Report to the DOE Nuclear Data Committee

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A. NUCLEAR DATA CALCULATIONS AND EVALUATIONS1. Charged-particle Evaluations for Fusion Applications (R. M. White)

The Livermore Nuclear Data Group has for over 10 years maintained an evaluated charged-particle library (ECPL) for p, d, t, ^3He , and ^4He particles incident on most light isotopes through ^{16}O . We have initiated a reevaluation of this library for three reasons: (1) to provide new evaluations which include the most recent measurements of important charged-particle reaction cross sections for fusion applications; (2) to provide accurate representation of angular distributions, energy distributions, etc., of reaction products for all-particle Monte Carlo type transport calculations; and (3) to provide the most accurate possible cross section data base against which to test effective nucleon-nucleon interactions in our shell model/R-matrix calculational program (see following section). To this end we have completed new evaluations of the $^2\text{H}(d,p)^3\text{H}$, $^2\text{H}(d,n)^3\text{He}$, and $^3\text{H}(d,n)^4\text{He}$ reactions from 50 eV to 20 MeV. These evaluations include over 60 angular distributions for the d-t reaction and

over 30 angular distributions each for the $^2\text{H}(d,p)$ and $^2\text{H}(d,n)$ reaction channels. Because the $^3\text{H}(d,n)$ and $^2\text{H}(d,n)$ reactions are widely used as neutron source reactions, there exist several reviews of these reactions in the literature. For our evaluations of these reactions we have used the work of Liskien and Paulsen,¹ Drogg,² and the recent experimental results of Jarmie, Brown and Hardekopf³ as well as the work of Brown, Jarmie and Hale.⁴ For the $^2\text{H}(d,p)$ reaction channel, we have obtained over 70 experimental angular distributions from 10 references which span the energy range of interest. In Fig. 1 we show the integrated results of some of these angular distributions as well as our evaluation of the integrated reaction cross section over the energy range of 100 keV to 1 MeV. The evaluation angular distributions were actually obtained from an evaluation of the Legendre expansion coefficients derived from fitting the experimental angular distribution data. In the coming year, we intend to begin work on the $d+^6\text{Li}$ reactions channels.

1. Nuclear Data Tables 11, (1973).
2. Nucl. Sci. Eng. 67, (1978) and Atoms and Nuclei 300, (1981).
3. Phys. Rev. C 29, (1984).
4. Phys. Rev. C 35, (1987) and private communication.

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Fig. 1 Integrated results of experimental angular distributions and our evaluation of the integrated cross section for the ${}^2\text{H}(d,p){}^3\text{H}$ reaction over the energy range 100 keV to 20 MeV.

2. Extension of the Shell Model/R-Matrix Approach to Allow the Calculation of Cross Sections Involving Multinucleon Particles (i.e., d, t, ${}^3\text{He}$, α , etc.) (D. A. Resler and H. D. Knox*)

Last year we reported how the shell model/R-matrix approach was being used to calculate cross sections of interest to the nuclear data community. In the example presented of the ${}^{14}\text{N}(n,x\gamma)$ production for 14 MeV incident neutrons, we were unable to calculate the entire gamma spectrum since we did not have the ability to calculate gamma rays resulting from the reactions $(n,d'\gamma)$, $(n,t'\gamma)$, or $(n,\alpha'\gamma)$. The ability to calculate cross sections for reaction channels involving multinucleon particles (i.e., d, t, ${}^3\text{He}$, α , etc.) requires the calculation of multinucleon spectroscopic amplitudes from shell model wavefunctions. In the shell model/R-matrix method of calculating reaction cross sections, a reaction $A(k,k')B$ can be represented as

where A' is the compound nucleus of the system. In general the size of the reaction cross section is related to how much the states of the compound system which can be populated by the entrance channel "look like" A and k coupled together and "look like" B and k' coupled together. As the projectile energy is changed, the compound states populated by the entrance channel change, and the amount that A and k "look like" A' change as does the amount that B and k' "look like" A' changes. Therefore we get a cross section which changes with the projectile energy since we are populating different states in the compound nucleus.

In terms of the R-matrix theory how much a channel "looks like" the compound system is given by a reduced width amplitude γ . This can be expressed in terms of a shell model spectroscopic amplitude $S^{1/2}$. A spectroscopic amplitude indicates how much a given wavefunction "looks like" two other wavefunctions coupled together. In the case of single nucleon transfer, the spectroscopic amplitude is very simple and consists of the product of two factors. The first factor is a constant which depends on the masses of the particles and some of the quantum numbers. The second factor is simply a doubly-reduced matrix element of a compound nucleus wavefunction dotted into the result of creating a single nucleon of the proper quantum numbers onto the target/residual nucleus wavefunction.

In the multinucleon case, the spectroscopic amplitude is more complicated. The first factor is the same as before. In the second factor, the creation of a single nucleon is replaced by the creation of a multinucleon cluster which now can contain many terms as do the wavefunctions for the compound, target, and residual nucleus. There is also a third factor which is for determining how much of the cluster wavefunction is in a relative s-state since we want the center-of-mass to carry all the quanta for the cluster. Finally, there can now be more than one cluster wavefunction of the required quantum numbers which can be coupled to the target/residual nucleus wavefunctions. Therefore, the final spectroscopic amplitude is a summation over these wavefunctions.

The theoretical details of these multinucleon spectroscopic amplitude calculations have been worked out for use in our m-scheme shell model code CRUNCHER. The new coding is very general--no restrictions on the number of particles in the cluster and no restrictions on the model spaces used. This is believed to be the first time such general coding has been put together for the calculation of multinucleon spectroscopic amplitudes. Extensive testing has been performed and results compared where possible with those in the literature. With the completion of this work, all sections of the coding used in our shell model/R-matrix approach to calculating nuclear reaction cross sections are general in that there are no restrictions in which two-body reaction channels can be included. Work on the complete calculation of the $^{14}\text{N}(n,\gamma)$ production is currently underway.

*Ohio University, Athens, Ohio

3. Development of an Evaluated Photonuclear Library (S. Warshaw)

To provide complete coupling between neutrons, charged-particles, photons (and electrons) in a new all-particle Monte Carlo transport code being developed at Livermore, the Nuclear Data Group is creating an evaluated photonuclear data library. The data for this library are being collected from three main sources: (1) the NBS 15-volume set of photo- and electro-nuclear citations and excerpts; (2) systematic scanning of Current Contents; and (3) the Dietrich and Berman photoneutron atlas published in

CRUNCHER

1988 as Atomic and Nuclear Data Tables, Vol. 38. This atlas includes data for 181 isotopic and natural targets culled from 64 journal articles, with a few redundancies. Its chief virtue is that it is the only large collection of monoenergetic photon-induced neutron production reaction 4π cross section data known to cover significant photon energy and nuclear mass ranges. From these sources 400 journal references have been collected to date and photocopies and a cross-referencing index started. In Fig. 2 we show the photoneutron cross-section for ^{208}Pb and its decomposition into various reaction channel multiplicity subsets. To date data have been processed for ^3H , ^3He , ^6Li , ^7Li , ^2H , ^9Be , $^{10,11}\text{B}$, and ^{208}Pb . The intent is to obtain evaluated photonuclear library files for each of the isotopes (~ 100) currently in the Livermore Evaluated Neutron Data Library (ENDL).

Fig. 2 Plot of total photoneutron cross section taken at Saclay in 1970, shown as a function of photon energy. The continuous curves represent a semi-analytic fit to the total (solid line) and the decomposition of the cross section into the different multiplicity channels (dashed, dotted, dot-dashed lines).

4. Calculation of Precompound Gamma-ray Spectra for Several Materials for Incident Neutrons from 3 to 30 MeV (M. Blann)

The high-energy gamma-ray spectra have been calculated for incident neutron energies from 3 to 30 MeV on natural vanadium, iron and lead, and on ^{238}U and ^{239}Pu . In this work, only gamma-rays with energies in excess of the neutron binding energy are calculated. These gamma-rays originate from a pre-equilibrium decay mechanism. Fig. 3 shows an example for iron and gives an estimate for the uncertainty in the calculations. For calculations of light isotopes such as ^{27}Al and ^{32}S the calculations do poorly. Calculated results, the physics employed in the model, and suggested alternative physical models which should work well in the light element regime are summarized in report UCRL-100324.

Fig. 3 Experimental and calculated (n,γ) spectra for ^{56}Fe . Experimental results are from Guelbar, et al., Nucl. Phys. **A310**, 40 (1969). The arrow beneath B_n represents the energy below which γ-rays may be emitted following neutron emission. The experimental points extend beyond the maximum γ-ray energy due to experimental energy resolution.

5. Improvements of the Precompound Exciton Model in the STAPRE Code
(D. Gardner and M. Gardner)

While our present precompound particle evaporation model adequately describes its total particle emission spectra, and thus its proper contribution to total reactions such as (n,n'), (n,2n), (n,3n), etc., the partition of such cross sections among ground and isomeric states may not be as accurately calculated. No formalism of which we are aware properly conserves spin and parity in precompound calculations. C. Y. Fu, H. Feshbach, G. Reffo, and others have attempted to follow aspects of the physics as the initial excited nucleus proceeds towards equilibrium, but there appear to be adjustable parameters that must be determined in some ad hoc manner. Our original version of STAPRE distributes the precompound contribution at each energy in the daughter nuclei using the same spin distributions in the continuum and over the discrete levels as in the compound case and disregards parity. Fu, Feshbach, Reffo, etc. have suggested the use of an exciton-dependent spin cut-off factor for the particle evaporation from each exciton configuration, as the nucleus approaches equilibrium. We implemented this approach but with some modifications.

For a given exciton state with N_p and $N_h = N$ particles and holes, the spin cut-off factor is taken as

$$\sigma_p^2(N) = \text{const.} * NA^{2/3}.$$

The spin distribution equation is the usual one. Our modifications consist of making the precompound spin cut-off parameter dependent on the energy in

each residual nucleus and on its proper normalization. The STAPRE code computes the number of exciton configurations required to "sufficiently" approach equilibrium from a given set of initial conditions. We can show that

$$\sigma_P^2(N_C) = \sigma_C^2(E_r),$$

which leads to

$$\sigma_P^2(N, E_r) = \frac{N}{N_C} \sigma_C^2(E_r),$$

where N_C is the particle-hole number of the final exciton configuration and

$$\sigma_C^2(E_r)$$

is the energy-dependent spin cut-off for the compound nucleus, computed in the usual way. Usually most of the precompound evaporation comes from the first exciton state, resulting in a shift in the population of the daughter nucleus to states of lower spin values. In the subsequent γ -ray cascade, for those states that do not particle decay, the lower spin isomers and/or ground state will tend to be favored over the higher spin states; the magnitude of this effect will depend on the relative amounts of the precompound and compound nucleus processes.

We have also allowed the state density and pairing gap values for the exciton model (including that of the residual nuclei) to be specified as input parameters. In many precompound models, the matrix element, $|M^2|$, for the residual interaction is taken to be excitation-energy and mass dependent, as $|M^2| = k_1 A^{-3} E^{-1}$. The new input option allows $|M^2|$ to be related to the Fermi gas level density parameter if desired. We are now conducting sensitivity studies to determine the importance of the above exciton model changes.

6. Evaluated Set of Neutron Cross Sections for ^{20}Ne from IDA Modeling Calculations (M. H. MacGregor, R. J. Howerton, and G. Reffo*)

As reported last year, the Nuclear Data Group has implemented the extensive system of nuclear modeling codes (IDA) developed by G. Reffo. These codes were used together with the very limited experimental data to obtain a complete set of evaluated neutron cross sections for ^{20}Ne from 0 to 30 MeV. The IDA codes are based on the Hauser-Feshbach statistical model formalism with width fluctuations included. In the ^{20}Ne evaluation, the IDA calculations, modified in some places to agree with experimental data, were used from 1 to 30 MeV. Below 1 MeV, cross sections were obtained from experimental neutron resonance parameters. The Livermore post-processing codes ALPHA and OMEGA were used to check energy balances for all of the reactions individually, so that the final evaluated data set accurately conserves energy. Figure 4 shows a comparison between the theoretical IDA (n, α) cross section curve and experimental data. As

can be seen, the theoretical curve gives the proper threshold behavior and a good fit to the data up to 4 MeV. Above 4 MeV, the evaluated data set was modified to match experiment.

*ENEA, Bologna, Italy

Fig. 4 Comparison between the calculated $^{20}\text{Ne}(n,\alpha)$ cross section using IDA and the experimental data of C. H. Johnson, *et al.* Phys. Rev. **82**, 117 (1951), and those of R. J. Bell, *et al.* Nucl. Phys. **14**, 270 (1959). The calculation was subsequently altered in the evaluation to fit the experimental data.

7. Measurement and Analysis of Neutron and Gamma-Ray Spectra Leaking from Several Materials Centrally Pulsed by 14-MeV Neutrons
(E. Goldberg, L. F. Hansen, T. T. Komoto, B. A. Pohl, R. J. Howerton, R. E. Dye, W. E. Warren, and E. F. Plechaty)

Monte Carlo calculational analysis of several integral measurements have been completed with two different data bases, ENDL and ENDF/B-V. The experiments utilized spherical assemblies, pulsed centrally with 14-MeV neutrons. The measured neutron and gamma-ray leakage spectra were compared to the spectra calculated with TART and SANDYL. Preparation of the ENDF/B-V data base for use in TART proved to be a formidable task. Figures 5a and 5b showing the neutron time-of-flight and recoil electron spectra for aluminum, typify the findings of the study. Both calculated neutron spectra agree reasonably well with the measurement. However, we see the ENDF/B-V-based recoil electron spectrum to be below the experimental data while the ENDL-based spectrum is in close proximity to the experimental points.

We have chosen as a measure of gamma-ray energy deposited in the NE-213 detector the quantity $\sum n_i c_i$ where n_i is the number of counts in channel c_i . Ratios of these summations, evaluated with the findings from the pulsed-sphere experiments, have been applied to TART calculations of simple one-zone, one-dimensional spheres. These results may be used by the

general audience as benchmark exercises. Table 1 lists our findings. We see immediately that silicon generates the largest gamma-ray element. If we rely upon the ENDL base we find that 2.008 MeV/n leaks from the centrally-pulsed sphere, while reliance on the ENDF/B-V base leaks 2.268 MeV/n. The maximum leakage is found to occur when $\rho R = 35 \text{ g/cm}^2$.

Fig. 5a

Fig. 5b

Figures 5a and 5b, showing the neutron time-of-flight and recoil electron spectra for aluminum, typify the findings of the study.

Table 1. Gamma Ray MeV Leaked/14-MeV Neutron, Normalized to Pulsed Sphere Experiments

Material	$(\gamma \text{ MeV/n})$		$(\gamma \text{ MeV/n})/(C/E)$		$(\rho R) \text{Max. } \gamma$ (g/cm^2)
	ENDL	ENDF/B-V	ENDL	ENDF/B-V	
C	0.90	0.85	0.99	1.03	40
N	1.35	1.14	1.38	1.46	40
H ₂ O	0.93	0.71	0.81	0.87	25
C ₂ F ₄	0.98	0.61	0.72	0.69	35
Al	1.97	1.58	1.82	1.98	35
Si	2.15	1.67	2.00	2.26	35
Ti	1.44	1.53	1.84	1.68	45
Fe	1.49	1.25	1.37	1.49	40
Cu	0.89	0.99	0.91	0.93	45
Ta	0.51	0.43	0.56	0.55	35
W	0.42	0.39	0.52	0.48	35
Au	0.33		0.35		40
Pb	0.35	0.29	0.30	0.31	35
²³² Th	0.34	0.29	0.35	0.34	35
²³⁸ U	0.38	0.32	0.37	0.38	35

8. Optical Model Calculations in the Actinid Region (H. S. Camarda*)

Phenomenological optical model calculations have been carried out which give satisfactory fits to the total and differential neutron cross sections for nuclei in the actinide region (Th-Pu) for incident neutron energies above 10 MeV. These calculations were performed by modifying one of Ohio University's global spherical optical potentials to include the nonsphericity of these target nuclei. The modified potential depends on the deformation parameter, B , which is determined by experimental data, e.g., Coulomb excitation to low-lying rotational states. With this modified potential, cross sections calculated for actinide nuclei where no experimental data exists can be carried out with some confidence.

A more sophisticated treatment of neutron interactions with actinide nuclei involves carrying out coupled-channel calculations where the rotational and vibrational degrees of freedom of the target nuclei can be taken into account more realistically. Preliminary coupled-channel calculations with the code ECIS have been performed on the Livermore Nuclear Data Group's Sun computer system. To date, equivalent calculations performed with ECIS on the Cray and the Sun computers are in good agreement.

*Pennsylvania State University

9. Further Developments in the Study of Our Neutron-Induced Cross-Section Library for Isotopes of Iridium (M. Gardner and D. Gardner)

As we mentioned last year in this report, iridium is often used as a detector to measure neutron fluences in underground nuclear tests. In order to fully exploit the potential of this detector, we have completed the calculation of a preliminary set of cross sections primarily for sensitivity studies. We computed 228 excitation functions for partial and total reactions among 22 ground and isomeric states of 10 iridium isotopes, from ^{187}Ir to ^{196}Ir . The principal problems we've encountered in our calculations lie in the fact that our radiochemical diagnostic measurements involve either single isomers or sums of the ground state plus one or more isomeric populations (since portions of some of the cross sections end up in long-lived isomeric states) and that the discrete-level information required in our computations, as well as most of the experimental reaction cross section data are presently incomplete and/or uncertain. In order to properly calculate the ground- and isomeric-state populations correctly, a complete set of reliable discrete nuclear levels and their multipole branchings must be available for each Ir isotope. Based on our initial calculations, we have been able to point out problems in the level information, particularly for the odd-odd Ir isotopes. Much new experimental and theoretical work is now under way by other members of our Nuclear Chemistry Division, primarily on the isotopes ^{191}Ir , ^{192}Ir , ^{193}Ir , ^{194}Ir .

We have undertaken the evaluation of the new data and information as they become available. These include the analysis of new average resonance capture (ARC) data from 2-keV neutrons on ^{191}Ir taken by R. W. Hoff, calculated gamma-ray production information from (n,n') reactions on ^{193}Ir , and statistical analyses on spin and parity distributions, spin cut-off parameters and level densities of new theoretical discrete level sets. We have designed, and with G. Lursen, essentially completed a computer program which will search for typographical and physics errors in large level sets and their multipole branches, and which will also calculate E1, M1, and E2 transitions among single-particle intrinsic states and among rotational bandheads with K-quantum number restrictions, if desired. Additionally we are carrying out sensitivity studies on the $^{191,193}\text{Ir}(n,xn)$ cross-section calculations to evaluate the improvements that we made in the precompound exciton model in our version of the STAPRE nuclear reaction code.

10. R-Matrix Code Improvement (D. A. Resler)

Last year we reported that the Ohio University R-matrix code was made operational on our Sun computer network. Extensive testing has been performed to verify the correct operation of the code. During an investigation of the low-energy d+t reaction, we discovered a problem with the calculation of the Coulomb wavefunctions since the original coding was not valid in this energy region. The calculation of the Coulomb wavefunctions has been upgraded to use the coding of Bardin et al.¹ which is valid for the entire (η, ρ) plane. Published R-matrix calculations from Jarmie, et al.² and Brown, et al.³ for the low-energy d+t reaction were extremely beneficial in verifying the correct operation of our coding as we have duplicated their very low-energy results to several significant digits.

1. C. Bardin, et al., Computer Physics Communications 3, 73 (1972).
2. N. Jarmie, R. E. Brown, and R. A. Hardekopf, Phys. Rev. C 29, 2031 (1984).
3. R. E. Brown, N. Jarmie, and G. M. Hale, Phys. Rev. C 35, 1999 (1987).

11. Computer Network for Nuclear Modeling Calculations (D. A. Resler, T. T. Komoto, and J. D. McGowan)

The Nuclear Data Group's network of Sun Microsystem computers, used for our nuclear modeling calculations, has been upgraded during the past year. The two Sun 3/260 servers have been replaced with Sun 4/260s. This upgrade gives us a factor of two increase in our calculational capability. In addition we have increased the memory of both machines for a total of 64 Mbytes on one and 16 Mbytes on the other. Many of the shell model/R-matrix calculations of nuclear reaction cross sections have required the full 64 Mbytes of the larger machine. We have also added a fast 8mm tape system to our network for backing up our 3 Gbytes of disk storage.

12. Upgrades to the Shell Model Code CRUNCHER (D. A. Resler and S. M. Grimes*)

Several major advances have been made to the shell model code CRUNCHER. The calculation of nuclear reaction cross sections has required the use of very large model spaces which in turn has required a large amount of computer resources. In a typical application of the shell model/R-matrix approach, the shell model part of the calculations can easily require over 95% of the total time. Therefore, it was worthwhile to better optimize the coding for these large problems. A major improvement was the use of multiparticle Hamiltonians for those problems considered "small" in terms of the computer size. Today a "small" problem can be a $2\hbar\omega$ model space description of a p-shell nucleus. Our previous method was to keep the Hamiltonian expressed in a two-body form. Now we can use the fast but large multiparticle Hamiltonian on the small problems and still use the slower but smaller two-body Hamiltonian for the larger problems. The use of the multiparticle Hamiltonian has resulted in two orders of magnitude improvement in the execution speed for these problems.

Improvements in the Ohio University version of the code have been incorporated into the LLNL version. Part of the effort at Ohio has been to improve the "unstable basis" portion of the code. This is very important for the calculation of level densities, the first stages in a diagonalization using a two-body Hamiltonian, and in the generation of a multiparticle Hamiltonian from the two-body Hamiltonian.

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B. NUCLEAR DATA MEASUREMENTS

1. Proton and Deuteron Excitation Functions for ^{151}Eu and ^{153}Eu (H. I. West, Jr., R. G. Lanier, M. G. Mustafa, R. N. Nuckolls, J. Frehaut*, A. Adam*, and C. A. Philips*)

We have measured the proton and deuteron excitation functions for ^{151}Eu and ^{153}Eu for the reactions $^{151,153}\text{Eu}(p,n)^{151,153}\text{Gd}$, $^{151,153}\text{Eu}(d,2n)^{151,153}\text{Gd}$, $^{153}\text{Eu}(p,3n)^{151}\text{Gd}$, $^{153}\text{Eu}(d,4n)^{151}\text{Gd}$, $^{151}\text{Eu}(p,3n)^{149}\text{Gd}$, $^{151}\text{Eu}(d,4n)^{149}\text{Gd}$, $^{151}\text{Eu}(p,(p2n,dn,t))^{149}\text{Eu}$ and $^{151}\text{Eu}(d,(p3n,d2n,tn))^{149}\text{Eu}$. These excitation functions are shown in Figures 1-6. In addition a new half-life of 9.282 ± 0.008 d was obtained for ^{149}Gd .

We used the stacked foil method for obtaining the data. Europium oxidizes rapidly in air bursting into flame at $150-180^\circ\text{C}$ thus posing a target problem. We solved this problem by mixing Eu_2O_3 with a resin which when polymerized is the equivalent of Kapton (a DuPont trade name).

Fig. 1

Fig. 2

The foils held up well under irradiation. Corrections were made for the charged-particle energy loss in the target foils in the rapidly varying region of the excitation functions. We plan to use a similar method in measuring the cross sections for iodine and bromine.

The measurements at less than 12 MeV were made using the Van de Graaff at Centre d'Etudes Bruyères-le-Châtel, France. The measurements at

Fig. 3

Fig. 4

Fig. 5

Fig. 6

the higher energies were made using the cyclotron at the Crocker Nuclear Laboratory, University of California at Davis. Although the data appeared to be of high quality we plan to make complementary measurements in the near future at 12 to 20 MeV using the Van de Graaff presently being installed at LLNL.

We have been modeling the data by means of the statistical model code STAPRE. However, one aspect of the data requires coupled-channel calculations. We find an interesting feature in the $^{151,153}\text{Eu}(p,n)^{151,153}\text{Gd}$ and $^{151,153}\text{Eu}(d,2n)^{151,153}\text{Gd}$ data; $\sigma(153)$ is enhanced at low energies relative to $\sigma(151)$. Results for (p,n) data are shown in Fig. 7. We note that the results obtained using a spherical optical potential are in poor agreement with the data. However, the results of a coupled-channel calculation, taking into account the fact that for ^{151}Eu the shape parameter $\beta_2 = 0.13$ and for ^{153}Eu $\beta_2 = 0.28$, are in reasonable agreement with the data at less than 10 MeV where the calculations are expected to be valid. Clearly, we have found a marked shape effect. The results have been prepared for submission to Physics Letters.

*Centre d'Etudes Bruyeres-le-Chateau, France

Fig. 7 Evidence of the effects of nuclear shape on reaction cross sections. The band shows the range that the data could take due to uncertainties in the I_γ 's used in calculating the cross sections. SPH shows results obtained using a spherical optical potential and CC shows results for a coupled channel calculation.

2. Comparative Study of Elastic Neutron and Proton Scattering and Analyzing Powers using Microscopic Optical Model Potentials in the Energy Range 8-26 MeV. (L.F. Hansen, F.S. Dietrich, and R. L. Walter*)

Differential cross sections and analyzing powers for neutrons elastically scattered from $^{10,11}\text{B}$, ^{28}Si , ^{54}Fe and ^{58}Ni measured by the TUNL (8-17 MeV) and Ohio (20-26 MeV) groups and the Eindhoven proton data (17-25 MeV) are compared with the predictions of microscopic optical model calculations using the JLM¹ and Yamaguchi *et al.*² potentials. The fits to the differential cross sections and analyzing powers (protons and neutrons) obtained with these two potentials are reasonably good using only three parameters, λ_V , λ_W and λ_{SO} , (normalizing constants for the real, imaginary and spin orbit potentials respectively). The values of these parameters are given in Table 1. The value of λ_R is unity for both neutrons and protons, which reduces the number of parameters to two over the energy and mass ranges. Fig. 4-10 illustrate the quality of the fits to the data for ^{58}Ni as function of neutron and proton energy.

* Physics Department, Duke University.

¹J.P. Jeukenne, A. Lejeune, and C. Mahaux, Phys. Rev. C **16**, 80 (1977);
M3Y spin-orbit, Bertsch *et al.*, Nucl. Phys. A **284**, 399 (1977).

²N. Yamaguchi *et al.*, Prog. Theor. Phys. (Japan) **70**, 459 (1983).

Fig. 8 Neutron elastic differential cross sections for ^{58}Ni . Calculations carried out with the microscopic OMP of Jeukenne-Lejeune Mahaux (JLM: solid lines) and that of Yamaguchi, et al. (YAM: dashed lines).

Fig. 9 Proton elastic differential cross sections for ^{58}Ni . Calculations carried out with the microscopic OMP of Jeukenne-Lejeune-Mahaux (JLM: solid lines) and that of Yamaguchi, et al. (YAM: dashed lines).

Table 1. Values of the three parameters used in the microscopic optical model calculations for all the nuclei and energies included in this report.

OMP		λ_V	λ_W	$\lambda_{S.O.}$
JLM	n	1.00 ± 0.04	0.94 ± 0.15	1.31 ± 0.05
	p	1.03 ± 0.06	0.91 ± 0.10	1.52 ± 0.05
YNM	n	1.00 ± 0.06	0.70 ± 0.10	1.45 ± 0.06
	p	1.02 ± 0.03	0.66 ± 0.07	1.54 ± 0.10

Fig. 10 Analyzing powers for neutron (left side) and proton (right side) elastic scattering from ^{58}Ni . Calculations carried out with the microscopic OMP of Jeukenne-Lejeune-Mahaux (JLM: solid lines) and that of Yamaguchi et al. (YAM: dashed lines).