Response of macroscopic nonlocal correlation detector to a phase transition

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Abstract. Macroscopic entanglement represents itself in nonlocal correlation of the entropy productions of classically insulated dissipative processes. Nonlocal correlation detector is a device including some, well protected from any local impacts, spontaneous dissipative probe-process, the entropy variation in which is related with a measurable variable (signal). Experimentally convenient example of the source-process is a phase transition. The experiment on measuring of response of electrode macroscopic correlation detector to the process of liquid nitrogen evaporation has been carried out. The signal extremum is reached much later than the end of evaporation. The detector response begins at once as the evaporation beginning, while classical local temperature impact has retardation equal to 1.5 hours. The form of response is essentially asymmetric, with long relaxation time.

1. Background

Macroscopic nonlocal correlation phenomenon theoretically is very complicated, and its strict description, compared with general level of physics of quantum information, still is in its infancy. The flow of publications, however, is growing fast facilitated by discovery of constructive role of dissipation in the entangled state generation, leading to with natural (weak but finite) entanglement of the macrosystems up to the cosmologic scale [1, 2]. Various frameworks for categorizing and quantifying such correlations have emerged in recent times [3,4]. Especially it should be noted the work [5], in which, on the base of various studies of macroscopic nonlocal correlations, the recipes of their detection by available for measuring macro-parameters have been presented. From another perspective, the role of temporal correlations, as different from more commonly studied spatial correlations, is being increasingly realized to play an important role in the specification of quantum features of macrosystems [6]. In a series of theoretical and experimental works (the starting motive of which was the view from modern positions on the early results on nonlocal correlations of dissipative processes [7]) [8-11] the approach adapted to observation of temporal macroscopic nonlocal correlations has been developed. The essence of the approach is that in the entangled states the entropy productions in various classically isolated dissipative processes nonlocally correlate. The experimental problem is to establish a correlation between the entropy productions (or the signals characterizing them) in an isolated probe-process in the detector and a source-process. The main part of our earlier
experiments was devoted to the study of the response of nonlocal correlation detectors to natural source processes (solar, global geomagnetic, synoptic activity, etc.). Experiments with them have a number of advantages. First, macroscopic nonlocal correlations reach a large value at extremely low frequencies (with characteristic times of the order of several months) and they are well distinguished in long-term experiments. Second, the combination of certain causal sources allows to prove nonlocal character of correlations by violation of the steering inequality. Third, many natural sources have a significant random component, which, in accordance with the principle of weak causality [12], allows us to observe the advanced component of non-local correlations (without the well-known classical paradoxes).

The experiments with artificial laboratory sources are deprived of these advantages, although, of course, they are necessary. Therefore, the experimental series with the artificial source – the process of phase transition (water evaporation) was also performed [8]. The electrode detectors were used, which proved to be the most reliable among the several developed types of detectors. The electrode detector is based on the measurement of spontaneous variations of self-potentials of weakly polarized electrodes in an electrolyte, which are directly related to entropy variations of a nanoscale double electric layer. Particular attention was paid to eliminating the influence of all noise-producing factors on the measured signal. As a result, a non-local response of the detector to the source-process was revealed. Its characteristic features were a significant (tens of minutes) retardation of the signal maximum relative to the moment of termination of the source, a significant spread of magnitude and retardation of response with multiple repetition of experiments under identical conditions and a large asymmetry of the response form (the signal growth time is on average 8 times less than the relaxation time).

2. Experiment

In this article we briefly present the results of the experiment, similar to the one described above, performed in 2018 on a renewed technical basis. The electrode detector with metrological Ag–AgCl electrodes HD-5.519.00 was used. These electrodes are the best in the world by the insensitivity of their self-potentials to the variability of environmental conditions. The only known factor affecting them is the temperature, which can be taken into account by its control. The process of phase transition (boiling of liquid nitrogen) was used as a source. In comparison with the previously used source – boiling of water, this process, at almost the same entropy production, allows much easier to protect from convective heat transfer and humidity, unenforceable to affect measuring circuits.

These circumstances made it possible to simplify the experimental setup (Figure 1). The temperature is controlled by three sensors, two of which ($t_1$ and $t_2$) are installed outside the housing at each electrode, and the third ($t_e$) at a distance of 1 m, characterizing the overall temperature in the laboratory at the height of the detector. The influence of temperature has been studied previously on the basis of multimonth continuous measurements of natural variations: temperature coefficient is $0.040 \text{ mV/K}$, retardation (caused by stabilizing action of water electrolyte) is 90 min. The detector signal $U$ and the temperatures are measured with frequency of 10 Hz and averaged over each minute. The relative error of measurement is not more than 0.01%. Nitrogen evaporation was carried out at the distance of 0.25 m from the detector. The volume of liquid nitrogen poured into the cuvette was 3 liters (or 2.6 liters). Given the long relaxation, the experiments were conducted at intervals of a day.

3. Results

Examples of the records of repeated experiments with the volume of evaporated liquid nitrogen 3 liters are shown in Figures 2 and 3, and with the volume 2.6 liters – in Figure 4.


**Figure 1.** Setup scheme. E are electrodes (complex internal device is not shown), the potential difference of which (U) is the detector signal; NaCl is electrolyte (3% aqueous solution); V is detector housing (ebonite); t₁, t₂, tₑ are temperature sensors; K is cuvette (quartz); N₂ is boiling nitrogen.

**Figure 2.** An example of record of the experiment. Start of evaporation at 10\textsuperscript{h} 12\textsuperscript{m}, end at 11\textsuperscript{h} 11\textsuperscript{m}. U is the detector signal with the removed temperature interference, t₁ is the temperature of the electrode near to the source, tₑ is the laboratory temperature.
Figure 3. Another example of record of the identical experiment. Start of evaporation at 10h 15m, end at 11h 14m.

Figure 4. An example of record of the experiment with 13% reduced in the amount of nitrogen. Start of evaporation at 10h 15m, end at 11h 06m.

Despite some similarities between the signal $U$ and temperature $t$ curves, it should be stressed that the classical local influence of temperature on $U$ is removed. Note that the characteristic rise in temperature before the experiment (indicated by the first vertical line), caused by the opening of the laboratory doors, almost does not affect the detector signal. The extreme proximity of the $t_l$ and $t_e$ curves indicates high temperature homogeneity. It is important that the response of the detector to the
inclusion of the source begins immediately (up to 1 minute), while the classical correlation with the temperature is retarded for 90 minutes.

There are noticeable differences in response to the same impact (Figures 2 and 3). The extremum $U$ is reached significantly later than the end of the action of the source (about 20 minutes in the examples of Figures 2 and 3, and 36 minutes in the example of Figure 4). The time for complete relaxation of $U$ is longer than the time of falling to the extremum in the examples in Figures 2 and 3, respectively, in 9.4 and 9.3 times, while in the example of Figure 4 -- in 7.3 times. These results are close to the early experiment with water evaporation [8].

The value of variation $U$ with a reduced amount of nitrogen is, as expected, less. However the observed significant increase in the time of retardation is an unexpected fact.

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