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Synchronous Differential Thermal Measurements and New Concept of Temperature

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Abstract- Using synchronous differential thermal measurements, the existence of the thermal surface energy (TSE), resulting from the oriented motion of the coupled field-particle system inside a material artefact, have been demonstrated experimentally with signal-to-noise ratio of several thousands. The TSE appears as a self-ordering evolution process when momentum and energy of an external electromagnetic field are absorbed in a material artifact. As the principle of superposition of EM fields is demonstrated not to be valid in case of TSE, any artefact is found to be in a continuous thermal evolution process (synthesis), which has no symmetry in space, is irreversible in time and is characterized by hysteresis effect with well-defined hysteresis loop. As the radiated energy, perceived by thermometers, is shown to depend on the oriented motion of the field-particle system, the concept of thermodynamic temperature has to be substituted by a more general one, which is valid in the general case and not only under the assumption of the illusionary, thermal equilibrium conditions.

Keywords: Surface energy, evolution process, hysteresis effect, symmetry violations.

1. Introduction

This paper will be started with reminding of A. Einstein's theoretical prediction that "classical thermodynamics can no longer be looked upon as applicable with precision…For the calculation of the free energy, the energy and the entropy of the boundary surface should also be considered" (Einstein,1905). And in the earlier paper, entitled "A Theory of the Foundations of Thermodynamics" [2], he unambiguously defined the basic assumptions of thermodynamics:" *Let the system be isolated, i.e., the system considered should not interact with other systems*". And further we find: "*Experience shows that after a certain time an isolated system assumes a state in which no perceptible quantity of the system undergoes any further changes in time; we call this state the stationary state*"(Einstein,1903). So, in accordance with A. Einstein, thermodynamics deals only with isolated systems, and when all the transient processes are already terminated in it. The recently proposed multi-channel synchronous detection technique (MSDT) (Titov, Malinovsky, 2005a), representing a differential type of thermal measurements, is very convenient for the studies of the energy propagation in the medium (Titov, Malinovsky, 2011). It can be also very useful to find out if the thermodynamic considerations or the assumptions of the Fourier heat conduction theory are still applicable to the experimental conditions, when the resolution of temperature measurements and stability of temperature standards is at the level of a few μK (Titov et al., 2001; Titov et al., 2005b)., when the time stability of the temperature-measurement equipment is achieved at the level of 9 μK/year (Titov, Malinovsky, 2005a) and the calibration uncertainty of SPRT of ~10μK is demonstrated (Titov et al., 2005b) for the temperatures close to 293K. This type of studies acquires special significance when we recall an observation of one of the most famous American scientists that "new discoveries are in the next decimal unit", or the fundamental Niels Bohr statements: "There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns what we can *say* about Nature", and "*Isolated material particles are abstractions*, their properties being definable and observable only through their interaction with other systems".

2. Thermal Surface Energy and Its Impacts

Our experimental set-up and the unprocessed results of the measurements performed for a steel artifact are presented in Fig.1. A steel length standard, which is called gauge block (GB), with dimensions 9x35x100 mm, is located horizontally on three small-radius, polished spheres inside a closed Dewar. The Dewar is kept in a temperature controlled room, where a typical standard deviation σ is ~ 50mK. Two thermistors R6 and R3, belonging to the channels 1 and 2 of the temperature measuring equipment (equipped with precision multi-meters HP-58A), are installed in copper adapters, whose axes are parallel to the gauging surfaces of the block. A 100-Ohm platinum resistance thermometer (PRT), also in a copper adapter, is located parallel and at equal distances from the thermistors. The PRT is connected to MI-bridge T615 (Canada), in which the current I is changed by step from 1 to 5mA (Fig.1). The period of a cycle is ~148 minutes. For the heating period of the modulation cycle, with the time duration of 37 minutes, the current I is 5mA, and for the cooling period (111 minutes) it is held at 1mA level. Thus, the PRT and the MI-bridge realize the modulation signal, delivering a calibrated input of thermal power to the block, and simultaneously form the third temperature measurement channel, so that the temperature differences between all the three channels can be precisely determined at any time moment.

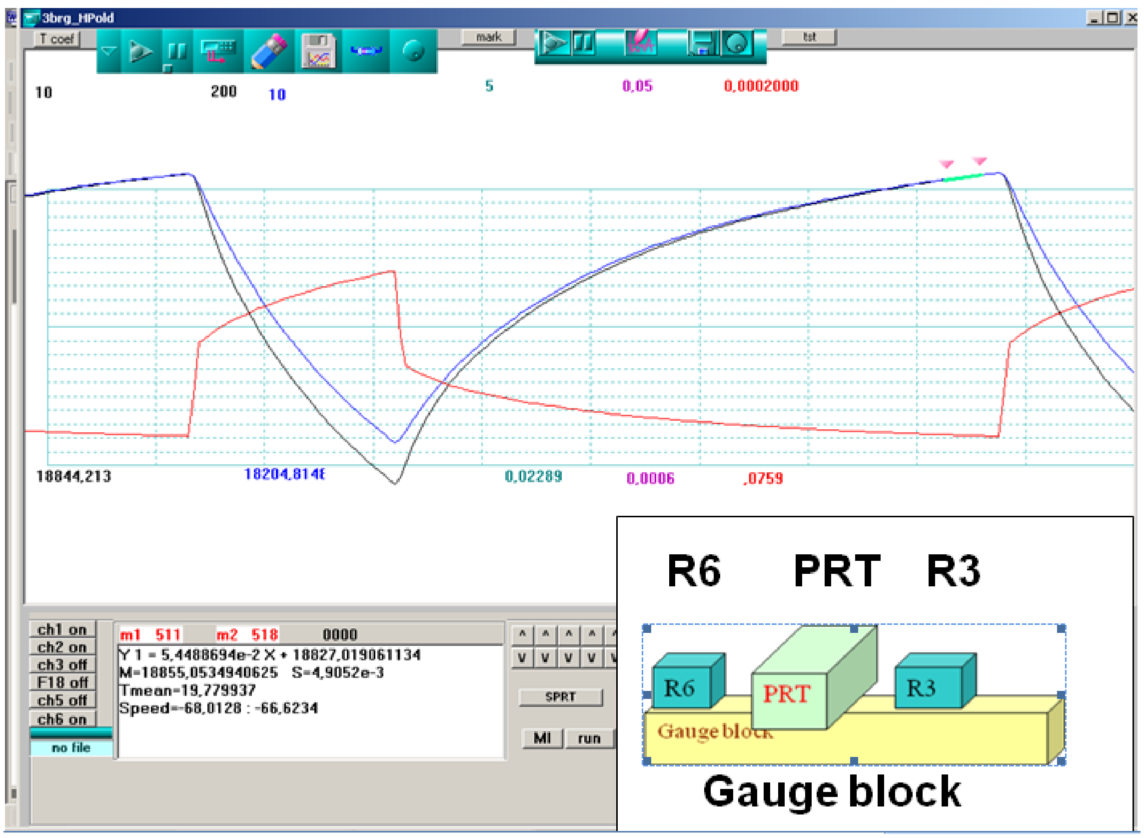

Fig. 1. Program for simultaneous measurements of temperatures in 3 channels. Insert shows the locations of thermistors and of the PRT on the GB surface.

In Fig.1, the temperature of the PRT corresponds to the record with faster transients. Two other records show the variations of resistances of the thermistors R6 and R3, which have negative temperature coefficients. Both thermistors have, practically, equal sensitivities. All the thermometers are calibrated to measure the temperature of a specified area on the surface of the block with reference to its own position, as described in detail in (Titov, Malinovsky, 2005a; Titov et. al., 2005b). The mean values of the temperature and of the temperature velocity, corresponding to the time interval (indicated by positions of the two cursors) are calculated by the program and are shown for one of the channels in the special window of the program in Fig.1. The measurements, performed in accordance with the indicated procedure for the records of Fig.1, have shown that for the last 25 minutes of the first cycle, the temperature difference between the channels T[1,2] is about 465.6μK. The corresponding σ-value for a single measurement point in that cycle is 3.3μK (for 5min. averaging time). For the next cycle, the value of T[1,2] for the reference points is 469.5μK with the σ-value of 2.3μK. These points define quite accurately the linear regression function at I=1mA, relative to which the *induced temperature variations* at I=5mA can be precisely determined. The result of a paramount importance, which can be clearly detected even from a couple of cycles of the unprocessed measurements of Fig.1, is that the *variations of the thermal energies, produced in a homogeneous artifact at equal distances from a heat source, are not equal, so that the arising distribution of thermal energy has no symmetry in space*. The thermometer, which is closer to the boundary, detects a higher level of the temperature variation during the heating period of the modulation cycle. And this is a demonstration of the existence of a *thermal surface energy*. Indeed, on one hand, the record is performed by thermometers and, consequently, this is a "thermal energy". And on the other, its value depends critically on the distance from the boundary of the artifact, as it is clearly demonstrated in Fig.2. So, this type of energy should be called "surface energy".

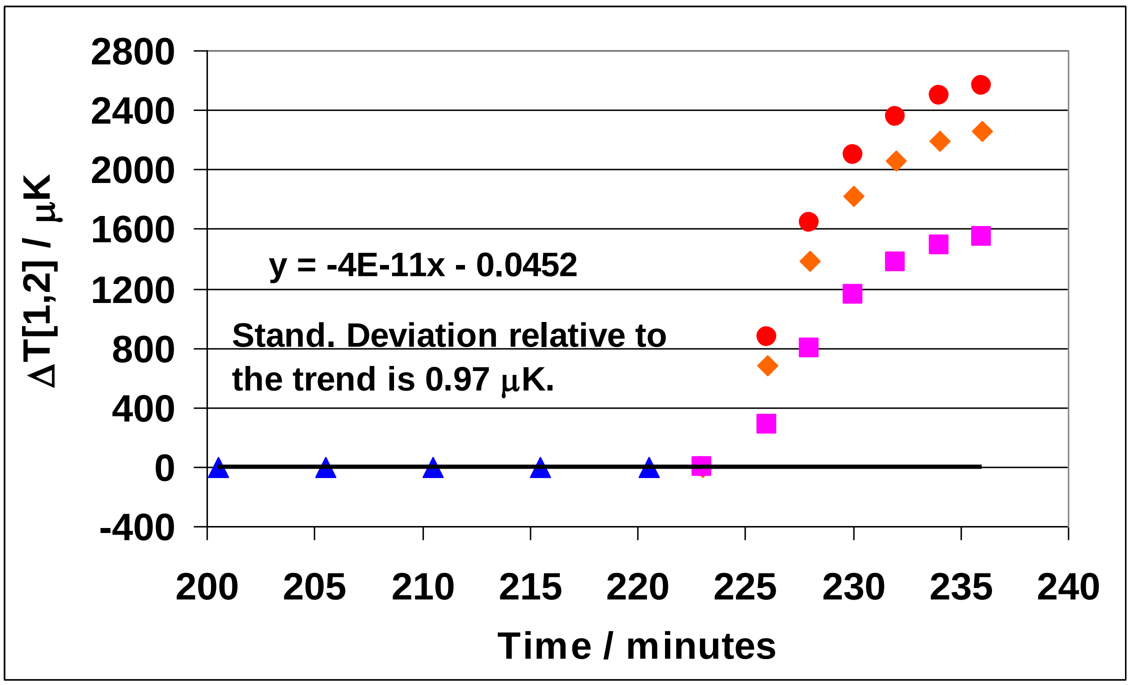

Fig. 2. Dependences of the vector quantity ΔT[1,2] on time for the separations of the R6 thermistor from the gauging surface of 4.5mm (dots), 9mm (rhombi) and 13.5mm (squares).

In Fig.2 the temperature difference between the synchronous indications of the channels 1 and 2 is presented. This difference appears purely as a result of the increase of the modulation current in the PRT and it is denoted by the quantity **ΔT[1,2]**. The dependences 1, 2, 3 in Fig.2 correspond to the first 13 minutes of the heating period of the modulation cycle. For the dependence 1, the separation of the axis of the thermistor R6 from the nearest gauging surface is 4.5mm. In this case, the side surface of the copper adapter of the thermistor coincides with the plane of the gauging surface. Thus, the dependence 1 corresponds to the nearest position of the sensor R6 from the gauging surface. The dependences 2 and 3 correspond to larger separations of the R6 thermistor from the artifact's boundary and these separations are chosen to be 9mm and 13.5mm, respectively. The induced temperature variations **ΔT[1,2]**, presented in Fig.2 as a function of time, are measured relative to the linear regression line, which is shown as a solid line in the figure and which corresponds to the temperature differences between the channels **T[1,2]**, obtained for the last 20 minutes of the cooling period of the modulation cycle. The experimental points for the temperature differences between the channels for the last 20 minutes at I=1mA will be called reference points and they are shown in Fig.2 as triangles. For a single measurement, the standard deviation of the reference points relative to the fit is only 0.97μK (insert of Fig.2), and the variation of the fit (reference function) for the whole time interval at I=5mA, which is shown in the figure, is well below 0.1μK. Taking into account that the induced temperature variations, represented by the quantity **ΔT[1,2]**, are measured relative to the fit and the maximum value for the dependence 1 exceeds 2500μK, we can conclude that the detection of the surface energy has been realized with the signal-to-noise ratio of several thousands. It should be specially emphasized that the induced temperature difference **ΔT[1,2]** is a vector quantity. Its positive value means that the thermal energy flux to the unit volumes, located in the vicinity of the gauging surface, is larger than the corresponding energy flux to the unit volume, located at the same distance from PRT in the direction of the bulk material (away from the gauging surface).

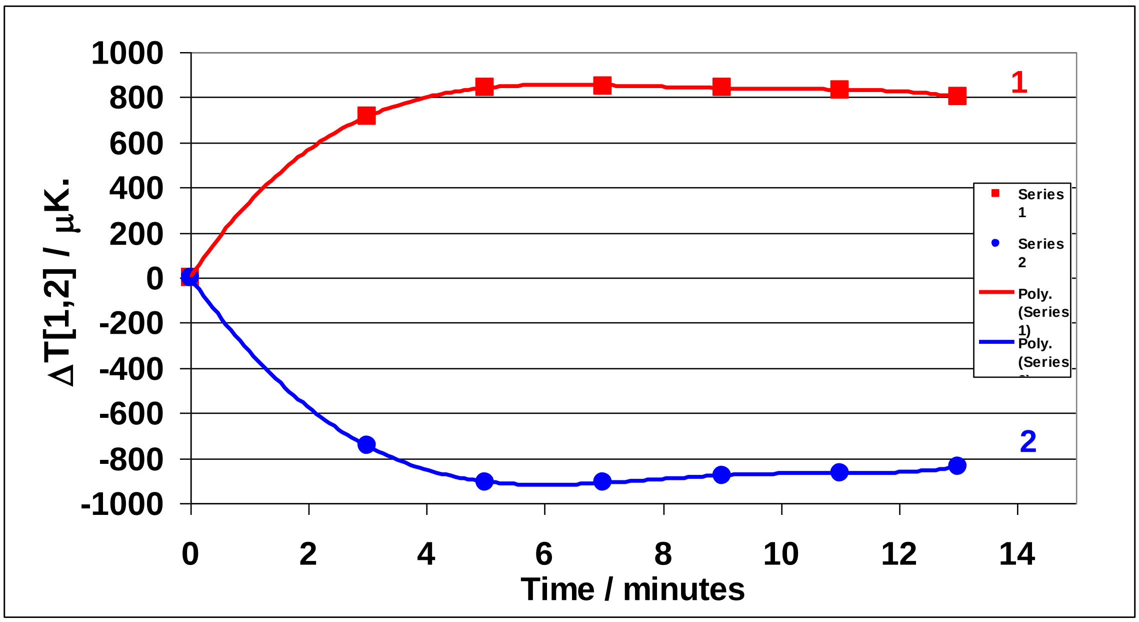

Fig. 3. Dependences of the surface energy ΔT[1,2] on time when the R6 thermistor is close to the gauging surface of the block (curve 1), and when the R3 thermistor is close to the opposite gauging surface (curve 2). See text for other details.

The experiment has shown that the process of creation of the surface energy in time can be crucially changed when using the artifact of different material. This property is illustrated by Fig.3, where the quantity **ΔT[1,2]** as a function of time is presented for a 100mm tungsten carbide (TC) gauge block. Dependence 1 in Fig.3 corresponds to the separation of 4.5mm from the gauging surface of the thermistor R6. Its comparison with the curve 1 in Fig. 2 shows that the magnitude of the surface energy in TC block is about 3 times smaller, but the evolution process is ~2.5 times faster than in a steel block. So, for the TC block a larger part of the process can be observed during the same observation time of 13 minutes. Dependence 2 in Fig.3 corresponds to the experimental conditions when the measuring system as whole is shifted to the other gauging surface of the block. In this case the thermistor R3 is closer to the other gauging surface, and the vector quantity **ΔT[1,2]** changes the sign, but the magnitude of the effect and its time dependence are, practically, the same. Thus, it has been experimentally demonstrated that the *distribution of the thermal energy in the block, made of the homogeneous material, has no spatial* *symmetry relative to the position of the external source of EM radiation (in the general case)*, as it is already clear from the unprocessed experimental results of Fig.1.

The other vector quantity, which is related to the surface energy and which can be obtained from the described experiments, is the difference in the induced temperature velocities **ΔV[1,2]**, recorded in the channels 1 and 2. Its dependence for the steel gauge block, under the experimental conditions of Fig.1, is shown in Fig.4. Here, the heating period of the modulation cycle is presented by dots, while rhombi show the obtained values of the induced thermal velocity **ΔV[1,2]** for the cooling period of the cycle. The reference points, whose magnitudes are below 1 μK per minute, are shown as squares. The physical meaning of the expression - thermal power recorded by thermometers - can be clarified from the basic Poynting theorem of classical electrodynamics (Jackson, 1999; Griffiths, 1999). In accordance with the integral form of Poynting theorem of classical electrodynamics, the rate of change of the electromagnetic energy in time within an artifact volume plus the rate of the total work, done by EM fields on charged particles within the artifact volume, is equal to the quantity of EM energy, which is delivered inside the artifact per unit time through its boundary surface by the Poynting vector (Jackson, 1999) .

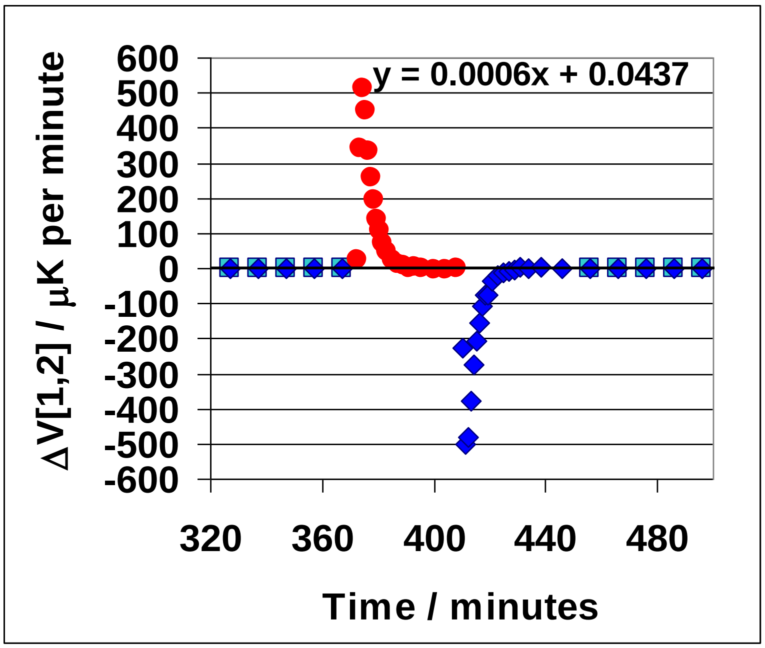

Fig. 4. Variations of the vector quantity ΔV[1,2] in time for I=5mA (dots) and for I=1mA (rhombi). The reference points are shown as squares.

The differential form of this theorem states that the rate of the change of the total-energy density, written for the particle-field system (Loudon et al., 1997), is defined by the divergence of the total-energy current density (see Eq. (2.14), (2.18) in (Loudon et al., 1997)). In other words, *the total power delivered to the elementary volume (dx dy dz), is defined by the total-energy flux of the coupled field-particle system* (Loudon et al., 1997) *that is delivered inside to this elementary volume through its boundary surface*. So, the results of experiments in Fig.4 give a clear indication that the difference in thermal powers (i.e. the difference in the time derivatives of the total field-particle energies that is recorded by the two channels) is the consequence of the additional, systematic flux of energy during the heating period of the modulation cycle to the volumes in the vicinity of the gauging surface (nearest to the heat source) relative to the volumes, which are located at the same distance from the heat source but in the opposite direction, away from the boundary of the artifact. As it follows from Fig.4, the additional thermal fluxes, which are responsible for the creation of the thermal energy **ΔT[1,2]** and for its disappearance, do exist only during a relatively short time interval after the change of the modulation current. Indeed, the quantity **ΔV[1,2]** is a vector quantity, and the change of its sign means the change of the direction. As the dependences in Fig.4 for the heating and cooling periods of the modulation cycle have, practically, the same magnitudes and shapes and differ only in sign, they describe the two, practically equal, energy fluxes, propagating in the opposite directions. But in accordance with Loudon et al., (1997) the energy current (flux) density defines the total force density, acting on the coupled field-particle system inside the material artifact. So, from the plot of Fig.4 it follows that during the modulation cycle, two forces of opposite directions and of practically equal amplitudes, are acting on the field-particle system at different time intervals.

Close correspondence between the properties of the thermal surface energy and the properties of ferroelectric materials (lack of symmetry in space and in time (Sivukhin, 2008a)) help to present the closed hysteresis loop for the thermal energy **ΔT[1,2]**, simply by inverting the time variable at the beginning of the cooling period of the modulation cycle. The hysteresis loop, under the experimental conditions of Fig.1 for the steel gauge block is presented in Fig.5. Here, between the time interval, indicated by the arrows 2 and 3, the time scale is the same as in Fig.2. For the time interval between the arrows 3-1, where the variations of **ΔT[1,2]** are negligible, the data points are presented for much larger time intervals, so that the end of the cooling period coincides with the beginning of the heating period. As the quantity **ΔT[1,2]** is measured relative to the mean value of the several reference points at the very end of the cooling period of the cycle, we have a perfectly closed loop, only with some random jitter at a few μK level, which is quite negligible in comparison with the magnitude of the TSE effect.

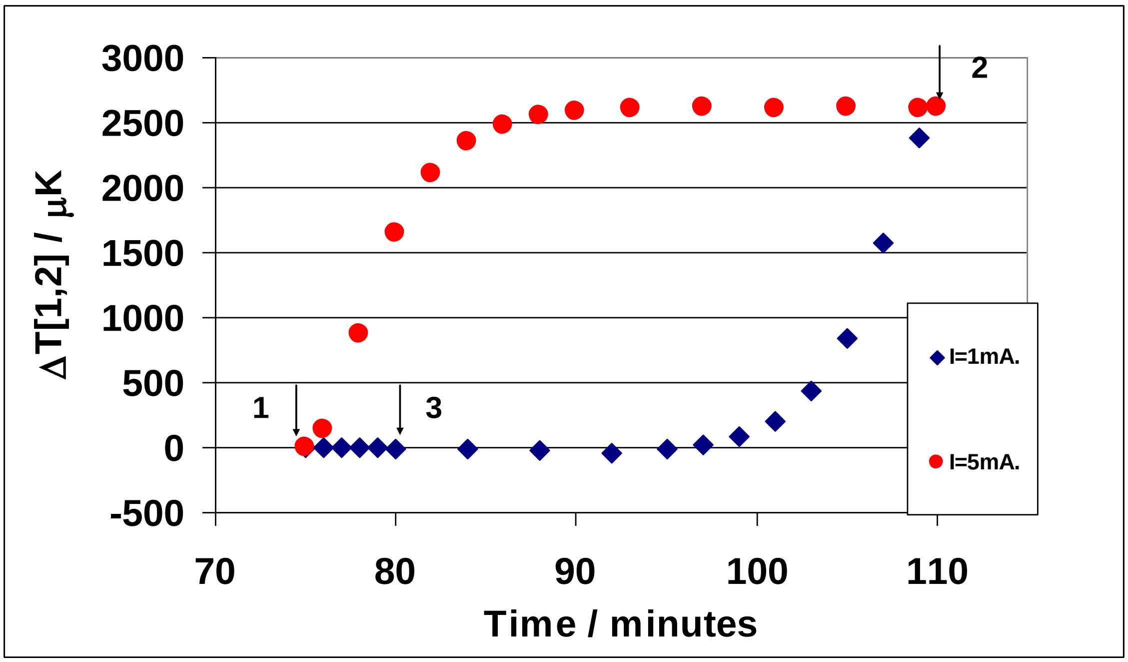

Fig. 5. Hysteresis loop for the magnitude of the thermal surface energy under experimental conditions of Fig.1. See text for other details.

The energy, which is radiated by the system during the modulation cycle and which is responsible for heating the environment, is defined by the form of the thermal hysteresis curve. As for the other, well studied hysteresis effects (Sivukhin, 2008a; Sivukhin, 2008b), the TSE process is an irreversible one. This conclusion immediately follows from the fact that for the reversed play of the record of the modulation cycle, the violation of the Second law of the Thermodynamics in Clausius-Plank formulation (Sivukhin, 2008c) is immediately observed.

Naturally, the demonstration of the thermal hysteresis loop assumes that the interaction of the external EM field with the material artifacts is a nonlinear one. This is experimentally confirmed by the plot of Fig.6, where the temperature variations **ΔT[1,2]**, induced by the modulation of the current in the PRT, are shown to be affected by the thermal radiation of an auxiliary energy source, located inside the Dewar system and producing the desirable temperature difference **T[1,2]** between the positions of the thermistors R6 and R3. Clearly, the presented experimental result is in agreement with the experiments of 1954 of P. Kusch (Ramsey, 1963), when the nonlinear character of interaction between the field and atomic system was demonstrated by using spectral response instead of an amplitude response in the described experiment, which is more appropriate in case of wide-band thermal radiation.

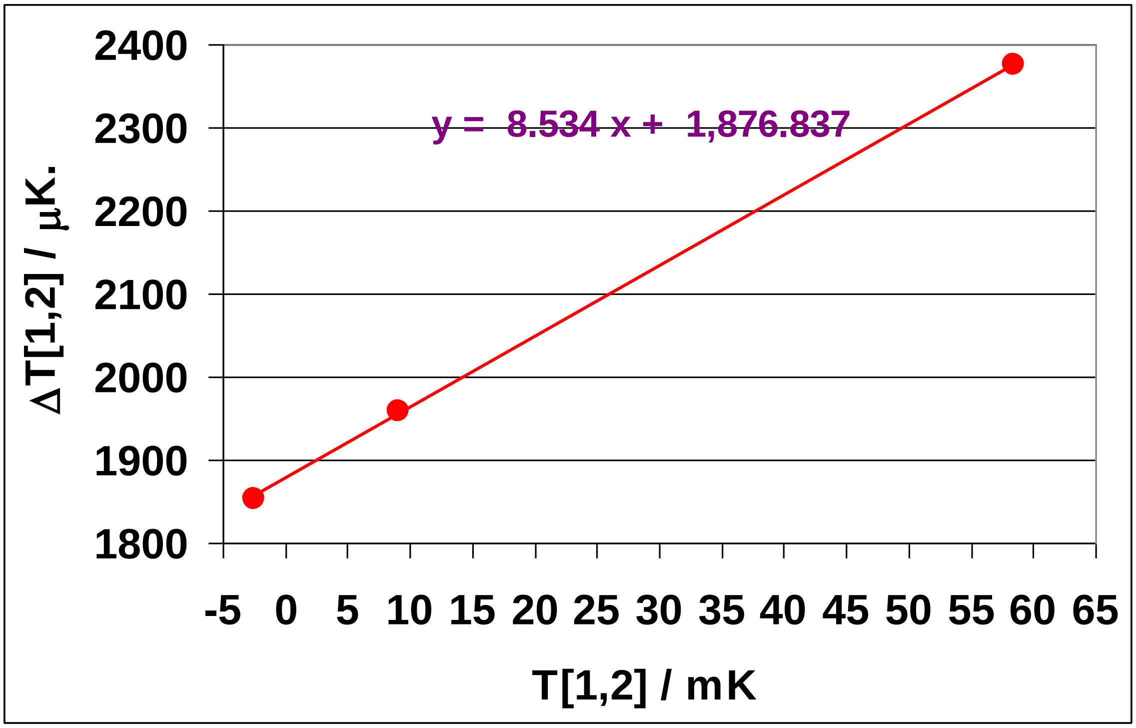

Fig.6. The variations of the magnitude of the thermal energy ΔT[1,2] under the application of the temperature difference T[1,2] between the positions of the thermistors R6 and R3 that is produced by an auxiliary heat source.

The very concept of thermal surface energy, representing the oriented motion of the coupled field-particle system with the quite precisely measurable values of the total momentum and of the energy densities, contradicts the primitive theoretical assumption of the isolated system in adiabatic enclosure. From the university physics course we can find that all the materials are becoming relatively transparent at high enough frequencies, so that the concept of thermodynamic temperature is not appropriate for plasma physics, where adiabatic enclosures do not exist in any approximation (Sivukhin, 2008d). For precise temperature measurements, achieved nowadays, the concept of thermodynamic temperature as a function of state is evidently obsolete, and may be substituted by the concept of temperature, representing the energy of the coupled field-particle system, which can be detected through the radiated EM field by different types of thermometers. Here, thermometers represent the devices, which effectively absorb the propagating EM field and which convert the oriented field propagation into the random motion of the charged particles, simultaneously transferring the corresponding field impulse to the Earth, or to the other material surrounding. This definition of temperature is, at least, in agreement with the Poynting theorem of classical electrodynamics and the fundamental observation of Ch. Kittel (2005) that the conserved quantity in solid state physics is the total momentum, consisting of the kinetic momentum of a particle and the potential momentum of the EM field. Without this new definition of temperature it is not possible to describe properly the already experimentally observed thermal surface energy and thermal evolution process.

3. Conclusions

Summarizing the results of this experimental study, we can emphasize that the fundamental properties of the thermal evolution process – the lack of symmetries in time and in space, the violation of the superposition principle for EM fields, the presence of the hysteresis effect and its dependence on the Poynting vector – inevitably result in the dramatic changes of the basic concepts of classical electrodynamics. The presented experimental studies give a clear confirmation to N. Bohr's fundamental observation that isolated material systems are only abstractions of theoretical physics, not valid even for macroscopic objects.

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