Selig (Chemistry Division)
Phys. Rev. 147, 348-354 (8 July 1966)

DEPENDENCE OF THE ANGULAR DISTRIBUTION OF THE (d,p) REACTION ON THE TOTAL ANGULAR-MOMENTUM TRANSFER. II

J. P. Schiffer, L. L. Lee, Jr., A. Marinov, and C. Mayer-Böricke
Phys. Rev. 147, 829-835 (22 July 1966)

 $W^{182}(d,p)W^{183}$ REACTION AT 7.5 AND 12 MEV: AN INVESTIGATION OF THE STRIPPING PROCESS ON A DEFORMED HEAVY NUCLEUS

R. H. Siemssen and J. R. Erskine
Phys. Rev. 146, 911-925 (17 June 1966)

* Oak Ridge National Laboratory.

[†] Wayne State University.

DISCREPANCIES IN PROTON-TRANSFER REACTIONS TO STATES
WITH DIFFERENT ISOBARIC SPIN

R. H. Siemssen, G. C. Morrison, B. Zeidman, and H. Fuchs^{*}
Phys. Rev. Letters 16, 1050-1054 (6 June 1966)

KINETIC ENERGIES OF PRODUCTS OF ION-MOLECULE REACTIONS

H. E. Stanton and S. Wexler (Chemistry Division)
J. Chem. Phys. 44, 2959-2968 (15 April 1966)

STUDY OF THE $K^{39}(p,\alpha)Ar^{36}$ REACTION

D. von Ehrenstein, L. Meyer-Schützmeister, and R. G. Allas
Nucl. Phys. 79, 625 (1966)

ABSTRACTS AND PAPERS PRESENTED AT MEETINGS

AIP Topical Conference on Bases for Nuclear Spin-Parity Assignments,
Gatlinburg, Tennessee, 11-13 November 1965

(d,p) AND (d,t) STUDIES OF THE STRUCTURE OF Yb ISOTOPES

D. G. Burke,† B. Elbek,† B. Herskind,† M. Olesen,†
and B. Zeidman
Bull. Am. Phys. Soc. 11, 600 (June 1966)

J DEPENDENCE IN (α,t) AND (α,He^3) REACTIONS ON Mg^{24}
AND Mg^{26}

D. Dehnhard
Bull. Am. Phys. Soc. 11, 599 (June 1966)

ANALYSIS OF DOUBLY MIXED γ - γ CASCADES BY USE OF
POLARIZATION-DIRECTION AND DIRECTIONAL CORRELA-
TIONS: DECAY OF $5-\gamma Rh^{101}$

G. T. Wood, S. Koićki,† and A. Koićki†
Bull. Am. Phys. Soc. 11, 595 (June 1966)

^{*}Hahn Meitner Institut, Berlin, Germany.

†Institute for Theoretical Physics, Copenhagen.

†University of Pennsylvania.

IMPROVED TIMING WITH NaI(Tl)

Frank J. Lynch

IEEE Trans. NS-13(3), 140-147 (June 1966)APS Topical Conference on Isobaric Spin in Nuclear Physics, Florida
State University, Tallahassee, Florida, 17—19 March 1966EXCITATION OF ISOBARIC-ANALOG LEVELS IN MEDIUM-
WEIGHT NUCLEI BY THE (He^3, α) REACTIONT. H. Braid, L. Meyer-Schützmeister, and D. D.
BorlinBull. Am. Phys. Soc. 11, 626 (June 1966)EVIDENCE FOR AN ISOBARIC-ANALOG STATE IN Mg^{25}
(7.75 MEV)

D. Dehnhard and J. L. Yntema

Bull. Am. Phys. Soc. 11, 627 (June 1966)EXCITATION OF ISOBARIC-ANALOG STATES BY THE (He^3, d)
REACTION ON Ni ISOTOPIC TARGETS

G. C. Morrison and J. P. Schiffer

Bull. Am. Phys. Soc. 11, 629 (June 1966)ISOBARIC-ANALOG STATES FROM PROTON SCATTERING
ON BARIUM TARGETS

G. C. Morrison and Z. Vager

Bull. Am. Phys. Soc. 11, 624 (June 1966)ISOTOPIC-SPIN EFFECTS IN $\text{B}^{10} + p$

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

Bull. Am. Phys. Soc. 11, 628 (June 1966)Twenty-Sixth Annual Conference on Physical Electronics, Massachusetts
Institute of Technology, 21—23 March 1966SECONDARY ELECTRON EMISSION FROM ALUMINUM AND
COPPER MONOCRYSTALS UNDER HIGH-ENERGY ION IMPACT

M. Kaminsky and P. Eastman

Report on the Twenty-Sixth Annual Conference on
Physical Electronics, Massachusetts Institute of
Technology, 21-23 March 1966 (Massachusetts
Institute of Technology, Cambridge, 1966),
pp. 331-332Bull. Am. Phys. Soc. 11, 639-640 (June 1966)

Twenty-Sixth Annual Conference on Physical Electronics, Massachusetts
Institute of Technology, 21-23 March 1966 (cont'd.)

POSITIVE-ION EMISSION FROM METAL MONOCRYSTALS
UNDER HIGH-ENERGY DEUTERON BOMBARDMENT

M. Kaminsky and K. Swenson

Report on the Twenty-Sixth Annual Conference on
Physical Electronics, Massachusetts Institute of
Technology, 21-23 March 1966 (Massachusetts
Institute of Technology, Cambridge, 1966),
pp. 316-321

Bull. Am. Phys. Soc. 11, 639 (June 1966)

NEW APPROACH TO NEUTRON RESONANCE SPECTROSCOPY

L. M. Bollinger

Bull. Am. Phys. Soc. 11, 660 (June 1966)

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

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

Bull. Am. Phys. Soc. 11, 477 (June 1966)

PLOTTING THE CURRENT-VOLTAGE RELATION FOR CORONA

Alexander Langsdorf, Jr.

Bull. Am. Phys. Soc. 11, 746 (July 1966)

STUDENT REPORTS

FADING AND LOW-LEVEL RESPONSE OF LITHIUM FLUORIDE
THERMOLUMINESCENT DOSIMETERS

James N. Beggs

ACM student report to St. Olaf College (8 July 1966)

MASS SPECTROMETRIC STUDY OF THE PHOTOIONIZATION OF
 H_2O , H_2O_2 , AND H_2S

Douglas B. Hunt

ACM student report to Knox College (8 July 1966)

* Indiana University.

STUDIES OF SECONDARY-ELECTRON EMISSION FROM METAL
MONOCRYSTALS UNDER HIGH-ENERGY ION IMPACT

Roman Kuc

Co-op student report to Illinois Institute of Technology
(February-June 1966)

THE DIRECTION OF THE INTERNAL MAGNETIC FIELD AT THE
TWO NONEQUIVALENT Fe SITES IN YIG

Robert G. Peterson

ACM student report to St. Olaf College (8 July 1966)

INFORMAL REPORTS

THE BRUECKNER-GOLDSTONE THEORY OF NUCLEAR MATTER

Ben Day

Argonne National Laboratory Informal Report PHY-1966C
(June 1966)

PROGRESS REPORT ON A STUDY OF PATTERN RECOGNITION
USING "DAPHNIS"

C. Harrison (Applied Mathematics Division), D. H. Jacobsohn
(Applied Mathematics Division), and G. R. Ringo

ANL Applied Mathematics Division Technical
Memorandum No. 123 (16 June 1966)

THE ISOBARIC-SPIN SPLITTING OF NUCLEAR EXCITATIONS

Malcolm H. Macfarlane

Argonne National Laboratory Informal Report PHY-1966B
(May 1966)

V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

NEW MEMBERS OF THE DIVISION

Resident Research Associate

Dr. Amnon Katz, Weizmann Institute of Science, Rehovoth, Israel.

Problems in relativistic field and particle theories.

Returned to Argonne on 15 July 1966.

Resident Research Associates (Post-Doctoral)

Dr. James MacKenzie, University of Minnesota. Theoretical nuclear physics. Came to Argonne on 29 August 1966.

Dr. J. A. Nolen, Jr., Princeton University. Direct reactions and analog state work. Came to Argonne on 1 July 1966.

Dr. Carl Rosenkilde, University of Chicago. Theoretical nuclear physics. Came to Argonne on 1 July 1966.

Resident Research Associates (Summer)

Dr. R. T. Carpenter, University of Iowa. Study of electromagnetic transitions in light nuclei. Returned to Argonne on 13 June 1966.

Dr. Yau Wa Chan, Brookhaven National Laboratory. Hyperfine structure of Rh¹⁰³. Came to Argonne on 5 July 1966.

Dr. Michael A. Grace, Oxford University, England. Mössbauer experiments. Returned to Argonne on 29 August 1966.

Dr. Kenneth Hartt, University of Missouri. Ground states of very light nuclei. Came to Argonne on 1 June 1966.

Dr. Linwood L. Lee, Jr., State University of New York, Stony Brook. Nuclear research at the Tandem. Returned to Argonne on 1 August 1966.

Dr. Lionel Lovitch, Columbia University, New York. Numerical analysis of muonic x-ray data. Came to Argonne on 6 June 1966.

Dr. Donald W. L. Sprung, McMaster University, Hamilton, Ontario. Properties of nuclear matter. Came to Argonne on 15 June 1966.

Faculty Summer Research Participation Program

Dr. Ram Chaturvedi, State University of New York, Cortland, New York. Level scheme of Te¹²⁴ from Te¹²³(n, γ) studies with the bent-crystal and Ge-diode γ -ray spectrometers. Came to Argonne on 24 June 1966.

Dr. Edward F. Kennedy, College of the Holy Cross, Worcester, Massachusetts. Lifetime measurements on light-medium nuclei. Came to Argonne on 13 June 1966.

Dr. Edward R. Sanford, Ohio University, Athens, Ohio. Mössbauer measurements. Came to Argonne on 1 August 1966.

Dr. H. John Sathoff, Bradley University, Peoria, Illinois. Decay scheme of Xe^{125} . Came to Argonne on 20 June 1966.

University Users of the ANL Tandem

Dr. Robert Beyer, Purdue University. Multiple Coulomb excitation and the reorientation effect. Started work at ANL on 29 July 1966.

Mr. Thomas Marvin, Indiana University. Started work at ANL on 22 June 1966.

Resident Student Associates (Summer)

Mr. Paul Eastman, graduate student, Michigan State University. Working with Manfred Kaminsky on stopping power of thin monocrystals and assembly of a heavy-ion source for the 2-MeV Van de Graaff. Returned to Argonne on 13 June 1966.

Mr. Michael Nagel, graduate student, University of Illinois. Working with J. P. Schiffer on Coulomb energies. Came to Argonne on 13 June 1966.

Mr. J. Curtis Siren, graduate student, Stanford University. Working with G. C. Morrison on level schemes of isotopes V^{47} , V^{48} , V^{49} , V^{50} , and V^{51} . Came to Argonne on 28 June 1966.

Miss Barbara Anne Tryba, graduate student, University of Illinois. Working with A. J. Hatch on computer reduction of data on plasma admittance. Returned to Argonne on 31 May 1966.

Student Aides (ACM)

Mr. David B. Johnson, Ripon College. Working with S. B. Burson and C. Dam on angular correlations. Came to ANL on 11 July 1966.

Mr. David R. Parks, Grinnell College, Iowa. Working with G. T. Wood on internal-conversion-electron spectroscopy with the 6-gap magnetic spectrometer. Came to ANL on 15 June 1966.

Mr. Frank Szitta, Lawrence University. Working with R. E. Côté on neutron time-of-flight experiments, particularly on a determination of the neutron-electron interaction through measurement of the transmission of a sample of liquid bismuth. Came to ANL on 11 July 1966.

Co-op Technicians

Mr. William Lang, Illinois Institute of Technology. Working with S. L. Ruby on experiments with the Mössbauer effect. Came to ANL on 22 August 1966.

Mr. Joseph A. Naser, Northwestern University. Working with J. P. Schiffer on data reduction in connection with charged-particle experiments at the Tandem. Came to ANL on 8 June 1966.

Mr. James Partak, Marquette University. Working with A. J. Elwyn on data reduction in connection with neutron experiments at the 4.0-MeV Van de Graaff. Came to ANL on 22 August 1966.

Mr. David Pollard, Northwestern University. Working with J. P. Schiffer on data reduction in connection with charged-particle experiments at the Tandem. Came to ANL on 13 June 1966.

Student Aides (Summer)

Mr. Marc A. Kastner, University of Chicago. Working with J. R. Erskine on correlation of spectrograph data. Came to ANL on 15 June 1966.

Mr. Leonard Olson, Cornell University, New York. Working with R. E. Holland on developing data processing programs for the PHYLIS system. Came to ANL on 14 June 1966.

Mr. Richard M. Ostermeier, University of Illinois. Working with D. S. Gemmell on analysis of theoretical and experimental values of scattering cross section for the reaction $\text{Li}^6(\alpha, \alpha)\text{Li}^6$. Came to ANL on 14 June 1966.

Technicians

Mr. Kenneth Ball joined the Physics Division on 20 June 1966 to work with D. S. Gemmell.

Mr. John Kielbasa joined the Physics Division on 30 June 1966 to work with J. R. Wallace.

Mr. Arthur Ruthenberg joined the Physics Division on 17 August 1966 to work with J. R. Wallace.

PROMOTIONS

Mr. William Evans has been promoted to Engineering Assistant.

Dr. Robert D. Lawson was appointed Senior Physicist on 1 June 1966.

Dr. Dieter von Ehrenstein joined the permanent staff on 1 July 1966.

LEAVES OF ABSENCE

Dr. Malcolm H. Macfarlane left ANL on 1 August 1966 on a Guggenheim fellowship for one year in the Department of Theoretical Physics, Oxford University, England.

DEPARTURES

Mr. Milton Feryance, technician, has been in the Physics Division since 18 November 1963. He terminated at ANL on 5 August 1966.

Mr. Andrew C. Jorgensen, technician, has been in the Physics Division since 21 June 1965. He terminated at ANL on 8 July 1966.

Dr. Raymond O. Lane has been on the staff of the Physics Division since 9 November 1953. He has worked on neutron scattering and polarization studies. He terminated at ANL on 17 June 1966 to go to Ohio University, Athens, Ohio.

Dr. Arthur I. Namenson, resident research associate (post-doctoral) from Columbia University has been in the Physics Division since 14 October 1963. He has worked on bent-crystal spectrometer, combination bent-crystal and Ge detector, and high-energy facility. He terminated at ANL on 31 August 1966 to go to Laboratory for Cosmic Ray Physics, Naval Research Laboratory, Washington, D.C.

Dr. Kamel M. A. Refaey, resident student associate (thesis) from Illinois Institute of Technology has been in the Physics Division since 15 June 1964. He has worked on (A) energy dependence of cross section for collision-induced dissociation and endothermic ion-molecule reactions and (B) photoionization of the lower aliphatic alcohols and ethylene. He terminated at ANL on 30 June 1966 to go to U.A.R. Atomic Energy Establishment, Cairo, Egypt.

Dr. Gert Roepstorff, resident research associate (post-doctoral)

from the University of Hamburg, Germany has been in the Physics Division since 1 September 1965. He has worked with F. Coester on three-particle scattering theory, axiomatic field theory, and current algebras and configuration mixing. He terminated at ANL on 31 August 1966 to go to II. Institut fuer Theoretische Physik, Universitaet Hamburg, Hamburg-Bahrenfeld, Luruper Chaussee 149, W. Germany.

Mrs. Marjorie Schmidt, secretary, has been in the Physics Division since 26 July 1965. She terminated at ANL on 19 August 1966.

Dr. Rolf H. Siemssen, resident research associate (post-doctoral)

from the University of Hamburg, Germany has been in the Physics Division since 2 October 1963. He has worked on charged-particle reactions on the tandem and the cyclotron and Doppler-shift lifetime measurements. He terminated at ANL on 26 August 1966 to go to the Physics Department, Yale Nuclear Structure Laboratory, Yale University, New Haven, Connecticut.