EFFECT OF OPTICAL POTENTIAL PARAMETERS AND NUCLEAR STRUCTURE IN REACTION CROSS SECTION CALCULATIONS

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ABSTRACT

The sensitivity of the excitation function calculation results to the optical potential parameters was investigated on the base of geometry dependent hybrid exciton model. The calculations of the excitation functions have been performed using various optical potentials. The effect of imaginary part of optical potential on the intranuclear transition rates in hybrid model, on the calculated nonequilibrium emission spectra was considered. The comparison of calculated and experimental spectra indicate the anomalous energy dependence of imaginary part of optical potential. The effect of the nuclear level density on the calculated reaction cross sections at intermediate energies was considered. The phenomenological approach based on generalised superfluid model as well as Fermi-gas model were used for nuclear level density calculations. It is shown that generalised superfluid model is preferable for the better description of experimental data.

1. THE SENSITIVITY OF THE EXCITATION FUNCTION CALCULATION TO THE OPTICAL POTENTIAL PARAMETERS.

The effect of the various optical potentials for the (p,xnyp) reaction cross section calculations in the energy region up to 300 MeV was investigated. The inverse reaction cross sections in neutron channel (σ_{inv}) were calculated using various types of the optical potentials. The following optical potentials were considered: Wilmore and Hodgson [1], Becchetti and Greenless [2], Bersillon and Cindro [3], Engelbrecht and Fiedeldey [4], Blann [5]. The typical results are presented in Figs. 1,2 with experimental data [6-8].

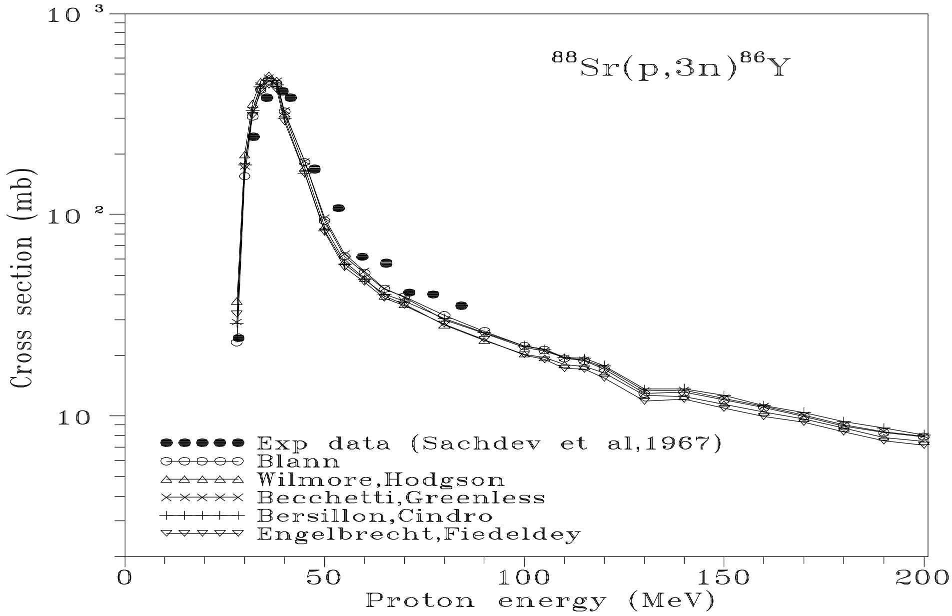

Fig. 1 The excitation functions for the ^{88}Sr(p,3n)^{86}Y reaction calculated using various types of the neutron optical potentials for the inverse reaction cross sections and experimenatal data [6].

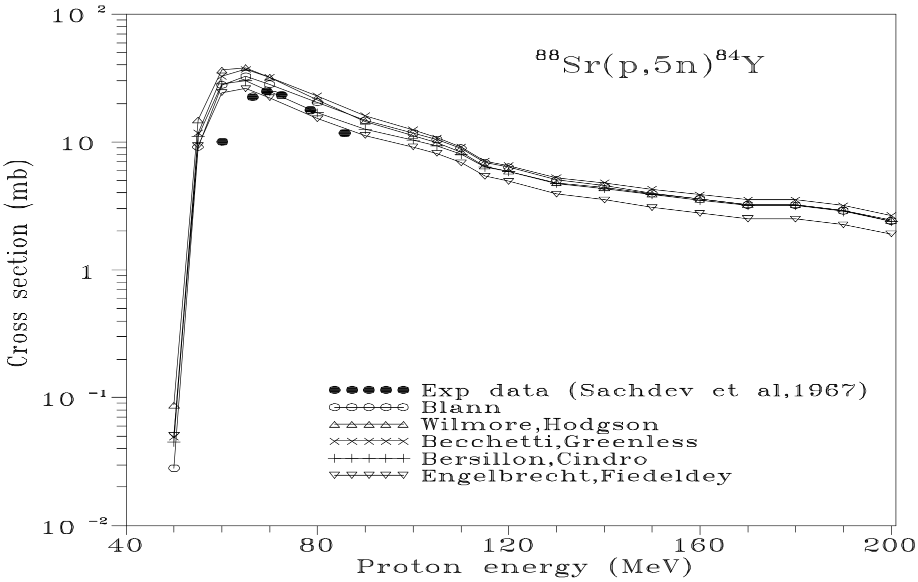

Fig. 2. The same, as in Fig. 1, for the ^{88}Sr(p,5n)^{84}Y reaction.

The potentials [1-3] was used up to 50 MeV, for the higher energies the reaction cross sections were taken equal to the value for 50 MeV. The potential [4] was used up to 150 MeV, but potential [5] up to 90 MeV.

One can see that the use of the optical potentials mentioned above [1-5] gives small effect on the reaction cross section values. The sensitivity of the excitation function calculation results to the imaginary part of the optical potential and to the value of the diffusiness of the potential was investigated also. The imaginary part of the optical potential determines the transition rate λ_+ in the hybrid model. The variation of the diffusiness reflects the difference of the interaction cross section of a nucleon with the nucleus in a ground and excited states (σ_{inv}). The excitation functions for the ^{59}Co(p,2np)^{57}Co reaction calculated with the use of different scaling factors for the free path of the nucleon (Λ~1/λ_+) and different diffusiness parameters "a", corresponding to the optical potentials used for the calculations of the inverse reaction cross sections are shown in Fig. 3 We see that the variation of Λ give the considerable effect on the excitation function values.

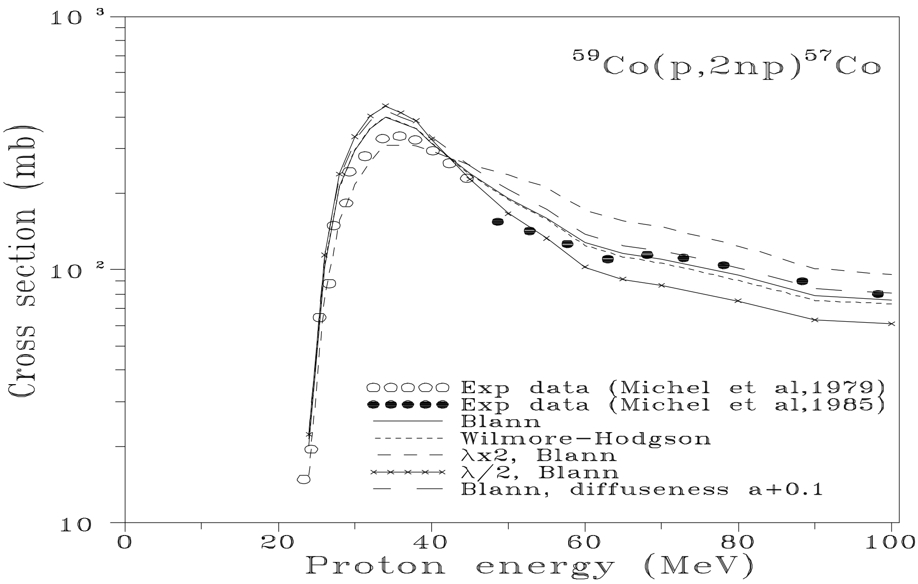

Fig. 3. The excitation functions for the ^{59}Co(p,2np)^{57}Co reaction calculated using various options.

2. THE ANOMALOUS ENERGY DEPENDENCE OF THE IMAGINARY PART OF THE OPTICAL POTENTIAL.

From the formal point of view in the geometry dependent hybrid exciton model (GDH) [5] there are no phenomenological parameters. However, the comparison of the calculated and experimental cross sections indicates that for the description of the experimental data it is necessary to introduce the scaling factor for the mean free path (Λ), which depends on the energy of incident particles. The use of such factor means the energy dependence of the imaginary part of the optical potential W which determines the intranuclear transition rate λ_+ ($\Lambda \sim 1/\lambda_+$, $\lambda_+ \sim W$). The data presented below show the necessity to use the λ_+ values which differ from the recommended ones [5]. The ratios of the (n,p) reaction cross sections at the energy of 14.5 MeV, calculated in the geometry dependent hybrid model (GDH), and determined from the analysis of the experimental data in Ref. [9] for 156 nuclei are shown in Fig. 6. The mean free path of nucleons was calculated using the nucleon-nucleon interaction [10] taking into account Pauli principle effect. The scaling factor for Λ was chosen to be equal to 1 or 0.2. One can see that the agreement with the experimental data is obtained if the mean free path is diminished as compared with the given in Refs. [5]. On the other hand, it follows from Figs. 2,3 that for the higher energies (62 MeV) the scaling factor for Λ should be 1 or 2.

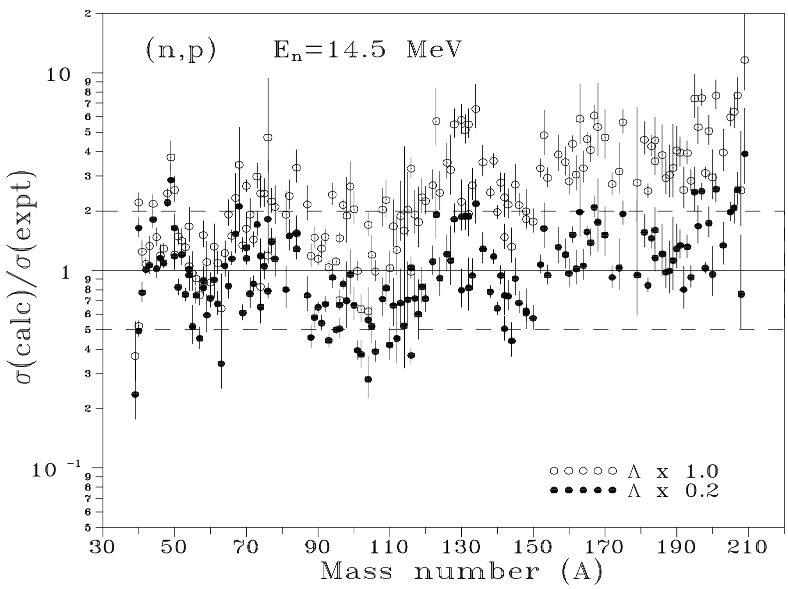

Fig. 4. The ratio of the (n,p) reaction cross section at the energy of 14.5 MeV, calculated in GDH model using various scaling factors for the nucleon mean free path in a nucleus, and determined from experimental data in Ref. [10] for 156 nuclei.

The increase of the scaling factor for Λ with the energy means that the effective value of the imaginary part of the optical potential W, which determine λ_+, decreases when the incident particle energy increases. Such energy dependence of W contradicts to the data for the elastic and inelastic scattering. Probably it is connected with surface absorption of nucleons. In this case the relation for $\Lambda \sim W$ may be rough approximation.

The reason for this anomalous dependence of W has not the proper explanation. However this result should be taken into account in the calculations with GDH model.

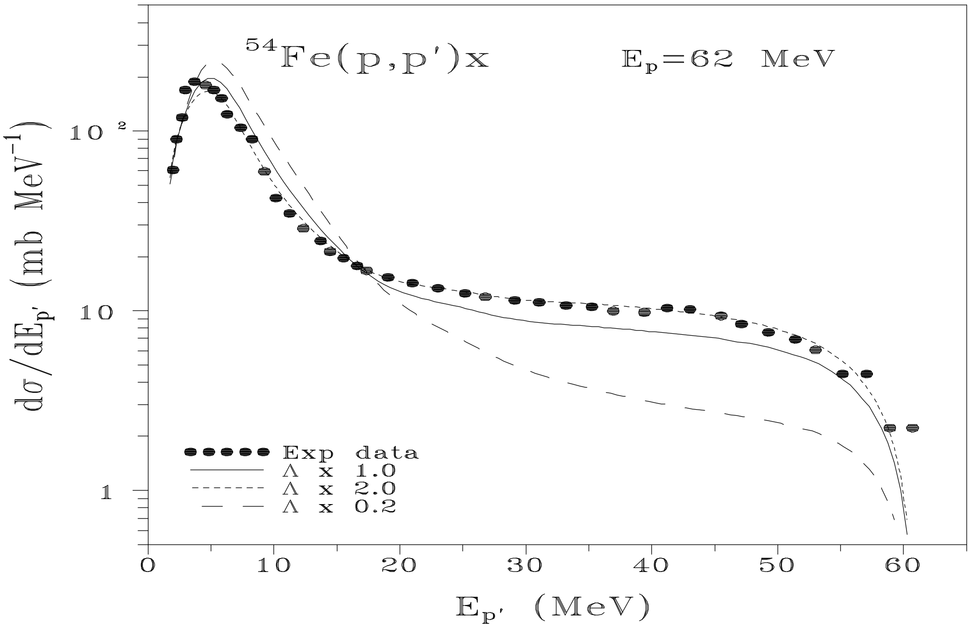

Fig. 5. The proton spectra from the ^{54}Fe(p,p') reaction at 62 MeV calculated in GDH model using different scaling factors or the nucleon mean free path.

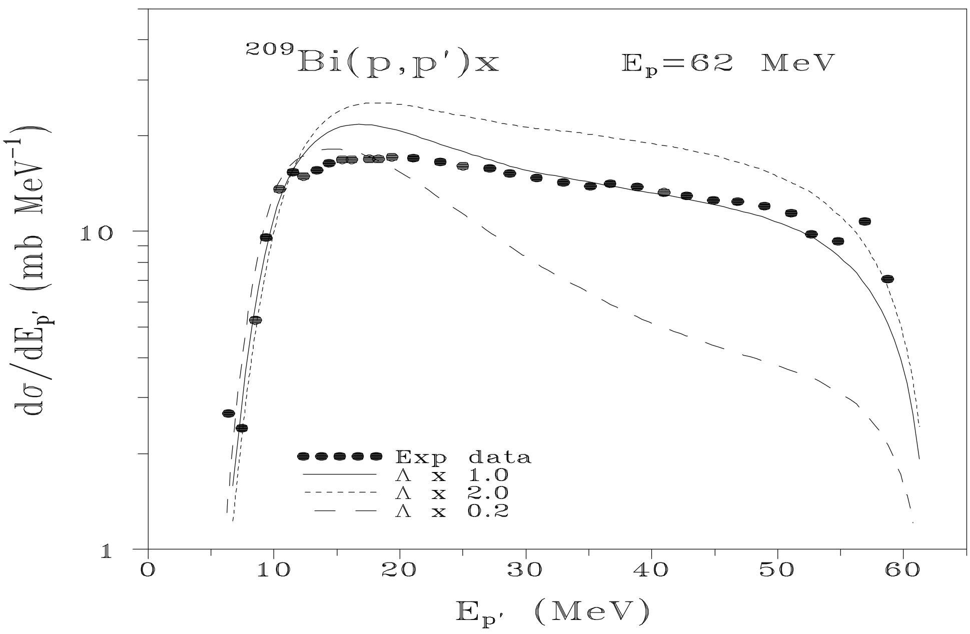

Fig. 6. The same as in Fig. 5 for the ^{209}Bi(p,p') reaction.

3. THE ENERGY DEPENDENCE OF THE INTRANUCLEAR TRANSITION RATE IN THE HYBRID EXCITON MODEL.

The difficulties in the description of the experimental data on the reaction cross sections for the energies up to several hundred MeV stimulated the investigations of the intranuclear transition rates in the hybrid exciton model using the approximation of the experimental data on the total and reaction cross sections in a wide energy region [11]. Using the relation between the total reaction cross section (σ_{tot}) and nonelastic cross section (σ_{non}), taking into account that λ_+ is the intranuclear transition rate (the complication of the configuration of the system at the first stage of a reaction), λ_{esc} is the particle emission rate, we can write:

$$\sigma_{non} = \sigma_{tot} \frac{\lambda_+}{\lambda_+ + \lambda_{esc}}$$

If we use σ_{tot} and σ_{non} from Ref. [11] and estimate the λ_{esc} value, then it is possible to determine the intranuclear transition rate for the definite energy of the incident particle (λ_+). The values λ_+^*, λ_{esc}^* were calculated with the ALICE-IPPE code for the first stage of the preequilibrium process in the hybrid exciton model. Assuming that $\lambda_{esc} = \lambda_{esc}^*$ and considering λ_+ as an experimental value, we can estimate energy dependence of the ratio of the mean free paths Λ, Λ^* for the first stage of the reaction ($\Lambda \sim 1/\lambda_+$, $\Lambda^* \sim 1/\lambda_+^*$). Here we present the results of the calculations for the following nuclei: ^{26}Al, ^{94}Zr, ^{96}Mo, ^{208}Pb, ^{209}Bi in the incident neutron energy region from 14 to 280 MeV. The results of the calculations of the experimental and theoretical mean free path ratio (Λ/Λ^*=1/k) as a function of the incident neutron energy are shown in Fig. 7.

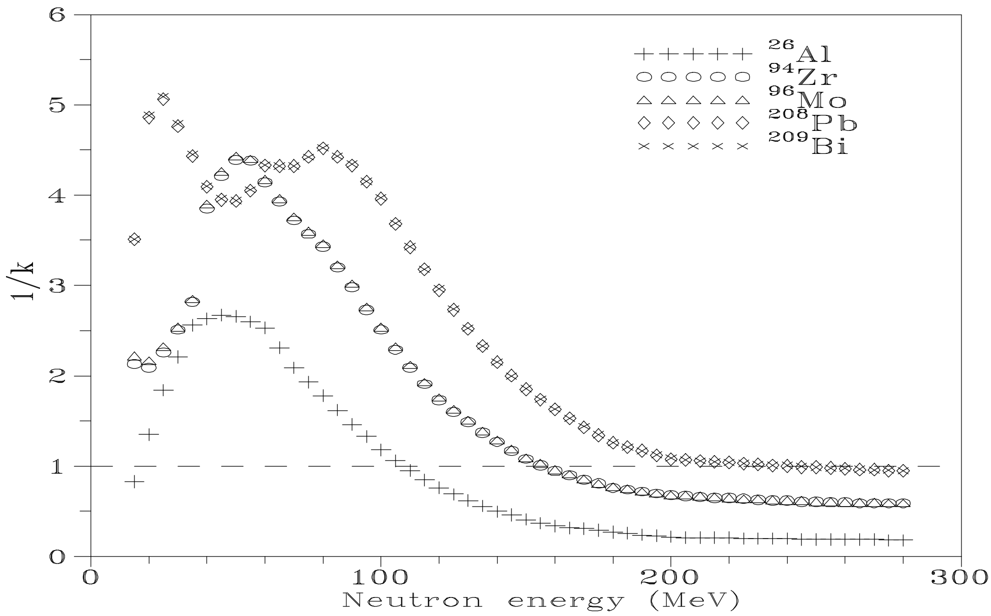

Fig. 7. Ratio of the "experimental" and calculated mean free path as a function of the incident neutron energy.

One can see the considerable difference between the "realistic" and theoretical mean free path. Therefore it is necessary to introduce the energy dependence of the mean free path. This result shows indirectly to the necessity to take into account the energy dependence of the imaginary part of the optical potential (and the intranuclear transition rate λ_+ ($\Lambda \sim 1/\lambda_+$, $\lambda_+ \sim W$)), or the variation of the optical model parameters.

4. NONELASTIC CROSS SECTION AND OPTICAL MODEL PARAMETERS

The spherical optical model (SOM) is used as a base for the theoretical analysis and evaluation of nuclear data. Besides the description of the elastic and inelastic scattering cross sections, and for neutrons also the total cross sections, the spherical optical model gives the transmission coefficients, which are used to analyse the partial cross sections in the frame of statistical theory of nuclei. For the evaluation tasks it is important to have the reliable parameters of the optical potentials which enable not only to describe the existing experimental data but to predict when they are not available.

Several sets of the global optical potential parameters were proposed earlier for the description of the neutron and proton scattering on the nuclei in the region of the mass numbers 22<A<240 and incident nucleon energies from 50 to 140 MeV [4,12,13]. The review of the spherical optical model status for the neutron energies up to 20 MeV was given in Ref. [14].

Because the many computer codes use the reaction cross sections only, but not the transmission coefficients, there were attempts to describe phenomenologically these cross sections with the comparatively convenient formulas. The most simple formulas were obtained in the frame of the quasiclassical “sharp cutoff” approximation [15]. For neutrons and protons more complicated formulas were proposed in the papers [11,16,17]. The empirical formulas based on the experimental data were proposed in paper [11] for the reaction cross sections. We made an attempt to describe these cross sections for neutrons and protons with the energy up to 300 MeV and for the mass numbers 22<A<160 in the frame of spherical optical model. The parameters of the spherical optical potentials obtained are given below.

Neutrons: 22<A<160, E_n < 300 MeV.

V=40.0
r_v=1.15 + (0.015-0.0002*E_n)*E_n, E_n<45 MeV
r_v=1.151 - 1.77*(A-2.*Z)*$A^{-1.33333}$, E_n>45 MeV
a_v=0.66
W=7. + 5.*F(A)+(15.625-(0.03-0.01*F(A)*E_n)*10^{-5}*E_n*E_n
r_w = r_v
a_w=0.48
V_{so}=7.0
r_{so} = r_v
a_{so} = a_w

Protons: 22<A<160, E_p < 300 MeV:
V=60.0
r_v=1.35 + (0.01-0.0003*E_p)*E_p , E_p<35 MeV
r_v=1.2, E_p>35 MeV
a_v=0.6
W=5. + (14.286-10.*F(A)-(0.035-0.03*F(A)*E_p)*10^{-5}*E_p*E_p
r_w = 1.45, Ep < 20 MeV
r_w = 1.45 + 0.0003*E_p, Ep > 20 MeV
a_w=0.5
V_{so}=7.5
r_{so} = r_w
a_{so} = 0.51
$r_{coulomb}$ = 1.3
F(A)=(A-27.)/81.

The resuts of the reaction cross section calculations for neutrons and protons, using various optical potentials and empirical formulas, are presented in Fig. 8. These parameters gave the possibility to use realistic representation of the transmission coefficients in the geometry dependent hybrid exciton model (GDH) [5].

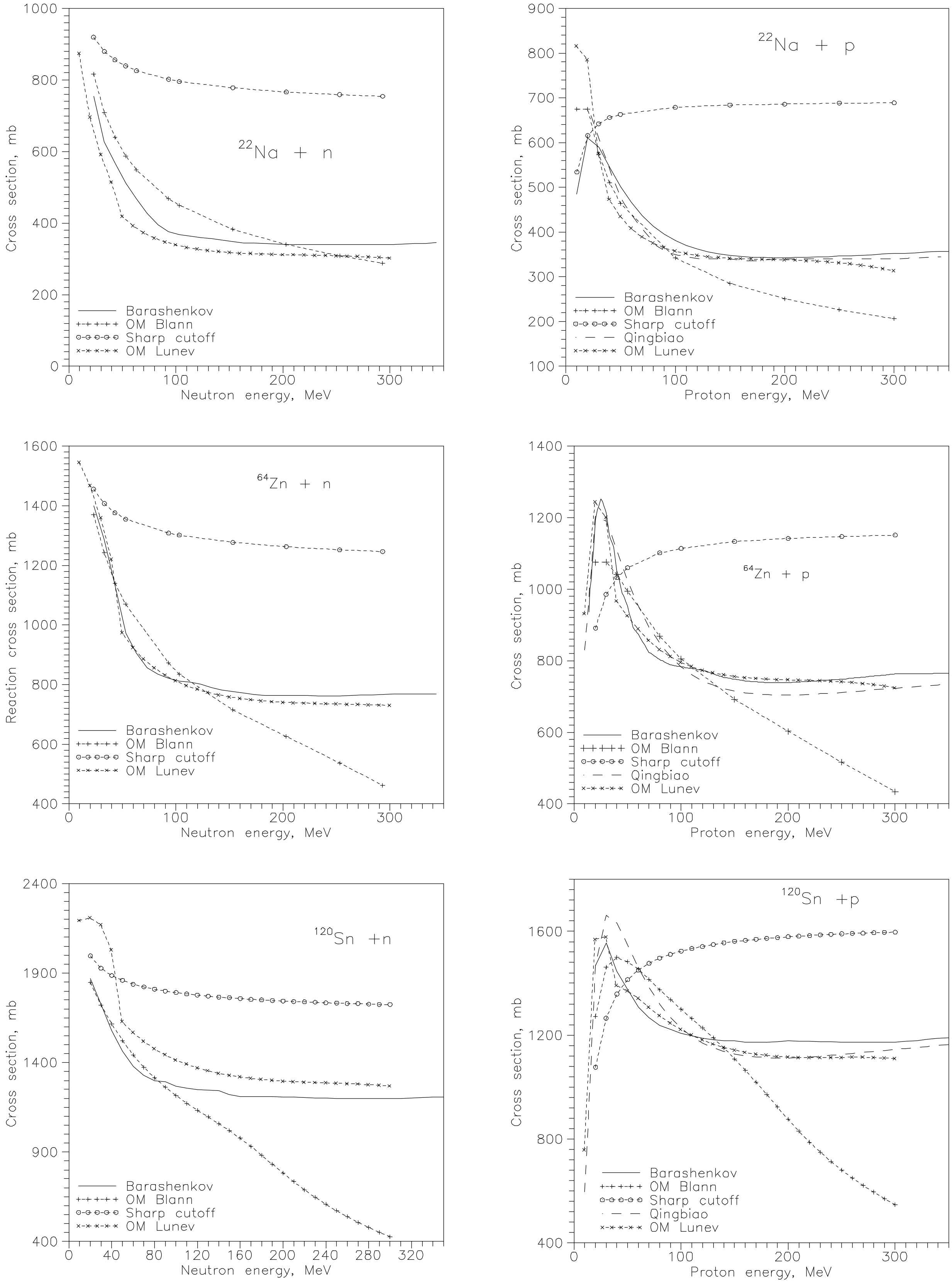

Fig. 8. Results of nonelastic cross section calculation in SOM for neutrons and protons and in various approximations.

5. THE EFFECT OF LEVEL DENSITY
ON THE REACTION CROSS SECTION CALCULATIONS

Level density plays a significant role for the description of the reaction cross sections in the statistical nuclear theory. To calculate it various versions of the Femi-gas model are used which are attractive owing to its simplicity [18,19]. However the analysis performed on the base of microscopic approaches, developed for the description of the ground and low-lying nuclear states, has shown that the Fermi-gas model does not take into account many fundamental properties of excited nuclei, connected with the shell structure of the single-particle spectrum, pair correlation of superconductive type and coherent collective excitations of nuclei in a consistent way. The existing accurate microscopic methods of the level density calculations [20-22] are cumbersome, and this circumstance strongly limits their using for the practical applications. That is why the investigations that are aimed at the search for the approach to the level density description, which took into account the basic theoretical ideas and was , on the other hand, simple enough for the practical use [23-27].

Here we investigate the effect of the level density calculation methods on the reaction cross sections at intermediate energies. The calculations of the level densities was performed on the base of the Fermi-gas model [18] and generalised superfluid model [23-26]. The results of the calculations were compared with the experimental data on the proton induced reactions with the emission of secondary particles in the energy range up to 200 MeV and for nuclei in the region $Z = 18 \div 83$. It is shown that the generalised superfluid model gives the better results as compared with the Fermi-gas model even in the cases when some uncertainty in the choice of the parameters exists.

In Figure 9 the typical results of the calculations using the Fermi-gas model and generalised superfluid model for the level density description are presented together with experimental data [6,28]. One can see that the use of the generalised superfluid model (GSM) for the level density calculations results in a better description of the experimental data than the Fermi-gas (F-G) model as it follows from the cross section comparison performed performed for 60 reactions with multiple particle emission.

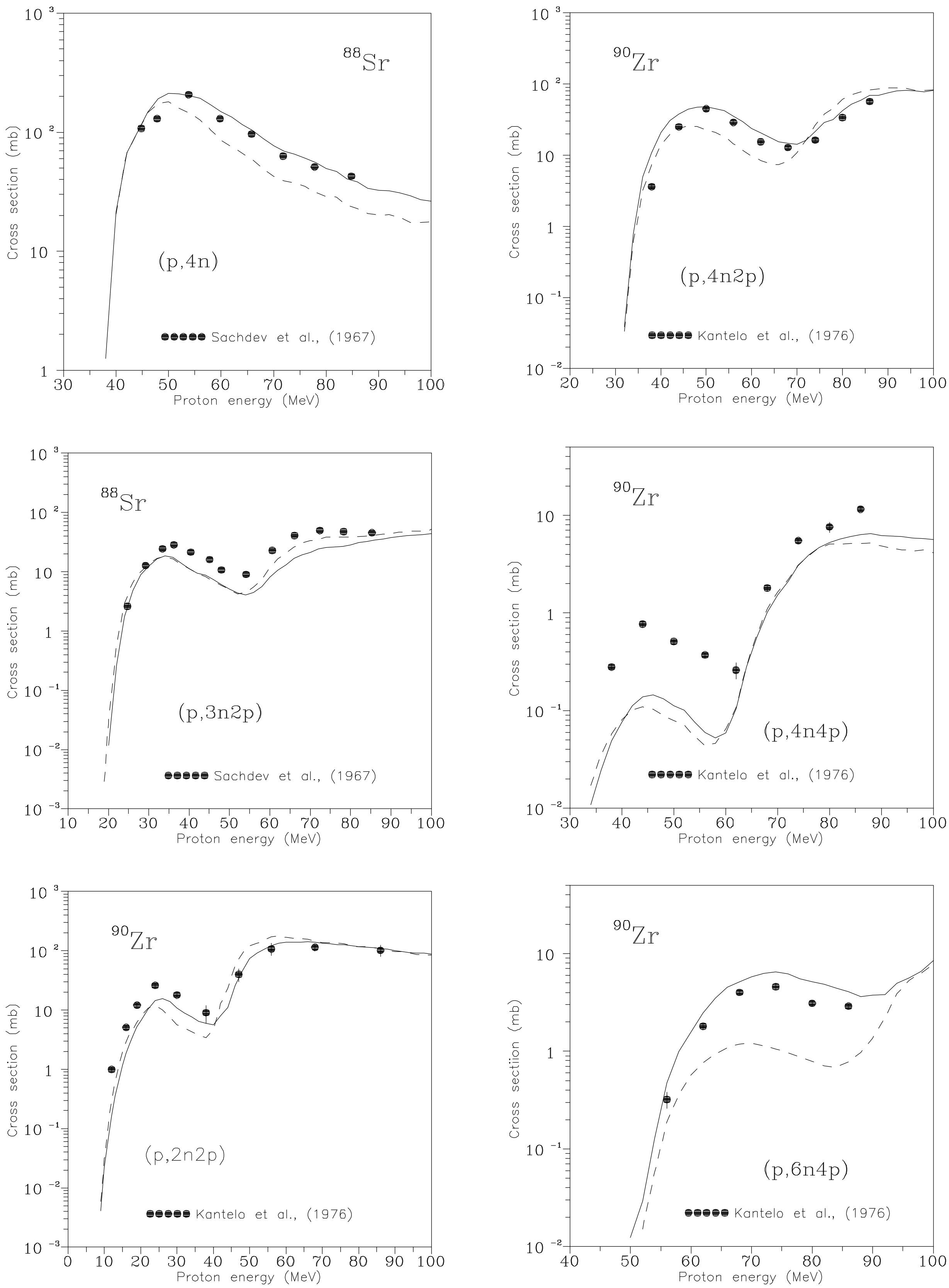

Fig. 9. Comparison between calculations using F-G (dashed line) and GSM (solid line) models for the level density description and experimental data Sachdev D.R., et al. [6] and Kantelo M.V. et al. [28].

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