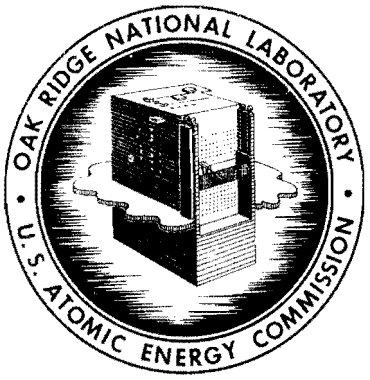

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Cross Section Program at ORNL, November 15, 1961 - March 1, 1962

J. A. Harvey and H. B. Willard

ABSTRACT

This memo reviews the cross section program at ORNL for the period November 15, 1961, through March 1, 1962.

OAK RIDGE NATIONAL LABORATORY

1. High-Resolution Neutron Total Cross-Section Measurements on $Sn^{116,117,118,119,120}$ --- F. A. Khan (Visiting Investigator from AEC, Pakistan), and J. A. Harvey

The following is an abstract of a paper presented at the Washington Meeting of the American Physical Society, April 23-26, 1962:

> The ORNL fast chopper and associated equipment were utilized in measuring the transmissions of one-inch thick metal samples of $Sn^{116,117,118,119,120}$ (enrichment over 95%) and normal tin. Measurements were made from 30 to 10,000 ev with a time resolution of 10 nsec/m using the 180-m flight-path spectrometer. The transmission data have been analyzed to give the parameters of the resonances using an area-analysis program (S. E. Atta and J. A. Harvey, Oak Ridge National Laboratory Report, ORNL-3205) which includes the effects of resolution and Doppler broadening. The observed level spacings of the even isotopes, $Sn^{116,118,120}$ ($D_{obs} \sim 240$ ev), were found to be about four times those of the odd isotopes, $Sn^{117,119}$ ($D_{obs} \sim 60$ ev). Parameters of the resonances, the s-wave strength functions, and nuclear radii of the isotopes are reported.

2a. Thermal Neutron Capture Cross Section and Resonance Capture of Ce^{144} --- P. M. Lantz

The following is an abstract of a paper submitted for publication in Nuclear Science and Engineering:

> The thermal cross section, σ_{th}, and the resonance capture integral, I_o, of Ce^{144} have been measured by an activation method. The values are: $\sigma_{th} = 1.00 \pm 0.10$, and $I_o = 2.60 \pm 0.26$ barns, respectively.

2b. Effective Neutron Capture Cross Section of Ce^{141} --- P. M. Lantz and C. R. Baldock

Two samples of approximately 10 milligrams of Ce^{140} were irradiated in the MTR to an integrated flux of 2.27×10^{21} and 6.66×10^{21} neutrons/cm^2 (monitored with Co^{59}). The Ce^{142} formed from the $Ce^{140} \xrightarrow{(n,\gamma)} Ce^{141} \xrightarrow{(n,\gamma)} Ce^{142}$ reaction was determined mass spectrographically and by neutron activation. A preliminary evaluation of the data yielded an effective cross section $\sigma_{eff} = 55$ barns for the reaction $Ce^{141}(n,\gamma)Ce^{142}$.

3. Correlated Energy Measurements of Fission Fragment Pairs --- F. J. Walter, A. Chetham-Strode, J. H. Neiler, and H. W. Schmitt

The following is an abstract of a paper presented at the Washington Meeting of the American Physical Society, April 23-26, 1962:

> The pulse-height distribution of correlated fragment pairs from thermal neutron induced fission of U-235 has been measured using two matched 4 cm^2 silicon surface barrier detectors and a 128 x 128 channel correlation recorder. The uncorrelated pulse-height spectrum exhibits a peak to valley ratio of twenty to one for both detectors. The pulse-height contours resulting from a correlation run containing $>10^6$ events will be shown; these data have been normalized to energies (E) obtained from time-of-flight measurements (W. E. Stein and S. L. Whetstone, Phys. Rev. 110, 476 (1958)) to determine correlated energy spectra, mass distributions and other pertinent correlations. The pulse-height (PH) response of surface barriers to fission fragments may be represented (H. W. Schmitt, et al., Bull. Am. Phys. Soc. Ser. II, 6, 3 (1961)) by $E = a \times PH + \delta$ where a and δ are empirically determined factors which depend on the time-of-flight data employed. The effect of these normalizations on the data, and the influence of prompt neutron emission on the determination of mass distributions is being studied.

4. Cooperative ORNL-RPI Capture Experiment --- R. C. Block (ORNL), J. E. Russell and R. W. Hockenbury (RPI)

The ORNL 1.25-meter diameter liquid scintillator capture detector has been installed at the Rensselaer Polytechnic Institute electron linear accelerator laboratory. This apparatus was placed at the 25-meter flight station and the electron accelerator was operated at an energy of $\sim$66 Mev, 2 amps of peak electron current, a pulse duration of 100 nsec, and a repetition rate of 60 pps (the latter limited by the duty cycle of the time analyzer). A 2-inch thick paraffin slab was employed to moderate the photoneutrons from a W target into the resonance energy range. The capture data were collected in the RPI 2000-channel time-of-flight analyzer with channel widths of 0.1 μsec. A resolution of 6 nsec/meter was observed in capture with this equipment at a neutron energy of one kilovolt.

This equipment has been operating since March, 1962, and capture data over an energy range from $\sim$10 kev to 85 ev have been obtained on samples of Fe, Zr, Ag, In, Sn, W, Pt, and Au. A strong but very narrow capture resonance was observed in Fe at 1154 $\pm$ 5 ev; this is in agreement with the observations of Isakov, Popov, and Shapiro [J. Exptl. Theoret. Phys. (USSR) 38, 989 (1960)] who found a level in Fe at 1180 $\pm$ 80 ev. These data are in the process of being analyzed for resonance parameters.

A paper describing this equipment has been presented at the 1962 Washington American Physical Society Meeting. This paper was entitled

"Neutron Time-of-Flight Spectrometer with the RPI Linear Electron Accelerator" by J. E. Russell, R. W. Hockenbury, and R. C. Block, Bull. Am. Phys. Soc. 7, 289, Series II (1962).

5. Gamma Ray Spectra from Capture of 30-kev Neutrons -- J. R. Bird (Visiting Investigator from AERE, Harwell, England), J. H. Gibbons, and W. M. Good

The following is an abstract of a paper presented at the Washington Meeting of the American Physical Society, April 23-26, 1962:

> A 9" x 12" NaI crystal (on loan from ORNL Neutron Physics Division) has been used with the ORNL pulsed Van de Graaff to study the γ-ray spectra from the capture of 30-kev neutrons. The technique is the same as was used by Firk and Gibbons (Proc. Saclay Symposium Neutron Time-of-Flight Methods, p. 213 (1961)) but improved γ-ray energy resolution (10% for 0.66 Mev) and sensitivity (3 mb cross sections observable) make it possible to obtain the strengths of individual transitions in many cases. Measurements have been made for F, Al, Ca, V, Cr, Fe, Cu, Ni, Y, and Pb (including separated isotopes of Cu, Ni), and in most cases the results differ from those of thermal neutron capture. The main factors causing the differences are (a) changes in relative capture cross sections of isotopes, (b) fluctuations in transition strengths from resonance to resonance, (c) averaging of transition strengths over many resonances, and (d) contribution from p-wave neutron capture for 30-kev neutrons.

6. 30-kev Neutron Capture -- R. L. Macklin, T. Inada (Visiting Investigator from AEC, Japan), and J. H. Gibbons

Two Moxon-Rae gamma-ray detectors have been used with the ORNL 3-Mv pulsed Van de Graaff accelerator to measure 30-kev capture cross sections of several elements and seven separated isotopes of tin. The overall time resolution for the second model was 3 to 4 nsec. A cross section 513 (±20%) mb was found for gold, in apparent agreement with the earlier large liquid scintillator and spherical shell transmission results, but not with the gold activation results. The tin isotope results, in combination with the isotopic abundances are of value in fixing the relative contributions of supernovae and red giant stars to the material of the solar system. Some results are tabulated below:

TABLE I

30-kev Neutron Capture Cross Sections

(1) Nucleus	(2) σ_c (mb)
Sn 116	92 ± 19[a]
117	390 ± 82[a]
118	59 ± 12[a]
119	243 ± 51[a]
120	35 ± 7
122	23 ± 5
124	23 ± 4

[a]This is the rms absolute error, the relative errors are estimated at ± 10%.

TABLE II

Z	Element	Neutron Capture Cross Sections for 30-kev Neutrons (mb)
		Present Work
42	Mo	141 (± 23%)
47	Ag	(951)
48	Cd	343 (± 21%)
50	Sn	124 (± 24%)
73	Ta	630 (± 20%)
74	W	184* (± 21%)
78	Pt	321 (± 23%)
79	Au	513 (± 20%)

*$\sim$ 300 using peak counts only.

7. Measurement of $\alpha = \frac{\sigma_c}{\sigma_f}$ as a Function of Neutron Energy --- G. de Saussure and L. W. Weston

A measurement of α for U^{235} at a neutron energy of 30 ± 10 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 30-kev neutrons obtained at the 3-Mv Van de Graaff by the $Li^7(p,n)Be^7$ reaction at the threshold. The ratio of the scintillator pulse-height spectrum in anti-coincidence with the fission chamber to that in coincidence with the fission chamber provides the value of α. The value obtained was

$$\alpha(U^{235},\ 30 \pm 10 \text{ kev}) = 0.375 \pm 0.053.$$

The major source of uncertainty (an uncertainty of ± 0.052) of the measurement 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 result is in good agreement with the result obtained by Hopkins and Diven for the same parameter ($\alpha = 0.376 \pm 0.036$, published in 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.

A measurement at 65 kev using the $T(p,n)He^3$ reaction at the threshold is now in progress. Measurements of the capture + fission spectrum with thick uranium samples will also be made soon to reduce the uncertainty due to the pulse-height extrapolation.

Measurements of α for Pu^{239} and U^{233} and measurements over a wide neutron energy range will be performed at a later date.

8. Total Cross Section of Pb^{208} --- J. L. Fowler and E. C. Campbell

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

> Measurements are reported on the total neutron cross section of isotopically enriched Pb^{208} (99.75%) for neutron energies in the range from 720 to 1890 kev with energy spread of about 3 kev. In this region at least 85 resonances are observed of which 24 are analyzed to give tentative spin assignments and reduced widths. For the J = 5/2 resonances at 723 and 821 kev, the reduced width estimates furnish evidence that these are even parity resonances. Differential cross sections of normal lead measured with 50 kev energy spread at 1.2, 2.2, and 3.2 Mev were used in estimating the in-scattering correction for the total cross section data and are included in this paper.

9. Differential Neutron Cross Sections with a few kev Energy Resolution --- J. L. Fowler

The following is an abstract of a paper presented at the Southeastern Meeting of the American Physical Society, April 5-7, 1962:

> In order to assign quantum parameters to neutron resonances of light nuclei and heavy nuclei near closed shells, it is often necessary to measure differential cross sections with a few kev energy spread. Apparatus utilizing a stilbene crystal as an efficient neutron detector has been set up for measuring such neutron angular distributions. $Li^7(p,n)$ neutrons are collimated by a doubly tapered slot through a 50 cm thick lithium-loaded paraffin shield. Dimensions of the throat of the slot are 1.2 cm wide and 4.6 cm long. The cylindrical sample which can be moved remotely is supported in the neutron beam in the center of a shielded space approximately 1 meter square and 60 cm deep. The 2.5 cm diameter neutron detecting crystal, from which pulses due to gamma rays are suppressed by pulse shape discrimination, is rotated about the sample also by remote control. Signal to background is considerably improved over that obtained with shadow shielding often used in such experiments. Differential measurements made at the 723 key and the 821 kev resonances in the neutron cross section of Pb^{208} indicate these are d-wave resonances.

10. Excitation of Collective States in Sn and Fe by Inelastic Scattering of 14-Mev Neutrons --- P. H. Stelson and R. L. Robinson

The following is an abstract of a paper presented at the Washington Meeting of the American Physical Society, April 23-26, 1962:

> A deuteron beam is chopped into 30 ns bunches at a repetition rate of 220 ns in the terminal of a 200 kv Cockcroft-Walton accelerator. Klystron bunching is used after acceleration to produce a deuteron pulse at the target which is less than 2 ns in width with a peak current greater than 3 milliamps. 14-Mev neutrons from the d-t reaction have been used to study inelastic scattering of Sn and Fe. A ring geometry is used. Neutron energies are determined by time-of-flight with a 9 meter flight path. With Sn there is clear evidence for the excitation of the quadrupole states at 1.1 ± 0.1 Mev. The differential cross section increases from (2.6 ± 0.5) mb/ster at 81° to (6.5 ± 1.2) mb/ster at 32°. The shape and magnitude of the cross section agree well with a theoretical calculation of the excitation of the quadrupole states by B. Buck (private communication). In addition to the quadrupole state there is a somewhat stronger excitation of a state at (2.15 ± 0.1) Mev which may be the octupole state. With the Fe scatterer, the 845-kev first 2^+ state is clearly seen. At some angles it is comparable to the elastic scattering cross section.

11. Effects of Nuclear Collective Motions on S-and P-Wave Strength Functions --- B. Buck and F. Perey

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

> The splitting of the peak around mass 160 in the S-wave strength function has previously been explained by strong permanent deformations of the rare earth nuclei. Many even-even nuclei while not permanently deformed are easily set into quadrupole vibrations. A strong coupling calculation has been set up to include the effects of collective states (vibrational and rotational) and applied to the calculation of the S- and P-wave neutron strength function. For S-wave the results are very similar to those of Chase, Wilets, and Edmonds. For P-wave the calculation reproduces the experimentally observed splitting of the peak around mass 100, a normal amount of spin-orbit coupling is used. The coupling of the 2^+ state to the ground state is obtained from Coulomb excitation measurements and the optical potential parameters are derived from a non-local energy independent optical model (WASH 1034, page 25) so that there is no free parameter in the calculation.

12. Excitation of Two Phonon States by Inelastic α-Particle Scattering --- B. Buck

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

> Recent experiments on inelastic scattering of 40-Mev α-particles have shown that the angular distributions from the excitation of some known 4^+ states in medium weight nuclei are not in accord with the Blair phase rule. Calculations are reported which indicate that the anomaly arises as an interference effect between two possible mechanisms for exciting the first 4^+ state, i.e., a direct transition and a multiple transition. This conclusion is contrary to previous interpretations based on plane-wave perturbation calculations. It is suggested that experiments on this type, and the analysis given here, promise to be a useful tool for the study of higher excited states.

13a. The Thermal Cross Section and Resonance Integral for the Reaction $Sm^{150}(n,\gamma)Sm^{151}$ -- J. Halperin, R. E. Druschel and C. R. Baldock

A measurement has been made of the activation thermal cross section and resonance integral of Sm^{150} by irradiating enriched Sm^{150} utilizing cadmium filters. The activation product was measured by mass analysis. A value of 97 ± 10 barns and of 255 ± 25 barns was found for the thermal cross section and resonance integral respectively. These values are of interest since Sm^{150} is the nuclide of lowest cross section in the sequence starting with Pm^{147} and which via successive neutron capture results in Gd^{156}.

Sm^{150} can effectively interrupt the chain of neutron losses at mass 150 in a high flux reactor.

13b. Activation Cross Section for the $Bi^{210}(n,\gamma)Bi^{211}$ Reaction --- J. Halperin and J. H. Oliver

A preliminary measurement of the activation cross section of Bi^{210} has been obtained by irradiating the 2.6×10^6 yr isomer (present to the extent of 8 ppm in previously irradiated bismuth as determined by measuring the 4.93-Mev alpha of Bi^{210}) to form the 2.15 minute alpha emitting Bi^{211} (AcC). The measurement was carried out in the pneumatic tube facility of the ORR. An effective thermal cross section for the reaction of 0.05 barns was found by measuring the alpha decay of Bi^{211}.

13c. Activation Cross Section for the $Nb^{95}(n,\gamma)Nb^{96}$ Reaction -- J. Halperin and R. E. Druschel

An initial measurement has been carried out of the activation cross section of the 35 day beta emitting Nb^{95}. The 23 hour Nb^{96} activation product was independently prepared from molybdenum enriched in the 96 isotope via the $Mo^{96}(n,p)Nb^{96}$ reaction and served to calibrate the analysis for the Nb^{96} formed from Nb^{95}. A preliminary value of about 1000 barns has been observed for this reaction.

14. Coulomb Excitation of Second 2+ States in Ge^{74}, Ge^{76}, Se^{76}, Se^{78}, and Se^{80} --- F. K. McGowan and P. H. Stelson

The location of a second 2+ has been established for five even-even nuclei by means of Coulomb excitation produced by 6-, 7-, and 8-Mev α-particles. The relatively weak excitation of these states is detected by a coincident measurement of the cascade gamma rays. The B(E2)'s for decay of the second 2+ state to the ground state by the crossover transition are rather small, being about single-particle value or a little less. For Ge^{74}, Se^{76}, and Se^{78}, the cascade/crossover ratio for the decay of the second 2+ state is known from radioactive decay measurements. The upper cascade $B(E2,2' \rightarrow 2)$'s exhibit enhancements comparable to those for the lower cascade $B(E2,2 \rightarrow 0)$'s. The ratios of the B(E2)'s for the decay of the first and second 2+ states are comparable to the predictions of several collective models. The $B(M1,2' \rightarrow 2)$ values for Ge^{74} and Se^{76} are small, being about 10^{-3} times the single-particle estimate. This result is in qualitative agreement with the collective models for vibrational excitations.

15. Level Structure in Ne^{22} and Si^{30} from the Reactions $O^{18}(\alpha,n)Ne^{21}$ and $Mg^{26}(\alpha,n)Si^{29}$ --- J. K. Bair and H. B. Willard

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

16. Level Structure of Ge^{71}, Ge^{73}, Ge^{75}, and Ge^{77} from the (d,p) Reaction -- R. J. Silva and E. Eichler

The following is an abstract of a paper presented at the Washington Meeting of the American Physical Society, April 23-26, 1962:

> Separated isotopes of germanium were bombarded with 5.2-Mev deuterons from the ORNL 5.5-Mv Van de Graaff accelerator. The energy spectra of proton groups leading to excited levels in Ge^{71}, Ge^{73}, Ge^{75}, and Ge^{77} up to approximately 1 Mev were obtained using a silicon surface-barrier detector. For the highest-energy proton group from Ge^{71}, Ge^{73}, Ge^{75}, and Ge^{77}. Q values of 5.140 ± 0.050, 4.429 ± 0.050, 4.200 ± 0.050, and 3.554 ± 0.050 Mev, respectively, were obtained. The first three of these values are in agreement with published Q values for ground-state transitions (Koenig, Mattauch, and Wapstra, Nuclear Data Tables - Part 2 (1960)). Within the measured resolution of the system (30-35 kev fwhm), proton groups corresponding to all previously known levels were observed with the exception of the 139-kev level in Ge^{75} and the ground state in Ge^{77}. The Q values for proton groups leading to newly observed levels were: Ge^{71} -- 4.625, 4.071 Mev; Ge^{73} --3.939, 3.789, 3.550, 3.417 Mev; Ge^{75} -- 4.158(?), 4.005, 3.959, 3.894, 3.627, 3.535, 3.335 Mev; Ge^{77} -- 3.484, 3.218, 3.092, 2.844, 2.709, 2.494 Mev. The relative error between the Q values for a given isotope is ± 10 kev.

17. Elastic Scattering Differential Cross Section for Protons on the Zirconium Isotopes at 10 Mev -- R. J. Silva and F. G. Perey

In order to investigate the effects of shell closure and the isotopic spin dependence of the optical model the scattering of protons on the even-even isotopes of Zr has been measured at 10 Mev using the ORNL Tandem Van de Graaff and with surface barrier detectors. Preliminary measurements have also been taken at 6.8 Mev. It is planned to extend the measurements over the energy range of the Tandem.

18. Interpretations of Low-Lying Levels in Zirconium Isotopes Inferred from (p,p'), (p,d), and (p,t) Spectra -- C. D. Goodman, J. B. Ball, and C. B. Fulmer

A paper by the above title was presented at the Washington Meeting of the American Physical Society, April 23-26, 1962.

19. Angular Momentum Effects in Compound Nucleus Reactions -- M. L. Halbert and F. E. Durham

The following is an abstract of a paper presented at the Washington Meeting of the American Physical Society, April 23-26, 1962:

> Energy distributions of alpha particles from 27-Mev N^{14} bombardment of C^{12}, O^{16}, Na^{23}, and Al^{27} were measured at laboratory angles from 0° to 165°. For a given channel energy the angular distributions are symmetric about 90° (c.m.) and are strongly peaked forward and backward. This behavior arises (T. Ericson and V. Strutinski, Nuclear Physics 8, 284 (1958)) from the limitation in the number of high-spin states in the residual nucleus, commonly expressed by the level density $\omega(E^*,J) \sim \omega(E^*,0)(2J+1) \exp\left[-J(J+1)/2\sigma^2\right]$. Least-squares fits to series in even Legendre polynomials were made for all the data. The table lists the fit to $1 + c_2P_2 + c_4P_4 + c_6P_6$ for $O^{16}(N^{14},\alpha)Al^{26}$ at 3 excitation energies. The parameter σ will be determined from the c_i using the IBM 7090, since the approximations usually made to simplify theory are invalid here.
>
> | E^*, Mev | c_2 | c_4 | c_6 |
> |---|---|---|---|
> | 4 | 1.20 ± .16 | 0.84 ± .22 | 0.44 ± .22 |
> | 8 | 1.29 ± .14 | 0.60 ± .19 | 0.04 ± .19 |
> | 12 | 0.93 ± .06 | 0.29 ± .10 | 0.27 ± .09 |
>
> Another effect of angular momentum limitation, the failure of the energy distributions to factor into ϵ, σ_c, and ω, was demonstrated by fitting the spectra from O^{16} with $\omega(E^*,0) = C \exp 2\left[a(E^*-b)\right]^{1/2}$. At all angles b was -1 ±1 Mev, but a increased from 1.0 Mev^{-1} at 0° to 1.5 at 80°.

20. Tandem Van de Graaff --- C. D. Moak

The ORNL Tandem accelerator was accepted on March 7, and has been placed in service. Experiments have been performed on elastic proton scattering from isotopes of Ni and Zr. At this writing the machine is being used to deliver 30 Mev N^{14} ions.

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