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ANALYSIS OF n + ^{197}Au CROSS SECTIONS FOR E_n = 0.01-20 MeV

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ABSTRACT

An analysis of n + ^{197}Au reactions has been completed for incident neutron energies between 0.01 and 20 MeV. The analysis involves use of a deformed optical model to calculate neutron transmission coefficients, a giant-dipole-resonance model and experimental data to determine gamma-ray transmission coefficients, and Hauser-Feshbach statistical theory to calculate partial reaction cross sections. Particular emphasis was given to obtaining gamma-ray strength functions that are consistent with spectral measurements of gamma-ray emission between E_n = 0.2 and 20 MeV by Morgan and Newman,[1] while at the same time requiring agreement with (n,γ) and (n,xn) cross-section data.

THEORETICAL CALCULATIONS

The deformed optical model parameterization by Delaroche[2] was utilized in our analysis. This parameterization gives good agreement with neutron total cross-section measurements on ^{197}Au between 10 keV and 27 MeV, elastic (n,n) angular distributions near 5 MeV, and, making use of isospin relationships, ^{197}Au(p,p) elastic scattering angular distributions at 13.8 and 55 MeV. The coupled-channel code ECIS[3] was used for our deformed optical model calculations. The lowest three states of the ^{197}Au ground state rotational band were coupled in the calculation ($J^\pi = 3/2^+, 5/2^+, 7/2^+$ at E_x = 0, 279, 548 keV, respectively). Neutron transmission coefficients were calculated to 20 MeV with ECIS and were collapsed to a form depending only on incident neutron energy and orbital angular momentum for use in Hauser-Feshbach calculations.

The Hauser-Feshbach statistical theory calculations were performed with the COMNUC[4] and GNASH[5] reaction theory codes. The COMNUC cross section calculations include width-fluctuation corrections, important at lower energies, and the GNASH calculations incorporate preequilibrium effects, which become significant at higher energies. COMNUC was used to calculate all cross sections below 3 MeV, whereas GNASH was used for cross sections above 3 MeV and for all spectra calculations. Both codes use the Gilbert and Cameron[6] level density formulation and the Cook[7] tabulation of level density parameters, modified slightly as described below. A maximum amount of experimental information on discrete energy levels was incorporated into the calculations, and the constant temperature part of the Gilbert and Cameron level density was matched to the discrete level data for each residual nucleus in the analysis.

Gamma-ray transmission coefficients were calculated from E1 and M1 strength functions. A giant-dipole-resonance shape[8] with the parameters E_R^{M1} = 8 MeV and Γ_R^{M1} = 5 MeV[9] was used for the M1 strength function. For radiative capture the shape of the E1 strength function was determined for $E_\gamma < 8$ MeV by trial-and-error calculation of the $^{197}Au(n,\gamma)$ spectrum measurements of Morgan and Newman[1] at $E_n = 0.2-0.6$ MeV. A second E1 strength function was similarly determined from the measured $(n,n'\gamma)$ spectrum at $E_n = 6-7$ MeV. Above $E_\gamma = 8$ MeV, the empirically determined E1 strength functions were joined to a giant-dipole-resonance shape.

The normalizations of the strength functions were determined with the relationship

$$\frac{\langle\Gamma_\gamma\rangle}{\langle D_0\rangle} = \int_0^{B_n} [f_{E1}(E_\gamma) + f_{M1}(E_\gamma)]\, E_\gamma^3 \rho(B_n - E_\gamma) dE_\gamma$$

where $f_{x\ell}(E_\gamma)$ are the gamma-ray strength functions, B_n is the neutron binding energy of ^{198}Au, $\langle\Gamma_\gamma\rangle$ is the average gamma-ray width (= 0.122 eV),[10] and $\langle D_0\rangle$ is the mean s-wave resonance spacing (= 16.2 eV).[10] Based on the review by Lone,[9] the ratio $\Gamma_{M1}/(\Gamma_{M1} + \Gamma_{E1}) = 0.12$ was assumed in the calculations.

The level density parameter 'a' for ^{198}Au was taken from the Cook tabulation.[6] Cook's values were slightly modified (within ± 15%) for ^{197}Au and ^{196}Au to concurrently optimize agreement with higher energy measurements of neutron emission spectra, (n,2n) and (n,3n) cross sections, and the gamma-ray emission spectra. At 14 MeV a preequilibrium fraction of 33% was used in the analysis.

RESULTS

The E1 gamma-ray strength functions that resulted from this analysis are compared in Fig. 1 with values inferred from experiments by Joly et al.,[11] Loper et al.,[12] and Veyssiere et al.[13] The present curve is quite similar to one also obtained from Morgan's data[1] by Kitazawa[14] using different neutron transmission coefficients and level density parameters. The two strength functions obtained in our analysis of the (n,γ) and $(n,n'\gamma)$ measurements are quite similar, differing mainly at the shoulder near $E_\gamma = 5-6$ MeV. While this difference is not large, significantly improved agreement with the higher energy data was obtained with the $(n,n'\gamma)$ E1 strength function. This strength function was also used in the $(n,2n\gamma)$ and $(n,3n\gamma)$ calculations.

The resulting $^{197}Au(n,\gamma)^{198}Au$ cross section from $E_n = 0.01-20$ MeV is compared with a selection of experimental data and with the ENDF/B-V evaluation[15] (with resonance structure averaged out) in Fig. 2. The pronounced peak in the theoretical cross section near $E_n = 12$ MeV results from inclusion of a semi-direct component,[16] which is necessary to reproduce the data near 14 MeV.

The calculated gamma-ray emission spectra are compared in Fig. 3 with Morgan and Newman's data at two neutron energies not involved in extracting the gamma-ray strength functions. The left side of Fig. 3 illustrates the calculated and measured data at $E_n = 1.0-1.5$ MeV. Above $E_\gamma = 1.5$ MeV, of course, the spectrum results entirely from radiative capture, and the agreement is seen to be reasonably good. The results for $E_n = 14-17$ MeV are shown in the right side of Fig. 3. In this case the spectrum is due mainly to to (n,2nγ) reactions, with a smaller but appreciable mixture of (n,n'γ) present. Again, within the accuracy of the experiment, the agreement is reasonable.

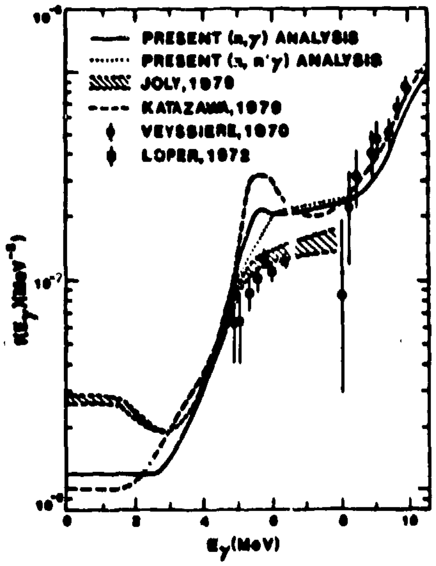

Fig. 1. E1 γ-ray strength functions inferred from $^{197}Au(n,\gamma)$ ^{198}Au and $^{197}Au(n,n'\gamma)$ ^{197}Au measurements.

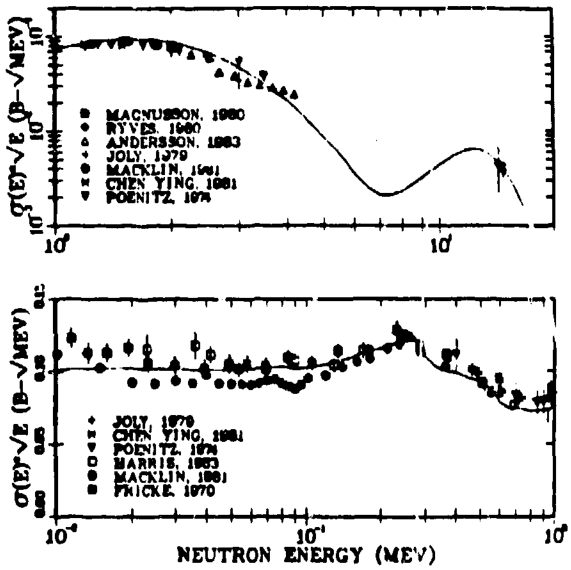

Fig. 2. Measured and calculated $^{197}Au(n,\gamma)$ ^{198}Au cross sections from 10 keV to 20 MeV. The dotted curve is ENDF/B-V.

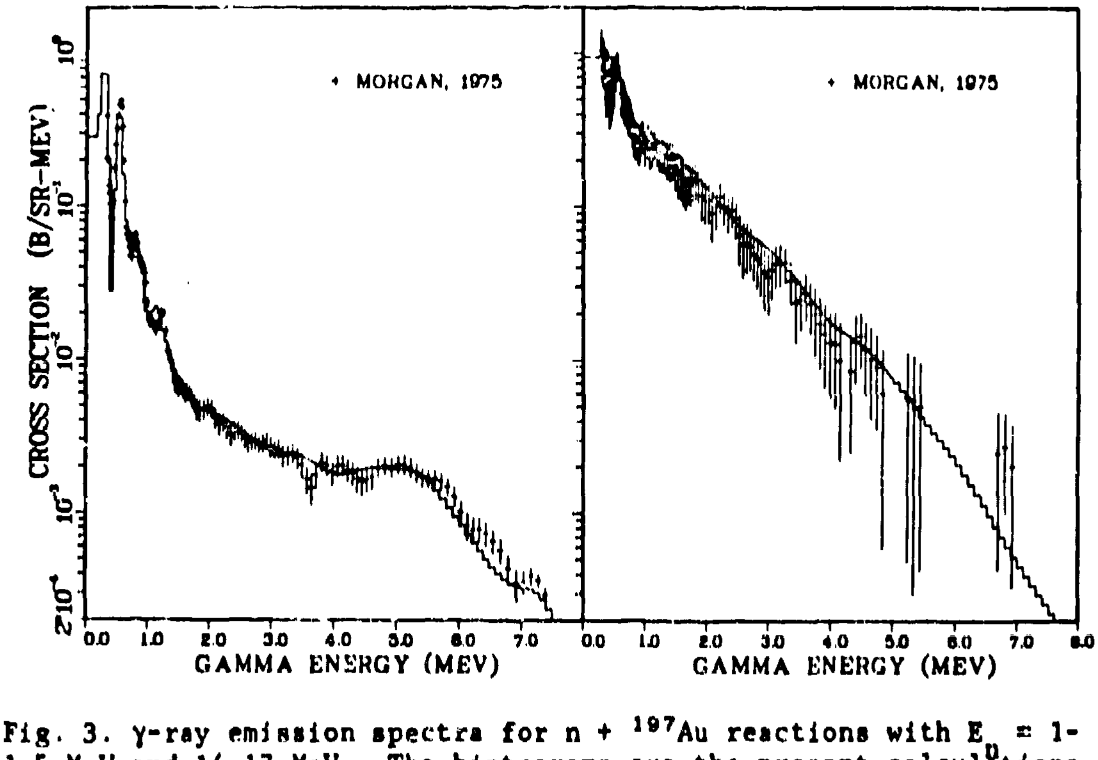

Fig. 3. γ-ray emission spectra for n + ^{197}Au reactions with E_n = 1-1.5 MeV and 14-17 MeV. The histograms are the present calculations.

CONCLUSIONS

The deformed optical model and Hauser-Feshbach statistical theory calculations and gamma-ray strength function formulations described here adequately represent available neutron-induced gamma-ray measurements on ^{197}Au between E_n = 0.01 and 20 MeV. Although not presented here, the calculations also reproduce measurements of the neutron total, (n,2n), and (n,3n) cross sections as well as neutron emission spectra from 14-MeV neutron reactions.

REFERENCES

1. G. L. Morgan and E. Newman, "The Au(n,xγ) Reaction Cross Section for Incident Neutron Energies between 0.2 and 20.0 MeV," Oak Ridge Nat. Lab. report ORNL-TM-4973 (1975).
2. J. P. Delaroche, "Potential Optique Nucleon ^{197} Au Entre 10 keV et 57 MeV," Int. Conf. Neutron Physics and Nucl. Data for Reactors and Other Applied Purposes, Harwell, England (1978), p. 366.
3. J. Raynal, "Optical Model and Coupled-Channel Calculations in Nuclear Physics, Int. At. Energy Ag. report IAEA SMR-9/8 (1970).
4. C. L. Dunford, "A Unified Model for Analysis of Compound Nuclear Reactions," Atomics Int. report AI-AEC-12931(1970).
5. P. G. Young and E. D. Arthur, "GNASH: A Preequilibrium-Statistical Nuclear Model Code for Calculations of Cross Sections and Emission Spectra," Los Alamos Sci. Lab. report LA-6947 (1977).
6. A. Gilbert and A. G. W. Cameron, Can. J. Phys. 43, 1446 (1965).
7. J. L. Cook, H. Ferguson, and A. R. Musgrove, Aust. J. Phys. 20, 477 (1967).
8. P. Axel, Phys. Rev. 125, 671 (1962); see also D. M. Brink, Nucl. Phys. 4, 215 (1957).
9. M. A. Lone, "Photon Strength Functions," Proc. Third Int. Symp. Neutron Capture Gamma-Ray Spectroscopy and Related Topics, Brookhaven, N.Y., Sept. 18-22, 1978 (Plenum Press, N.Y, 1979), p. 161.
10. S. F. Mughabghab and D. I. Garber, "Neutron Cross Sections, Vol. 1, Resonance Parameters," Brookhaven Nat. Lab. report BNL-325, 3rd Ed., Vol. 1 (1973).
11. S. Joly, D. M. Drake, and L. Nilsson, Phys. Rev. C 20, 2072 (1979).
12. G. D. Loper, L. M. Bollinger, and G. E. Thomas, "Search for the Pygmy Resonance in ^{197}Au(n,γ)^{198}Au," in Argonne Nat. Lab. report ANL-7971, Phys. Div. Ann. Review, 1 April 1971-1 March 1972 (1972), p. 7.
13. A. Veyssiere, H. Beil, R. Bergere, P. Carlos, and A. Lepiêtre, Nucl. Phys. A 159, 561 (1970).
14. H. Kitazawa, Y. Harima, H. Yamakoshi, Y. Sano, T. Kobayashi, and M. Kawai, "Gamma-Ray Production Cross Sections for MeV Neutrons," Proc. Int. Conf. on Nucl. Cross Sections for Technol., Oct. 22-26, 1979, Knoxville, Tenn. (NBS Special Pub. 594, 1980), p. 775.
15. S. F. Mughabghab, ENDF/B-V Data File for ^{197}Au (MAT 1379), described in BNL-NCS-17541 (ENDF-200), R. Kinsey, Ed., Nat. Nucl. Data Center, Brookhaven Nat. Lab., Upton, N.Y. (July 1979).
16. E. D. Arthur, "Calculation of Neutron Cross Sections on Isotopes of Yttrium and Zirconium," Los Alamos Sci. Lab. report LA-7789-MS (April 1979) p. 24.