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Cross Section Program at ORNL, March 1, 1962 -- October 1, 1962

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ABSTRACT

This memo reviews the cross section program at ORNL for the period March 1, 1962, through October 1, 1962.

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1a. Parameters of Neutron Resonances in the Tin Isotopes -- T. Fuketa (Visiting Investigator from JAERI, Tokai, Japan), and J. A. Harvey

The following is an abstract of a paper to be presented at the Cleveland Meeting of the American Physical Society, November 23-24, 1962:

Measurements were done in the energy range from 30 to 10,000 eV with a time resolution of 10 nsec/m using the ORNL fast chopper and the 180-m flight path (measurements on the other five tin isotopes were reported by F. A. Khan and J. A. Harvey, Bull. Am. Phys. Soc. 7, 289 (1962)). The metallic sample thicknesses were 0.20 in. and 0.15 in. for Sn^{112} and Sn^{114}, respectively, and 1.0 in. for Sn^{122} and Sn^{124}. The sample of Sn^{115} was an oxide powder, and had a thickness equivalent to 0.057 in. metal. We observed 12, 7, 4, 6, and 5 resonances in $Sn^{112,114,115,122}$, and 124, respectively, in this energy range. Measurements were also made with a 45-m flight path upon 4-in. thick natural tin and all ten enriched isotopes from 50 to 0.2 eV with an energy resolution of 1.5%. Even below 30 eV several new resonances, which had not been previously observed, were found. Detailed corrections for "missed" resonances must be made to obtain average level spacings and strength functions. The resonance parameters, average level spacings, the s-wave strength functions, and the nuclear radii are reported.

1b. Parameters of the Neutron Resonances of the Stable Isotopes of Tin -- F. A. Khan (Visiting Investigator from the Pakistan AEC), T. Fuketa (Visiting Investigator from JAERI, Tokai, Japan), and J. A. Harvey

A paper by the above title was presented at the Low-Energy Nuclear Physics Conference, Harwell, England, September 12-14, 1962.

2. Neutron Total Cross Section and Capture Measurements on Separated Zr Isotopes -- R. C. Block

The following is an abstract of a paper presented at the Low-Energy Nuclear Physics Conference, Harwell, England, September 12-14, 1962:

The ORNL fast chopper time-of-flight neutron spectrometer was utilized to make transmission measurements on isotopically enriched samples of Zr^{90} (97.8% enrichment), Zr^{91} (90.9%), Zr^{92} (95.7%), Zr^{94} (96.5%), and Zr^{96} (57.3%). In the energy range from $\sim$ 0.5 eV to 40 keV, there were approximately 3 resonances observed in Zr^{90}, 5 resonances observed in Zr^{92}, 5 resonances observed in Zr^{94}, and $\sim$ 7 resonances observed in Zr^{96}. Eleven resonances were resolved in Zr^{91} up to 3000 eV, and an s-wave strength function of $(1.0 \pm 0.3) \times 10^{-4}$ is assigned to Zr^{91}. A new weak resonance was observed in Zr^{91} at $\sim$ 450 eV in these transmission measurements; this level was also observed in capture measurements with the Rensselaer Polytechnic Institute's linear accelerator. It is interesting to note that of the 7 resonances observed in Zr^{91} below 1600 eV, 4 of these resonances

had a Γ_n^o of less than 3% of the average Γ_n^o for all 7 levels. This indicates that some of the small resonances in Zr^{91} may be due to p-wave neutrons.

3. Neutron Radiative Capture Measurements with the RPI Electron Linear Accelerator -- J. E. Russell (RPI), R. W. Hockenbury (RPI), and R. C. Block (ORNL)

The W capture data have been combined with transmission data in order to analyze the resonance parameters. The following spin assignments have been made in resonances observed in the target nucleus W^{183}:

$$E = 144.8 \text{ eV}, \; g = 1/4$$
$$E = 154.8 \text{ eV}, \; g = 1/4$$
$$E = 157.6 \text{ eV}, \; g = 3/4$$
$$E = 174.6 \text{ eV}, \; g = 3/4$$

4. Gamma Ray Spectra from Low Energy Neutron Capture -- G. G. Slaughter, J. R. Bird (Visiting Investigator from AERE, Harwell, England), G. T. Chapman, and J. A. Harvey

The following is an abstract of a paper to be presented at the Cleveland Meeting of the American Physical Society, November 22-24, 1962:

Equipment for the study of gamma-ray spectra from low energy neutron capture has been installed at the Oak Ridge Research Reactor. The fast chopper, with the high intensity rotor, is used to provide a neutron beam, and the gamma-ray detector is a heavily shielded 9 in. by 12 in. NaI crystal. A flight path of 5 meters allows the determination of neutron energies with an energy resolution of approximately 15%. Two types of measurement have been made in initial experiments: (a) the study of thermal neutron capture in small quantities of separated isotopes; (b) the study of capture in the resonance region. For example, thermal capture spectra have been observed for nine of the isotopes of tin. Each spectrum shows a number of prominent gamma rays as well as many that are poorly resolved. Capture in copper has been compared for the first two resonances at 227 eV (Cu^{65}) and 580 eV (Cu^{63}) and for the nonresonant capture at various energies below the resonances. The nonresonant spectra are very similar and differ from the spectrum for the 580 eV resonance which is similar to that observed at higher neutron energies (J. R. Bird, J. H. Gibbons, and W. M. Good, Physics Letters 1, 262 (1962)). These results are of interest for testing the suggestion that direct capture is important in copper.

5a. Thermal Neutron Capture Cross Section and Resonance Capture Integral of Ce^{140} -- P. M. Lantz

A measurement has been made of the activation thermal cross section and resonance integral of Ce^{140} by irradiating Ce^{140}

resulting from the decay of fission product Ba^{140} in which cadmium filters were utilized. The activation product, Ce^{141}, was measured by 4π beta-gamma coincidence counting and beta absorption in aluminum using a calibrated end window Geiger-Müller tube. The measurements were made in the pneumatic tube facility of the LITR. A value of 0.59 ± 0.06 barns and of 0.48 ± 0.05 barns was found for the thermal cross section and resonance integral respectively.

5b. Effective Neutron Capture Cross Section of Ce^{141} -- P. M. Lantz and C. R. Baldock

The effective neutron cross section of Ce^{141} has been measured by irradiating Ce^{140} in the MTR to form Ce^{142} by a double neutron capture reaction. The Ce^{140} source was very pure having only 9 ppm Ce^{142} measured by neutron activation and mass analysis. The Ce^{142} produced in the 113 and 226-day irradiations, monitored with dilute cobalt, was determined mass spectrographically and by neutron activation. Measurement of the Ce^{142} by neutron activation entailed the beta counting of 13.8-day Pr^{143}, the daughter of 3-min Ce^{143}. A value of 30 ± 3 barns was found for the effective neutron cross section where the Φ_{th}/Φ_r was 12.

6. Correlated Energy Measurements for Thermal-Neutron-Induced 3-Particle Fission of U^{235} -- H. W. Schmitt, J.H.Neiler, F. J. Walter, and A. Chetham-Strode

Energy correlation measurements of particles emitted in 3-particle fission have been carried out in a three-parameter experiment involving 128 x 128 x 4 channels. Particles from the thermal-neutron-induced fission of U^{235} were incident on silicon surface barrier detectors. Silicon of 600 ohm-cm was used for the heavy-fragment detectors, silicon of 3400 ohm-cm was used for the two third-particle detectors. All detectors were about 4 cm^2 in area and were operated under essentially optimum conditions (see, for example, Schmitt, Neiler, Walter, and Silva, Bull. Am. Phys. Soc. II, 6, 240 (1961)). The energy of each of the two heavy fragments was recorded in 128 channels; the third-particle energies were divided into four groups in the range 6 to 30 MeV. Mass distributions and other correlation data for binary and ternary fission of U^{235} are compared. The strong preference for emission of the alpha particles at an angle somewhat less than 90° with respect to the light fragment, as reported by Titterton (Nature 168, 590 (1951)), was observed.

7. Neutron Capture -- R. L. Macklin, T. Inada (Visiting Investigator from NIRS, Chiba, Japan), and J. H. Gibbons

Further measurements of 30 and 65 keV neutron capture cross sections have been made with the 1.2 meter liquid scintillator. The results are shown in Table I. Cross sections at 30 keV have been measured for Sm, Sr, and Zr isotopes using the fast Moxon-Rae

detector at the ORNL pulsed 3-MV Van de Graaff. Capture cross sections (from 10 to 55 keV) were measured with Y-89, Pb-206, Pb-207, F-19, sulfur and Sn-116, 117, 118, 119, 120 samples.

TABLE I

ELEMENTAL NEUTRON CAPTURE CROSS SECTIONS

Z	Element	σ_c (mb)	
		$E_n = 30 \pm 7$ keV	$E_n = 65 \pm 20$ keV
15	P	7 ± 1	0.5 ± 0.2
17	Cℓ	11 ± 4	4 ± 2
19	K	16 ± 2	4 ± 1
20	Ca	10 ± 1	3 ± 1
22	Ti	29 ± 3	5 ± 1
25	Mn	22 ± 2	9 ± 1
31	Ga	103 ± 9	56 ± 5
33	As	350 ± 32	175 ± 16
34	Se	94 ± 8	51 ± 5
37	Rb	180 ± 16	89 ± 8
52	Te	97 ± 9	35 ± 3
56	Ba	61 ± 5	33 ± 3
63	Eu	2560 ± 230	1580 ± 140
72	Hf	510 ± 45	330 ± 30
75	Re	900 ± 80	525 ± 50
76	Os	300 ± 27	175 ± 16
77	Ir	795 ± 70	450 ± 40

8a. Evidence Concerning the Importance of "Direct" or "Potential" Neutron Capture at Low Energies -- J. R. Bird (Visiting Investigator from AERE, Harwell, England), J. H. Gibbons, and W. M. Good

The following is a paper presented at the International Symposium on Direct Interactions and Nuclear Reaction Mechanisms, Padova, Italy, September 3-6, 1962:

> It has been recognized for several years that "direct" capture processes can be important at low energies. Lane and Lynn have shown that an appreciable fraction of certain thermal cross sections may be due to this process. Neutron capture γ-ray spectra have been measured in the resonance region ($\bar{E}_n$ = 30 keV) and compared with corresponding thermal capture spectra. Major differences occur for many nuclei. In particular, isotopes of nickel, copper and lead show many γ rays which would be expected following compound nucleus formation, but which are weak or absent in thermal capture. Such results support the conclusion that these mass regions are important in the consideration of direct capture.

8b. Gamma Rays from Neutron Capture in Lead -- J. R. Bird (Visiting Investigator from AERE, Harwell, England), J. H. Gibbons, and W. M. Good

The following is an abstract of a paper to be presented at the Cleveland Meeting of the American Physical Society, November 23-24, 1962:

> Measurements of 30 keV neutron capture (J. R. Bird, J. H. Gibbons, and W. M. Good, Physics Letters 1, 262 (1962)) have been extended to allow results to be obtained for a variety of neutron energies. A neutron flight path of 50 cm and a time resolution of 12 ns FWHM makes possible the observation of individual resonances in the energy range 10-100 keV. A three-dimensional analyzing system with 16 x 128 channels is used for the simultaneous measurement of neutron and gamma-ray energy. Targets of natural and radiogenic lead show resonances in Pb^{206} at 18, 22(?), 27, 45 keV as well as the well-known resonance in Pb^{207} near 45 keV. The shape of the latter for the 7.41 MeV ground state transition in Pb^{208} has been studied and intensities of three transitions in Pb^{207} have been obtained for each of the other four resonances. These intensities change markedly from resonance to resonance but the average values cannot be explained in terms of the expected multipolarities unless p-wave capture is important for these resonances.

9. Measurement of $\alpha = \sigma_c/\sigma_f$ as a Function of Neutron Energy -- G. deSaussure and L. W. Weston

> A measurement of α for U^{235} at neutron energies of 30 $\pm$ 10 keV and 64 $\pm$ 20 keV was performed using a 30-plate fission chamber in the center of a 1.2-m diameter liquid scintillator tank. The chamber was bombarded by pulses of neutrons obtained at the 3-MV

Van de Graaff by the $Li^7(p,n)Be^7$ and $T(p,n)He^3$ reactions at the threshold. The ratio of the scintillator pulse-height spectrum in anticoincidence with the fission chamber to that in coincidence with the fission chamber provides the value of α. The values obtained were

$$\alpha(U^{235}, 30 \pm 10 \text{ keV}) = 0.372 \pm 0.026$$

$$\alpha(U^{235}, 64 \pm 20 \text{ keV}) = 0.315 \pm 0.060.$$

The major source of uncertainty of the measurements is associated with the extrapolation of the pulse-height spectra below a bias of about 2-MeV γ-ray energy. (Background radiation below 2 MeV is too large to permit accurate measurement of the pulse-height spectra.)

The results are in good agreement with the result obtained by Hopkins and Diven for the same parameter (Nuclear Science and Engineering 12, 169 (1962)). Of course, the two measurements are not entirely independent as the somewhat arbitrary extrapolation of the pulse-height spectra to zero pulse height was obtained, in both experiments, with similar criteria.

10. Fission Cross Section and Fragment Angular Distribution for Fast Neutron-Induced Fission of U^{234} -- R. W. Lamphere

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

The fission cross section of U^{234} has been remeasured to 4 MeV neutron energy with greater detail in order to accurately delineate the extrema. Results are believed to be somewhat more accurate than those previously reported by the author. The fragment angular asymmetry A defined as the ratio of fragment emission at zero degrees to that at ninety degrees to the neutron beam was measured from 0.4 to 3.8 MeV. At 843, 1050, and 3740 keV the 30/60 degree fragment intensity ratio was also measured and normalized to A. Strong sidewise peaking with A = 0.50 (normal to the neutron beam) was found at 500 keV at which point the total fission cross section is 0.50 barn and rising smoothly. At 843 keV the cross section passes through a maximum of 1.26 barns coincidentally with a maximum of 1.80 in A. From 843 to 1050 keV both cross section and A fall smoothly to minima of 1.10 barn and 1.13, respectively. Above 1050 keV both cross section and A rise somewhat irregularly. A remains very nearly constant at 1.20 between 1.5 and 3.8 MeV.

As suggested by Wheeler the dip in cross section can be explained in terms of enhanced competition from inelastic neutron scattering. A modified Hauser-Feshbach type of analysis indicates that scattering to vibration-rotational levels known to exist above 790 keV in U^{234} serves to depress the cross section for fission.

The changes in A are explained in terms of the theory of A. Bohr which postulates that fission occurs through distinct channels akin to the K-band structure seen in heavy aspherical nuclei at low excitations. On this basis approximately 62% of fission at 500 keV goes via a 3/2-band while most of the remainder goes via a 1/2+ band. At 843 keV only 14% goes through the 3/2- band, the rest proceeds via a strong 1/2- band and the much weaker 1/2+ band. The reason for the strong fall in A between 843 and 1050 keV is unclear. Some possibilities are suggested.

The sequence of K bands indicated for U^{235*} near the saddle point deformation is 1/2+, 3/2-, 1/2-, with separations of the order of a few hundreds of kilovolts.

11. Differential Neutron Cross Sections with a Few KeV Energy Spread -- J. L. Fowler

Apparatus designed to determine neutron angular distributions with good energy resolution (J. L. Fowler, Program of the Southeastern Section Meeting of the American Physical Society, Abstract I3, 1962) has been used to measure the differential cross sections of neutrons scattered from Pb^{208} (99.75%) at twenty-one different energies between 700 keV and 1750 keV. Fourteen of the measurements were at resonant energies (J. L. Fowler and E. C. Campbell, Phys. Rev., Sept. 15 issue (1962)). For the first several prominent resonances the interference between the resonant phase shifts and potential scattering (predominantly s-wave) allows one to assign the ℓ-value by inspection. These assignments are as follows:

E_o (keV)	Γ (keV)	J	ℓ	Parity
723	5.0 ± 1.0	5/2	2	+
769	5.5 ± 1.0	3/2	1	-
821	10.0 ± 1.0	5/2	2	+
855	5.0 ± 1.0	3/2	2	+

As the neutron energy increases, potential scattering phase shifts other than s-wave become important, so that a more quantitative analysis becomes necessary. A Fortran code has been written for the 7090 computer to calculate theoretical angular distributions as a function of resonance parameters and potential scattering phase shifts in order to compare with the experimental results.

12a. Excitation of Collective States by Inelastic Scattering of 14-MeV Neutrons -- P. H. Stelson and R. L. Robinson

Neutrons of 14-MeV energy from the d-t reaction have been used to excite collective states in lead, bismuth, nickel, zinc, and sulphur. Absolute differential cross-sections have been obtained for the excitation of the octupole (2.5 MeV) and hexadecapole (4.1 MeV) states in lead and of the quadrupole (2.24 MeV) state in sulphur. The results are in general agreement with the predictions of the direct interaction theory of Buck and of Bassel, Drisko, and Satchler.

12b. Excitation of Collective States by Inelastic Scattering of 14-MeV Neutrons -- P. H. Stelson and R. L. Robinson

A paper by the above title was presented at the International Symposium on Direct Interactions and Nuclear Reaction Mechanisms, Padova, Italy, September 3-6, 1962.

13. (p,n) Cross Sections -- J. K. Bair, C. M. Jones, and H. B. Willard

Preliminary measurements of (p,n) total cross sections have been made, utilizing the Tandem Van de Graaff and the graphite sphere neutron detector. Elements bombarded to date are Li^6, Li^7, Be^9, B^{10}, and B^{11}.

14. The Optical Model with Non-Local Potentials -- F. Perey

A paper by the above title was presented at the International Symposium on Direct Interactions and Reaction Mechanisms, Padova, Italy, September 3-6, 1962. It has been published, F. Perey and B. Buck, Nuclear Physics 32, 353 (1962).

15. The Calculation of Elastic and Inelastic Proton Scattering with a Generalized Optical Model -- B. Buck

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

An extension of the optical model is considered in which a state of quadrupole collective motion is strongly coupled to the nuclear ground state. The calculations include a spin-orbit potential and the simultaneous coupled differential equations of the problem are solved numerically on a high-speed computer. Experimental data on the scattering of medium energy protons from Ti, Cr, Fe, Ni, and Zn are analyzed. A good average optical potential is determined and conclusions are drawn about the energy dependence of the parameters. Evidence is presented for the validity of the collective model. Nuclear deformabilities derived by fitting the inelastic differential cross sections are in good agreement with

those determined by electromagnetic methods. Various limitations and ambiguities of the model are discussed and possible improvements are indicated.

16. Analysis of Angular Correlation for Inelastic Proton Scattering on Fe^{56} and Ni^{58} -- G. R. Satchler and E. Sheldon (Visiting Investigator from E. T. H., Zurich, Switzerland)

A paper by the above title was presented at the International Symposium on Direct Interactions and Reaction Mechanisms, Padova, Italy, September 3-6, 1962.

17. The Elastic Scattering of Alphas by O^{18} -- D. Powers, J. Ford, T. Hayes, and H. B. Willard

Differential elastic scattering cross sections have been measured for 2.4 to 3.5 MeV alphas on O^{18} at center-of-mass angles corresponding to the first 4 zeros of the Legendre polynomials. Of the eight resonances previously observed in this energy region by the $O^{18}(\alpha,n)Ne^{22}$ reaction, spin and parity assignments have been made to six levels by the combined experimental data.

18. Coulomb Excitation of Osmium Nuclei -- F. K. McGowan, P. H. Stelson, and R. L. Robinson

Coulomb excitation measurements have been made by proton and α-particle bombardment of metallic targets enriched in the different isotopes of osmium. The B(E2)'s for excitation of the first 2+ state in Os^{188}, Os^{190}, and Os^{192} are larger than the single-particle estimate by factors ranging from 70 to 100. The B(E2) for excitation of the second 2+ state is about 0.1 of the B(E2) for excitation of the 2+ state. The sign of $\delta = (E2/M1)^{1/2}$ in the $2 \rightarrow 2$ transition is negative and the $B(M1, 2 \rightarrow 2)$'s are exceedingly small, being about 10^{-3} times the single-particle estimate.

States in Os^{187} at 74, 75, and 187 keV and in Os^{189} at 69.5, 95, and 219 keV are directly Coulomb excited. The predictions of the symmetric rotator model of Bohr-Mottelson with rotation-particle coupling included do not agree with the experimental results for Os^{187}.

19. Coulomb Excitation with Ne^{20} Ions -- R. C. Ritter, P. H. Stelson, F. K. McGowan, and R. L. Robinson

The following is an abstract of a paper submitted for publication in Physical Review:

Neon ions with energies ranging from 8 to 15 MeV have been obtained by the acceleration of doubly and triply charged ions in a 5.5-MV Van de Graaff. These projectiles have been used to study Coulomb excitation in 18 nuclei ranging from Li^7 to Th^{232}. In particular, the levels of Ti^{47}, V^{51}, Fe^{57}, Ni^{61}, Zn^{67}, Ge^{73}, and As^{75} were investigated. New spin assignments were obtained for the 93- and 184-keV states in Zn^{67}. A unique spin assignment is obtained for the 320-keV state of V^{51} and the multipolarity mixture of γ ray is established.

20. A Comparison of (p,d), (p,t), and (p,α) Reactions Exciting the Same Final States -- J. B. Ball, C. B. Fulmer, and C. D. Goodman

A paper by the above title was presented at the International Symposium on Direct Interactions and Reaction Mechanisms, Padova, Italy, September 3-8, 1962.

21. (p,t) Double Pickup Reactions with 22-MeV Protons -- C. D. Goodman, J. B. Ball, and C. B. Fulmer

Energy spectra and angular distributions of (p,t) reactions on zirconium isotopes and neighboring nuclides were measured. Only a few final levels are strongly excited. These are interpretable as the results of pickup of two neutrons from shell model states. Levels are observed which represent the different possible couplings of the angular momenta of the resultant hole states.

22. (p,d) Pickup Reactions with 22-MeV Protons on Targets Near N = 50 -- C. D. Goodman, J. B. Ball, and C. B. Fulmer

(p,d) energy spectra and angular differential cross sections have been measured and are compared for seven neighboring nuclides. The cross section for the d 5/2 neutron pickup increases as the level fills. Comparison of reduced widths extracted with distorted wave calculations shows an effect of shell model residual interactions. Residual interactions are also observed through other features of the spectra.

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

With O^{4+} ions accelerated by the Tandem Van de Graaff, the excitation function for the reaction $C^{12}(O^{16},\alpha)Mg^{24}$ was measured for the first five states in Mg^{24}. The overall resolution was 45 keV (center of mass), and strong fluctuations in the excitation function were observed throughout the investigated energy region, from 25.10 to 26.10 MeV excitation in the compound nucleus Si^{28}. If the resonances are due to the interference of randomly distributed levels in the compound nucleus, one may conclude that its lifetime is no shorter than 0.7×10^{-20} sec.

24. Charged-Particle Cross-Section Compilation -- F. K. McGowan and W. T. Milner

The purpose of this activity is to continue the compilation of nuclear cross sections for charged-particle-induced reactions. In scope and form, the compilation will follow the plan of previous versions in Los Alamos Reports LA-2014 and LA-2424. The "best values" of the cross sections will be presented in graphical form with the grid lines reproduced. In addition, the data will be given in tabular form for all charged-particle-induced reactions, including heavy ions, at all energies.

A literature search for the years 1948-1961 has been completed. The bibliography contains abstracts of all the papers from this literature search. Data for the elements manganese through tin are being compiled in tabular form.

25. ORNL Tandem Accelerator -- C. D. Moak

The voltage rating of the Tandem accelerator has been increased from 6 megavolts to 7.5 megavolts; thus the proton energy range has been extended from 12 MeV to 15 MeV and data have been taken at 15 MeV. Oxygen ion energy range is increased from 42 MeV to 52.5 MeV. The accelerator has been used to calibrate special fission detectors using bromine ions as artificial fission fragments with energies ranging up to 100 MeV. For heavy fragment calibrations, iodine ions are now being used.

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