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LETTERS TO THE EDITORS

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Comment on the paper "Realization of discrete states during fluctuations in macroscopic processes" [1]

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From Board of Editors. The article by S É Shnoll et al. "Realization of discrete states during fluctuations in macroscopic processes" [*Phys. Usp.* **41** 1025 (1998)], as we had expected, stirred up active response from the readers owing to the highly unconventional findings of the authors. We elected to publish some comments on this paper together with the final account by the authors, and thereby close the discussion.

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The authors of Ref. [1] affirm that the scatter in the results of measurements for many process, represented as a histogram (the frequency of occurrence of a given value versus its magnitude), exhibits 'fine structure' that in addition oscillates in time with a certain 'cosmophysical' rhythm. Most surprisingly, this phenomenon was observed in the course of measuring the rate of nuclear radioactive decay. So far it has been assumed (and before issuing of Ref. [1] there was no experimental proof to the contrary) that the rate of radioactive decay is described by the Poisson distribution which gives the probability of observing x events in a given time interval with the proviso that the events are independent and occur at a constant rate. When $x \to \infty$ (and practically for $x > 10$), the Poisson distribution is well approximated by the continuous Gaussian distribution. In principle, the authors of Ref. [1] agree that the rate of radioactive decay obeys the Poisson distribution, but they believe that "the existing goodness-of-fit tests for hypotheses are insensitive to the fine structure of the distributions".

Now let us look at the results of measuring the rate of radioactive decay in paper [1]. Figure 1 taken from Ref. [1] shows four histograms plotted "without shifting and smoothing", each based on 1200 consecutive measurements of activity of ^{55}Fe radioactive source. The mean counting rate was 31500 pulses per series in 36 seconds; accordingly, the distribution ought to be well approximated by the Gaussian distribution

$$\eta(x) = S \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-x_0)^2}{2\sigma^2}\right]. \qquad (1)$$

For the cumulative (upper) histogram the number of consecutive measurements is $S = 1200$, the mean counting rate $x_0 = 31500$ pul/36 s, and the variance $\sigma^2 = 31500$. Given that the step of the histogram is 30 pulses, and the number of events in a cell of the histogram obeys the binomial law, the expected value of $\eta(x_0)$ ought to be 81 ± 9. For all four histograms, however, this value is close to 140, which is practically improbable (the probability of getting a value greater than 140 comprises 3.6×10^{-10}). Thus, the histograms with 'fine structure' shown in Fig. 1 of Ref. [1] do not agree with the Poisson distribution when the χ^2 criterion is used.

Figure 2 in Ref. [1] displays the results of 15000 consecutive measurements ($S = 15000$) of activity of ^{239}Pu radioactive source with the mean counting rate of $x_0 = 90$ pul/6 s. From Eqn (1) it follows that when the step of the histogram is equal to 1, the value of $\eta(x_0)$ ought to be equal to 630; in Fig. 2 from paper [1], however, $\eta(x_0) = 340$, at the same time the total number of registered events is 15000. The fact is that the standard deviation σ arrived at is twice as large as that expected for a Gaussian distribution. This is a relatively common occurrence which implies that there was an additional source of nonstatistical errors that could have been associated with the ^{239}Pu sample, with the detector of α decay, or with the electronics. It is surprising then how the 'fine structure' of the rate of radioactive decay could have been preserved.

Figure 6 in Ref. [1] depicts the distribution of time intervals between the histograms of 'similar' shape. There appears a maximum for histograms measured after 24 hours. If the criterion of 'similarity' remains the same, there ought to be another maximum after 48 hours; however, there is none, which casts doubt on the results of the measurements.

In the summary, the authors of Ref. [1] call upon all skeptics to confirm or refute the results obtained, so we decided to reproduce the measurements in strict accordance with the procedure of work [1]: take multiple readings of a detector that registers the number of decays over a certain time interval, and plot histograms with the number of counts on the x-axis, and the number of series covering a given number of counts on the y-axis. According to Ref. [1], if such measurements are multiply repeated, then the following new phenomena will make themselves evident: like histograms will follow one after another; two independent detectors, even separated by a large distance, will concurrently generate similar histograms, and, finally, similar histograms will be repeated first with the period of 24 hours.

Experiment. Recording of X-ray radiation accompanying the K-capture by ^{55}Fe nuclei, and γ quanta resulting from α

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decay of ^{241}Am nuclei, was done simultaneously with two independent Si(Li) detectors. The detectors were placed in vacuum cryostats at liquid nitrogen temperature, and had identical spectrometric channels: a preamplifier with continuous sink coupling and a cooled FET, an amplifier stage with a pulse shaping time of 2 microseconds, an overlap selection circuit with a time resolution of 300 nanoseconds, and a 12-bit analog-digital converter. The resolution of the detectors, measured with respect to the 59-keV γ line of ^{241}Am, was 1.1 keV. The energy intervals used for measuring the counting rate were 4.5 – 7.5 keV for ^{55}Fe and 46 – 70 keV for ^{241}Am, and they were selected in such a way that the change in the counting rate caused by the possible variation in the conversion factor of the energy released in the detector into the channel number should not exceed 3×10^{-4}. The time intervals were measured with the system timer of the computer. In addition, the instruments were placed in different rooms.

The mean counting rate for the decay of ^{55}Fe nuclei was made the same as in Ref. [1]: $x_0 = 31430$ pul/36 s. In accordance with the procedure outlined in Ref. [1], we carried out 4 series of measurements, each 12 hours long, plotting the histograms of counting rates every hour. Figures 1 – 4 show our histograms together with the expected distribution $\eta(x)$; the theoretical curve was plotted simply from Eqn (1) without any fitting. Figure 1 also displays the distribution of counting rates from Ref. [1] reproduced from the journal with the aid of a ruler. Our values of normalized χ^2 are close to 1, which is an indication that our measurements do not contradict the Poisson distribution. Observe that owing to the relatively short half-life of ^{55}Fe ($T_{1/2} = 2.7$ years), the center of the Gaussian distribution x_0 shifts by 7×10^{-4} per day, which corresponds to a shift by almost one cell for histograms separated by 24 hours. It is not clear how the 'fine structure' of histograms could be preserved in the measurements when the change in the counting rate is comparable with the size of the histogram cell. In our measurements we did not observe any 'fine structure' similar to that shown in Fig. 1 in Ref. [1].

Similar measurements were made with alpha decay of ^{241}Am. The counting rate was selected close to that measured

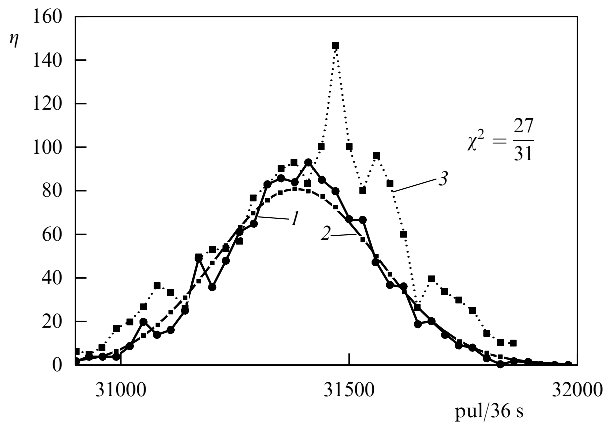

Figure 1. *1* — The first out of four 12-hour measurement series of pulse counting rates from the decay of ^{55}Fe (following Ref. [1], we indicate that the measurements started at 00:38 on 5 December 1998, and ended at 00:38 on 7 December 1998); *2* — a Gaussian distribution calculated according to Eqn (1) for $x_0 = 31430$ without any fitting; *3* — similar histogram reproduced from Ref. [1].

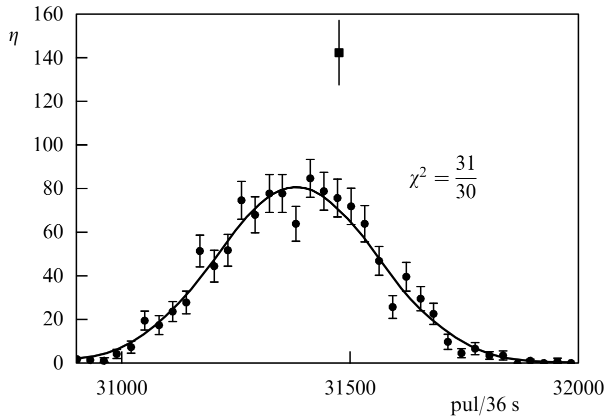

Figure 2. Distribution of counting rates for the second series of measurements with ^{55}Fe. Experimental points are given with expected errors. The solid curve depicts a Gaussian distribution. Shown at the top is the central point of the distribution obtained under the same conditions in Ref. [1].

in Ref. [1] ($x_0 = 87$). Like in Ref. [1], we performed 15000 consecutive measurements, each 6 seconds long. The resulting distribution is shown in Fig. 5 in comparison with the results of Ref. [1]. Again we see that our measurements comply with the expected Gaussian distribution without any broadening. In this way, we have once again proved that the results of measurements of the rates of radioactive decay under these conditions obey the Poisson distribution.

Next we checked the assumptions of similarity of adjacent histograms, similarity of simultaneous histograms, and similarity of histograms taken with 24-hour intervals. We took 88 one-hour series with the above-described detectors, one of which measured the activity of ^{55}Fe, and the other that of ^{241}Am. The counting rate of both detectors was adjusted, like in Ref. [1], to be practically equal to 31500 pulses in 36 seconds, which allows comparison of simultaneously taken histograms. For assessing the similarity of adjacent histograms and histograms displaced in time by 24 hours, we used the readings of the detector measuring the activity of ^{55}Fe.

The authors of Ref. [1] did not define any quantitative criteria of similarity of histograms. Our comparison is based on the definition

$$\delta = \sum_i |X_i - Y_i| ,$$

where X_i, Y_i are the numbers of events registered in the ith channel of the histograms X and Y under comparison. For the histograms considered similar by the authors of Ref. [1] (see Figs 4, 5 in their paper [1]), the value of δ must be less than that for the unlike histograms, and also less than the mean 'similarity factor' of a given histogram with all other N histograms:

$$\Delta = \frac{1}{N} \sum_k \sum_i |X_i - Y_i^k| .$$

The resulting averaged values of δ and Δ are shown in Table 1. We see that the excess of the mean δ above the mean Δ is the largest for histograms following one another, and constitutes about 3%. The standard deviation of δ is 9.5, so assuming that the standard deviation of the mean is smaller by a factor of $\sqrt{87}$, we find that this deviation is not significant. The excess of the mean δ over the mean Δ for simultaneously produced histograms is less than 1%, while for the histograms

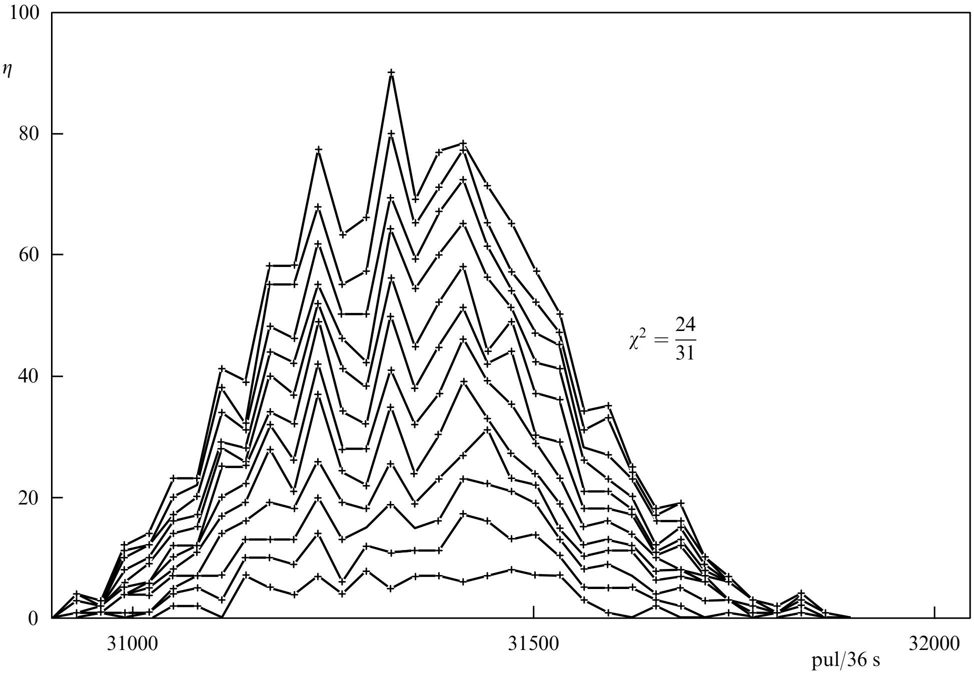

Figure 3. Third series of measurements. Continuous lines, like in Ref. [1], are drawn after every 100 series of 36 seconds each. We believe that the local maxima and minima are the result of 'statistical inertia'.

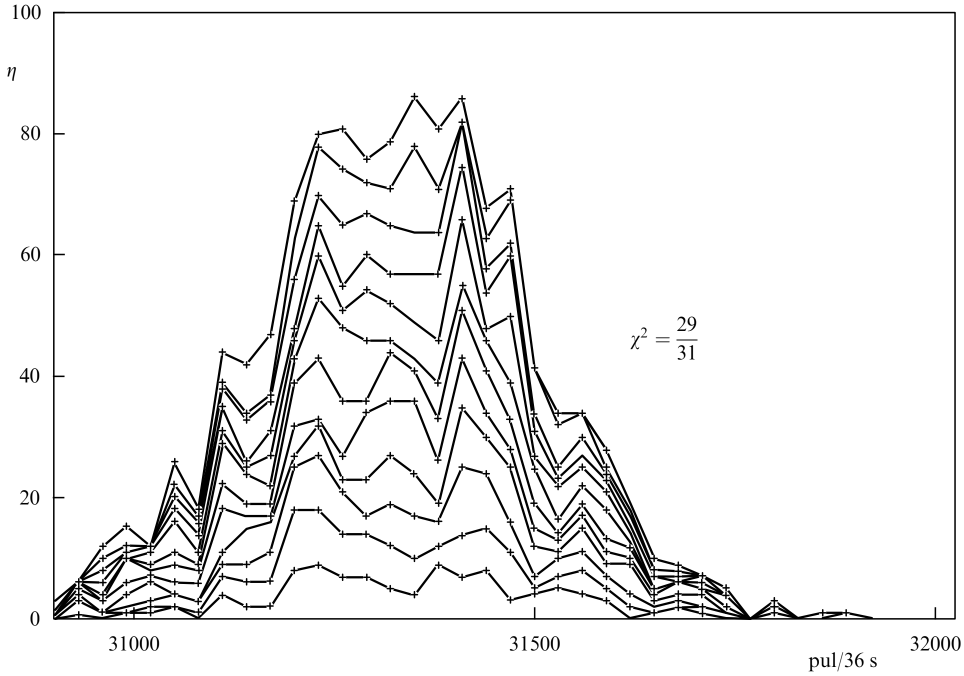

Figure 4. Fourth series of measurements. Continuous lines, like in Fig. 3, are drawn every hour. According to Ref. [1], this histogram should have a shape similar to that of the previous histogram.

displaced in time by 24 hours the mean δ, on the contrary, is less than the mean Δ. The expected values of δ were also simulated by the Monte Carlo method. The value produced for the mean δ turned out to be 55.7, and the standard deviation for the 10 simulated 88-hour series was 0.91, in complete agreement with the experimental results.

In this way, our data contradict the results reported in Ref. [1], where 'fine structure' and time fluctuations were observed in the histograms describing the distribution of the measurement results of nuclear radioactive decay. At the same time, our results do not contradict the assumption that the decay rate obeys the Poisson distribution.

Table 1.

Histograms	Mean Δ	Mean δ
Adjacent	55.7	57.3
Simultaneous	56.7	57.2
Displaced in time by 24 hours	56.9	56.5

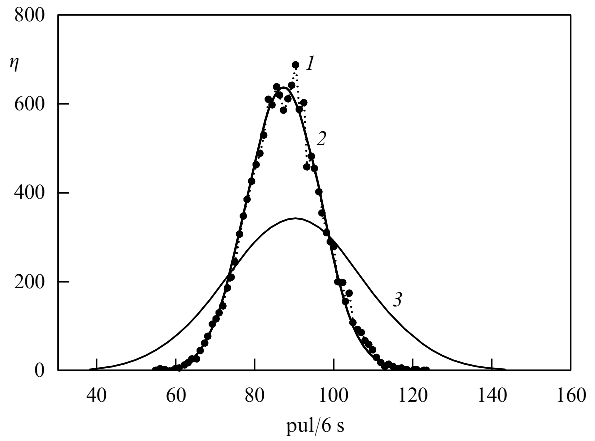

Figure 5. *1* — Distribution of the alpha-decay counting rate from ^{241}Am, obtained by us for 15000 series of 6 seconds each; *2* — Gaussian distribution for $x_0 = 87$; *3* — distribution corresponding to that shown in Fig. 2 in Ref. [1] (without reproduction of the 'fine structure').

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Notes added in proof

(1) We understand the possible causes for the discrepancy between Fig. 2 in Ref. [1] and the Poisson distribution: the Gaussian curve has broadened (almost twofold) because of some additional source of disturbance. This is a warning sign, and it is hard to say why the fine structure of the original distribution remains not blurred. In order to explain this, one must introduce a strict correlation between the main and the secondary distribution — that is, between the rate of radioactive decay and, for example, the instability of the threshold set for the onset of particle registration.

(2) We do not understand, however, how to explain the disagreement between Fig. 1 in Ref. [1] and the Poisson distribution. We were not able to trace this to the electronic circuit, the detector, or the radioactive source. If this is not an artifact, we believe that it is this effect that ought to be made the main subject of paper [1].

(3) We have questions to the new diagrams [2] as well. The distribution of the number of similar pairs depending on the time lag between them (shown in Fig. 3 in Ref. [2]) is not symmetric: according to our estimates, 630 out of the 1390 like histograms are shifted left from the center, and 760 to the right. The difference amounts to 5 standard deviations. Figure 3 in Ref. [2] also shows two lines corresponding to the 95% confidence interval. We see, however, that only one point out of 95 (not counting the central point) falls beyond this interval. This implies that the distributions of like histograms based on expert estimates are in poor agreement with the binomial distribution, so one has to be cautious when using the binomial distribution for making conclusions concerning the probability of deviations. It is also pertinent to note that, although this will not increase dramatically the value of probability, one should use not the probability of occurrence of the peak with $N = 64$, but rather the probability of occurrence of a peak with $N \geqslant 64$.

(4) In Figs 3 and 4 in Ref. [2] there is no peak corresponding to histograms displaced in time by 24 hours. It seems that, like the peak corresponding to the 48-hour time displacement in Ref. [1], it may or may not be there.

(5) We believe that it is mandatory to perform numerical comparison of the shapes of histograms. It remains not clear why for the histograms plotted on the same scale with respect to the X-axis one needs smoothing (moreover, repeated smoothing according to a specially designed procedure), and to adjust the degree of linear stretching and shifting with respect to the X-axis. All this should apparently only lead to blurring of the fine structure, had it been present in the original distribution. We also believe that the expert evaluation of similarity of histograms depends essentially on the selected method of smoothing, and if the effect exists on a broad time scale (from 6 seconds to 1 hour), then in place of smoothing 'for facilitating the comparison' one should use histograms with more extensive statistics. It would also be useful to know the values of ΔS (and their errors) not just for 6 selected histograms (see Fig. 2 in Ref. [2]), but for the totality of like and unlike histograms, so as to be able to assess the real efficiency of this criterion for smoothed histograms.

References

1. Shnoll S É et al. *Usp. Fiz. Nauk* **168** 1129 (1998) [*Phys. Usp.* **41** 1025 (1998)]
2. Shnoll S É et al. *Usp. Fiz. Nauk* **170** 214 (2000) [*Phys. Usp.* **43** 205 (2000)]