

PHYSICS OF OUR DAYS

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Realization of discrete states during fluctuations in macroscopic processes†

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Abstract. **It is shown that due to fluctuations, a sequence of discrete values is generated by successive measurement events whatever the type of the process measured. The corresponding histograms have much the same shape at any given time and for processes of a different nature and are very likely to change shape simultaneously for various processes and in widely distant laboratories. For a series of successive histograms, any given one is highly probably similar to its nearest neighbors and occurs repeatedly with a period of 24 hours, 27 days, and about 365 days, thus implying that the phenomenon has a very profound cosmophysical (or cosmogonic) origin.**

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1. Introduction

This article is a review of studies performed at our laboratory over more than forty years. Having started with biological objects, our studies have gradually moved into the purely physical domain. From time to time, the milestone results of these studies have been published mostly in biological and biophysical journals, and are little known to physicists. We believe, however, that our findings may have important implications for the general concepts of physics.

In 1955, measuring the rates of biochemical reactions, we observed a strange distribution of the results — the readings tended to group around two or three discrete values, while readings in between were quite rare. We were measuring the rate of fermented ATPase reaction: hydrolysis of muscle proteins, myosin and actomyosin. Initially we attributed this effect to the specific features of fibrillary proteins, to the existence of discrete conformations of their molecules and concerted fluctuative transitions of molecules from one state to another [1]. After several years of experiments, however, we obtained similar patterns for solutions of globular proteins. As a control, we performed experiments with purely chemical reactions of low-molecular compounds, and also obtained distributions of the results of measurements with several distinctive discrete peaks.

It was shown that these distributions do not reduce to a trivial effect of insufficient measurements or some other artifact. We observed a striking similarity in the fine structure of histograms in different experiments, and an obvious regularity as they changed their shape in consecutive experiments. The first assumption was that this was a manifestation of some special properties of water, a common

† The effect described in this paper may well surprise the reader. It relates to the fundamentals of physics, and so far has not been explained. This is the reason why, somewhat out of line with our common policy, we decided to add the reviewer's postscript to this publication. (*Editorial Board*)

solvent in all these reactions. However, similar distributions of reaction rates were observed when studying the reaction in non-aqueous solvents. Then (in 1979), by way of the 'last control' we obtained detailed distributions of measurements of radioactivity. The effect was stunning: the fine structure of the distribution of the results of radioactivity measurements (the shape of the relevant histograms) was very similar for the measurements of two radioactive preparations in two independent automatic measuring stations (Fig. 9).

Twenty-five years of research brought us to the conclusion that the discrete nature of the distributions of measured quantities is a nontrivial and universal feature. We could mention that these studies, begun with solutions of proteins, stimulated a search for and the study of oscillatory processes in biochemical, chemical and physico-chemical systems [3]. In particular, our work has brought on considerable progress in the study of the Belousov – Zhabotinsky homogeneous oscillatory reaction [4, 5]. It is not possible, however, to attribute the discrete distributions to oscillatory regimes.

By 1983 we were quite certain that 'macroscopic quantization' is characteristic of processes of a fundamentally different nature. It is observed in biochemical reactions with protein macromolecules, in homogeneous chemical reactions with low-molecular compounds, as well as in diverse physico-chemical measurements: (a) velocities of latex particles in an electric field; (b) discharge time delay in a neon lamp RC oscillator; (c) transverse relaxation time τ_2 of water protons using the spin echo technique; (d) amplitude of concentration fluctuations in the Belousov – Zhabotinsky reaction; (e) radioactive decay of various isotopes [6].

Because of the oddity of this phenomenon, we subjected it to a long, thorough and comprehensive investigation. For obvious reasons, our experiments mainly consisted in the measurements of different types of radioactivity.

Special care has been taken to eliminate possible artifacts [6 – 11]. It was demonstrated that the results do not depend on the measurement techniques and the nature of the phenomena under investigation. The measurements of radioactivity, for example, were performed with Geiger counters, liquid and solid scintillation counters, and solid state detectors. The beta activity of ^{3}H, ^{14}C, ^{32}P, ^{60}Co, and ^{204}Tl was measured, as well as the secondary x-ray quanta at 5.9 keV and 6.3 keV which accompany the K-capture associated with the ^{55}Fe to ^{55}Mn transformation. The bulk of the experimental data, however, were derived from measurements of the alpha activity of ^{239}Pu specimens firmly attached to silicon solid state detectors. Control measurements were performed as necessary for eliminating the dependence of the results on the instability of the ambient temperature, power surges, the amplitude cut-off regime, etc. The problem of elimination of artifacts will come up from time to time in our subsequent discussion.

It ought to be noted that the phenomenon in question does not contradict any 'fundamentals of science'. In particular, the stochastic nature of radioactive decay and its compliance with Poisson statistics are not questioned. It is only that the existing criteria of validity are insensitive to the fine structure of the distributions. For this reason, the conclusion regarding the regularity of discrete distributions especially clearly follows from the detailed similarity of the shapes of histograms obtained independently in different series of measurements. We have observed such similarity of histograms for simultaneous independent measurements of quite different processes, in laboratories sometimes separated by hundreds and thousands of miles.

By itself, the existence of several narrow peaks and troughs (the 'polyextremity' of the histograms) is apparently due to purely arithmetic reasons — the algorithms of interaction of 'reactants' in the studied processes. In the most general case, these algorithms are based on the operations of multiplication, division, raising to a power. The results of such operations are necessarily discrete — the probability of a certain reading (for example, the reaction rate) is higher, the greater the number of combinations of multipliers (for example, the instantaneous reactivities) that yield the given value after multiplication (see below). The shape of the relevant distributions — the fine structure of the histograms — will be determined by the distribution of the number of multipliers on the relevant segment of the number axis. This applies to processes of whatever nature. Hence it follows that the conventional Gaussian or Poisson distributions are, as a rule, the result of smoothing of histograms. In a sense, it is the smooth distributions that may be regarded as artifacts — the consequence of intentional averaging of the results [9].

We see that the discrete distribution of the results of measurements as such is not surprising. The regular time evolution of the fine structure of histograms, however, the similarity of patterns obtained from independent measurements of entirely different processes cannot be attributed to purely mathematical causes, and is a manifestation of the fundamental physical properties of our universe.

Without trying to explain the nature of these properties, we may state that:

because of fluctuations, any sequence of measurements of processes of arbitrary nature yields a series of discrete values. Some of such values occur much more often than others — we observe 'allowed' and 'forbidden' states of macroscopic objects. The corresponding histograms exhibit extrema — peaks and troughs. The shape of the spectrum of allowed and forbidden states — the relative distances between the levels and their populations — is at all times similar for processes of different natures, and is very likely to vary synchronously for different processes, even when they occur in laboratories many miles away from each other. There is a certain 'lifetime' for the given shape of histograms: in a series of consecutive histograms, a histogram is most likely to be similar to its closest neighbors. The shapes of histograms are very likely to recur with a period of 24 hours, 27 days, or 365 days. All this (regular time variation of consecutive histograms, similarity of histograms for simultaneous independent measurements of processes of different natures and possibly occurring at different geographical points) points to the existence of a universal cosmophysical (cosmogonic) cause of this phenomenon.

Presented below are some basic facts that support this statement.

2. Non-randomness of the fine structure of the distributions of results of measurements of processes of different natures

Figure 1 shows four 'layered' histograms plotted without shifting and smoothing, each based on 1200 consecutive measurements of the radioactivity of an ^{55}Fe preparation. Measurements were performed with a scintillation counter and an ORTEC amplitude analyzer by counting the secondary x-ray quanta at 5.9 keV and 6.3 keV which accompany the

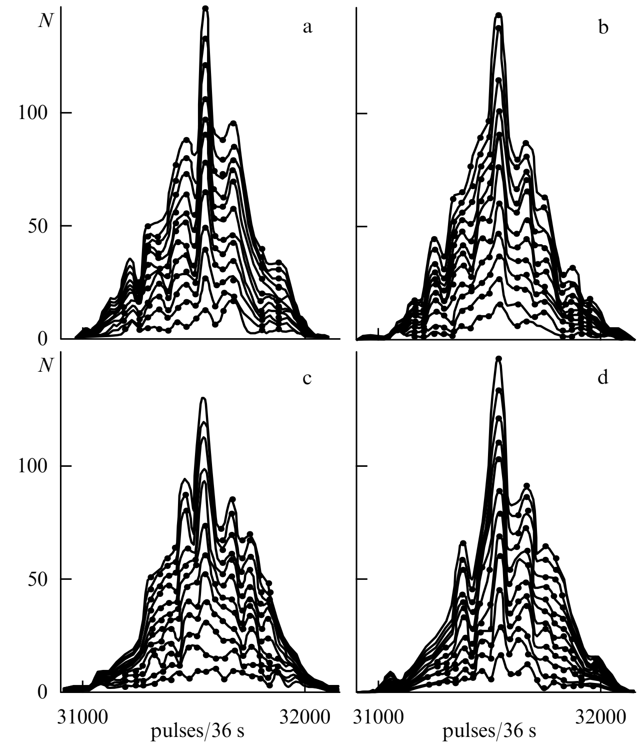

Figure 1. Illustration of the non-randomness of the fine structure of distribution of results of measurements of radioactivity. Four histograms are plotted without shifting and smoothing, each from the results of 1200 consecutive measurements of the radioactivity of a ^{55}Fe preparation. Measured with a scintillation counter and the amplitude analyzer ORTEC by counting the secondary x-ray quanta at 5.9 keV and 6.3 keV which accompany the K-capture associated with the ^{55}Fe to ^{55}Mn transformation. The mean activity is about 31500 pulses per 36 seconds. The steps along the horizontal axis are 30 pulses. Layer lines are drawn after each 100 measurements.

K-capture associated with the ^{55}Fe to ^{55}Mn transformation. The mean activity is about 31500 pulses in 36 seconds. The step of the histogram along the horizontal axis is 30 pulses. The 'layer' lines are plotted duration every 100 measurements. The total duration of 1200 measurements in each histogram is 12 hours. The measurements were started at 23:00 on 18 February 1982, and finished at 23:00 on 20 February 1982. Figure 1 illustrates the similarity of shapes of all four independently obtained histograms.

Figure 2 shows the distribution of results of 15000 measurements of alpha activity of a ^{239}Pu preparation, firmly attached to a solid state detector. The length of one measurement is 6 seconds. Such measurements have been carried out in our laboratory round the clock for many years using several detectors. The results of measurements are stored in a computer archive. The horizontal axis in Fig. 2 is graduated in the rate of radioactivity (number of pulses per 6 seconds). The mean activity is about 90 pulses per 6 seconds. The ordinate is the number of measurements that yielded a given rate of alpha activity. The 'layer' lines are plotted every 1000 measurements.

Figures 1 and 2 show the presence of relatively narrow extrema — certain values of the measured quantity are more likely than others. *This 'polyextremity' is not due to an insufficient number of measurements*: the 'discreteness'

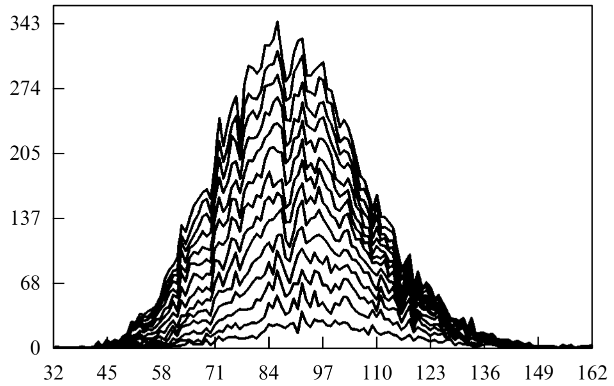

Figure 2. Distribution of results of 15000 measurements of radioactivity of a ^{239}Pu preparation, firmly attached to a solid state detector, without shifting and smoothing. The duration of one measurement is 6 seconds. The horizontal axis is graduated in units of radioactivity (pulses per 6 seconds). The mean activity is about 90 pulses per 6 seconds. The vertical axis shows the number of measurements that yield a given value of alpha activity. Layer lines are drawn after each 1000 measurements.

increases with the number of measurements — the peaks become taller, and the troughs deeper. *Neither can it be attributed to 'statistical inertia'*: the shape of the histograms is independently repeated for simultaneous or nearly simultaneous measurements. Coarsening the histogram (increased pitch or step) smooths out the polyextremity. *The polyextremity of the histograms does not contradict the Poisson statistics of radioactive decay*: the existing statistical criteria of conformity of hypotheses are insensitive to the fine structure of such histograms. The conclusion concerning the non-randomness of the fine structure follows from the similarity of shape of independently obtained histograms.

The relatively narrow 'peaks' and 'troughs' indicate that the polyextremity of the histograms is not a consequence of probabilistic causes. The width of these extrema in accordance with Poisson statistics ought to be of the order of $\sqrt{N}$, where N is the arithmetic mean. The values N_i for adjacent extrema are very close, and the relevant distributions ought to be overlapping.

From Figs. 1 and 2 we see that, as the number of measurements increases, the shape of the layer lines becomes more and more articulate. If, however, we use fewer readings for constructing the histograms, we find that the shape of histograms changes continuously. For example, Fig. 3 shows the first 12 out of 150 histograms plotted from 100 consecutive measurements, the same as those used for plotting the layer histogram in Fig. 2. The histograms are smoothed to facilitate visual comparison. We see that the shape of consecutive histograms is different. These differences could have been attributed to an insufficiently large number of samples and to the stochastic nature of the shapes observed. We see, however, that the shapes of some histograms are miraculously similar (*1* and *2*, *7* and *8*, *7* and *12*).

For conspicuity, in Fig. 4 we present juxtapositions of some histograms from this series. Figure 5 shows the typical distinguishable shapes of histograms. In these diagrams, similar histograms are superimposed to illustrate the adopted criteria of similarity. One can reliably distinguish 15 to 25 shapes (fine structure of discrete distributions) — the spectra of states realized in the course of fluctuations.

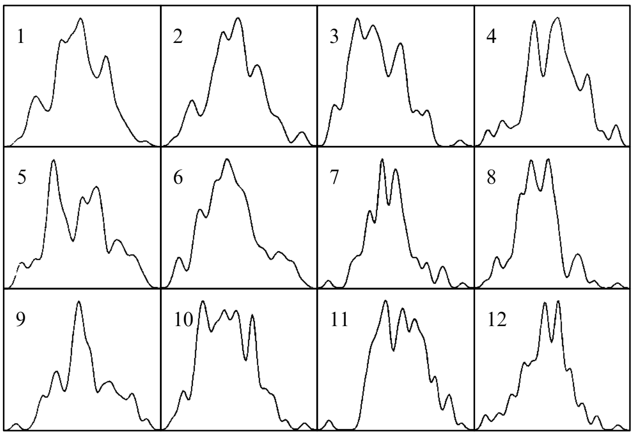

Figure 3. First 12 out of 150 histograms plotted from 100 consecutive measurements, the same as those used for plotting the histograms in Fig. 2. Smoothed to facilitate visual comparison.

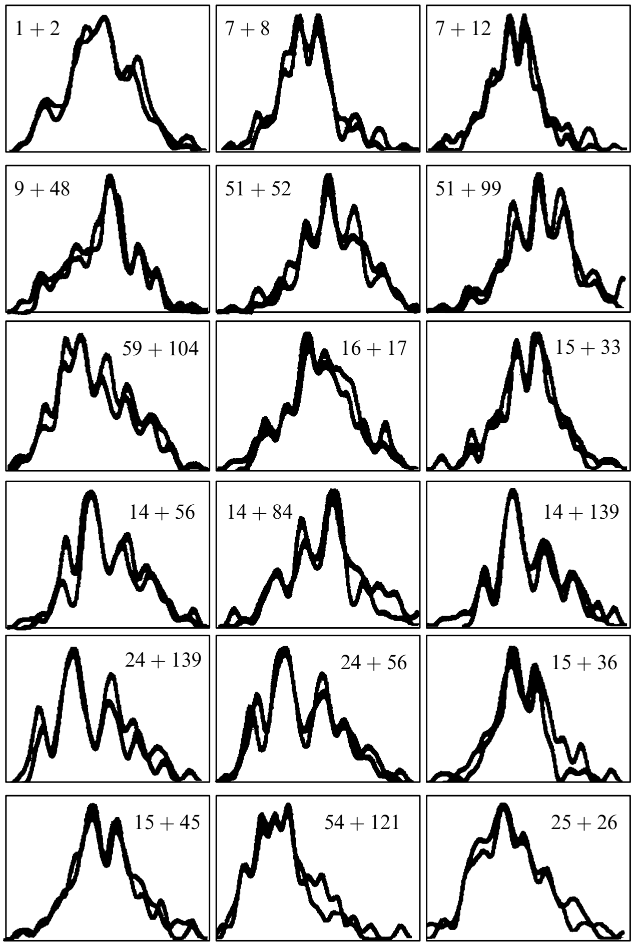

Figure 4. Juxtapositions of certain histograms from Fig. 3. Illustration of similarity.

3. Non-randomness of periodic recurrence of the shape of histograms

Obviously, the likelihood of recurrence of a histogram of an intricate shape is quite small. Even more convincing evidence of the non-randomness of the fine structure of distributions of the results of measurements is the fact that they recur periodically time after time. To show this, we transform the time series into a series of histograms representing the results of measurements (distributions of 60 to 100 consecutive numbers). To compare the shapes of histograms and identify the time between two similar histograms, we used the 'Histogram Manager' software developed by one of the authors (E V Pozharskiĭ). To facilitate visual comparison, the histograms are smoothed. The criteria of similarity allow horizontal stretching or contraction of histograms. To eliminate subjective effects in evaluating the similarity, the numbers of consecutive histograms are scrambled. The conclusions are based on comparison of tens and hundreds of thousands of combinations of histograms. As a rule, the number of similar pairs of histograms is from 2 to 5% of the total number of possible combinations.

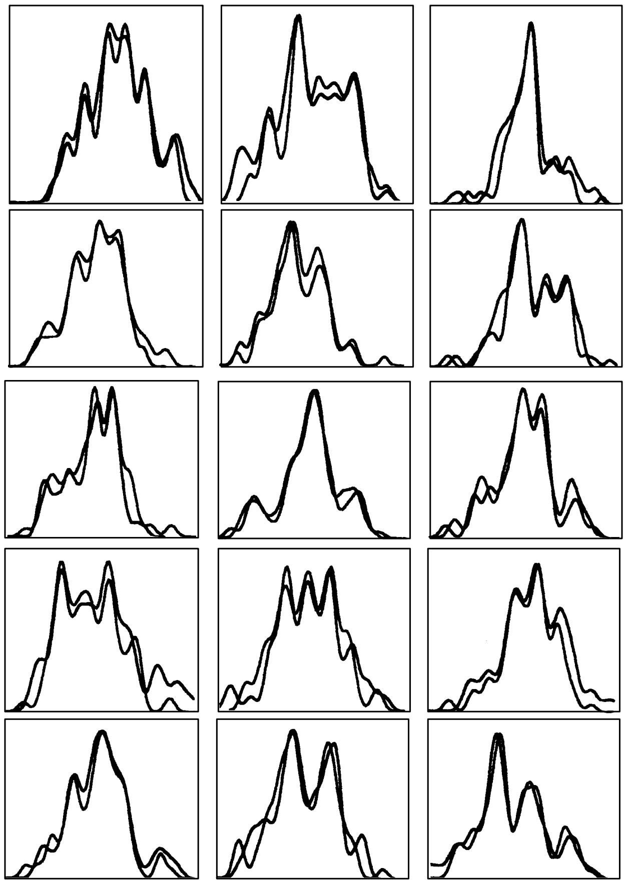

Figure 5. Typical distinguishable shapes of histograms. Similar shapes superimposed to illustrate the adopted criteria of similarity.

This analysis *revealed that a similar shape in the series of consecutive histograms is most likely to occur at the nearest moment of time*. This can be seen from Fig. 6a, b, which show the distribution of time intervals between histograms of similar shape. The histograms were plotted each from the results of 60 measurements of alpha activity of ^{239}Pu preparation over 6 seconds — that is, over a total time of 6 minutes. The step along the horizontal axis in Fig. 6a is 6 minutes. We see that the probability that a given shape of histogram will be repeated is highest in the next time interval: the number of such cases in Fig. 6a is 51. There are 34 such repetitions in the next interval, then 24, and so on, down eventually to 10 – 15 cases. For the same results of measurements, in Fig. 6b the step along the axis of abscissas is coarsened to 1 hour (10 histograms). We see that the number of similar pairs is 275 in the next hour, 210 in the hour after the next; 4 or 5 hours later the number of similar pairs reduces to 110 per hour.

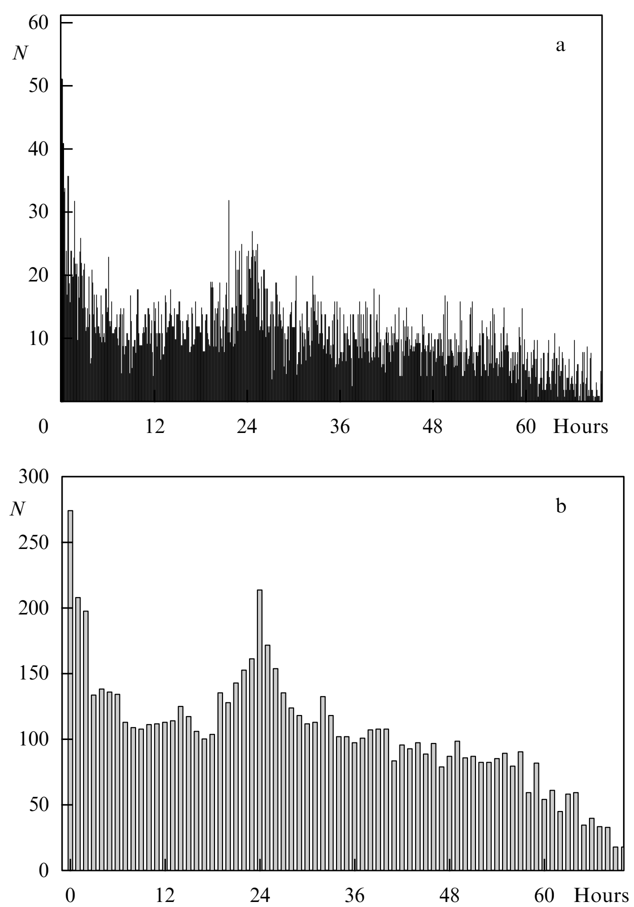

Figure 6. Distribution of time intervals between histograms of similar shape. Histograms are plotted each from 60 results of 6-second measurements of alpha activity of ^{239}Pu preparation — that is, over 6 minutes each; (a) the step along the horizontal axis is 6 minutes; (b) the step along the horizontal axis is 1 hour (10 histograms).

The similarity of histograms in 'close neighborhood' is remarkable. The histograms are plotted from non-overlapping series of results of independent measurements. Radioactive decay obeys Poisson statistics; the atoms split independently of one another. Therefore, there must be an external cause of the similarity of the respective histograms. What is more, the 'idea of shape' has a certain 'lifetime' — the probability of recurrence of a given shape is plausibly and reproducibly higher for the nearby time intervals, and falls off with time. Hence it follows that each of the distinguishable shapes of histograms is not random. This non-randomness is not attributable to the properties of the measuring devices: the counters operate according to 0,1 logic. The shape of the histograms does not depend on the pulse discriminator cut-off amplitude, measurement techniques, or some 'selective preferences' of counting circuits.

However, numerous attempts to find the time characteristic of the 'external force', which determine the shape of spectrum of the realized states, failed. We plotted our histograms from one and the same number of measurements of varying length, so that the intervals between histograms varied from 1 hour to 1 second. Nevertheless, the shape of the distribution of intervals was the same — in all cases, the histogram closest in time was the most likely to be similar. Such obvious fractality calls for further investigation.

Recurrence of histograms of the given shape with the periods of 24 hours, 27 days, 365 days, points to the existence of a cosmophysical factor that determines the shape of the histograms.

An analysis of the distribution of intervals between similar histograms in the long-time series indicates that there is not only a relative time dependence (like in the 'immediate neighborhood'), but also an absolute time regularity of recurrence of similar histograms.

As follows from Fig. 6, there is a credible increase of the probability of recurrence of a given histogram shape after 24 hours. It is very important that this 24-hour period is observed for both the 6-second measurements (one histogram in 6 minutes), and for the 60-second measurements (one histogram in 60 minutes). In both cases there is a credible increase of the probability of recurrence of a given shape of histograms after 24 hours.

The 24-hour period, like the similarity of 'immediate neighbors', is an indication of the existence of an external agent that influences the object of study. It would be most natural to associate this with the rotation of the Earth. Of course, it is desirable to measure this period with a higher accuracy, which requires further investigation.

Apart from this 'link with the external world' there are others, no less important. We refer to the recurrence of the given histogram shapes with 27-day and 365-day periods. Figure 7 shows the distribution of intervals of recurrence of a given histograms shape around 27 days. These histograms are plotted from 60 results of 6-second measurements of alpha activity of ^{239}Pu preparation. The step in Fig. 7 is 1 hour (10 histograms). The sharpest in Fig. 7 is the extreme corresponding to 27.28 days, which is precisely the synodic period of the Sun with respect to the Earth.

Figure 8 shows the distribution of recurrence of the given histogram shapes after 360–367 days. We note three sharp extremes: 364.4, 365.2, and 366.6 days. The second of these seems 'natural' — it is the time of the Earth's orbit around the

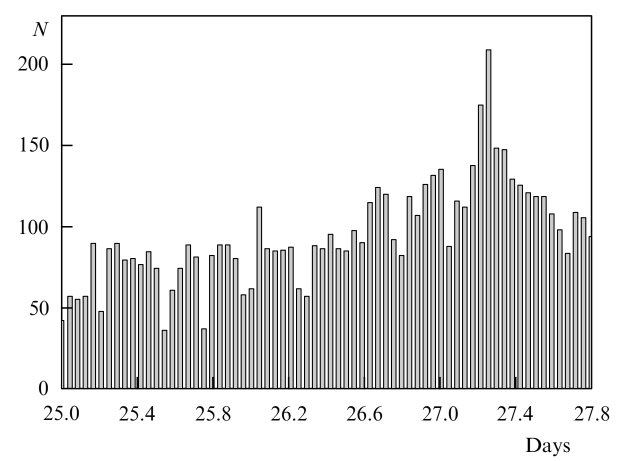

Figure 7. Distribution of intervals between recurrence of histograms of a given shape around 27 days. Histograms plotted from 60 results of 6-second measurements of alpha activity of ^{239}Pu preparation. The step of distribution is 1 hour (10 histograms).

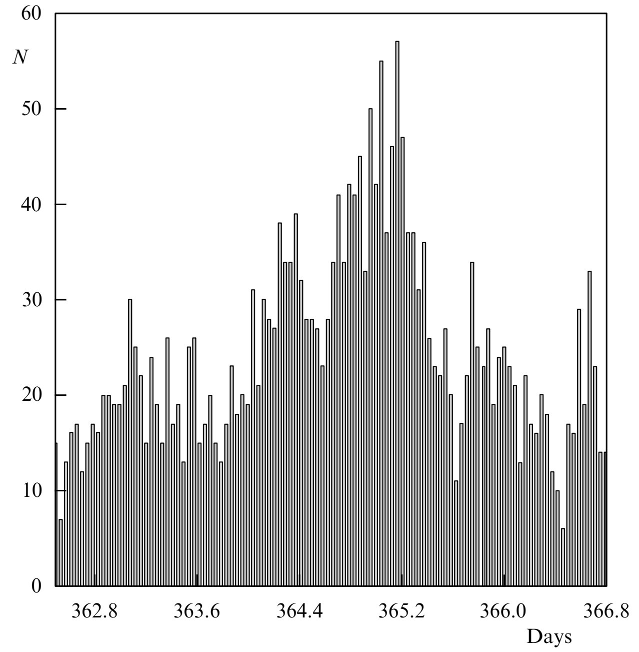

Figure 8. Distribution of intervals between recurrence of histograms of a given shape around 360 – 367 days. Histograms plotted from 60 results of 6-second measurements of alpha activity of ^{239}Pu preparation. Observe three sharp extremes, corresponding to recurrence of histograms after 364.4, 365.2, and 366.6 days.

Sun. The other two figures call for special interpretation.

From the data presented above it follows that the *'idea of shape' — the fine structure of distributions of results of measurements of processes of diverse nature — is determined by cosmophysical factors.*

4. Concerted realization of histogram shapes in processes of diverse natures

The high likelihood of occurrence of histograms of similar shape in simultaneous independent measurements, including those of processes of diverse natures and at remote geographical locations, is substantial proof of the fundamental nature of the phenomenon under discussion.

The first such result was obtained in December 1980, from measurements of beta activity of two ^{14}C preparations of approximately equal activity with two measuring stations. The histograms exhibited detailed similarity (Fig. 9). Such similarity could not be reduced to any trivial reasons. Subsequently, we have observed this phenomenon over and over again.

An important indication of the nontrivial similarity of the fine structure of the distribution of the results were similar observations related to measurements of processes of diverse natures. We observed similar histograms for simultaneous measurements of the beta activity of ^{3}H or ^{14}C, the reaction rate of ascorbic acid (AA) and dichlorophenolindophenol (DCPIP), the alpha activity of a ^{239}Pu preparation, the electrophoretic mobility of latex particles, the transverse relaxation time T_2 of water protons, the time delay of a neon lamp discharge in an RC oscillator, and measurements of fluctuations of amplitudes of oscillations in Belousov – Zhabotinsky reaction. In all these combinations we used different techniques, the nature of the processes was different, but the shapes of the histograms were similar with high probability [6 – 11].

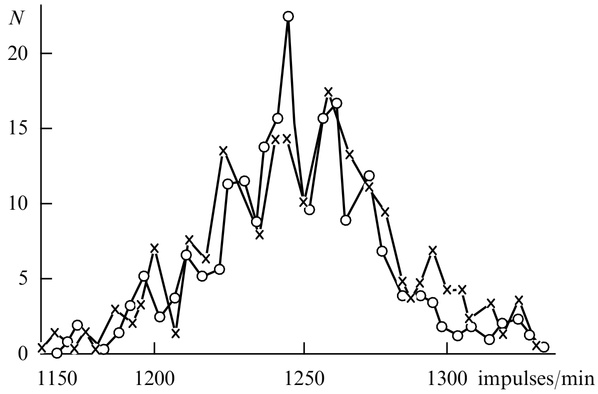

Figure 9. Synchronous measurements of the radioactivity of two ^{14}C preparations with two independent automatic measuring stations SL-30 and SL-40 give very similar histograms. Experiment on 28 December 1980.

The similarity of histograms obtained from measurements of processes of different natures is illustrated in Fig. 10 [6, 7]. This diagram shows a superposition of two histograms obtained on 4 July 1984: one is plotted from 250 measurements of the reaction rate of AA and DCPIP, the other from the same number of simultaneous measurements of beta activity of ^{14}C. Measurements were carried out in nearby buildings with

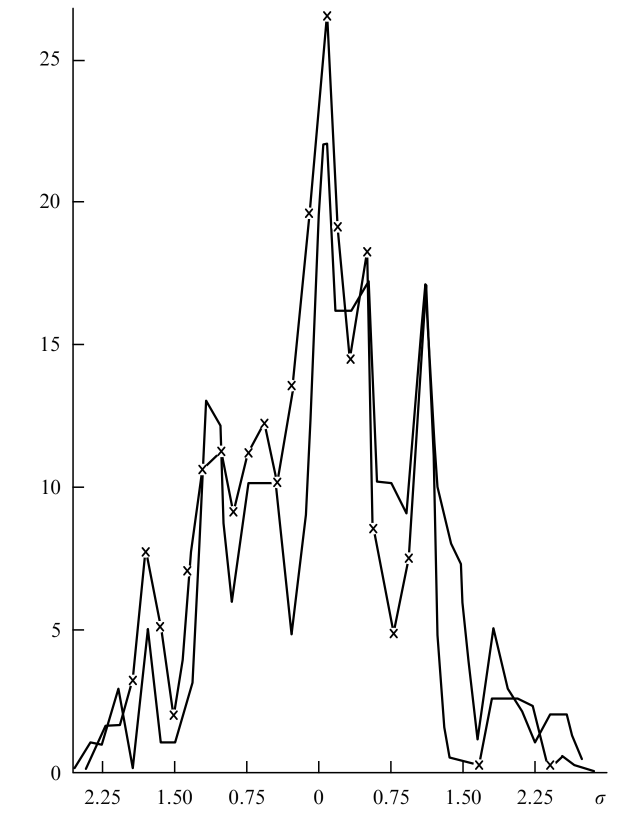

Figure 10. Similarity of histograms obtained from simultaneous measurements of processes of different natures [6, 7]. Juxtaposition of two histograms obtained on 4 July 1984: one is plotted from 250 measurements of the reaction rate of AA and DCPIP, the other from the same number of simultaneous measurements of the beta activity of ^{14}C.

different techniques. The reaction rate was measured with a photocolorimeter by the change of optical density, the radioactivity with a liquid scintillation counter in automatic mode. Correct selection of scale along the horizontal axis is important for juxtaposition of histograms that characterize different processes. In this case the scale is expressed in units of mean square deviation for both processes.

The credibility of this effect can be evaluated from the distribution of intervals between similar histograms. Figure 11 shows such a distribution obtained from comparison of histograms plotted from measurements of the alpha activity of two ^{239}Pu preparations with two independent solid state detectors. We see that the probability that two histograms are similar is much higher for simultaneous histograms (time lag zero) than for histograms obtained at different times. From 541 pairs of similar histograms in this distribution, 154 pairs have been taken simultaneously. The probability of getting similar histograms is high enough in the adjacent time intervals to each side, and falls rapidly thereafter.

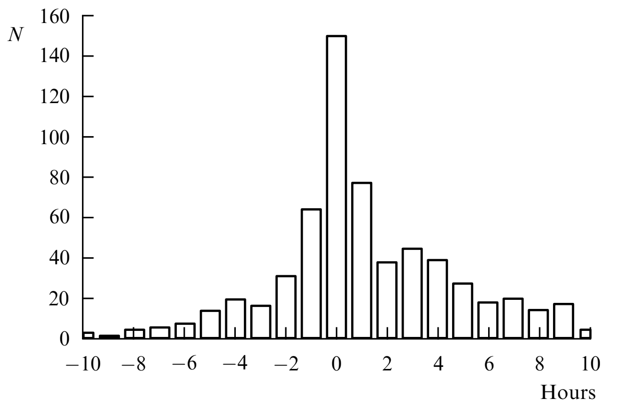

Figure 11. Distribution of deviations from exact synchronous coincidence of the shape of histograms plotted from the results of measurements of alpha activity of two preparations of ^{239}Pu in Pushchino on 31 January — 2 February 1996. The horizontal axis is graduated in time lag intervals; the vertical axis shows the number of pairs of histograms corresponding to the given deviation.

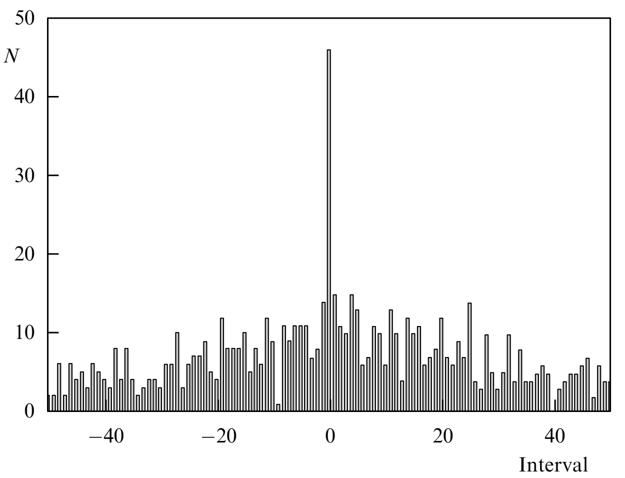

Figure 12. Distribution of intervals between similar histograms plotted from the results of measurements of alpha activity of ^{226}Ra, ^{218}Po, and ^{214}Po with one solid state detector equipped with amplitude analyzer. Similar histograms are most likely to occur simultaneously (time lag zero).

A much sharper pattern was obtained by one of the authors (I M Zvereva) from measurements of the alpha activity of various isotopes of the ^{226}Ra family, which is in secular equilibrium with the products of decay ^{222}Rn, ^{218}Po, ^{214}Po, ^{210}Po [12]. The different energies of alpha particles from these isotopes permit separate measurement of the alpha activity of each isotope with one and the same solid state detector equipped with an amplitude analyzer. Figure 12 shows the distribution of intervals between similar histograms, plotted from the measurements of alpha activity of ^{226}Ra, ^{218}Po, and ^{214}Po. We see that the probability of independently obtaining similar histograms is much higher for simultaneous measurements (time lag zero) than for any other time interval. This phenomenon has been discussed at length in a special publication [13].

5. Concerted realization of shapes of histograms at different geographic locations

In the experiments performed in March – July of 1982, we compared the shapes of histograms plotted from synchronous measurements of alpha activity of ^{239}Pu preparation using a solid state detector in Moscow (MIFI, N B Khokhlov, M P Sharapov), and measurements of beta activity of ^{14}C using a scintillation counter in Pushchino (IBF, V I Bruskov, V D Razhin). With the laboratories separated by more than 100 kilometers, over 60% of synchronous pairs of histograms were similar in shape.

In 1983 – 1984, similar comparisons of histograms were performed from measurements of beta activity of ^{3}H in Leningrad (A Yu Sungurov), and alpha activity of ^{239}Pu preparation in Pushchino (V A Kolombet). With a distance between the laboratories of over 700 kilometers, we found a credible similarity of the shapes of histograms plotted from these measurements.

Similar results were obtained from comparison of the shapes of histograms plotted from measurements of fluctuations of parameters of the Belousov – Zhabotinsky reaction in Tomsk (L P Agulova), and fluctuations of the reaction rate of AA and DCPIP in Pushchino.

Measurements of the alpha activity of a ^{239}Pu preparation were performed by A N Zaikin in 1987 aboard a ship in the Pacific, in 1988 in the Indian Ocean, and in 1990 by one of the authors (V A Kolombet) beyond the Arctic Circle at the Belomor [White Sea] biological station of Moscow State University. In all cases the results were compared with synchronous measurements in Pushchino.

Figure 13 shows the distribution of time intervals between similar histograms plotted from the measurements on board ship in the Indian Ocean and in the laboratory in Pushchino. We see that the likelihood of obtaining similar histograms is high for synchronous measurements. Similar results were obtained for measurements in the Arctic region.

We ought to note that the measurements on board ship in the Indian Ocean, at the Belomor biological station of Moscow State University, and in Pushchino were performed in the same time zone: the longitudes of these locations are close.

The synchronous measurements in the Pacific and in Pushchino give a more intricate pattern: the distributions of time intervals between similar histograms show several credible extremes. Their subsequent analysis may reveal more complicated time regularities at different geographical locations.

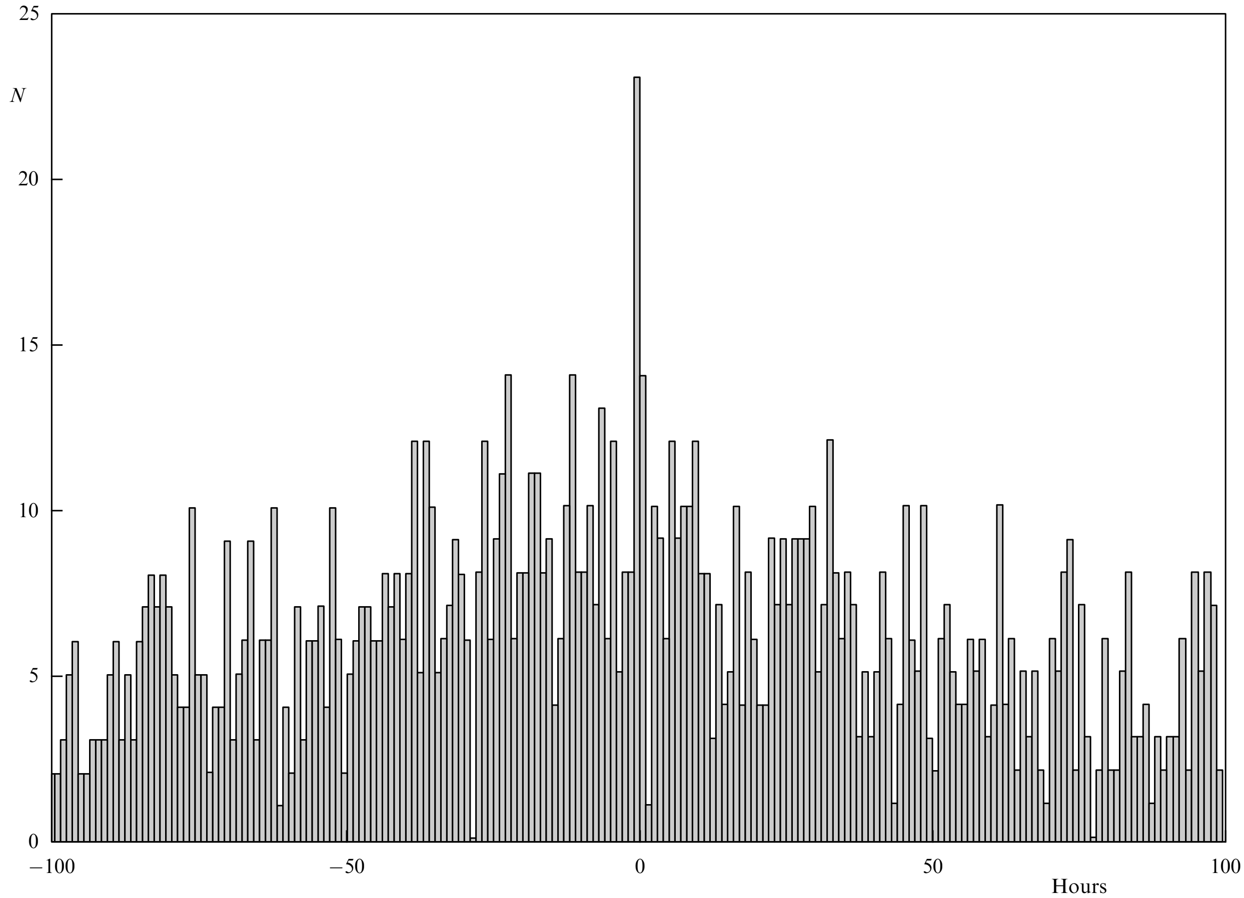

Figure 13. Distribution of intervals between similar histograms plotted from the results of measurements performed on board ship in Indian Ocean and in the lab in Pushchino. Similar histograms are most likely to occur simultaneously (time lag zero).

Among other things, the juxtapositions of histograms plotted at different geographical locations dispel suspicions that these effects may be attributable to some artifacts like variations of frequency or voltage in the mains, temperature drift, radio static. Measurements carried out with autonomous power supply, inside the steel hull of the ship, with miles of seawater under keel, yield histograms that are similar to those obtained thousands of miles away in the institute laboratory in Pushchino — this can hardly be attributed to artifacts.

6. Random number generators. Arithmetic nature of the fine structure of histograms. Change of shape of histograms as a result of fundamental physical causes

In view of the arguments developed above, it would be natural to compare the fine structures of distributions derived from two random sources: a physical source (radioactive decay), and a mathematical random number generator (a computer program). The result that we obtained many years ago was striking: the shapes of computer-generated histograms simulating Poisson statistics were exactly the same as those plotted from measurements of radioactivity.

We plotted a finite number of clearly distinguishable shapes, and these typical shapes were quite similar for the two sources. Further analysis, however, revealed a fundamental distinction between the two 'generators'. The probability of recurrence of computer-generated histograms does not decrease as the time interval increases — there is no effect of 'immediate neighborhood', and there is no periodicity. Accordingly:

1. The characteristic discrete shapes of histograms as such are attributable to arithmetic causes, which are similar for physical processes and for computer programs.

2. In the case of physical processes, however, the arithmetic causes that give rise to discrete distributions are controlled by an external, universal, global agency.

The main arithmetic cause of discrete distributions of results in physical and mathematical generators of random numbers are apparently the algorithms of multiplication, division, raising to a power, which are similar in both cases [9].

As a matter of fact, all physical processes are based on interactions. In the case of inelastic interactions of fluctuating quantities, the rates of the processes under consideration are most generally determined by the product of instantaneous values of reactivities (concentrations) or reactants:

$$V_t = k[A]_t[B]_t ,$$

where V_t, $[A]_t$, $[B]_t$ are the instantaneous values, respectively, of the reaction rate (that is, the measured quantity), and the concentrations of reactants A and B. If the measurement is repeated many times, the quantity V_t will be determined by the random combination of $[A]_t$ and $[B]_t$. It is obvious that some values of V_t will occur more frequently than others (if there are many possible combinations of $[A]_t$ and $[B]_t$ that give the same value of V_t). The product will never be a prime number. In other words, the frequency of occurrence of a given V_t is determined by the number of all possible factors that give this number. These simple considerations indicate that the realization of all possible combinations of factors (which in our case are the instantaneous values of $[A]_t$ and $[B]_t$) ought to give discrete distributions of the probability of realization of V_t. In the limit, the shape of these distributions will be determined by the distribution of the number of factors over the natural number axis. It ought to be observed that the shape of distributions will be more regular, the more exhaustive is the involvement of all possible random combinations of the possible factors.

In this way, discrete distributions with sharply uneven probability of realizations of different values of measured quantities are a necessary consequence of the algorithms of interactions in most diverse processes. Real physical processes may involve more complicated stagewise processes. This, however, will only further increase the discrete nature. Smooth distributions only result from artificial procedures: averaging and smoothing of histograms.

In the computer generators of random numbers the situation is similar. All these generators are based on the algorithms of multiplication and division — the counterparts of inelastic interactions in physics. The attempt to 'randomize' the result further by deleting first or last digits in decimal numbers does not remove the discreteness caused by the operations of multiplication or raising to a power.

In view of this, the computer generators of random numbers may serve as a valuable model for studying the arithmetic nature of discrete distributions.

It is much more difficult to envision the nature of the universal agency that controls the realization of particular shapes of discrete distributions. One possibility is the change of scale in the natural numbers — the change of the 'size of unity'. One may think of the unit of time, for example. Such global change of the universal scale may be caused by gravitational factors — a change in the spacetime curvature. A sound analysis of such a hypothesis will possibly require experiments under different gravitational perturbations.

7. Stochasticity of the initial time series according to standard criteria. Regularity of fine structure as a possible consequence of low-frequency 1/*f* modulation

It would be natural to inquire into the linkage of discrete distributions with the regularities of time evolutions of the processes under consideration. Numerous applications of traditional techniques failed to reveal such a linkage for the processes of our concern. As ought to be expected, the process of radioactive decay according to conventional criteria is fairly stochastic — it is a 'white noise' [14]. One could draw an analogy with atomic spectra: the energy levels are discrete, and transition between the levels is a random process. In our case, however, only the shape of the histograms is invariant: the relative distance between levels, and the relative 'population' of these levels. Absolute distances (in units of the measured parameters for different processes) may differ, but the similarity of shape of the relevant histograms remains. This allows linear stretching and compression of the diagrams to be performed. Thus, the 'macroscopic quantization' differs from the quantization of energy.

The mean square amplitude of macroscopic fluctuations apparently varies with the time independently of the shape of the histograms. There are reasons to believe that this parameter also depends on cosmophysical factors. In particular, the mean square amplitude of the 'spread of results' in the studies of chemical and biochemical processes exhibits almost an exactly inverse correlation with solar activity. This is illustrated in Fig. 14 [6, 7].

The statement that there is no linkage between the varying shapes of histograms and the features of time series may have to be revised because of a very conspicuous mirror symmetry in the series of consecutive histograms. Many histograms (about 30%) will coincide if mirror-rotated with respect to the vertical axis. This also applies to histograms of a very complicated shape. This mirror effect, and the existence of 'right-hand' and 'left-hand' histograms, could be explained through the low-frequency $1/F$ modulation of the time series. In this case the characteristic shape of histograms will be determined by the relative amplitude and frequency of such modulation, and the mirror effect could be interpreted as a phase shift of the segments of time series used for plotting the histograms [15].

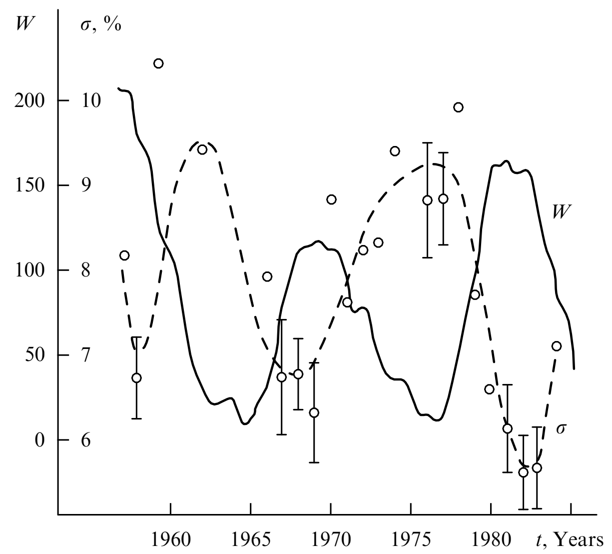

Figure 14. Relative mean square amplitude of 'data scatter' (σ, %) in the measurements of chemical and biological processes is inversely correlated with solar activity — the Wolf numbers W [6, 7].

The purpose of this paper being the phenomenological presentation, we shall confine ourselves to the above discussion.

8. Conclusion

Concluding this brief account of studies performed at our laboratory, we would like to anticipate some naturally arising questions. Forty years have passed since our first publication in 1958 [1]. Why then there have been no results from other laboratories? We believe that the main reason is that other researchers are too well aware of the 'principles of science'. We are talking of the 'spread of readings' of measurements. The 'spread of readings' is something to be eliminated rather than studied. When physicists or chemists get a scatter of data greater than anticipated on account of inaccuracies of individual stages of investigations, the physicist will reach out for his soldering iron and screwdriver, and the chemist will check the purity of reactants and the quality of distilled water. Another reason is that the accepted methods of statistical data processing based on the central limit theorems are not suited for analysis of the fine structure of the distributions. The criteria of conformity of hypotheses just ‘overlook’ this fine structure. The distributions are averaged and smoothed, which does not hinder calculation of the first three statistical moments. Moreover, the majority of problems do not require knowledge of the fine structure of the distributions. A third reason is a lack of confidence in that this phenomenon is at all possible. The scatter of data is associated with the concept of ‘error’. We have spent many years looking for possible artifacts. Our main task therefore consisted in proving the ‘theorem of existence’. This task may be deemed completed. The acceptance of the phenomenon itself — the realization of the discrete spectrum of allowed states, which at any given time is similar for processes of entirely different nature, and which is attributable to cosmophysical forces — requires some psychological effort. It ought to be observed that for many years the process of plotting and comparing histograms was extremely laborious and time-consuming. It was only the development of computer software by one of the authors (E V Pozharskiĭ) that has facilitated this process and greatly improved the efficiency of our daily work. The proof of existence of the phenomenon is the first necessary step. There are many interesting problems that have to be studied. A number of theorems need to be proved, and new computer techniques developed. Experiments must be performed on satellites and space stations. A network for simultaneous measurements at different geographical locations ought to be organized. Finally, and most importantly, we need to develop a theory that will explain the nature of this phenomenon. All this is to be done in the future. The task of this paper is accomplished — we have introduced the object of future research.

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Postscript

The paper that you have just read is somewhat out of the ordinary. Professor Shnol’ is a known biologist, but the paper deals not so much with biology as with pure physics — radioactive decay. Many years of experiments have led to the discovery of several (to be more precise, two) new phenomena.

The purpose of this comment is to discuss why these phenomena may be of interest to physicists, and what role they may play in the development of science. We assume that the results of these experiments are credible and are not artifacts. The doubtful may repeat the experiments and confirm (or refute) the results.

The first phenomenon is associated with the peculiar nature of fluctuations in radioactive decay and in other processes. Let us explain it using the example of alpha decay. Consider a series of measurements of the number of fissions. Select a time interval Δt such that the mean number of fissions $\bar{n}$ over the time Δt is much greater than one (for example, $\Delta t = 6$ s, and $\bar{n} \approx 100$). Assume that the total time of measurements T is long enough, $T \gg \Delta t$, so that the number of intervals is much greater than one. In each particular interval Δt_i the number of fissions is different from the mean value $\bar{n}$.

Now we count the number of intervals for which the number of fissions is n_i. We denote this number by $N(n_i)$, and make it the ordinate; the abscissa is n_i. This is the procedure for plotting the histograms discussed in this paper.

The phenomenon consists in the following.

At first sight it would seem that the maximum of such a histogram will correspond to the mean number of fissions $\bar{n}$, and the height of the bar will decline monotonically as n_i recedes from $\bar{n}$. This prediction is based on the assumption that the bigger the fluctuation, the less probable it is.

Moreover, imagine that some theoretician has decided to simulate the time sequence of alpha decays and plot the appropriate histogram. He knows quantum mechanics well enough to be able to calculate the probability of alpha decay. Now he needs to calculate the probabilities of fluctuations. For doing this, he has two options.

First, he may assume that the fluctuations are distributed at random and obey a certain law that states that large fluctuations are rare compared to small fluctuations (for example, according to Poisson’s law). Then he will get a histogram which decreases monotonically with increasing deviation from the mean.

Alternatively, he may use an ‘ideal’ random function and produce a computer simulation of the time series. If he elects to use an ‘ideal’ random number generator, he will also get a monotonically decreasing histogram. (Observe that the concept of an ‘ideal’ generator calls for clarification itself.)

But here ‘the frog jumps into the water’ — professor Shnol’ and colleagues demonstrate that the experiment does not agree with the theoretician’s assumptions — and this is what the first phenomenon is about.

It turns out that the number of fluctuations depending on the magnitude of deviation may fall or grow again, and behaves non-monotonically. More precisely, the overall decline exhibits a clearly periodic pattern, such as shown, for example, in Fig. 9.

Moreover, this pattern is found to be reproducible — it repeats itself under certain conditions.

Now the question is why our intuition has failed us, and why our theoretician is wrong. The only arguable point in his reasoning related to the interpretation of the concepts of ‘probability’ and ‘stochasticity’. These concepts by themselves do not yet predetermine the answer to the question concerning the distribution of fluctuations.

The concepts of ‘probability’ and ‘stochasticity’ are closely associated with the concept of ‘chaos’, which, as we know now, needs to be revised. We know that there are many different ‘chaoses’, and the distributions of fluctuations are not the same in all of them. One may prepare such a ‘chaos’ in which the probability of fluctuation will fall monotonically with its magnitude. We may agree that it is this chaos that is real (or ideal). We may also, however, invent such a chaos in which the distribution of fluctuations will be non-monotonic, and will correspond to the histograms presented in this paper.

Two conclusions follow.

I. The histograms of S E Shnol’ et al. contain new information about the nature of a random process which until now has passed unnoticed.

II. The postulate of measurement in quantum mechanics is at least not complete. Indeed, when we say that ‘alpha decay occurs at random, so that the probability of detecting... etc.’, we ought to specify what kind of randomness it is, and what chaos it is based upon. Otherwise we are not able to predict a number of phenomena observed.

This proves the importance of the first phenomenon described in the paper.

The second phenomenon consists in the periodical change of the fine structure of histograms. It is demonstrated that the fine structures of histograms for quite diverse random processes (physical, chemical, biological, etc.) are similar and vary in sympathy. Moreover, these periodical changes correlate with the changes in our solar system, and possibly in our universe. To evaluate properly this phenomenon we first ought to understand the cause and mechanism of the first phenomenon.

The authors do not suggest any explanation of the phenomena discussed, and make no hypotheses concerning their possible mechanisms, and quite rightly so! The reader must start thinking on his own, which certainly is the main intent of this publication.

D S Chernavskiĭ