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**The Experimental Discovery of the Phenomenon
of Controlling and Changing Probability and Time of Spontaneous Decay
and Gamma-Transmutation of Excited Nuclei States**

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Abstract

The paper discusses the process of controlling the probability of spontaneous decay of radioactive and excited Mossbauer nuclei. For the first time two experiments have proved the possibility of changing the life time of radioactive nuclei by surrounding them with screens having resonant absorption frequency equal to the nuclear transition frequency. For the first time in the experiments with gamma sources $\text{Co}^{57}(\text{Fe}^{57})$ and $\text{Sn}^{119\text{m}}$ and with gamma absorbers Fe^{57} and Sn^{119} we have discovered the change of Mossbauer transition life-time by 20-100% and total life-time (including non- Mossbauer radiation and electron conversion) by 0.6-2%.

1. Theoretical model

The problem of controlling of nuclei decay is one of the most important in the physics. As far as we know, none of the previously conducted researches contain reliable data confirming the possibility of such controlling. We have carried out investigation aimed at experimental discovery (based on our original theory [1]) of this important phenomenon.

In [1] we have considered the possibility of controlling the probability of decay A_{ij} of excited Mossbauer nuclei by controlled mode restructuring of electromagnetic vacuum. The main idea of the spontaneous decay velocity control is in a strong influence of averaged modes density in a unit frequency interval

$$\langle \rho(v_{ij}) \rangle = \iint \rho(v_n) f(v_n, v_{ij}, \Omega) dv_n d\Omega, \quad \rho(v_n) = 8\pi v_n^2 / c^3 \quad (1)$$

upon the final possible decay and radiation life-time τ of excited nuclei

$$A_{ij} \equiv 1/\tau = (8\pi^3 v_{ij} / 3h) \langle |\mathbf{d}_{ij}|^2 \rho(v_{ij}) \rangle \quad (2)$$

Here $f(v_n, v_{ij}, \Omega)$ is spectral-angular density of mode, having central frequency v_n , spectral width γ_n and spreading in the direction of solid angle Ω . Usually

$$f(v_n, v_{ij}, \Omega) = \gamma_n / 8\pi^2 [(v_n - v_{ij})^2 + \gamma_n^2 / 4], \quad \gamma_n = \gamma_n(v_n, \Omega). \quad (3)$$

In case of nuclei transition with high multipolarity $L > 1$ the dipole moment \mathbf{d} ($L=1$) in (2) and other equations is replaced with multipole moment $\mathbf{Q}^{(L)}$. The rule for the substitution is

$$|\mathbf{d}_{ij}|^2 \rightarrow \{6\pi(L+1)/L[(2L+1)!!]^2\} (2\pi v_{ij}/c)^{2L-2} |\mathbf{Q}^{(L)}_{ij}|^2$$

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Spectral width of mode γ_n is defined by time of life of photon $\Delta t_\gamma = Q_n/v_n$ in this mode. Here Q_n - quality of mode v_n .

In case of free space time of life of photon is unlimited large and $\Delta t_\gamma \rightarrow \infty$. In result

$Q_n \rightarrow \infty$, $\gamma_n = v_n/Q_n \rightarrow 0$, $f(v_n, v_{ij}, \Omega) \rightarrow \delta(v_n - v_{ij})$ (Dirac δ -function) and from (1) - (3) we have

$$\langle \rho(v_{ij}) \rangle = \rho(v_{ij}), \quad \tau = A_{ij}^{-1} = 3hc^3/32\pi^3 v_{ij}^3 |d_{ij}|^2. \quad (4)$$

In case of frequency non-selective absorption time of life of all photons Δt_γ decreases, $\gamma_n = \text{const} \neq \gamma_n(v_n)$ and for usual case $\gamma_{n(\text{max})} \ll v_n$ we have the same result (4).

Another situation appears with presence of a frequency-selective (resonant) absorber (for instance, sphere of radius R or its part in solid angle $\Delta\Omega$) acting as a "black" screen in a narrow frequency band $\Delta\nu$ near ν_0 (for instance, near resonant frequency ν_0 of Mossbauer transition in source). In this case time of life of resonant photons is defined by their run $\Delta t_\gamma \approx 2R/c$ between frequency-selective absorber walls and $\gamma_n(|\nu - \nu_0| < \Delta\nu/2, \Delta\Omega) \approx c/2R$.

On the other hand, the nonresonant photons pass through the absorber freely and for them $\gamma_n(|\nu - \nu_0| > \Delta\nu/2, \Delta\Omega) \approx 1/\Delta t_\gamma \ll c/2R$. The decrease of quality $Q_n = v_n/\gamma_n \approx 2Rv_0/c$ of modes lying within a small interval $\Delta\nu \leq c/2R$ of frequencies near ν_0 causes an essential change of averaged modes density

$$\langle \rho(v_{ij}) \rangle = \rho(v_{ij})F(v_{ij}), \quad F(v_{ij}) = \iint f(v_n, v_{ij}, \Omega) dv_n d\Omega$$

As a result it leads to change of time of decay (life-time)

$$\tau^* = 3hc^3/32\pi^3 v_{ij}^3 |d_{ij}|^2 / F(v_{ij}) \equiv \tau / F(v_{ij}) \quad (5)$$

and to a decrease (at $\nu = \nu_0$) and increase (at $\nu \approx \nu_0 \pm \Delta\nu/2$) of the probability intensity of spontaneous decay.

This effect also leads to change (decrease at $\nu = \nu_0$) of the spectral widths of Mossbauer transition and radiation (in the radiation channel of nuclear decay) $\Gamma^* = 1/\tau^* = \Gamma F(v_{ij})$.

The similar situation takes place also in the more real case, when part of the space (where the excited nuclei are situated) is bounded by interval $([0, l], \Delta\Omega)$ between nonresonant absorber (for instance - basis or support for excited nuclei) and resonant one. In this case the domains of localization and the spectral properties of resonant and nonresonant modes are different - resonant mode is localized in bounded interval $[0, l]$ and has large width γ_n , while nonresonant one is localized in endless domain $[0, \infty]$ and has little width γ_n . It's also of great importance, that the results of effect on electromagnetic mode caused by only nonresonant absorber and by the combination of resonant absorber and nearly (with distance $\delta/l \rightarrow 0$) nonresonant one are equal. The latter remarks are directly related to our experiments.

The equation for changes of population $n_2 \equiv n_e$ of excited nuclei (defined by partial probabilities of Mossbauer radiation in blocked angle $P^*_M = f \Delta\Omega / 4\pi\tau^*$, Mossbauer radiation in non-blocked angle $P_M = f(1 - \Delta\Omega / 4\pi)/\tau$, non-Mossbauer radiation

$P_{NM} = (1 - f)/\tau$ and electron conversion $P_\alpha = \alpha/\tau$) has a form

$$dn_2/dt = \sum_{i>2} n_i / \tau_{i2(\text{tot})} - n_2 / \tau^*_{\text{tot}},$$

$$\tau^*_{\text{tot}} = [P^*_M + P_M + P_{NM} + P_\alpha]^{-1} \equiv \tau / \{1 + \alpha - (1 - \tau/\tau^*) f \Delta\Omega / 4\pi\} \quad (6)$$

Here α is a coefficient of electron conversion, f - parameter of recoil-free resonant radiation (parameter of Mossbauer), $\Delta\Omega$ - a solid angle blocked by the resonant absorber, $1/\tau_{i2(\text{tot})}$ - total probability of transition from level $E_{i>2}$ to level E_2 , τ^*_{tot} - total life-time of excited nuclei with present of resonant absorber. In equilibrium state $dn_2/dt = 0$ and the relation of

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population of excited nuclei n_2^* for $\Delta\Omega \neq 0$ (with selective absorption) to population of excited nuclei n_2 for $\Delta\Omega = 0$ (without selective absorption) has a form

$$n_2^*/n_2 = 1/\{1 - (1 - \tau/\tau^*) f \Delta\Omega / 4\pi (1+\alpha)\}. \quad (7)$$

For optimal case ($\Delta\Omega \approx 4\pi$, $\tau \ll \tau^*$, $f \rightarrow 1$, $\alpha \rightarrow 0$) $n_2^*/n_2 \approx 1/\{1 - f/(1+\alpha)\} \gg 1$.

Total intensity J_γ^* of Mossbauer radiation in non-blocked direction ($4\pi - \Delta\Omega$) also changes and $J_\gamma^* = J_\gamma n_2^*/n_2$. Let's describe this change as $J_\gamma^* = J_\gamma / (1 - g)$. Then we have

$$g = 1 - J_\gamma / J_\gamma^* \equiv (1 - \tau/\tau^*) f \Delta\Omega / 4\pi (1+\alpha) \quad (8)$$

In this case

$$\tau^* = \tau / \{1 - 4\pi g (1+\alpha) / f \Delta\Omega\}. \quad (9)$$

2. Experimental results and discussion

Two experiments on controlling of the nuclei decay were performed based on our theory.

The aim of the first experiment was to measure the changing of total intensity J_γ^* (8) of Mossbauer radiation (as a result of changing life-times τ_{tot}^* and τ^*) in non-blocked direction ($4\pi - \Delta\Omega$). The layout of the first experiment is presented on Fig. 1

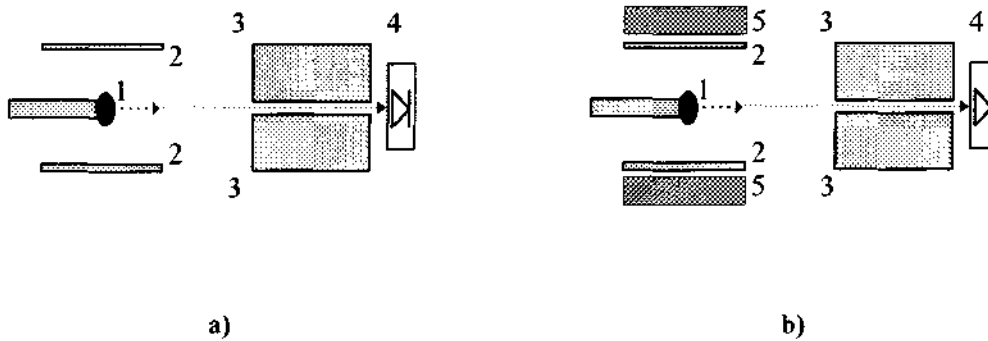


Fig. 1. Experimental layout for detecting of the effect of controlling the time of radiation nuclear decay based on the method for measurement of intensity direct beam change.

A $\text{Co}^{57}(\text{Fe}^{57})$ isotope ($h\nu_0=14,4 \text{ KeV}$, $\alpha=9$) with activity of 10 mCi in a chromium matrix was used as a source of Mossbauer radiation 1. This source had a spectrum in the form of single line of natural width.

The source was fixed in the Plexiglas disc and put in the center ($l=2,5 \text{ cm}$) or near the diaphragm-oriented edge ($l=1 \text{ cm}$) of the resonant absorber 2, having a form of cylinder with diameter $D=2 \text{ cm}$ and length $L=5 \text{ cm}$, made of stable Fe^{57} isotope (200 mg) in stainless steel (100 mg). The thickness (surface density) of absorber $\sigma_m \approx 7 \text{ mg/cm}^2$ provided the requirement of total absorption of resonant radiation (for $|\nu - \nu_0| < \Gamma/2$ the coefficient of transparency equals $K \approx 10^{-3}$) and almost full transparency for non-resonant radiation ($K \approx 0,95$ for $|\nu - \nu_0| \gg \Gamma/2$).

The lead diaphragm 3 had a hole with diameter $D_0 = 1 \text{ cm}$ and length $L_0 = 2,5 \text{ cm}$. Behind the diaphragm there was amplitude detector 4 - $\text{NaJ}(\text{Ti})$ crystal with width 10^{-2} cm and photo-

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electronic multiplier. The signal processing system picked out the part of amplitude specter close to the gamma-line with $E_\gamma \approx 14,4$ KeV.

The measurements of the quanta counts N with direct gamma-beam (traveling from source 1 through diaphragm 3 to amplitude detector 4) were performed in two regimes.

In the first regime (see Fig. 1, case a) the quanta count $N^* = J_\gamma \Delta t$ corresponds to presence of resonant absorber cylinder 2 only .

In the second regime (see Fig.1, case b) another cylinder 5 made of lead with diameter $D_1=2,2$ cm, length $L_1=5$ cm and thickness $\Delta D_1=0,2$ cm was put around the resonant absorber cylinder. It totally absorbed both resonant and non-resonant radiation in the range of energies close to $E_\gamma \approx 14,4$ KeV. This corresponds to completely non-selective absorber and leads to the intensity of registered flux of gamma-quanta J_γ and the quanta count $N = J_\gamma \Delta t$. Such method excludes the uncontrolled influence of reverse scattering of resonant gamma-quanta after changing resonant absorption to non-resonant (which would occur when resonant absorber cylinder is simply taken off the source).

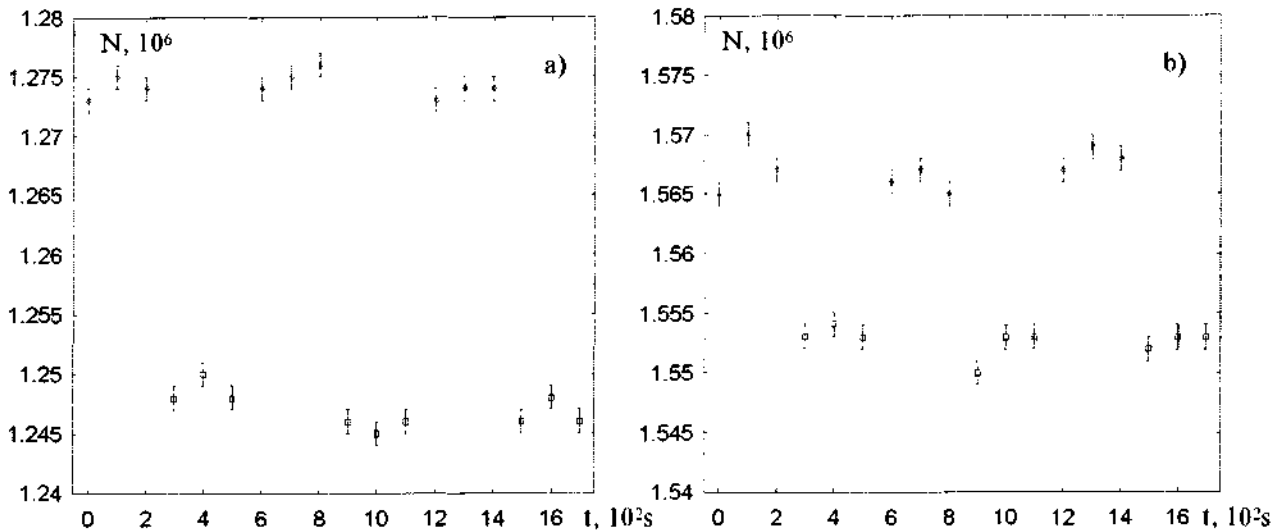


FIG. 2. The influence of spatial position of non-resonant totally absorbing screen 6 upon the intensity (the quanta count $N = J_\gamma \Delta t$) of direct beam of gamma-quanta: circles (upper points) — screen is put around the resonant absorber, squares (lower points) — screen is taken off. The case a) corresponds to the source 1 situated in the center of the resonant absorber ($l=2.5$ cm), the case b) - the source is at $l=1$ cm.

Each measurement lasted $\Delta t=100$ s. The results of measurements are presented on Fig.2.

It can be seen, that the presence of additional non-selective absorber in side direction reduced the intensity of radiation coming from the source in the direction of detector. It fully agrees with the theory described in [1] and above. The change in count rate $(N^* - N) / N = g / (1-g)$ is defined by $g = 0.022 \pm 0.002$ for $l=2.5$ cm and $g = 0.008 \pm 0.002$ for $l=1$ cm, with corresponding changes (increases) of radiation time (9) of nuclear decay (life-time) of Fe^{57} ($E_\gamma=14,4$ KeV) for Mossbauer component $\tau^* \approx 2\tau$ for $l=2.5$ cm and $\tau^* \approx 1.4\tau$ for $l=1$ cm.

In fact, considering the scattering of non-resonant gamma-quanta (in region $E_\gamma \approx 14,4$ KeV) from lead absorber, which increases J_γ , this increase of life-time τ^* is even greater.

Changed total life-time for Fe^{57} equals $\tau_{tot}^* = \tau_{tot} / (1-g)$. Here $\tau_{tot} = \tau / (1+\alpha) = 9,8 \cdot 10^{-8}$ s — standard total life-time for Fe^{57} . For both cases the change of total life-time $(\tau_{tot}^* - \tau_{tot}) / \tau_{tot}$ equals 2,2% and 0,8%.

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The aim of the second experiment was to measure the changing (decreasing at $v = v_0$) of the spectral width of Mossbauer radiation (as a result of changing life-times τ_{tot}^* and τ^*).

The anticipated change in natural and total widths of gamma-spectrum increases with the decrease of life-time. In order to reduce the influence of technical fluctuations the isotope $\text{Sn}^{119\text{m}}$ with $\tau_{\text{tot}} = 1,85 \cdot 10^{-8}$ s, $\alpha = 5,5$ and $\tau = 1,2 \cdot 10^{-7}$ s was used instead of Fe^{57} with $\tau = 10^{-6}$ s.

The layout of the second experiment is presented on Fig. 3.

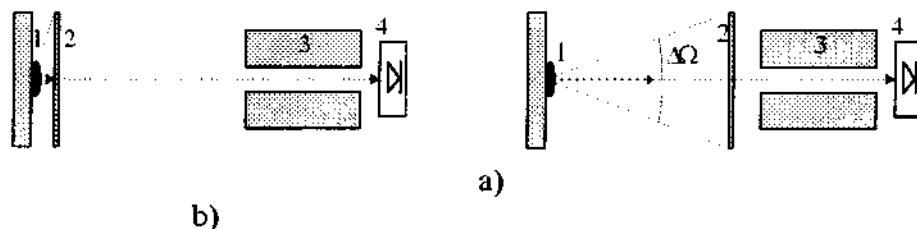


Fig. 3. Experimental layout for detecting of the effect of controlling the time of radiation nuclear decay based on the method for measurement of width of gamma-spectrum in the system source - absorber - resonant detector.

The excited $\text{Sn}^{119\text{m}}$ isotope (chemical compound $\text{CaSn}^{119\text{m}}\text{O}_3$) with activity of 5 mCi was used as a source of Mossbauer radiation 1 with the energy of quanta $E_\gamma = 23,8$ KeV. This source had a spectrum in the form of single line of nearly natural width.

The resonant absorber 2 had a form of disk with diameter $D \approx 3$ cm, made of stable Sn^{119} isotope (chemical compound $\text{Sn}^{119}\text{O}_2$, surface density $\sigma_m \approx 1,39$ mg/cm²). This absorber has a spectrum of absorption in the form of nearly natural width. The thickness (surface density) of resonant absorber satisfied two contradictory requirements. First it is necessary to have $\sigma_m \rightarrow \infty$ and $K \rightarrow 0$ to maximize the influence upon resonant electromagnetic mode. But to lower the statistical errors the quanta count has to be increased, thus requiring $\sigma_m \rightarrow 0$, $K \rightarrow 1$. The value $\sigma_m \approx 1,39$ mg/cm² (for which a coefficient of resonant transparency equals $K \approx 0,5$) is nearly optimal.

The lead diaphragm 3 had a hole with diameter $D_0 = 1$ cm and length $L_0 = 2,5$ cm. Behind the diaphragm there was a resonant detector 4 (a compound $\text{CaSn}^{119}\text{O}_3$ was used as a resonant detector) and a system for changing the Doppler velocity of detector 4.

The measurements with gamma-beam (traveling from source through resonant absorber and diaphragm to resonant detector) were performed in two regimes too.

In the first regime (Fig. 3, case a) the resonant absorber 2 was fixed in position near source 1. For this regime the solid angle blocked by the reso-

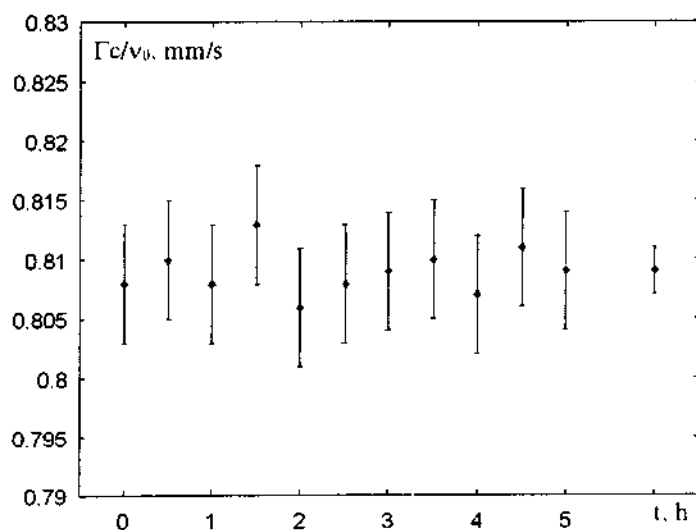


FIG. 4. Width of gamma-spectrum in the system source — resonant detector. The rightmost point represents the average value.

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nant absorber equals $\Delta\Omega \approx 2\pi$ and $F(v_{ij}) < 1$, $\tau^* > \tau$.

In the second regime (Fig. 3, case b) the resonant absorber 2 was fixed at $l=3$ cm from source in position near diaphragm 3. For this regime $\Delta\Omega \approx (D_0/16 l)^2 \approx 7 \cdot 10^{-4}$ and $F(v_{ij}) \approx 1$, $\tau^* \approx \tau$.

In the regimes (a) and (b) the total widths $\Gamma^* = \Gamma_s^* + \Gamma_d + \Delta\Gamma$ and $\Gamma = \Gamma_s + \Gamma_d + \Delta\Gamma$ of gamma-spectrums including both the sum of source (Γ_s) and resonant detector (Γ_d) resonant-line widths, and a broadening $\Delta\Gamma$ (as a result of resonant absorption) in absorber 2.

In order to verify the stability of gamma-line position and width the measurement of gamma-spectrum was performed in the system source 1 - detector 4 without the resonant absorber 2. The results of this measurement are presented on Fig. 4.

The resulting value $\Gamma_s + \Gamma_d = \Gamma_{s0} + \Delta\Gamma_{s0} + \Gamma_{d0} + \Delta\Gamma_{d0} \approx 0.809$ mm/s (in Doppler velocity units $v = c\Gamma/v_0$) demonstrates that the broadening $\Delta\Gamma_{s0} \approx \Delta\Gamma_{d0} \approx 0,081$ mm/s small in relation to natural widths $\Gamma_{s0} = \Gamma_{d0} = 1/\tau_{tot} \approx 0,323$ mm/s takes place in the source and detector.

For the regime (a) we have $\Gamma_{d0} = 1/\tau_{tot}$, $\Gamma_{s0} \rightarrow \Gamma_{s0}^* = 1/\tau_{tot}^* \equiv \Gamma_{s0} [1 - (\tau_{tot}^* - \tau_{tot})/\tau_{tot}^*]$ and

$$\Gamma^* = \Gamma_{s0} - \Gamma_{s0}(\tau_{tot}^* - \tau_{tot})/\tau_{tot}^* + \Delta\Gamma_{s0} + \Gamma_{d0} + \Delta\Gamma_{d0} + \Delta\Gamma.$$

For the regime (b) we have $\Gamma_{d0} = 1/\tau_{tot}$, $\Gamma_{s0} = 1/\tau_{tot}$ and $\Gamma = \Gamma_{s0} + \Delta\Gamma_{s0} + \Gamma_{d0} + \Delta\Gamma_{d0} + \Delta\Gamma$.

Then (from (6), using the obtained results for Γ^* and Γ) we find

$$\tau_{tot} / \tau_{tot}^* = 1 - \tau_{tot}(\Gamma - \Gamma^*),$$

$$\tau / \tau^* = 1 - \tau_{tot}(\Gamma - \Gamma^*) [4\pi (1 + \alpha) / f \Delta\Omega] \equiv 1 - (1 - \tau_{tot} / \tau_{tot}^*) [4\pi (1 + \alpha) / f \Delta\Omega] \quad (9)$$

Each measurement of Γ (or Γ^*) in both cases lasted $\Delta t = 0,5$ hour. The results are presented on Fig. 5 for two series of experiments (each with a duration about one or two days). The average values measured were $\Gamma = (1,184 \pm 0,003)$ mm/s, $\Gamma^* = (1,167 \pm 0,003)$ mm/s, with corresponding changes (increases) of total life-time of $\text{Sn}^{119\text{m}}$ $(\tau_{tot}^* - \tau_{tot})/\tau_{tot} = (0,63 \pm 0,12) \cdot 10^{-2}$ and life-time for Mossbauer component of $\text{Sn}^{119\text{m}}$ $\tau^* = (1,20 \pm 0,04)\tau$.

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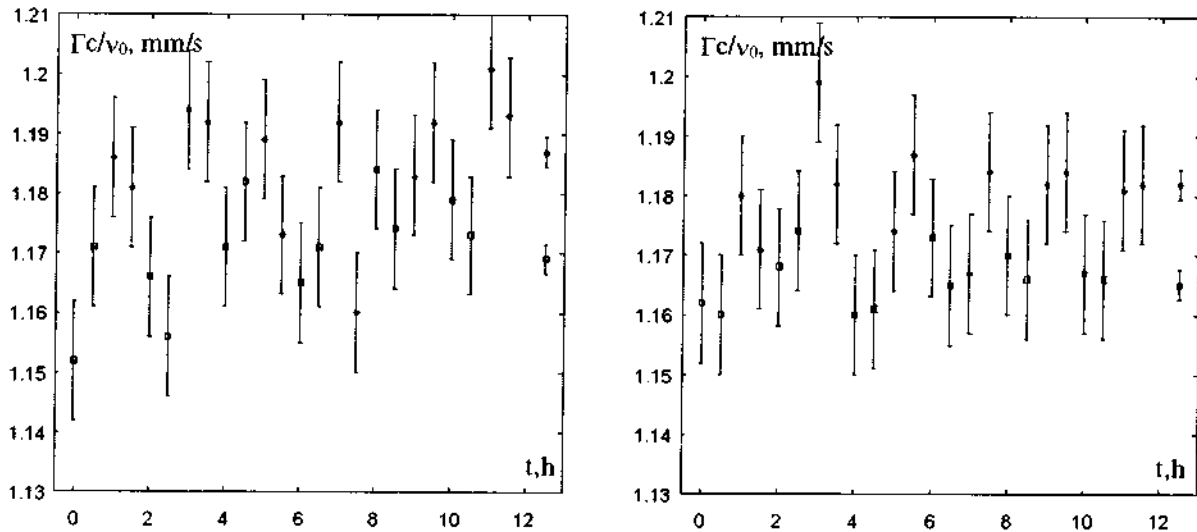


FIG. 5. The influence of position of resonant absorber upon the width of gamma-spectrum for gamma-quanta passing through this absorber, for two series of independent measurements: squares — absorber is situated near source; circles — absorber is situated near diaphragm. The points to the right are the result of averaging the data for all measurements.

The results of all experiments are approximately corresponding to estimations based on the theoretical model for $F(\nu_{ij})$.

When the experiment is performed in vacuum (which increases the quality Q_n of non-resonant modes compared to experiments described here, that were performed in air) with only resonant absorber present, $\Delta\Omega = 4\pi$ and the gamma-transitions with $f \cong 1$ and $\alpha \cong 0$ are employed, it is possible to increase $\tau_{tot}^* \gg \tau_{tot}$ by several orders of magnitude.

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Reference

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