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ABSORPTION CROSS-SECTION OF CHARGED PARTICLES BY NUCLEI IN THE GROUND AND EXCITED STATE

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Abstract: In the frameworks of modern theoretical models of nuclear reactions an analisis of the excitation functions and emission spectra of the neutron threshold reactions at neutron energies up to 20 MeV has been done. The results of the analisis indicate the considerable difference between the alpha-particle transmission coefficients for the excited and ground state nucleus.

(Nuclear reaction, absorption cross-section, charged particle emission spectra, excited nucleus, ground state)

Introduction

The present work deals with the analysis of excitation functions and particle emission spectra in neutron reactions with an energy up to 20 MeV with nuclei in the mass range $50<A<70$ within the framework of theoretical models of nuclear reactions. The basic prominence has been given to consideration of the problem of the possible difference of the charged particle absorption cross-sections by nuclei in the ground and excited state, wich has been under discussion for a long time /1,2,5/.

In refs./2/ on the basis of excitation function analysis of (n,p), (n,α), (n,2n) reactions according to the statistical theory it was concluded that for experimental data description the selection of varying level density parameters for the same residual nuclei in neutron and proton channels was required. A probable difference between the inverse reaction cross-section and the absorption cross-section calculated by optical models was pointed to as one of the possible reasons for this mismatch.

In ref./3/ on the basis of α-particle emission spectra analysis in the (n,α) reactions a conclusion was made about the essential difference of absorption cross-sections for excited and cold nuclei. The present work applies the results of recent investigations obtained in nuclear level density descriptions /5/ to look into this problem in more detail. The results of this work were reported at the 2nd Meeting of the IAEA Coordinated Research Programme on "Methods for the Calculation of Fast Neutron Nuclear Data for Structural Materials"/7/.

Models used in the experimental data analysis.

The approach to particle emission spectra and cross-section analysis is based on the reaction mechanism being divided into three components: direct, preequilibrium and equilibrium ones. The reaction equilibrium component is calculated within Hauser-Feshbach formalism.

The preequilibrium part is calculates within the exciton model /12/ and the direct component within the framework of the couple channel method or distorted wave Born approximation.

Contributions of the above mentioned mechanisms vary depending on individual properties of nuclei, interaction energy and reaction type. For the reaction (n,p) and (n,α) on the nuclei, considered in this work, and in the energy up to 20 MeV the main contribution to the total reaction cross-section is made by the equilibrium component, whereas the contributions of the preequilibrium and direct mechanisms are insignificant. For the (n,n') reaction on the same nuclei at the energy $E_n \geqslant 10$ MeV the contribution of the preequilibrium and direct components is no longer insignificant and it should be taken into account not only for the adequate description of cross-sections and spectra in a neutron channel, but also for the proper normalization of cross-sections and spectra in other reaction channels.

The main factors affecting the absolute value and the emission spectrum shape in different reaction channels are residual nuclei level density and transmission coefficients of particles in exit channels.

The relations of Fermi-gas model /4/ are most frequently used in the calculations of level density. The model, however, ignores a number of essential properties in nuclear excited state spectra such as the shell structure of a single-particle spectrum, correlation effects of superfluid nature and coherent collective effects. These effects can be taken into account most consistently by the microscopic approach within the framework of the unified superfluid model (USM) of nucleus /5/.

Ref./6/ puts forward a phenomenological version of USM taking into account collective, superfluid and shell effects in level density and quotes the systematics of USM parameters for nuclei in the mass range $40 < A < 150$ obtained from the analysis of experimental data on neutron resonance density and on low-lying nuclear levels. The calculations of level density on the basis of suggested approach agree with the results of the microscopic level density calculations.

The relations of both statistical and preequilibrium models incorporate inverse reaction cross-sections or cross-sections of particle absorption by residual nuclei built-up in exit channels of reactions. A significant factor is that it is necessary to know the cross-sections of particle absorption by excited nuclei. The dependence of absorption cross-section on nuclear excitation energy commonly being unknown, the optical model calculation results for a nucleus-target in the ground state are adopted as such data.

Calculation results.

Fig.1 shows the calculation results of proton and α-particle emission spectra for ^{56}Fe, ^{52}Cr and ^{60}Ni nuclei in comparison with the S.M. Grimes /9/ experimental data for 15 MeV incident neutron energy. Solid curves correspond to the calculations with the V.M. Bychkov /10/ and L. McFadden and G.R. Satchler /11/ parameters of optical potential for protons and α-particles, respectively.

For α-particle emission spectra a systematic effect is observed: a displacement of the theoretical curve to the right with respect to the experiment in the low α-particle energy range. This displacement can be eliminated with none of reasonable variations of level density parameters either in USM or in the back-shift Fermi-gas model.

It is important to note, that these effects are not peculiar to our calculation codes. For example, the same displacement of α-particle emission spectra was reported by M. Ivascu /8/ when analising experimental data for $^{50,52}Cr$ and $^{54,56}Fe$ nuclei within the framework of the theoretical model of nuclear reactions.

Therefore, this effect can be interpreted as suggesting there is a need for a modification of transmission coefficients in the alpha-channel, the modification involving an effective reduction of Coulomb barrier for alpha-particles.

This correction for alpha-particle transmission coefficients was performed by way of increasing the real potential diffuseness parameter a_R by 20-25%. A dashed line in fig.3 shows a cross-section of alpha-particles absorption by ^{59}Co nucleus obtained in this way. The calculations of alpha-particle emission

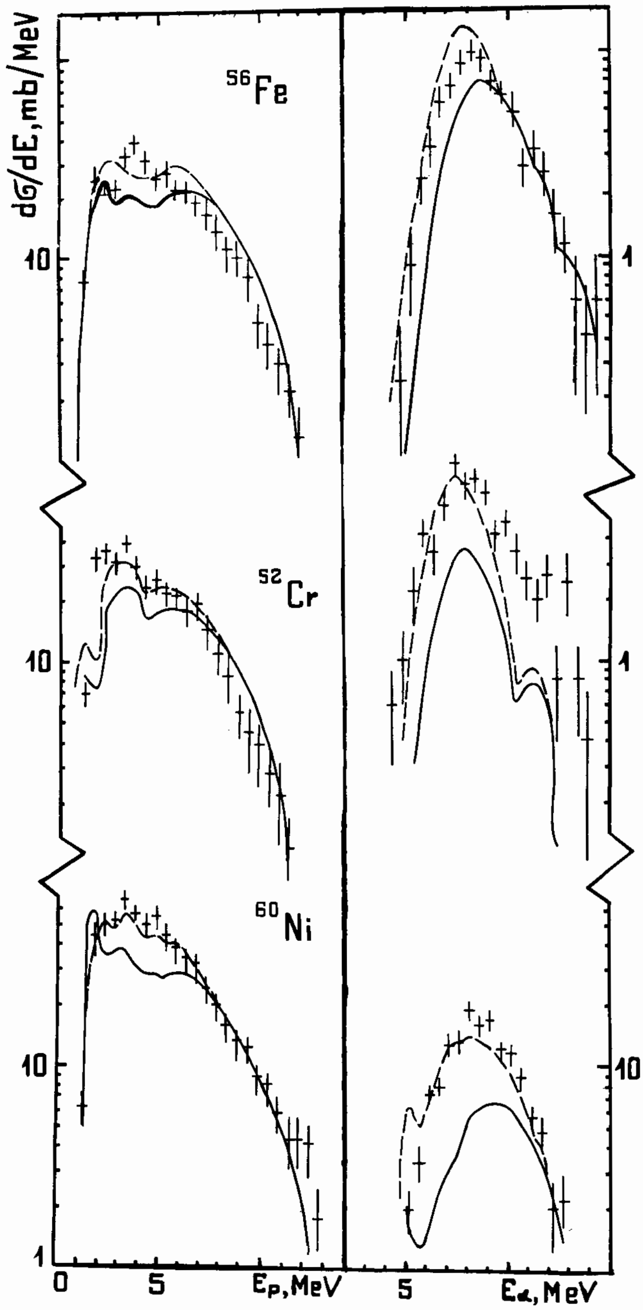

Fig.1 Proton and alpha-particle spectra (for detailes, see text).

spectra corresponding to these modified transmission coefficients are shown in fig.1 by dashed lines. The experimental data description improves considerably in this case. This very effect is demonstrated by the calculation of (n,α) excitation function on ^{54}Fe nucleus taken as an example (Fig.4).

As one can see in fig.3 the modified absorption cross-section is displaced in terms of energy to the left with respect to the experimental data. Apparently it points to an considerable difference in the absorption cross-section for cold and excited nuclei. This effect can be seen clearly on the alpha-particle emission spectra (Fig.1), due to the $(n,n\alpha)$ reaction contribution being negligible with the neutron energy under

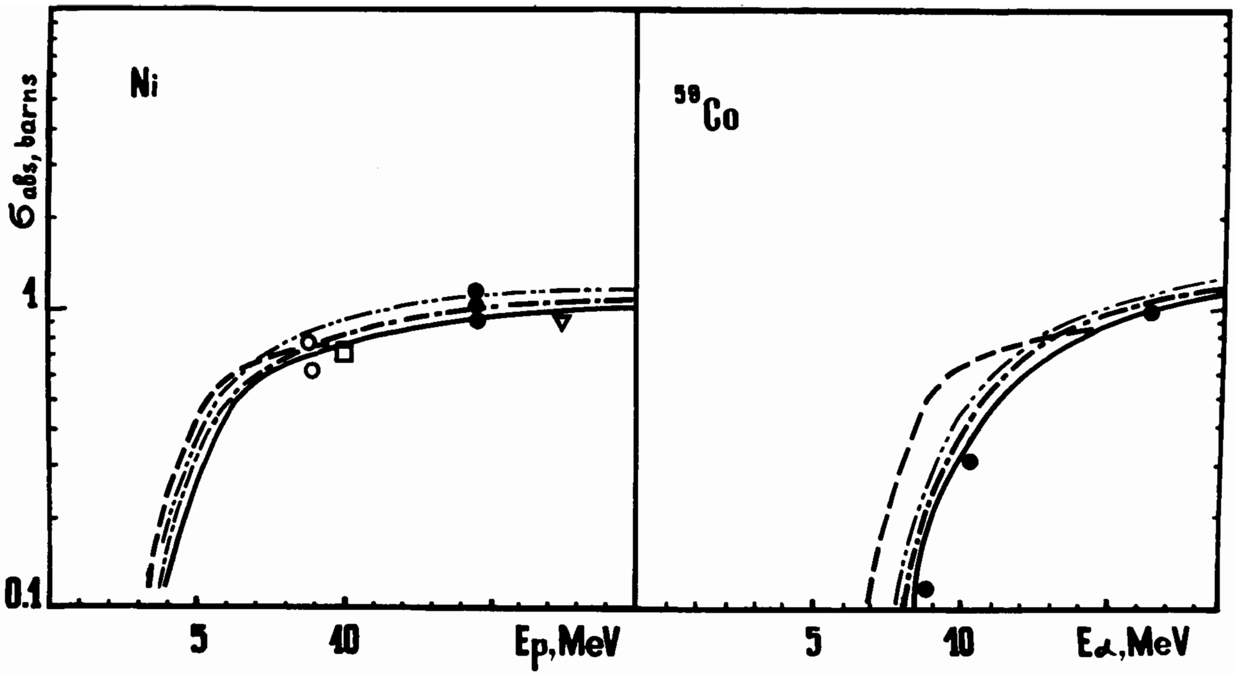

Fig.2 Proton absorption cross-sections: experiment from /16,17/; calculation results:
——— - potential from /10/;
– – – - /10/ with enhanced a_R ; –·–·– -/16/;
–··–·· - /17/.

Fig.3 Alpha-particle absorption cross-sections: experiment from /20/; calculation results:
——— - potential from /11/;
– – – - /11/ with enhanced a_R ; –·–·– -/13/;
–··–·· - /14/.

consideration. In the case of proton emission spectra the (n,np) reaction contribution is no longer insignificant, that is why analysis of the soft part of the proton spectrum of the (n,p) reaction is more intricate. However, in fig.1 the effect of transmission coefficient differences for the excited and cold nuclei is also noticeable. The dashed line shows the calculations with the transmission coefficients obtained with the real potential diffuseness a_R increase by 20-25%.

It is noteworthy, that from the condition of spectrum shape description it follows, that the similar variation of transmission coefficients is required only at the proton and α-particle energies below the corresponding Coulomb barrier. The method of the corresponding modification of transmission coefficients involves a smooth agreement of the increased and initial diffuseness of the real potential in the region of Coulomb barrier. Figs.2 and 4 demonstrates the effect of these variations of optical transmission coefficients for protons with the calculation of ^{60}Ni (n,p) reaction cross-sections taken as an example.

An addition to these arguments a similar conclusion about the difference of the cross-section of α-particle and proton absorption by a nucleus in the ground and excited states was made in the work by McMahan and Alexander /15/ when analising spectra in the reaction $^{12}C + {}^{122}W$.

The Roumanian group's results /18/ in the description of (n,p) reaction excitation functions on titanium isotopes may serve as an indirect evidence for the validity of the suggested explanation of the observed differences in the calculated spectra of charged particles emission from the experimental data. In the report /18/ it was actually shown, that different parameters of optical potential are required for the description of the $^{45}Sc(p,n)^{45}Ti$ and $^{46}Ti(n,p)^{46}Sc$ reaction cross-sections. It took a significant increase of the imaginary part of the potential for the second reaction (i.e. proton absorption increase).

Hence, the question of a difference of charged particle absorption cross-sections for the excited and ground states of the atomic nucleus may well be posed with fair validity. This statement is useful for the solution of an old problem of nuclear level density analysis in various reactions, i.e. the level density parameters obtained by the analysis of charged particles emission spectra being different from the values known from the neutron data. The difficulty is removed with the help of transmission coefficients modification performed in this work.

There seem to be sufficient data supporting such an assertion. However, it should be noted, that the proton absorption cross-sections and particularly those for alpha-particles have not been investigated much experimentally. The optical model parameters for the particles with energies below the Coulomb barrier have not been investigated much either. That is why it seems to be pre-

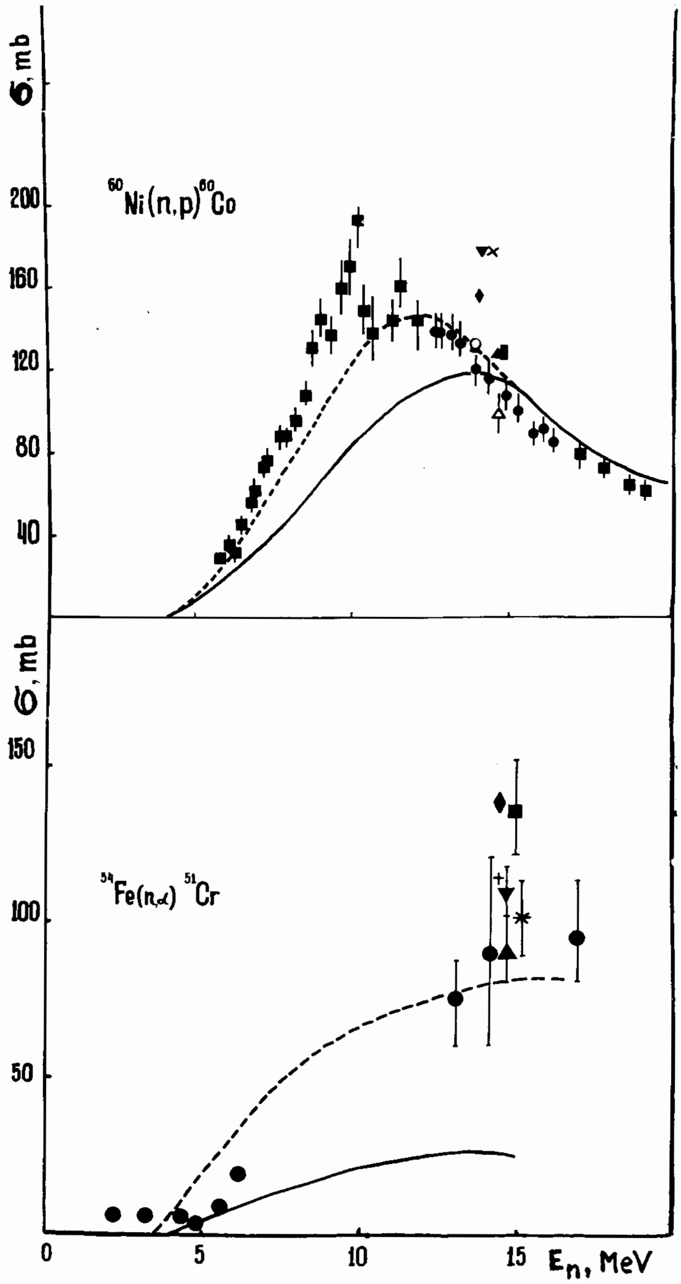

Fig.4 (n,p) and (n,α) reaction cross-sections (for detailes, see text); experiment from /19/.

mature to make conclusions about the absolute value of the effect and its theoretical interpretation. To solve this problem it is essential to analyze a wide range of nuclei and excitation energies and probably a wider class of reactions.

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