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NUCLEAR-STRUCTURE STUDIES
VIA NEUTRON INTERACTIONS

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"Nuclear Structure Studies via Neutron Interactions"

ABSTRACT

Results of the analysis of gamma rays following thermal neutron capture in ^{32}S , ^{33}S , ^{34}S suggest evidence of nonstatistical behavior in these isotopes. Comparison of measured partial capture cross sections with hard sphere and channel capture calculations indicates good agreement. A preliminary manuscript outline, tables and figures have been prepared in preparation for publication while consideration is currently being given to expansion of theoretical calculations. A remote terminal capability has been established on campus incorporating graphics and printing terminals. Data files have been prepared for the analysis of isotopes of tin and osmium using the fitting code SAMMY on the ORNL computer. Debugging and familiarization with new features of the fitting code are nearing the point at which the analysis of transmission data will be routine. In the case of ^{187}Os , preliminary analyses have resulted in isotope peak identification in the energy range, 28-200 eV, where peak energies and relative reduced neutron widths have been obtained. Current efforts are directed toward proper determination of the non resonant contribution and possible J-value assignments from shape analysis of the resonances.

-2-

I. Scope of Investigations Undertaken

A. Sulfur Isotopes

Completion and interpretation of a systematic investigation of sulfur isotopes directed toward producing definitive level schemes for ^{33}S , ^{34}S , ^{35}S via the thermal neutron capture reaction have been carried out in collaboration with Oak Ridge and Los Alamos Laboratories.

We have investigated the extent to which these reactions evince non-statistical effects and have compared direct capture calculations with results for levels populated in both (d,p) and thermal (n, γ) reactions. A manuscript outline, tables, and figures have been prepared in connection with publication of results for all isotopes investigated. These and preliminary theoretical calculations have been brought to the attention of J. E. Lynn, who has consented to reconsider a rather successful theory with a view toward possible refinements, in light of new data obtained and insights gained since its inception, which might lead to a clearer understanding of the complexities involved in neutron capture and thus of nuclear structure.

B. Remote Terminal Facility

Remote terminal capability has been established incorporating a Tektronix 4051 graphic computing terminal (with RS 232 interface) and a DECwriter III printing terminal. Communication has been established with the Oak Ridge host computer for batch and interactive processing. Efforts are underway to develop software necessary to gain a temporary plotting

-3-

capability for more effective data analysis feedback. In connection with A above, programs have also been written in support of these calculations. In support of remote terminal activity, Data, Input, Parameter, Plotting and Batch files have been prepared for ^{122}Sn , ^{124}Sn , ^{186}Os , ^{187}Os , ^{188}Os in a format compatible with the fitting code.

C. Computer Code Use

Introduction of a Severely Altered Multi code (SAMMY) to the system has necessitated re-familiarization in the use of the fitting code. The new version incorporates a method for determining the parameters of the R-matrix formulation from experimental data based upon the utilization of Bayes' Theorem. This makes provision for including non diagonal correlations, more realistic assessment of parameter uncertainties, and the ability to perform sequential analysis of independent data sets and obtain results equivalent to a simultaneous analysis of the same data. This has resulted in reduced concern about the closeness of the initial parameter estimates to final values, and has reduced running time (typically 1 iteration while 5 iterations are not uncommon in MULTII). Recent refinements incorporated into SAMMY include parameterization of the external R-matrix as a logarithmic function of energy. These and other factors have resulted in some effort being devoted to debugging and gaining facility in the use of these and other features of SAMMY.

D. Osmium Isotopes

Transmission data for ^{186}Os , ^{187}Os , and ^{188}Os , previously taken at ORELA, have been reduced and data files have been prepared for use with

-4-

SAMMY. Plotting files have been prepared to permit isotope identification for each peak in the transmission data. Identification has been accomplished for each of the data sets in the energy range 28-200 eV. Current efforts involve parameter determination and J-value assignments for those resonances large enough to manifest shape differences.

II. Significant Results Obtained

A. Final State Correlations -- Nonstatistical behavior in neutron radiative capture was first suggested by observed correlations in thermal capture between reduced γ -ray intensities and spectroscopic factors of the final states.¹ The statistical description of radiative capture dictates that the gamma intensities be reduced by the phase space factor, E^3 , for dipole transitions. However it has been pointed out²⁻⁴ that stronger correlations are obtained for certain nuclei when the reduction factor is reduced. These nuclei, as a result are candidates for nonstatistical behavior. Furthermore, the reduction factor for which maximum correlation is obtained is a partial signature of the type of capture process involved.⁵ As a climax to the interpretation of thermal (n, γ) data⁶ for ^{33}S , ^{34}S , ^{35}S , we have carried out a correlation analysis using the expression

$$\rho(a,b) = \frac{\sum_i [(a_i - \bar{a})(b_i - \bar{b})]}{[\sum_i (a_i - \bar{a})^2 \sum_i (b_i - \bar{b})^2]^{1/2}}$$

where $a = I_\gamma/E^n$; $b = (2J+1)S_{dp}$.

Values used for spectroscopic factor, S_{dp} , are from references 7-9. The

-5-

result of variations of n , for each of the isotopes, is shown in Figure 1. As can be seen, the maximum correlation for the odd A nuclei is obtained for $n \approx 1$ and for the even nucleus the result is $n \approx 2$. The maximum correlation coefficients obtained for ^{33}S , ^{34}S and ^{35}S were 0.996 ± 0.20 , 0.88 ± 0.20 and 0.97 ± 0.10 , respectively.

The significance of the value of n for which strong correlation is obtained is related to the energy dependence of the dipole matrix element in the potential cross section and n thus becomes a partial signature of direct capture.

Mughabghab and Chrien,¹⁰ in pointing out that correlations are not sufficient evidence for nonstatistical effects, have suggested that a more specific test lies in comparison of measured thermal partial cross sections with predictions of potential capture theory. Favorable comparisons have been made for elements in the range, $A = 140-170$ but not in the range, $A = 30-70$.

B. Potential Capture Calculations -- A highly successful approach to understanding correlations in neutron capture was developed by Lane and Lynn¹¹⁻¹³ in the framework of the R-matrix by expressing the collision matrix in terms of internal and external components, the latter giving rise to nonstatistical behavior. Explicit expressions derived therein¹² to express channel and hard sphere contributions to the capture process are based upon the assumption of the strong interaction model and thus ignore other possibly significant contributions to the cross section. Channel and hard sphere contributions have been calculated for ^{33}S and ^{35}S

-6-

and the results are presented in Figs. 2,3. From this it can be seen that only approximately 50% of the measured partial cross section is accounted for by hard sphere capture. Furthermore, inclusion of the channel component is still insufficient. It would be of interest to see if consideration of other contributions would be adequate to account for observed capture in this region. It has been shown¹⁴ that other effects can be nontrivial in this range when channel capture is appreciable. Results will be published as soon as the theory section is complete.

C. Preliminary Results for ^{187}Os , 28-200 eV — A total of 57 resonances have been identified from transmission in ^{187}Os up to 200 eV. These resonances have been analyzed, using the R-matrix code SAMMY, to obtain energies and reduced neutron widths. Of these resonances, 47 have been identified with the 187 isotope. Results will be presented at future appropriate meetings.

III. Summary

Significant results have been obtained and important goals have been achieved during the performance period. Most notable among these are the interpretation of results of thermal neutron capture on sulfur isotopes and the initiation of a remote analysis capability at MTSU. At this point, all aspects of the latter seem to be operational and techniques and procedures have been established to facilitate future routine analysis of transmission data.

-7-

Of the total expected effort of the principal investigator on the project, approximately 70% has been devoted at the present point in the performance period. Approximately 30% of total effort will be devoted during the remainder of the term. This is expected to result in extension of the analysis of the transmissions for ^{187}Os to 1 keV. In addition all preliminary preparations have been made for the analysis of the remaining isotopes outlined in the proposal. Except in the case of ^{122}Sn , the analysis would appear to be straight-forward and subject only to time constraints. Preliminary analyses of the ^{122}Sn data indicate that statistical data uncertainties would argue in favor of the collection of additional data before further analysis. This is to be included in the renewal proposal.

Figure 1. Correlation between G and I_γ/E_γ^n , where G is the (d,p) strength and I_γ is the primary γ -ray intensity.

Figure 2. Comparison between measured and calculated cross sections for $^{32}\text{S}(n,\gamma)^{33}\text{S}$ assuming channel and hard sphere capture.

Figure 3. Comparison between measured and calculated cross sections for $^{34}\text{S}(n,\gamma)^{35}\text{S}$ assuming channel and hard sphere capture.

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