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METHODS FOR THE CALCULATION OF NEUTRON INDUCED REACTIONS

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This work was performed under IAEA Research Contract No. 4325/R1/RB

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1/ Introduction

This Progress Report covers the time period December 1, 1986 - December 31, 1987. In that period our group has been working actively on the objectives of the contract which have been formulated as follows:

- The further development and improvement of the microscopic quasiparticle - phonon theory of direct continuum neutron inelastic scattering and the calculation of double - differential inelastic cross sections of 25.7 MeV neutrons on ^{56}Fe;

- The optimization of the microscopic neutron optical potential calculation in the Jeukenne - Lejeune - Mahaux aproach and the calculation of the neutron optical potential for $^{54,56}Fe$ nuclei in the energy range 11-26 MeV;

- Study of the neutron - γ competition and the influence of nuclear structure on a preequilibrium γ - emision.

2/ Description of research and results

a/ The advanced microscopic approach to the calculation of the direct contribution to the double - differential neutron inelastic cross sections has been further improved. The model was applied to the calculation of spectra and angular distribution at 25.7 MeV. The comparison has shown that the one - step DWBA approach is unsufficient to describe the experimental data at this energy. It seems that two-step DWBA contributions are required. Such calculations are in progress now. The influence of the fragmentation of one - phonon states and the contribution of two - phonon states are also studied.

b/ The approach of Jeukenne, Lejeune and Mahaux /JLM/ has been used to calculate the microscopic neutron optical potential for the $^{54,\ 56}Fe$ and ^{208}Pb nuclei in the energy range 11-40 MeV. This approach consists of solving a scattering equation for an incident and target nucleon in nuclear matter using Reid's hard core NN potential

as the basic nuclear force. To construct the OMP in a finite nucleus the JLM use an improved local density approximation /LDA/ which consists of identifying the quantity $V(\rho,E)/\rho$ with the strength of the complex reaction matrix which is considered as an effective interaction. The folding of this effective interaction with the ground state density yields the desired OMP to be used for the calculation of scattering from the finite nucleus.

Thus, two main components in these calculations are the folding procedure and the ground state nuclear density.

In our calculations we have used the improved LDA given by eq.

$$V_R(\vec{r}) = \frac{1}{(t_R\sqrt{\pi})^3}\int v_R(E,\rho(\vec{r}))\,\rho(\vec{r}')\exp\left[-|\vec{r}-\vec{r}'|^2/t_R^2\right]d\vec{r}' \quad (1)$$

for the real part of the OMP, where $v_R(E,\rho(\vec{r}))$ is the real part of the complex effective interaction which depends on the incident neutron energy and the local density $\rho(\vec{r})$. The similar equation may be given also for the imaginary part of OMP.

The spin - orbit potential V_{so} was taken to be real and spherical and given by the expression

$$V_{so}(r) = -V_s\,\frac{\pi}{3}\,\frac{1}{r}\,\frac{d}{dr}\left(2\rho_n(r)+\rho_p(r)\right) \quad (2)$$

where the indices n and p refer to neutrons and protons, respectively, and the factor $\pi/3$ results from the isovector component of this potential.

The nuclear densities are important components of this microscopic calculation. We use the densities calculated in the framework of the relativistic mean field theory /RMFT/. Such an approach to the calculation of ground - state properties of finite nuclei seems to be very promising and should be preferable to nonrelativistic calculations. The free parameters of the RMFT model Lagrangian were ad-

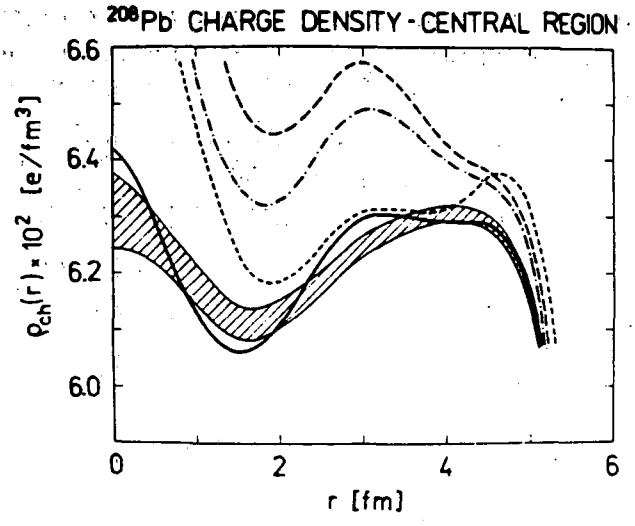

Fig. 1: Our calculation of the ^{208}Pb charge density (solid line) compared to the experimental data (shadowed area) and predictions of other theories.

justed such that model reproduces as good as possible the measured ground state properties of the ^{208}Pb nucleus; the charge density in a central region, the charge rms radius and the binding energy per nucleon. Our calculation of the charge density is compared to the experimental data in Fig. 1. The predictions of other theories are also given there. One may see that our calculation reproduces the experimental charge density very well; the agreement is much better than other theories reached.

The calculations of the neutron differential cross sections were made with the modified spherical optical model code CRAPONE. The free parameters in these microscopic calenlations were the effective folding ranges t_R, t_I and the normalization parameters λ_R, λ_I for the real and imaginary potentials, respectively, and the strength of the spin - orbit potential V_{so}. In practice, only three parameters were varied for the present calculations, λ_R, λ_I and V_{so}. The values of t_R =1.006 and t_I =1.108 were taken as an average of several testing calculations.

The dependence of normalization parameters on the incident neutron energy has been studied by fitting neutron scattering data at several energies. The results of our calculations on ^{208}Pb at an energy interval 20-40 MeV are summarized in Table 1. The calculated neutron differential cross sections are com-

TABLE 1: Values of the parameters used in the calculations of the microscopic OMP as a function of neutron energy for ^{208}Pb.

En /MeV/	t_R/fm/	t_I/fm/	λ_R	λ_I	V_{so} /MeV fm^5/
20.0	1.006	1.108	1.096	0.797	32.47
24.0	1.006	1.108	0.923	0.850	35.50
30.3	1.006	1.108	1.074	0.977	35.00
40.0	1.006	1.108	1.038	1.104	34.01

TABLE 2: The same as Tab.1 for the ^{54}Fe nucleus

En /MeV/	t_R/fm/	t_I/fm/	λ_R	λ_I	Vso /MeV fm^5/
12.0	1.006	1.108	0.662	1.050	36.00
14.0	1.006	1.108	0.721	1.024	48.49
20.0	1.006	1.108	0.852	0.759	36.00
22.0	1.006	1.108	0.947	0.705	33.00
24.0	1.006	1.108	0.977	0.612	33.00
26.0	1.006	1.108	1.112	0.808	36.00

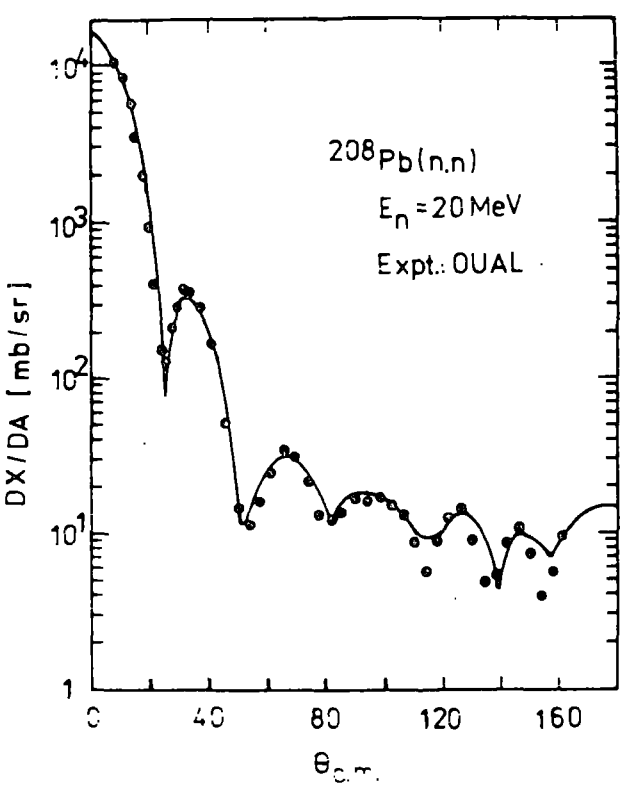

Fig. 2: A comparison of the calculated elastic cross section for the 208-Pb (solid line) to experimental data at 20 MeV.

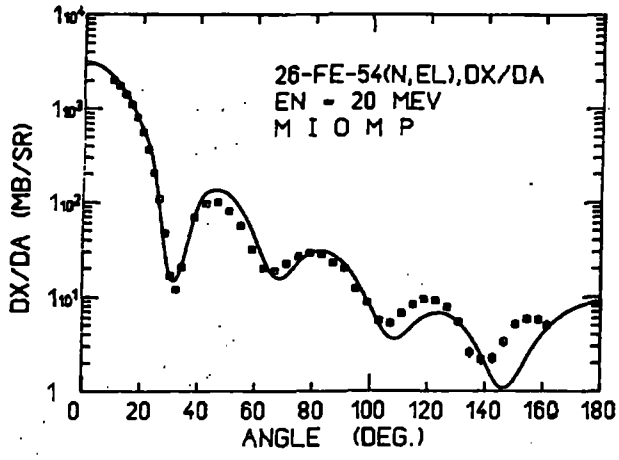

Fig. 3: The same as Fig. 2 for the ^{54}Fe nucleus.

pared to experimental data in Fig.2 at energy 20 MeV. Similar calculations for the ^{54,56}Fe nuclei are summarized in Table 2, and compared to experimental data in Fig.3. One may see that the agreement is fairly well, although not so good as in the phenomenological or model independent analyses. We may conclude, however, that present calculations are fully approved for the routine nuclear reaction calculations, since the present JLM approach is able to cover a broad region of nuclei and energies.

c/ A wide activity was developed within the spin - independent version of the exciton model. The so - called realistic exciton level densities were incorporated to the code PEQGM and the set of nucleon energy spectra from nucleon - induced reactions /Einc = 10-65 MeV/ over the wide range of atomic nuclei was calculated. Therein, the great emphasis was put on the manifestation of closed shells near Ni, Sn and Pb nuclei. The value of the transition matrix element of the residual nuclear interaction was treated as a parameter. The quality of the agreement between the calculation and the experimental data depends, of course, on the single - particle level scheme used as a basis for the calculation. Though the overall agreement was found to be acceptable, the remaining discrepancies clearly indicate presence of some effects, which cannot be simply related to the level density. An example may be seen in Fig.4.

Very encouraging results were obtained in colculating the gamma production cross sections of 14 MeV neutron indu-

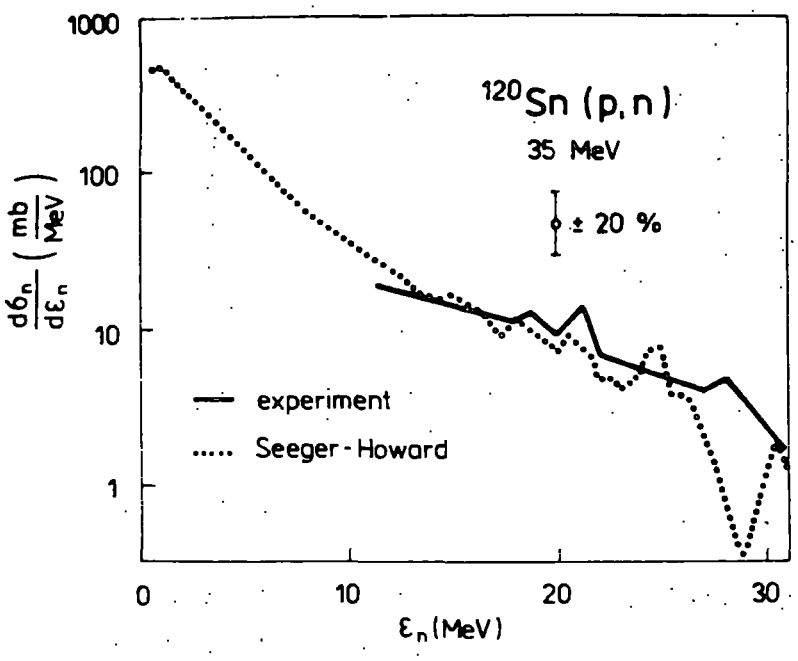

Fig. 4: The calculated neutron spectrum compared to the experiment for the ^{120}Sn(p,n) reaction at 35 MeV.

TABLE 3: Gamma production cross sections of some neutron induced reactions

Target	σ (ε_γ>14 MeV) [mb]		σ(11.5 MeV< ε_γ < 14 MeV) [mb]	
	exp.	calc.	exp.	calc.
^{45}Sc	800±115	960	400±200	192
^{51}V	875±195	872	250±150	279
^{56}Fe	850±120	960	900±180	595
^{59}Co	1005±155	980	330±180	295
^{88}Sr	1345±250	977	900±300	589
^{89}Y	1490±210	1026	1100±250	708
^{209}Bi	880±165	753	950±230	587

ced reactions on ^{45}Sc, ^{51}V, ^{51}V, ^{56}Fe, ^{59}Co, ^{88}Sr, ^{89}Y and ^{209}Bi using the simple equidistant - spacing model. There in, the calculations within this single mechanism are capable to deseribe satisfactorily both the spectral intensity between 11.5 and 14 MeV, as well as above 14 MeV. The results are summarized in Table 3.

3/ Conclusions

Interesting results have been obtained in all three directions of our research.

To further refine the microscopic model of the direct contribution to the continuum particle spectra, the fragmentation of one - phonon states will be studied and two - step contributions may be required to correctly describe the experimental data at higher energies.

The microscopic neutron optical potential will be further improved by using the results of the relativistic mean fild theory in finite nuclei.

The attempt to calculate gamma - ray spectra within the exciton model with the use of the realistic level densities is in progress now.