

Nonlocal Influences of Natural Dissipative Processes on the Kullback Measure of Voltage Fluctuations on an Electrolytic Cell

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ABSTRACT

Here are the results of comparison of the Kullback measure recordings for fluctuations of voltage in small amounts of electrolyte in two independent electrolytic cells and external natural dissipative processes. The experiments were conducted over a period of four years, from 2011 to 2015. On the basis of analysis of the results, we concluded that there is a nonlocal influence of external dissipative process on the variations of the Kullback measure of voltage fluctuations on electrolytic cells. We found the correlation coefficients of the Kullback measure of voltage fluctuations, the meteorological factors and the density of entropy production during transformation of solar radiation into the Earth's thermal radiation. Mechanisms, associated with entanglement of the macroscopic systems states or with the influence of entropy production in the presence natural dissipative processes on the intensity of time fluctuations can be considered as hypotheses.

Key Words: dissipative processes, entropy production, nonlocal interactions, Kullback's measure, time fluctuations

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Introduction

Some experimental data have appeared recently that indicate a possibility of mutual influences of processes occurring in different macroscopic systems (Julsgaard *et al.*, 2001; Xu *et al.*, 2005). A number of experiments were conducted, which prove a connection between electroencephalographic brain activities of two people who are distant from each other (Dotta *et al.*, 2009). This line of inquiry is extremely interesting, but at this juncture to go to the rigorous explanation of the processes occurring at the level of brain activity it is necessary to understand

simpler phenomena of the same physical nature in non-living systems.

The assumption about persistence of quantum nonlocality in a macroscopic limit (Benatti *et al.*, 2003; Dur and Briegel, 2004) and the role of dissipation in the generation of entangled states (Basharov, 2002; Jakobczyk 2002) act as a possible theoretical justification of the existence of the mutual influence.

We examined experimentally the assumption about the influence of macroscopic dissipative processes on the parameters of the measuring system, measuring electrode potentials

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in an electrolyte (Korotaev *et al.*, 2002, 2005, 2007). The Brownian motion can be another probe process (Morozov and Turchaninov, 1992; Morozov, 1996a, 1996b; Morozov and Skripkin, 2011), the variations of which can be recorded by measuring the characteristics of voltage fluctuations on an electrolytic cell.

The aim of this work is a discussion of experimental results of long-term measurements of Kullback's measure for voltage fluctuations on two independent electrolytic cells and finding correlation and regression coefficients that describe the influence of natural dissipative processes (including meteorological ones) on statistic characteristics of ion mobility fluctuations in electrolytes.

Description of experimental installations and data processing

We conducted measurements of voltage fluctuations in a small amount of electrolyte, placed in two independent electrolytic cells, from March 20, 2011 to April 8, 2015 (with small breaks from December 20, 2012 to March 10, 2013 and from June 19, 2013 to September 24, 2013). The overall duration of the experiments was 31,084 hours or 1,295 days, not including the above-mentioned two breaks.

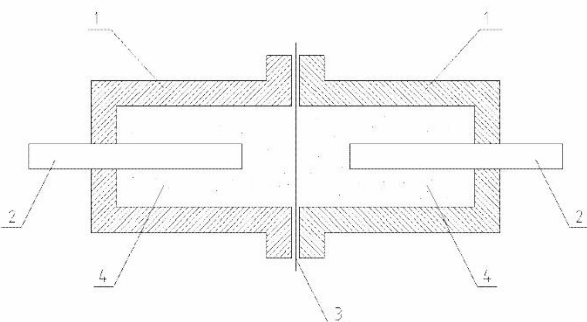


Figure 1. An electrolytic cell. 1 – vessels with electrolyte, 2 – electrodes, 3 – thin mylar film with openings, 4 – electrolyte.

The electrolytic cells consist of two vessels with distilled water, separated with a $h = 3 \mu\text{m}$ thick mylar film, which has openings (thin canals), $0.2 \dots 0.4 \mu\text{m}$ in diameter (Korotaev *et al.*, 2002; Morozov, 2011). The amount of the electrolyte in thin canals was approximately equal to 10^{-14}m^3 , which corresponded to the number of ions in the stated quantity of electrolyte of around 10^{10} . The design of electrolytic cells is shown in Figure 1.

Each of the vessels contained graphite electrodes connected to an input of an amplifier which amplifies voltage fluctuations on an electrolytic cell by a factor of 10^5 in a band of $5 \dots 15 \text{kHz}$. The resistance of the electrolytic cells during the experiments varied in the range of $15 \text{--} 100 \text{k}\Omega$. The voltage values after the amplifier with the sampling frequency of 30kHz were read by a PC, with $N = 1800000$ values per minute. According to the values of voltage fluctuation U_i , recorded in one minute, we calculated the dispersions D_1, D_2 and the Kullback measures H_1, H_2 for two experimental installations with the help of the following formulae (Morozov, 2011):

$$D = \frac{1}{N} \sum_{i=1}^N U_i^2, \quad (1)$$

$$H = \sum_{k=0}^K f_k \ln \left(\frac{\sqrt{2\pi} \sigma_U}{\Delta U} f_k \right) + \frac{1}{2}, \quad (2)$$

where $f_k = \frac{N_k}{N}$ is the ratio of the number of measurements N_k , falling into the interval of voltage values from U_k to $U_k + \Delta U$, to the total number of measurements N , K and ΔU is the number of partitions of the measured voltage values when plotting a histogram and the interval of these partitions, U_0 and U_K are the minimal and the maximal voltage values, $\sigma_U = \sqrt{D}$.

The choice of the Kullback measure as one of the parameters characterizing voltage fluctuations on electrolytic cells is determined by the fact that this measure has found wide application in describing unbalanced thermodynamic systems (Kullback and Leibler, 1951; Klimontovich, 1991; Kullback, 1997; Morozov, 2011). For the case under consideration, this measure characterizes the difference between the function of fluctuation partitioning on an electrolytic cell and the Gaussian distribution.

Concurrently with recording signals from the electrolytic cells, we measured the air temperature T_1 outside, in close proximity to the experimental installations and the temperature T_2 inside a passive thermostat, where the installations were located. The experimental installations were located in a basement, and the electrolytic cells were shielded from electromagnetic interference, hermetically sealed and heat-insulated from



environmental impact (Korotaev *et al.*, 2002; Morozov, 2011).

We then averaged and refined all the recorded experimental values of dispersions of the voltage fluctuations on electrolytic cells (D_1, D_2), Kullback measures (H_1, H_2) and temperatures (T_1, T_2) over a time period of one hour.

For further analysis of the impact of the external meteorological state on experimental installations, we used the data of the air temperature T , dew point temperature Td , wind speed V , relative air humidity Rh and the value of atmospheric pressure P , which were taken from the *Weather and Climate* website (www.pogodaiklimat.ru) for a Moscow weather station located at the *Exhibition of Achievements of National Economy* (WMO index: 27612). We calculated the relative air humidity Ro and the saturated vapour pressure Po according to the methodology given in (Sonntag, 1994; Murphy and Koop, 2005).

In Refs (Morozov, 2011, 2013, 2015a, 2015b), we conducted a preliminary analysis of the results of the long-term recording of Kullback measures for voltage fluctuations on two isolated electrolytic cells. We demonstrated that the values of the Kullback measure on them correlated with each other as well as with variations of the meteorological conditions, but the reason of the stated correlation was not discovered. In this work, we provide the results of processing experimental data that we obtained over the whole period of measurements, and discuss the hypothesis about a possible impact of the external dissipative processes on the character of voltage fluctuations in a small amount of electrolyte.

One of the basic parameters characterizing dissipative processes is entropy production (Kondepudi and Prigogine, 1998). For this reason, to verify the hypothesis about the impact of external dissipative processes on the values of the Kullback measure for voltage fluctuations on an electrolytic cell, we calculated entropy production caused by transformation of solar radiation into thermal radiation of the Earth's surface.

The choice of transformation of the solar radiation into thermal radiation as the external dissipative process is related to the fact that this process is the strongest for the Earth's conditions (Izakov, 1997). The density of entropy production for a unit of Earth's surface for the process under

consideration can be calculated in the first approximation as follows (Izakov, 1997):

$$\sigma_s = \frac{4}{3} \left(\frac{W_T}{T_3} - \frac{W_C}{T_C} \cos \gamma \right), \quad (3)$$

where: $W_T = \sigma T_3^4$ is the power of the Earth's thermal radiation from one square meter, $\sigma = 5,67 \cdot 10^{-8} \text{ W/(m}^2\text{K}^4)$ is the Stefan-Boltzmann constant, T_3 is the temperature of the Earth, $W_C = 1368 \text{ W/m}^2$ is the intensity of solar radiation falling on Earth, $T_C = 5778 \text{ K}$ is the temperature of solar radiation, γ is the angle of the solar rays falling on the Earth's surface, which depends on the time of the year and the day. To calculate entropy production σ_s in the first approximation, we shall consider that the temperature of the Earth's surface T_3 is equal to the temperature of the dew point Td in the surface boundary layer of the atmosphere.

The above-mentioned time series went through two types of filtering: band-pass and low-pass ones. With the band-pass filtration, we calculated the filtered values according to the formula:

$$\tilde{X}_i = \frac{1}{A_1} \sum_{j=i-24}^{j=i+24} \left(\frac{\sin(\pi(j-i)/24)}{\pi(j-i)/24} X_j \right) - \frac{1}{A_2} \sum_{j=i-600}^{j=i+600} \left(\frac{\sin(\pi(j-i)/600)}{\pi(j-i)/600} X_j \right), \quad (4)$$

where

$$A_1 = \sum_{j=i-24}^{j=i+24} \left(\frac{\sin(\pi \cdot j / 24)}{\pi \cdot j / 24} \right),$$

$$A_2 = \sum_{j=i-600}^{j=i+600} \left(\frac{\sin(\pi \cdot j / 600)}{\pi \cdot j / 600} \right). \quad (5)$$

The application of the expression (4) provided filtration of constituent signals with the periods of between 600 hours (25 days) and 24 hours (1 day).

With the low-pass filtration, instead of the expression (4) we used the formula:

$$\tilde{X}_i = \frac{1}{A} \sum_{j=i-240}^{j=i+240} \left(\frac{\sin(\pi(j-i)/240)}{\pi(j-i)/240} X_j \right), \quad (6)$$



where

$$A = \sum_{j=i-240}^{j=i+240} \left(\frac{\sin(\pi \cdot j / 240)}{\pi \cdot j / 240} \right), \quad (7)$$

which ensured the signal filtration with the period of under 240 hours (10 days).

Results of the experiments with band-pass filtration

Let us examine the results obtained from application of the band-pass filtering. In this case, to eliminate the dependence of the Kullback measure on the dispersion of the voltage fluctuations and the temperature of the installations, using the method of sliding regression, we calculated the following values:

$$\hat{H}_k = \tilde{H}_k - r_{Dk} \tilde{D}_k - r_{Tk} \tilde{T}_2, \quad (8)$$

where: r_{Dk} is the regression coefficient of the Kullback measure \tilde{H}_k and dispersion \tilde{D}_k , r_{Tk} is the regression coefficient of the difference $\tilde{H}_k - r_{Dk} \tilde{D}_k$ and the installation temperatures \tilde{T}_2 , $k=1,2$ is the number of the experimental installation.

Figure 2 presents a graph of the correlation coefficient $K(\hat{H}_1, \hat{H}_2)$ of the Kullback measures \hat{H}_1 and \hat{H}_2 for two independent experimental installations. As we can see from this figure, a small correlation $K(\hat{H}_1, \hat{H}_2) = 0,173 \pm 0,048$ of the Kullback measures \hat{H}_1 and \hat{H}_2 for two installations with practically zero shift of these time series. For calculation of the correlation coefficient and the standard deviation, we used the formulae from (Max, 1989). From the results shown, it follows that the signal/noise ratio for correlation $K(\hat{H}_1, \hat{H}_2)$ is equal to 3.6. According to Student's distribution, the possibility of the presence of value correlation of the Kullback measures \hat{H}_1 and \hat{H}_2 between two independent installations is equal to: $P = 0,9996$ (Jahnke *et al.*, 1960).

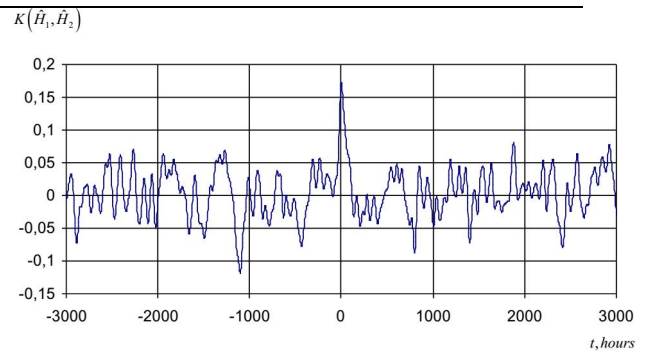


Figure 2. The correlation coefficient of the Kullback measure values \hat{H}_1 and \hat{H}_2 for two independent installations.

Table 1 presents the correlation coefficients, the signal/noise ratios, probability and time of correlation delay of the Kullback measure values for the two installations, as well as correlation coefficients of the average value of the Kullback measure

$$\hat{H}_{1,2} = (\hat{H}_1 + \hat{H}_2) / 2 \quad (9)$$

and the above mentioned values of meteorological parameters: \tilde{V} , \tilde{P} , $\tilde{R}h$, \tilde{T}_1 , \tilde{T} , $\tilde{T}d$, $\tilde{R}o$ and $\tilde{\sigma}_s$.

Table 1. Correlation coefficients, signal/noise ratio, probabilities and times of correlation delays.

Correlation coefficients	Correlation value	Signal/Noise ratio	Probability of correlation presence	Advance ment (delay), hours
$K(\hat{H}_1, \hat{H}_2)$	0.173±0.048	3.6	0.9997	0
$K(\hat{H}_{1,2}, \tilde{V})$	0.152±0.061	2.5	0.988	-51
$K(\hat{H}_{1,2}, \tilde{P})$	0.115±0.052	2.2	0.972	-33
$K(\hat{H}_{1,2}, \tilde{R}h)$	-0.215±0.064	3.3	0.9991	-33
$K(\hat{H}_{1,2}, \tilde{T}_1)$	-0.220±0.062	3.5	0.9995	-18
$K(\hat{H}_{1,2}, \tilde{T})$	-0.252±0.062	4.1	0.99996	-30
$K(\hat{H}_{1,2}, \tilde{T}d)$	-0.340±0.075	4.5	0.999994	-30
$K(\hat{H}_{1,2}, \tilde{R}o)$	-0.372±0.073	5.1	>0.999999	-30
$K(\hat{H}_{1,2}, \tilde{\sigma}_s)$	-0.347±0.075	4.6	0.999997	-30

From this table, we can conclude that the correlation coefficients of the average value of



the Kullback measure $\hat{H}_{1,2}$ with the wind speed \tilde{V} , the atmospheric pressure \tilde{P} and the relative air humidity $\tilde{R}h$ have a small enough signal-to-noise ratio (and therefore, a possibility of the correlation presence). The correlation of the Kullback measure $\hat{H}_{1,2}$ with the air temperature \tilde{T}_1 outdoors in close proximity to the experimental installations is lower than that with the air temperature \tilde{T} according to the data of the weather station WMO: 27612; at the same time, the delay of the Kullback measure $\hat{H}_{1,2}$ relative to the temperature \tilde{T}_1 is lower, than relative to the temperature \tilde{T} , which can be explained by remoteness of the weather station WMO: 27612 from the experimental installations, located on the premises of Bauman Moscow State Technical University.

Further in our analysis, we will consider the correlation with parameters that have the highest signal/noise ratio: \tilde{T} , $\tilde{T}d$, $\tilde{R}o$ and $\tilde{\sigma}_s$. We should point out that the correlation coefficient of the Kullback measure $\hat{H}_{1,2}$ with the saturated vapour pressure $\tilde{P}o$ practically coincides with the correlation coefficient for the absolute air humidity $\tilde{R}o$, and for that reason, it is not included in Table 1.

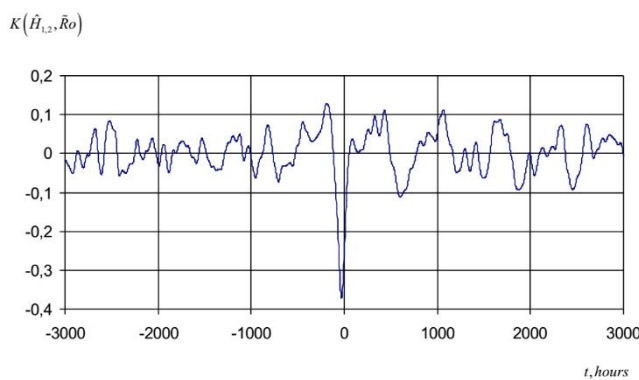


Figure 3. The correlation coefficient of the average value of the Kullback measure $\hat{H}_{1,2}$ and the variations of the absolute air humidity $\tilde{R}o$.

The graph in Figure 3 illustrates the correlation function of the average value of the Kullback measures $\hat{H}_{1,2}$ with the most

significant meteorological parameter: absolute air humidity $\tilde{R}o$.

The presented graph gives us a clear view of the presence of a negative correlation of the average value of the Kullback measure $\hat{H}_{1,2}$ and the variations of the absolute air humidity $\tilde{R}o$ with the time delay of about 30 hours.

Results of the experiments with low-pass filtration

We will further examine the case of applying low-pass filtration. To perform the calculations, the values of the Kullback measure \tilde{H}_1 , \tilde{H}_2 were subject to correction in order to exclude the impact of the values of dispersions \tilde{D}_1 , \tilde{D}_2 and the temperature \tilde{T}_2 of electrolytic cells, which were changed during the experiments. Applying the linear dependence of the Kullback measures and the standard deviation $\tilde{\sigma}_k = \sqrt{\tilde{D}_k}, k=1,2$, established in (Morozov, 2011), as well as small deviation of the temperature \tilde{T}_2 from its average value $\langle \tilde{T}_2 \rangle$, we can write the formula for calculating the Kullback measures \hat{H}_1 , \hat{H}_2 , with above mentioned correction:

$$\hat{H}_k = \tilde{H}_k - \chi_{\sigma k} \tilde{\sigma}_k - \chi_{T_k} (\tilde{T}_2 - \langle \tilde{T}_2 \rangle), k=1,2, \quad (10)$$

where: $\chi_{\sigma k}$ is the regression coefficient between the values of the Kullback's measures \tilde{H}_1 , \tilde{H}_2 and the standard deviations $\tilde{\sigma}_k = \sqrt{\tilde{D}_k}, k=1,2$, χ_{T_k} is the regression coefficient between the values of the Kullback measures \hat{H}_1 , \hat{H}_2 and the variations of the installations temperatures: $\Delta \tilde{T} = \tilde{T}_2 - \langle \tilde{T}_2 \rangle$.

Table 2 presents the values of the mentioned regression coefficients.

Table 2. Regression coefficients for two installations.



Regression coefficient	Installation 1	Installation 2
$\chi_{\sigma_k}, 10^{-4}B^{-1}$	3.332	3.011
$\chi_{T_k}, 10^{-6}K^{-1}$	1.692	0.258

Table 3. Correlation coefficients of the Kullback measures and meteorological parameters.

Correlation coefficients	Installation 1	Installation 2
$K(\hat{H}_k, \tilde{T})$	-0.252±0.060	-0.182±0.054
	-0.206±0.113	-0.844±0.062
$K(\hat{H}_k, \tilde{T}d)$	-0.276±0.073	-0.246±0.055
	-0.201±0.113	-0.873±0.057
$K(\hat{H}_k, \tilde{R}o)$	-0.288±0.070	-0.297±0.057
	-0.151±0.115	-0.852±0.061
$K(\hat{H}_k, \tilde{\sigma}_s)$	-0.283±0.072	-0.251±0.055
	-0.210±0.114	-0.847±0.062

Table 3 presents the correlation coefficients (and their standard deviations) for two installations, calculated using the band-pass filtration of the Kullback measure variation and meteorological parameters (the upper values in the corresponding table cells) and under the low-pass filtration of these values (the lower values in the corresponding table cells).

From this table we can conclude that the highest correlation is observed for the second experimental installation for the coefficient $K(\hat{H}_2, \tilde{T}d)$ under the low-pass filtration. Under the above-mentioned filtration, the values of the correlation coefficients for the first experimental installation are considerably less significant, which is due to a higher level of the low-frequency noise, observed in the results of the experiment, which were obtained from this installation.

Figure 4 presents comparison of the graph of dependence of the Kullback measure \hat{H}_2 on time and a similar graph for the dew point temperature $\tilde{T}d$, received during the experiment for the measurement period from March 20, 2011 to April 8, 2015. We can clearly observe the inverse dependence of the Kullback measure \hat{H}_2 on the dew point temperature $\tilde{T}d$ of the atmospheric air.

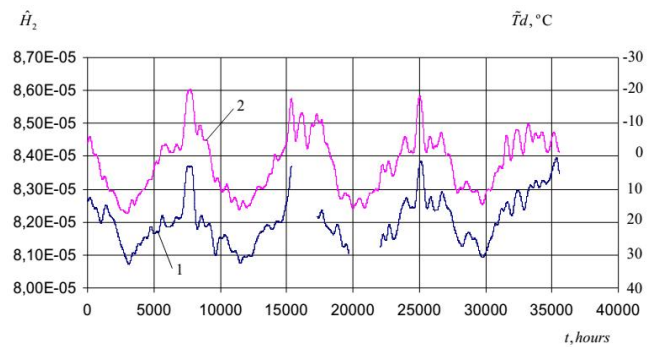


Figure 4. Graphs of dependence of the Kullback measures \hat{H}_2 (1) and the dew point temperature $\tilde{T}d$ (2).

Let us evaluate the impact of different meteorological parameters on the values of Kullback's measure. Table 4 presents calculated regression coefficients and their standard deviations for the meteorological parameters that have the biggest impact in case of band-pass filtration (upper values in the corresponding table cells) and low-pass filtration (lower values in the corresponding table cells). It follows from the results shown that the regression coefficients for the second installation in case of low-frequency filtering exceed the similar coefficients, calculated in case of band-pass filtration by a factor of 3-5. In case of band-pass filtration, the regression coefficients for the first installation are 1.5 to 2 times higher than for the second one.

Table 4. Regression coefficients.

Regression coefficients	Installation 1	Installation 2
$R(\hat{H}_k, \tilde{T}), 10^{-8} 1/K$	-2.33±0.38	-1.35±0.26
	-1.71±0.77	-6.53±0.39
$R(\hat{H}_k, \tilde{T}d), 10^{-8} 1/K$	-2.86±0.37	-1.67±0.25
	-1.93±0.76	-7.75±0.35
$R(\hat{H}_k, \tilde{R}o), 10^{-10} m^3/kg$	-0.82±0.04	-0.56±0.03
	-0.36±0.08	-1.88±0.04
$R(\hat{H}_k, \tilde{\sigma}_s), 10^{-6} m^2K/V$	-1.75±0.04	-1.02±0.03
	-1.20±0.08	-4.48±0.04



Conclusion

Based on the results obtained we can conclude that there is impact of the external meteorological state on the character of voltage fluctuation in a small amount of electrolyte. The above influence reveals itself in the change of the Kullback's measure for voltage fluctuations on an isolated electrolytic cell. A mechanism, related to the macroscopic nonlocal entanglement states of macroscopic systems (Korotaev *et al.*, 2002) can be considered as a hypothesis explaining the observed effects. This phenomenon, evidently, reveals itself in the impact of external dissipative processes on the character

of ion fluctuations in electrolyte. The impact of entropy production under natural dissipative processes on the intensity of time fluctuations could be another possible mechanism (Morozov, 2014).

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