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Possible Observation of the First Excited State of He^4 NucleusAccording to the γ-Emission Data in KD_2PO_4 Crystals upon Transition through Curie Point

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Abstract

The spectrum of γ-radiation (in the range of 3.0-8.5 MeV), generated by KD_2PO_4 crystals on the phase transition through Curie point, was studied by the use of a semiconductor, low-background detector. The maximum γ-radiation with the energy of 4.1±0.3 MeV and the width Γ=0.6±0.4 was detected. The maximum has been recorded in the course of the ferroelectric phase transition on KD_2PO_4 single crystals, and proves the decay of the first excited state of He^4 nucleus.

1.Introduction

Recently, in studies [1-4] an approach has been developed, permitting interpretation of the observable reaction of nuclear fusion in deuterated solids from the standpoint of the transfer of the energy of optical phonons of crystalline lattice (multiphonon excitations) directly to deuterium nuclei.

In particular, J.Schwinger et.al. [1,4] have examined a hypothetical possibility of the formation of the first excited state of He^4 as a result of the transfer of a multiphonon excitation with total energy E≥4 MeV to a compound He^4 nucleus which has been formed on the collision of accelerated deuterons in a nonequilibrium crystalline lattice. It has also been noted that the reactions of such a type are impossible on collisions of free deuterons, taking place in hot plasma or in a vacuum (on accelerants), since in such processes there does not exist a mechanism that could be able to provide excess energy of about 4 MeV for transferring the compound He^4 nucleus from the ground to first excited state ($j_p=0^+$, T=0), localized by 20.1 MeV higher than the ground state. The first excited state of He^4 is stable in relation to the decay along the He^3+n channel (situated below the threshold of that channel, which is equal to 20.578 MeV), but is unstable with regard to the decay along the T^3+p channel (19.875 MeV). Hence, that supposition could explain the asymmetry of the channels of solid-state dd-fusion which is predominantly of neutron-free character, simultaneously generating considerable amounts

of T^3. If this hypothesis were true, then rigid γ-quantums with energy E≃4 MeV, forming during the decay of the first excited state of He^4 along T^3+p channel, should be observed in nonequilibrium deuterated solids, in particular, on the controllable phase transitions that is, on the removal of excitation according to the scheme:

$$Ph + [d+d] \dashrightarrow {}^4He^* \dashrightarrow {}^3T + p + \gamma(4.0\ MeV)$$

In the present work, for the purpose of verification of the above hypothesis strict spectral measurements of γ-emission in KD_2PO_4 (DKDP) single crystal have been performed, upon a ferroelectric phase transition in the range of the energy of γ-quanta of 3.0-8.5 MeV.

2.Methods

To this aim KD_2PO_4 single crystals were used, grown from a solution of D_2O (contained 97.0%±1.0% deuterium), in which we had earlier observed the generation of neutrons and tritium on transition through T_C≃221 [5,6]. In total, 7 crystalline plates cut out from one single block in the (001) direction were used. In connection with a fairly rapid degradation of DKDP single crystals during thermocyclization, the average number of thermal cycles per crystal proved to be up to 15 [6]. The crystal were placed into a brass cryostat having walls 20 mm thick (h≃20 mm) [6]. They were cooled (or heated) in the linear regime at a rate of 0.1 K/s in the temperature range of 212-222 K, in which the maximums of the heat of ferroelectric transition had been localized according to the data of differential-scanning calorimetry. A semiconductor, coaxial, low-background HP Ge-detector GEM-20180-P (EG & G ORTEC), made on the basis of a high-purity germanium crystal with dimansions 50.7[64.4 mm having the energy resolution FWHM=1.73 KeV and the proper efficiency of 25% at the energy of γ-quata equal to 1.33 MeV (Co^{60}), was applied to record γ-quanta. The schematic diagram of the experimental setup for registration of γ-quanta is presented in Fig.1. The γ-background of the setup, to be measured before the beginning of the experiments, between these, and after their completion, reveals numerous γ-lines of radionuclides as contained in the surrounding medium, whose energy is within the range of 0.1-2.6 MeV. In the working range E≥3.0 MeV, the detector background is uniform on the scale of energies, and does not contain γ-lines. The detector was calibrated using a standard Na^{22} (γ-lines of 0.511 MeV and 1.27 MeV). While accounting for the energies, γ-quanta to be recorded, and the geometry of the setup employed, the total efficiency of the detector in the range of 3.0-8.5 MeV amounted to $3.1\cdot10^{-3}$-$1.9\cdot10^{-3}$.

3. Results

The recording of γ-quanta during thermocyclization of crystals in the temperature ranges localized outside the ΔT range corresponding to the phase transition ($T<<T_C$ and $T>>T_C$), was resorted to as control experiments. In total 100 temperature cycles (transitions through T_C) were performed on 7 crystals cut out from a single monoblock. The energy distribution of γ-quanta in the control experiments is well described (Fig.2, curve 1) by the distribution of the cosmic background of the detector, to be recorded in large time intervals (Fig.2, curve 2). Now, using the DKDP samples in the range of ΔT=212-222 K the values were obtained exceeding the background of the control experiments. The exesses in intensity are especially distinctly expressed in the range of 3.5-4.5 MeV and less distinctly in the range of 6.0-7.0 MeV (Fig.2, curve 3). In Fig. 3, the results are presented of subtraction of the data on curve 1 from these on curve 3. The parameters of the excess estimations over the background (so-called peaks) are given in Table 1. Note that excess estimations over the background of control measurements within the range of 3.5-4.5 MeV were observed for all 7 DKDP crystals used, which is especially well discernible during the first 10 cycles. Then the emission of γ-quanta would cease, which is associated with the degradation of crystals (cracking). (Similar degradation effects were also noted in [6] when measuring the emission of neutrons). On the basis of the statistics thus obtained the position of peak I (about 3.5-4.5 MeV and its width are determined as E_1=4.1±0.3 MeV and Γ_I=0.6±0.3 MeV, respectively. For peak II (6.0-7.0 MeV) these values are E_{II}=6.7±0.3 MeV and Γ_{II}0.5±0.4 MeV, respectivelly. The data on the position of peak E_I and width Γ_I to a sufficientl degree correspond to a possible position of γ-peak, which is likely to be observed on the decay of the first excited state of He^4 (E=4.1 MeV, Γ=0.6 MeV).

The appearance of wide intensity maxima in the rigid part of γ-spectrum (E>3 MeV) cannot be explained by the presence of radionuclides in the medium in the course of measurements, since, as has alredy been pointed out above, the range of γ-radiation of the given radionuclides corresponds to energy E<2.6 MeV. Moreover, the presence of radionuclides in the medium is not at all associated with the ferroelectric phase transition in the DKDP crystals, and, therfore, the γ-emission as caused by the radionuclides, should be revealed in the control experiments, too.

Another possible source of rigid γ-radiation could be

a nonelastic scattering of rapid background neutrons in the lead protection and a DKDP crystal during the ferroelectric phase transition [7]. For the purpose of verifying this supposition, we have exposed a cryostat-detector system (Fig.1) to irradiation by Cf^{252} source of neutrons (at an intensity $I=3\cdot10^{2}$ n/s in 4π), and repeated the control experiments with the thermocyclization of DKDP crystals in the vicinity of T_C.

The measurements have shown that in the range of 3.0–7.0 MeV already in the control experiments there is recorded a considerable increase in background counts (by a factor of 3–5) as compared to the background data obtained without the use of a neutrons source (Table 1). Now, in the energy range $\Delta E\simeq3.5\div4.5$ MeV during thermocyclization in the vicinity of T_C the excess value above the background of control experiments is retained, and its absolute value approximately coincides ($n_\gamma=2.10\pm0,51$ γ/s) with that of intensity, which has been obtained in the experiments carried out without a neutrons source. At the same time, the intensity of peak II, localised in the range of 6.0–7.0 MeV, becomes comparable to the background level of control experiment.

4. Discussions

The eperiments with the exposition of DKDP crystals to the irradiation from a Cf^{252} neutrons source, having a wide energy spectrum from kT to 10 MeV ($E_m=2.3$ MeV), enable one to reach conclusion that the appearance of the maximum of intensity of γ-counts within the range of 3.5 to 4.5 MeV on the phase transition through T_C is not at all conected with γ-radiation of inelastic scattering and capturing of background neutrons, whereas the maximum II in the range of 6.0–7.0 MeV should possibilly be attributed to that process [8]. From the aforesaid and the supposition on the collective transfer of the energy of phonons to the compound nucleus of He^4 ($E_\gamma=4.1$ MeV), it is possible to come to a conclusion that the decay of the first excited state of the nucleus of He^4 ($E_\gamma=4.1$ MeV) does actually correspond to the maximum in the range of 3.5–4.5 MeV. In this case, the excitation, can be provided due to the concentration of the energy of optical phonons generated in the course of the ferroelectric phase transition. Elementary estimations show that with an average domain size in the DKDP crystal equal to about $2\cdot10^{-5}$ cm [9] and at the Debye frequency $\omega_D\simeq8\cdot10^{13}$ Hz [10], the total energy of optical phonons in one domain during a phase transition amounts to $E_{ph}\sim5$–10 MeV, which

is sufficient for creation of the first exited state of He^4. If the energy of the domain wall in the DKDP crystal $W_d \simeq 40$ erg/cm^2 and its thickness $h \simeq 10$ Å corresponding to the depth of an elastic layer [9] were taken into account, then the energy of one domain at the moment of the ferroelectric transition would amount to $\Delta E = 5 \cdot 10^{-8}$ erg. Since the total number of domains $N = 1.1 \cdot 10^{14}$ g^{-1}, then the total energy of the domain wall per unit mass of DKDP will be equal to $\sum_{i=1}^{N} (\Delta E_I) = 5.4 \cdot 10^6$ erg/g. The elastic portion of the energy of the domain wall is determined as the ratio of the volume of the elastic layer to the volume of the whole domain $\beta \simeq 6 \cdot 10^{-2}$, whence $\Delta E_d = 3.3 \cdot 10^5$ erg.g. Therefore, the number of gigantic phonon fluctuations (N_s) with energy $W_s \simeq 10$ MeV, which are possible during the ferroelectric transition, will amount in the first approximation to $N_s = \Delta E_{el} / E_{ph} = 1.5 \cdot 10^{10}$ g^{-1} with an yield of γ (4.1 MeV)- quanta $n_\gamma = 2 \cdot 10^2$ /transition

To ensure the process of the formution of the compound nucleus of He^4 requires the approaching of two deuterons to each other, for the purpose of the overcoming the Coulomb barrier, which can be guarunted through acceleration of deuterons in the DKDP crystalline lattice on its repolarization (on transition through T_C) up to the energy of about 200 eV [11].

5. Conclusions

Thus, this study enabled us to substantiate the hypothesis on a possibility of the population of the first excited state of He^4 in nonequilibrium, deuterated solids. Note, however, that the decay of He^4 according to the T+p scheme cannot, probably, serve as the main tritium generation channel in the DKDP on the ferroelectric phase transition, since the really produced tritium concentrations are by 5 to 6 orders of magnitude higher (10^7–10^8/transition) [6].

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Table1.
The parameters of the ranges featuring excess above the background level and shown in Fig.3.

ΔE (MeV)	$N_b \cdot 10^{-2}$ (count/s)	$N_b \cdot 10^{-2}$ (count/s) with Cf^{252} source	n_γ (γ/s)	n_γ (γ/s) with Cf^{252} source
3.5-4.5	1.51±0.12	5.62±0.65	2.43±0.40	2.10±0.51
6.0-7.0	1.20±0.09	2.58±0.90	1.25±0.32	0.20±0.32

where N_b is the number of background counts in the control experiments and n_γ is the intensity of the γ-radiation on subtracting the background of the control experiments, taking into account the efficiency of the detector.

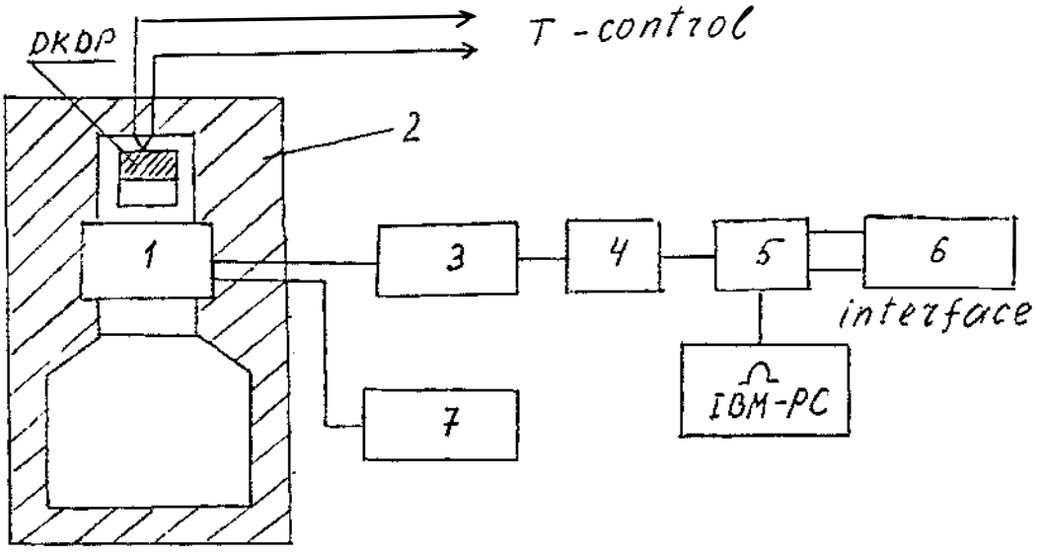

Fig.1. Shcematic diagram of the experimental setup for monitoring the emission of γ-quanta.

Key: (1) Ge-detector; (2) lead protection; (3) preamplifier; (4) amplifier together with a discriminator; (5) multichannel analyzer; (6) stabilizator; (7) high-voltage supply; (8) IBM computer.

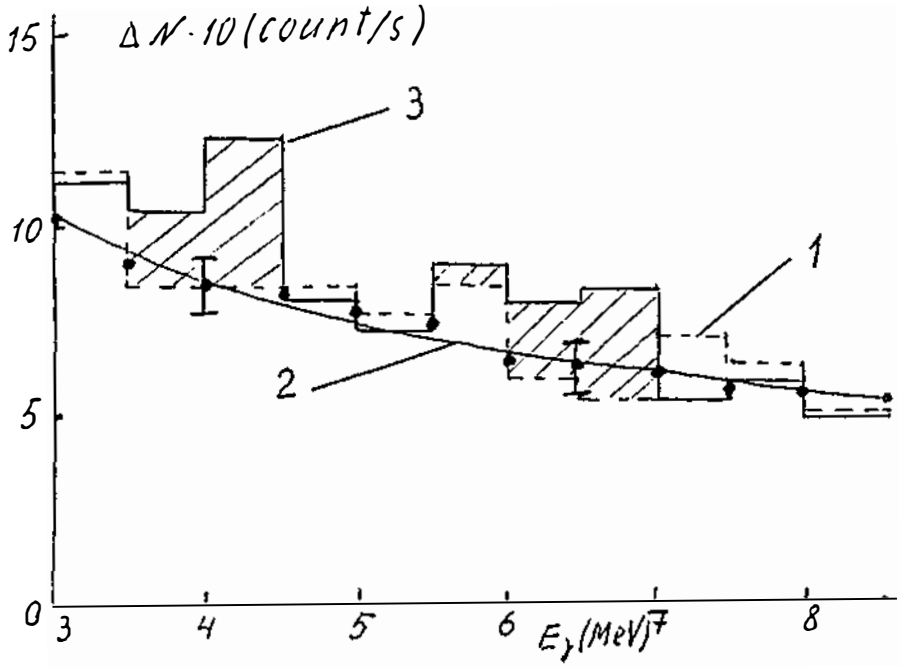

Fig.2. Energy distribution of γ-quanta as recorded: (1) in the control experiments (curve 2) during thermocyclization of DKDP crystals in the ranges $T<<T_C$ and $T>>T_C$. The exposure time E_τ=9461 s; (2) at T=300 K (the total exposure time $\tau=10^5$s); (3) during thermocyclization of the DKDP in the vicinity of T_C (in the range ΔT=212-222 K) $\Sigma\tau$=9461 s (100 transitions through Curie point (T_C)).

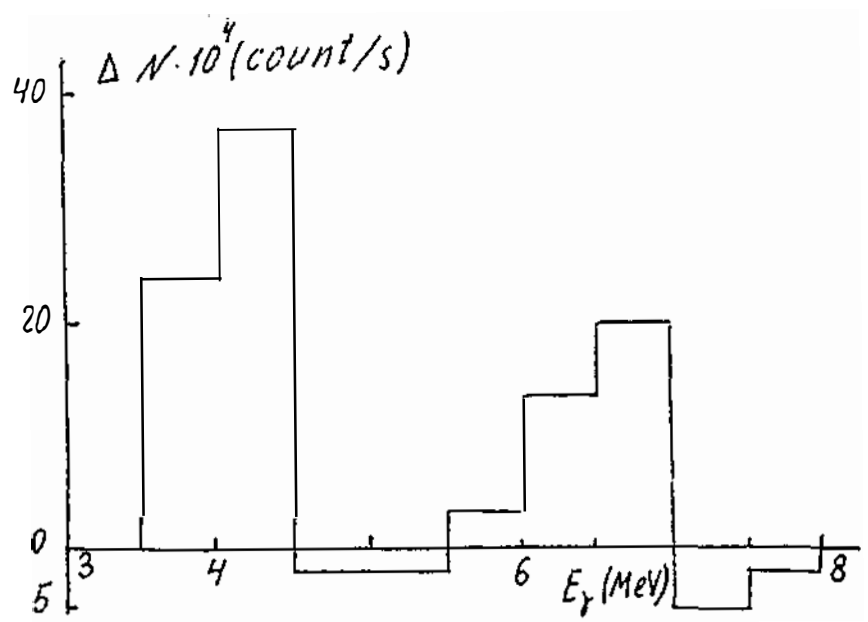

Fig.3. Result of subtracting curve 3 and 1, represented in Fig.2.