Letters to the Editor

ON THE $\Delta n = 0$ TRANSITIONS IN THE EXCITON MODEL OF NUCLEAR REACTIONS

О $\Delta n = 0$ ПЕРЕХОДАХ В ЭКСИТОННОЙ МОДЕЛИ ЯДЕРНЫХ РЕАКЦИЙ

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The preequilibrium model of nuclear reactions has been attracting much attention in this decade (see e.g. Ref. [1] for a review). In the last years, several papers have appeared [2—6] that study different aspects of the set of master equations of the preequilibrium decay. The set can be written in the form [7—8]

$$\frac{dP(n,E,t)}{dt} = P(n-2,E,t)\lambda_+(n-2,E) + \tag{1}$$

$$+ P(n+2,E,t)\lambda_-(n+2,E) -$$

$$- P(n,E,t)[\lambda_+(n,E)+\lambda_-(n,E)+L(n,E)].$$

Here, all the notations have the same meaning as in Ref. [8]. The presence of the emission term, $L(n,E)$, in the equations leads to the decay of nuclei in the reaction, so that at infinite time no nuclei are excited [4, 5, 8], i.e.

$$\text{for } t\to\infty \quad P(n,E,t)\to 0. \tag{2}$$

Integrating Eqs. (1) in time and summing over excitons n we arrive at [5]

$$\sum_n P(n,E,t=0) = \sum_n L(n,E)\int_0^\infty P(n,E,t)\,dt, \tag{3}$$

which is the conservation law of a reaction: the l.h.s. is the number of the excited nuclei at the beginning of a reaction, and on the r.h.s. there are nuclei decayed within the reaction.

If we put a limit case $L(n,E)\to 0$ in Eqs. (1), we obtain by a similar procedure

$$\sum_n P(n,E,t=0) = \sum_n P(n,E,t), \tag{4}$$

which keeps all the time. In this case nuclei cannot decay, the only development within the reaction is the equilibration, which results in $P(n,E,t\to\infty) = \omega(n,E)/\sum_n \omega(n,E)$ [8], where $\omega(n,E)$ is the total density of n-exciton states at the excitation energy E.

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In Eq. (1) two types of intranuclear transitions are written explicitly, i.e. the transitions leading from n-exciton states to the states with $(n\pm 2)$ excitons. However, the nucleus equilibration, caused by residual energy-conserving two-particle interactions leads to three possible transitions, $\Delta n = -2, 0, +2$. In order to include also the $\Delta n = 0$ transitions, Wu and Chang [3] mechanically extended the set of master equations. Their equations differ from (1) by the last term which in their paper reads — $P(n,E,t)\times[\lambda_+(n,E)+\lambda_0(n,E)+\lambda_-(n,E)+L(n,E)]$. If we repeat the integration in time and summation over excitons with the extended equations set, we get an equation with two terms on the r.h.s. instead of Eq. (3). As an addition to the emission term there stands $\sum_n \lambda_0(n,E)\int_0^\infty P(n,E,t)\,dt$, which expresses that only a part of the original nuclei decays by emission and the rest vanishes by the $\Delta n = 0$ transitions. But this second process physically does not lead to the change of the number of nuclei within the reaction, so that we can conclude that the attempt of Ref. [3] is physically incorrect (though the numerical influence of the erroneous extra term is not great). Even in the limit case of no emission we get $\sum_n P(n,E,t) = \sum_n P(n,E,t=0) - \sum_n \lambda_0(n,E)\int_0^t P(n,E,t')\,dt'$, which means a decrease of the number of composite nuclei.

A study of the presence of the $\Delta n = 0$ term in the master equations set is also contained in a paper of Luider [4]. It is based on the balance of processes in nuclei and concludes (as we do here) that the extension of master equations as done by Wu and Chang is unacceptable.

What is the solution of the problem? Let us restrict ourselves only to the simple formulation of the exciton model, where one does not consider the γ-emission. Probably the best way has been suggested (though not used) by Gudima et al. [9]. We can introduce some additional subscript into the occupation probabilities which will distinguish among different states with the same exciton number. As this method means introducing one more dimension into the problem, it is seldom used in usual preequilibrium calculations. But in the two-component formulation of the problem, i.e. in the case when one distinguishes proton and neutron excitons, we also have an additional subscript in the equations, though in a restricted sense. In this case the set of master equations is [10]

$$\frac{dP(n_\pi,n_\nu,E,t)}{dt} = P(n_\pi+2,n_\nu,E,t)\lambda_-^\pi(n_\pi+2,n_\nu,E) \tag{5}$$

$$+ P(n_\pi-2,n_\nu,E,t)\lambda_+^\pi(n_\pi-2,n_\nu,E)$$

$$+ P(n_\pi-2,n_\nu+2,E,t)\lambda_0^{\pi\nu}(n_\pi-2,n_\nu+2,E)$$

$$+ P(n_\pi,n_\nu+2,E,t)\lambda_-^\nu(n_\pi,n_\nu+2,E)$$

$$+ P(n_\pi,n_\nu-2,E,t)\lambda_+^\nu(n_\pi,n_\nu-2,E)$$

$$+ P(n_\pi+2,n_\nu-2,E,t)\lambda_0^{\pi\nu}(n_\pi+2,n_\nu-2,E)$$

$$- P(n_\pi,n_\nu,E,t)[\lambda_+^\pi(n_\pi,n_\nu,E)$$

$$+ \lambda_+^\nu(n_\pi,n_\nu,E)+\lambda_0^{\pi\nu}(n_\pi,n_\nu,E)$$

$$+ \lambda_0^{\nu\pi}(n_\pi,n_\nu,E)+\lambda_-^\pi(n_\pi,n_\nu,E)$$

$$+ \lambda_-^\nu(n_\pi,n_\nu,E)+L(n_\pi,n_\nu,E)].$$

Here the subscripts π and ν refer to the proton and neutron excitons, respectively, and $\lambda_0^{\nu\pi}(n_\pi,n_\nu,E)$ stands for a process, when a neutron particle interacts with a so far unexcited proton, which results in filling a neutron hole and a creation of the proton particle-hole pair (and analogically $\lambda_0^{\pi\nu}(n_\pi,n_\nu,E)$), so that $\Delta n_\pi = -\Delta n_\nu$ and the total number of excitons remains unchanged. The transitions without exciton

number change appear organically in Eqs. (5) and they can be identified as the change of proton to neutron or vice versa [10]. Thus we see that for the two-component description at least some of the $\Delta n = 0$ transitions stand explicitly in the set of master equations.

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EPR INVESTIGATION OF Cu-DOPED Ge-S GLASSES

ИССЛЕДОВАНИЕ СТЁКОЛ Ge-S С ПРИМЕСЬЮ МЕДИ МЕТОДОМ ЭПР

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In our recent paper the results of an EPR investigation of Ag-doped Ge-S glasses wer presented [1]. Unlike Watanabe et al. [2] we have found a new reproducible EPR signal that is closely associated with the concentration of Ag. The origin of this signal is not clear at present. The aim of this letter is to report further results of the EPR investigation performed on the Ge-S glasses.

The Ge-S system has two glassforming regions [3]. We chose a glass with the composition of $Ge_{40}S_{60}$. The samples of $Ge_{40}S_{60} + x$ at % Cu, where $x = 0.01$, 0.1, 0.3, 0.7, 1, 2, 3 and 5, were prepared from elemental materials of 5N purity. The elements of the desired proportions were placed in quartz ampoules, evacuated to 10^{-5} Torr and sealed. The the materials in the ampoules were melted at 900 °C for 4 hours and finally quenched in air. The vitreous character of all the samples was confirmed by X-ray reflection photographs. EPR measurements were performed at various tepmperatures ranging from 298 to 77 K using the Varian E-4 spectrometer operating at na X band with a 100 kHz field modulation.

In undoped $Ge_{40}S_{60}$ glasses we found the same signal as that observed by Arai and Namikawa [4]. The signal is slightly asymmetric and nearly Gaussian with $g = 2.006 \pm 0.0002$ and a linewidth ΔH (peak-to -peak) of 19 G. It was concluded [2, 4] that the signal orgininates from the dangling bonds of S and Ge.

Doping by Cu up to a concentration of 0.3 at % only alters the centre density, the g-value and the ΔH of the Gaussian signal as was observed by Watanabe et al. [2]. When the concentration of doped Cu reaches the value of 0.7 at % a new kind of signal is observed, which exhibits a Lorentzian shape with $g = 2.0033 \pm 0.0002$ and a ΔH of 5 G. The development of the new Lorentian signal with a Cu concentration is shown in Fig. 1. The intensity of the new signal increases with an increasing Cu concentration but the total centre density decreases with an increasing Cu concentration. The situation is shown in Fig. 2.

EPR spectra at 77 K have the same features as those at room temperature. The temperature dependences of the relative intensity for chosen samples are shown in Fig. 3. The relative intensity of EPR signals increases with decreasing temperature and the increase becomes steeper with an increasing Cu concentration.

In order to investigate the influence of heat treatment on samples which exhibit the Lorentzian signal, the glasses of $Ge_{40}S_{60} + 0.7$ at. % Cu were subjected to annealing for 2 hours at temperatures near the T_g and subsequently quenched in air. It was found that the heat treatment resulted in the reduction of the EPR signal. The centre density after the heat treatment is approximately twice smaller.

From the comparison of the present results with the results of our recent paper [1] it follows that there is no qualitative difference between the influence of Ag or Cu doping on the EPR spectra of the Ge-S glasses. The only exception is the shift of the appearance of the Lorentzian signal to a higher concentration of Cu.

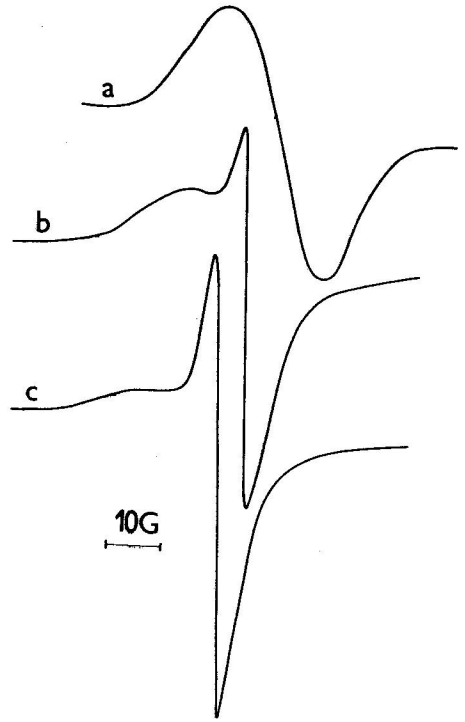

Fig. 1. EPR spectra for Cu-doped Ge-S glasses at 77 K: a — $Ge_{40}S_{60} + 0.1$ at % Cu; b — $Ge_{40}S_{60} +$ 0.7 at % Cu; c — $Ge_{40}S_{60} + 5.0$ at % Cu.

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Our attempts to induce further paramagnetic defect centres in undoped, Ag and Cu-doped Ge-S glasses by irradiation of the samples with X and Γ-rays at room temperature and 77 K have failed.

As for the origin of the new Lorentzian signal, it is possible to ascribe on the basis of our EPR investigation of Ag and Cudoped Ge-S glasses and preliminary results with neutron irradiation of the above mentioned glasses, the Lorentzian signal to the paramagnetic defects centred on the metal.

Additional and more complex studies are at present in progress.

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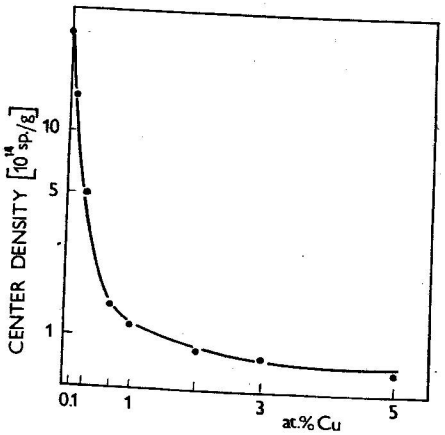

Fig. 2. Center density as a function of Cu concentration.

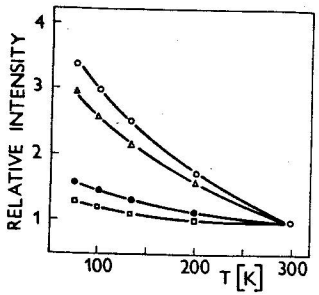

Fig. 3. Temperature dependences of relative intensity of EPR signals: □ — $Ge_{40}S_{60}$, ● — $Ge_{40}S_{60}$ + 0.1 at % Cu, △ — $Ge_{40}S_{60}$ + 0.7 at % Cu, ○ — $Ge_{40}S_{60}$ + 0.5 at % Cu.

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