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Cross Section Program at ORNL, Oct. 1, 1962 -- Feb. 15, 1963

H. B. Willard and J. A. Harvey

ABSTRACT

This memo reviews the cross section program at ORNL for the period Oct. 1, 1962, through Feb. 15, 1963.

1. Shell Structure Effects on S-Wave Neutron Strength Functions and Level Spacings of the Tin Isotopes -- T. Fuketa (visiting scientist from the Japan Atomic Energy Research Institute, Tokai, Japan), F. A. Khan (visiting scientist from the Pakistan Atomic Energy Commission), and J. A. Harvey.

The following is an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> About one hundred resonances have been assigned to the ten tin isotopes in the energy range of 0.2 to 10,000 eV from the ORNL fast chopper measurements (F. A. Khan and J. A. Harvey, Bull. Am. Phys. Soc. 7, 289 (1962) and T. Fuketa and J. A. Harvey, Bull. Am. Phys. Soc. 7, 552 (1962)). The average level spacing in each isotope depends clearly upon whether the mass number is even or odd, i.e., the spacings are large for the even target isotopes and small for the odd ones. The spacings for the even target isotopes increase with mass number indicating the effect of the neutron binding energy. The s-wave strength function for the even target isotopes shows a steep decrease from Sn^{118} to Sn^{120}. This dependence of the strength function on mass number agrees well with the calculations by Carl Shakin (Annals of Physics (to be published)) computing the three quasi-particle model states based on the nuclear shell model and the optical model.

2. Gamma-Ray Spectra from Low Energy Neutron Capture -- G. G. Slaughter, J. R. Bird (visiting investigator from Harwell, England), G. T. Chapman, and J. A. Harvey.

The following is a paraphrase of an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> The large NaI crystal was used to obtain gamma-ray spectra due to thermal neutron capture in isotopes of Ca and Ti exposed to the open-rotor neutron beam. The spectra for $Ca^{40,42,44}$ targets were dominated by strong gamma rays involving transitions to excited states near 2 MeV. The same states have been observed to show large reduced widths in the (d,p) reaction, with $\ell_n = 1$, implying strong single particle levels. If the absorption cross-section and gamma-ray multiplicity of a nuclide are low, then the effects of direct capture may be evident. It is reasonable to

assume, therefore, that these particular levels observed in $Ca^{41,43,45}$ consist of the target nucleus as a core and the odd neutron in the shell model $2p_{3/2}$ orbital. Other weaker gamma rays in these Ca isotopes show this correspondence to transitions to levels that are observed to have $\ell_n=1$ in the stripping reaction; it is proposed that these levels are $2p_{1/2}$ shell model states. The results from the Ca^{43} target showed, as expected, a more complicated spectrum tending more toward a continuum than the spectra from even-even targets. The results for the Ti isotopes were dominated by capture in Ti^{48}. It was not possible to assign any strong gamma rays to Ti^{46} or 50 targets. Ti^{48} target nuclide results were similar to those for the even-even Ca target nuclides.

3. Neutron-Capture Measurements on Tungsten and Hafnium -- J. E. Russell and R. W. Hockenbury (Rensselaer Polytechnic Institute), and R. C. Block (ORNL).

The following is an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> The RPI linear electron accelerator has been used as a pulsed-neutron source for time-of-flight measurements with the ORNL 1.25-m diameter liquid-scintillator capture γ-ray detector operating at a flight path of 25 m. (J. E. Russell, R. W. Hockenbury, and R. C. Block, Bull. Am. Phys. Soc. 7, 289 (1962)) 7 thicknesses of natural-tungsten samples from 0.001 - 0.120 in. have been measured with a resolution of $\sim$6 nsec/m. Samples of separated isotopes of hafnium enriched in $Hf^{176,177,178,179,180}$, as well as several thicknesses of natural hafnium, have also been measured at a resolution of $\sim$16 nsec/m. Resonance parameters for tungsten resonances in the region 5 - 500 eV are presented. Isotopic assignments and average level spacings for resonances in hafnium and parameters for the larger resonances are presented over the same energy region.

4. Mass Distribution and Kinetics of U^{235} Thermal-Neutron-Induced Three-Particle Fission -- H. W. Schmitt, J. H. Neiler, F. J. Walter, and A. Chetham-Strode.

The following is an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> A three-parameter correlation experiment has been performed in which the energies of the two heavy fragments and of the third light particle (usually a long-range alpha particle) have been measured in coincidence. Surface barrier detectors

were used in conjunction with standard low-noise amplifier systems; events were serially recorded by a 128 x 128 x 4 channel punched-paper-tape correlation recorder. The data were sorted, summed, and correlated through the use of computers, and results have been obtained giving the mass distribution, mass-energy correlations, and other kinetic parameters associated with U^{235} thermal-neutron-induced three-particle fission. A comparison of the mass distributions thus obtained for particles from binary and ternary fission shows that the long-range alpha particles are emitted principally at the expense of nucleons in the light fragment for near-symmetric fission and at the expense of nucleons in the heavy fragment for more asymmetric fission. It is shown that the nucleon clusters containing the closed shells N = 50 or N = 82 tend to remain intact and are important in both ternary and binary fission, for U^{235} + n (thermal).

5. Fragment Mass Distribution for Thermal and Resonance Neutron-Induced Fission of Pu^{239} -- F. J. Walter, J. H. Neiler (Oak Ridge Technical Enterprises Corporation), and H. W. Schmitt.

The following is an abstract of a paper to be presented at the Washington meeting of the American Physical Society, April 22-25, 1963:

The fragment mass distributions for thermal- and resonance-neutron-induced fission of Pu^{239} have been determined from correlated energy measurements of fragment pairs. Surface barrier detectors were used in conjunction with low-noise amplifiers; events were serially recorded by a 128 x 128 correlation recorder. Specially designed fast coincidence and inspection circuits were used to eliminate events in which alpha particle pile-up occurred. Fission events resulting primarily from the 0.3 eV resonance of Pu^{239} were obtained by filtering techniques. The data obtained thus far indicate that the mass distributions peak to valley ratio for the 0.3 eV resonance is 2.0 $\pm$ 0.4 times as large as the ratio for "thermal" fission. This result supports the suggestion by Wheeler (J. A. Wheeler, Physica 22, 1103 (1956)) that fission from different spin states of the compound nucleus might show different ratios of asymmetric to symmetric fission. When appropriate corrections are made for the contribution of the 0.3 eV resonance to the "thermal" cross section this result is in agreement with previous radiochemical determinations (R. B. Begier et al, Phys. Rev. 119, 2017 (1960)). The experiment is being extended to the use of cold neutrons in order to increase the relative contribution from the bound state.

6. Resonance Fission of Oriented U^{235} Nuclei -- J. W. T. Dabbs, F. J. Walter, and G. W. Parker.

The following is an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> Previous studies (L. D. Roberts et al, Proceedings of the International Conference on Nuclear Structure, edited by D. A. Bromley and E. W. Vogt (University of Toronto Press, Toronto, 1960)) of the angular distribution of fission fragments from thermal-neutron-induced fission of aligned U^{235} in the temperature region 77° - $1.3^{\circ}K$ have been extended to $0.45^{\circ}K$ and to the study of resonance-neutron-induced fission. Such angular distributions are primarily determined by the K-quantum-number values that are involved in passing over the barrier (see above ref.). The attainment of nuclear alignment of $0.45^{\circ}K$ for the long periods of time required by low counting rates was accomplished with a continuously circulating He^3 refrigerator and the use of He^3 exchange gas to cool the single crystal $UO_2Rb(NO_3)_3$ sample. Monochromatic neutrons were obtained from a Be-crystal monochromator at the Oak Ridge research reactor. The results at 0.14 eV and for the 1.14- and 8.8-eV resonances yield values $A=0.050\pm0.002$, 0.044 ± 0.006, and 0.051 ± 0.009, respectively, where A is the coefficient in $W(\theta)=1+(A/T)P_2(\cos\theta)$. The earlier "thermal" results and preliminary results for the 0.28-eV resonance give values $A=0.035\pm0.005$ and 0.028 ± 0.003, respectively. The α-particle anisotropy, measured simultaneously and used as a monitor of the nuclear orientation, gave $A= -0.070\pm0.002$, in accord with earlier work. A comparison with recent theoretical suggestions is given.

7. Isotopic Neutron Capture Cross Sections Near 30 keV -- R. L. Macklin, T. Inada (visiting scientist from NIRS, Japan), and J. H. Gibbons.

The following is an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> Several isotopic capture cross sections of astrophysical interest have been measured with the Moxon-Rae detector in addition to the results for tin isotopes previously reported (R. L. Macklin, T. Inada, and J. H. Gibbons, Nature 194, 1272 (1962)). At 30 keV we find for Sm^{144} 119 ± 55 mb, Sm^{147} 1173 ± 192 mb, Sm^{148} 258 ± 48 mb, Sm^{149} 1622 ± 279 mb, Sm^{150} 370 ± 72 mb, Sm^{152} 411 ± 71 mb, Sm^{154} 325 ± 61 mb. The Sm^{148} and Sm^{150} show closely the predicted

(E. M. Burbidge, G. R. Burbidge, W. A. Fowler, and F. Hoyle, Revs. Modern Phys. 29, 547 (1957)) inverse proportionality to the observed isotopic abundance. We find for Zr^{90} 11±3 mb, Zr^{91} 59±10 mb, Zr^{92} 34±6 mb, Zr^{94} 19±4 mb, Zr^{96} 40±12 mb. The result for Zr^{94}, compared with those of the lighter three isotopes, is an indicator of the branching ratio at Zr^{93} (enhanced β^- decay vs further neutron capture) in element formation in red giant stars (E. M. Burbidge, G. R. Burbidge, W. A. Fowler, and F. Hoyle, Revs. Modern Phys. 29, 547 (1957)), and is therefore sensitive to the temperature during nucleosynthesis. For isolated resonances in Y^{89}, Pb^{206}, Pb^{207}, and F^{19} time-of-flight neutron capture measurements have been made, over a 7 cm flight path with 3 ns resolution.

8. Average Radiative Capture Cross Sections for 30- and 65-keV Neutrons -- R. L. Macklin, J. H. Gibbons, and T. Inada (visiting scientist from NIRS, Japan).

The following is an abstract of a paper accepted for publication in Nuclear Physics:

> Neutron radiative capture cross sections near 30 and 65 keV have been measured for a large number of elements by means of a large liquid scintillator and a pulsed neutron source. The results show definitive even vs odd A effects as well as systematic variations due primarily to effects of nuclear shells. Calculations of the scintillator efficiency for various capture γ-ray cascade modes are in good agreement with experimental results.

9. Neutron Capture Cross Sections near 30 keV Using a Moxon-Rae Detector -- R. L. Macklin, J. H. Gibbons, and T. Inada (visiting scientist from NIRS, Japan).

The following is an abstract of a paper accepted for publication in Nuclear Physics:

> Neutron radiative capture cross sections have been measured using a Moxon-Rae detector, for neutrons near 30 keV. A time-of-flight system with less than 3 nanosecond resolution and a 7 cm flight path has been shown applicable to small sample measurements. Cross sections at 30 keV for Mo, Cd, Sn, Ta, W, Pt, and Au, and cross sections versus energy for fluorine, sulfur, and yttrium are presented.

10. Neutron Capture -- R. L. Macklin and J. H. Gibbons.

A preliminary measurement was made on a sample of Mo^{92} powder, using the ORNL pulsed 3-MV Van de Graaff and the fast Moxon-Rae detector. The n,γ cross section found was 37 ± 12 mb at an average energy of 35 keV ($\pm$ 15 keV spread). This result is based on a tantalum standard and assumes the few percent of other isotopes in the sample have the same cross section. More precise experiments are planned as soon as the powder has been converted to more compact and stable sample shapes.

11. Resonance Neutron Capture Spectra in F, Ca, and Pb -- J. H. Gibbons, W. M. Good, and J. R. Bird (visiting scientist from AERE, Harwell, England).

The following is an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> Neutron capture γ-ray spectra are being studied as a function of neutron energy in a manner previously described (J. R. Bird, J. H. Gibbons, and W. M. Good, Bull. Am. Phys. Soc. 7, 552 (1962) and J. R. Bird, J. H. Gibbons, and W. M. Good, Physics Letters 1, 262 (1962)). Resonances are observed in fluorine at 27 keV and 49 keV. These are known to be p-wave in character, and indeed the spectra show marked differences from the spectrum at thermal. Specifically, the supposedly 2+ state of F^{20} should strongly depress capture to ground in the case of thermal capture and permit the p-state capture to ground via electric dipole radiation. Just the opposite experimental situation seems to prevail. The resonant capture spectrum observed in calcium contains substantially the same lines as thermal capture, but the relative line intensities are completely different. The capture is attributed to small resonances at about 20 keV and 50 keV not previously observed in transmission experiments. The rather frequent appearance of relative transition intensities which seemingly contradict assignments of spins and parities obtained from other types of experiments make it of interest to study as many cases as possible, especially those in which the character of the capturing state is known.

12. Resonant Neutron Capture Spectra in $Fe^{54,56}$, and $Ca^{40,42,44}$ --

J. A. Biggerstaff, J. R. Bird (visiting scientist from AERE, Harwell, England), J. H. Gibbons and W. M. Good.

The following is an abstract of a paper to be presented at the Washington meeting of the American Physical Society, April 22-25, 1963:

> By employing time-of-flight and a crude two-dimensional analyzer in the manner described previously (J. H. Gibbons, W. M. Good, and J. R. Bird, Bull. Am. Phys. Soc. 8, 81 (1963)), measurements were made on the neutron capture gamma-ray spectra for the cases of target nuclei Ca^{40}, Ca^{42}, Ca^{44}, Fe^{54}, and Fe^{56}. The time resolution was only 100 ns/M, but changes of spectra with energy were clearly evident. It is supposed that the capture was dominated by the resonances at 52 keV and 74 keV in the isotopes Fe^{54} and Fe^{56}, respectively. Transitions were observed to the ground, 0.413-, 0.93-, 1.413-, 2.058-, 2.47-, 2.94-, and ground, 1.26-, 1.62-, 2.51-, and 2.83-MeV states in Fe^{55} and Fe^{57}, respectively. Hence, these spectra differ appreciably from the corresponding thermal spectra. The relative intensities of the transitions fluctuated considerably with neutron energy. A target of natural calcium exhibits capture resonances (see above ref.) attributable to Ca^{40} in the neutron energy region being investigated. Sufficiently good resolution cannot be attained on Ca^{42} and Ca^{44} targets because of size, to ascertain the character of the capture in these cases. Principally of interest in the case of the spectra observed in the Ca isotopes is the indication of two states between ground and the 1.95-MeV level in Ca^{41}, and a level between the 0.59 and 0.99 levels in Ca^{43}. Need for further investigation is indicated.

13. Differential Cross Section for Neutron Scattering from Pb^{208} --

J. L. Fowler.

The following is an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> Apparatus designed for determining neutron angular distributions with good energy resolution (J. L. Fowler, Bull. Am. Phys. Soc. 7, 576 (1962)) has been used to measure differential cross sections for neutron scattering from Pb^{208} (99.75%) at a number of energies between 700 and 1750 keV. Collimated Li(p,n) neutrons were incident upon the 128-gm cylindrical sample in the center of a shielded region. The scattered neutrons were detected with a stilbene crystal from which γ-ray pulses were suppressed by use of pulse-shape discrimination. For several prominent resonances below 1000 keV (J. L. Fowler and E. C.

Campbell, Phys. Rev. 127, 2192 (1962)), the interference between the resonant and potential scattering (predominantly s wave) allows one to assign ℓ values by inspection. This information, together with published data (J. L. Fowler and E. C. Campbell, Phys. Rev. 127, 2192 (1962)), gives the following resonance parameters: 723(5/2),+,0.02), 769(3/2,-,0.01), 821(5/2,+,0.04), and 855(3/2,+, 0.02), where the resonant energy in keV is followed by the information in parenthesis, which includes the J value, parity, and the reduced width in units of $3\hbar^2/2ma^2$. As the neutron energy increases, potential-scattering phase shifts other than s wave become important, so that a more quantitative analysis is necessary.

14. Differential Cross Sections for Neutron Scattering from Pb^{208} -- J. L. Fowler, M. J. Mader, and J. F. Agnew.

The differential neutron cross section of Pb^{208} (99.75% separated isotope) has been measured at 20 resonant and 10 nonresonant energies with a few kilovolt resolution in the energy range 715 to 1761 keV (J. L. Fowler, Bull. Am. Phys. Soc. 8, 82 (1963)). Multiple scattering corrections (max. $\sim$ 10 - 20%) are being made by a method outlined previously (J. L. Fowler and H. O. Cohn, Phys. Rev. 109, 89 (1958)). For the higher energy data, there is also a small correction for the effect of the second group of neutrons from the Li(p,n) neutron source reaction. The spins, parity, and reduced widths have been assigned for the first four prominent resonances (J. L. Fowler, Bull. Am. Phys. Soc. 8, 82 (1963)). Above 1 MeV the rather large number of partial waves involved makes the ℓ-value assignment, based on the qualitative features of the differential cross-section curves, impractical. The Fortran code, which has been used for calculating theoretical angular distributions averaged over the experimental energy spread, is being incorporated into a least squares fitting routine in order to use the computer to search out the best fit to the experimental data.

15. Elastic Scattering of 17- to 21-MeV Neutrons from C^{12} -- M. V. Harlow, Jr., R. L. Robinson (ORNL), and B. B. Kinsey (University of Texas).

The following is an abstract of a paper to be presented at the Washington meeting of the American Physical Society, April 22-25, 1963:

> Relative yields of 17- to 21-MeV neutrons that were elastically scattered from a carbon annulus having diameters of 6" and 3" and a thickness of 1.1" have been measured for laboratory angles of 51°, 60°, and 85°. The neutrons which were produced by the d,t reaction were detected with a 1" x 1" stilbene crystal placed 18" from the tritium target. Pulse shape discrimination techniques were employed. At each angle a broad resonance was observed for a laboratory neutron energy of 19.3±0.25 MeV. Its width at half maximum was approximately 0.8 MeV; its peak height was between 10% and 20% of the value of the continuum. This resonance, which is believed to result from a state in the compound nucleus C^{13}, appears similar to the resonance reported previously (B. B. Kinsey, Phys. Rev. 99, 332 (1955); J. K. Dickens, D. A. Haner, and C. N. Waddell, Bull. Am. Phys. Soc. 7, 285 (1962)) for elastic scattering of 22.5-MeV protons on C^{12}. The total cross section has also been measured for neutrons with energies between 13.5 and 20 MeV. Here the resonance effect was not evident.

16. A Study of the Reactions $Be^{9}(He^{3},n)C^{11}$, $Li^{7}(He^{3},n)B^{9}$, and $C^{13}(He^{3},n)O^{15}$ -- J. L. Duggan, P. D. Miller, and R. F. Gabbard.

A paper by the above title has been accepted for publication in Nuclear Physics.

17. The Elastic Scattering of Alpha Particles by O^{18} -- D. Powers, J. K. Bair, H. B. Willard, J. L. C. Ford, Jr., and T. M. Hayes.

A paper by the above title will be presented at the Houston meeting of the American Physical Society, February 28 - March 2, 1963.

18. The $O^{18}(\alpha,p)F^{21}$ Reaction and the Beta Decay of F^{21} -- J. L. C. Ford, Jr., J. K. Bair, C. M. Jones, and H. B. Willard.

A paper by the above title will be presented at the Washington meeting of the American Physical Society, April 22-25, 1963.

19. Coulomb Excitation of Br^{79} -- R. L. Robinson, F. K. McGowan, and P. H. Stelson.

A paper by the above title was presented at the New York meeting of the American Physical Society, January 23-26, 1963.

20. Alpha Particles from the Bombardment of B^{10} and B^{11} by Li^{6} and Li^{7} -- P. D. Miller (ORNL), G. C. Morrison, Noel Gale, and Geoffrey Dearnaley (AERE, Harwell).

A paper by the above title will be presented at the Washington meeting of the American Physical Society, April 22-25, 1963.

21. Fluctuations in the Reaction $C^{12}(O^{16},\alpha)Mg^{24}$ -- M. L. Halbert, F. E. Durham, C. D. Moak, and A. Zucker.

A paper by the above title was presented at the New York meeting of the American Physical Society, January 23-26, 1963.

22. Angular Distribution of N^{15} Particles from the Transfer Reaction $Al^{27}(O^{16},N^{15})Si^{28}$ -- E. Newman and K. S. Toth.

A paper by the above title was presented at the New York meeting of the American Physical Society, January 23-26, 1963.

23. Proton Scattering by Isobars -- C. B. Fulmer (ORNL), and J. Benveniste and A. C. Mitchell (LRL, Livermore).

A paper by the above title was presented at the New York meeting of the American Physical Society, January 23-26, 1963.

24. Scattering of 22.5-MeV Protons from Separated Isotopes of Zirconium -- J. B. Ball and C. B. Fulmer.

A paper by the above title was presented at the New York meeting of the American Physical Society, January 23-26, 1963.

25. The (p,d), (p,t), and (p,α) Reactions to the Same Final States in Fe^{56} and Zr^{90} -- J. B. Ball, C. B. Fulmer, and C. D. Goodman.

A paper by the above title has been accepted for publication in The Physical Review.

26. Analog States in Isobaric Nuclei -- C. D. Goodman.

A paper by the above title has been accepted for publication in Phys. Rev. Letters.

27. Excited Core Model of Odd-A Nuclei and the $Cu^{63}(p,p')$ Reaction -- F. Perey, R. J. Silva, and G. R. Satchler.

A letter by the above title has been accepted for publication in Physics Letters.

28. Distorted-Wave Survey of Stripping Reactions -- R. H. Bassel, R. M. Drisko, and G. R. Satchler.

The following is an abstract of a paper presented at the New York meeting of the American Physical Society, January 23-26, 1963:

> A realistic survey was made of the predictions of the "zero-range" distorted-wave theory for stripping reactions, and comparison was made with experiments. The calculations were restricted to the use of optical potentials that give agreement with the applicable deuteron and proton elastic-scattering data. It is found that potentials that give equivalent fits to deuteron elastic scattering give different predictions for the stripping angular distributions and, further, show discrepancies with experiment. Invoking lower cutoffs on the distorted-wave radial integrals, in general improves the agreement between the various calculations and with the measurements. The effects of spin-orbit interactions in initial and final channels and variations of the bound-state function, including the effective binding energy, were also studied. Results are shown.

29. Scattering from Oriented Deformed Nuclei -- K. T. R. Davies, G. R. Satchler, R. M. Drisko, and R. H. Bassel.

The following is an abstract of a paper submitted for publication in Nuclear Physics:

> The elastic scattering of particles from oriented, deformed, odd nuclei is studied, using the collective model of the nucleus. Numerical results, obtained using the distorted-waves Born approximation, are presented for some typical cases, namely neutrons of 2, 5, and 14 MeV, protons of 5 and 14 MeV, and alphas of 43 MeV, incident on Mn^{55} and Ho^{165} target nuclei. It is found that the differential cross section shows large azimuthal asymmetries when the target is oriented perpendicular to the incident beam. The experimental observation of this effect would be valuable; for rotational nuclei it could measure the sign and magnitude of the deformation, while for vibrational nuclei it could yield important information about the coupling of the odd nucleon to the core.

30. Quasi-particle Description of Higher Excited States of Vibrational Even Nuclei -- T. Tamura (ORNL), and T. Udagawa (Tokyo Institute of Technology).

A paper by the above title will be presented at the Washington meeting of the American Physical Society, April 22-25, 1963.

31. Response of Silicon Detectors to High Energy Bromine and Iodine Ions -- F. J. Walter, C. D. Moak, and H. W. Schmitt (ORNL); J. H. Neiler (Oak Ridge Technical Enterprises, Corp.); W. M. Gibson (Bell Telephone Laboratories), and T. D. Thomas (Princeton University and BNL).

A paper by the above title was presented at the New York meeting of the American Physical Society, January 23-26, 1963.

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