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Study of the thermoelectric effect in the animal's blood

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The paper presents the results of experimental measurements of thermoelectromotive force and electrical conductivity of animal blood samples and Ringer's medical solution, which are similar in their properties and chemical composition to human blood. The influence of the contributions of the ionic component and the contribution of blood corpuscles on the value of the thermoelectromotive force coefficient is analyzed. The effect of dilution with distilled water on thermoelectric properties and electrical conductivity of blood has been studied. The influence of the ionic composition of a model medical Ringer's solution on the coefficient of thermoelectromotive force is analyzed. The experimental results show that the coefficient of thermoelectromotive force of the blood samples under study is determined to a greater extent by the colloidal component of the shaped elements than by the contribution of the ionic subsystem. The results obtained indicate that thermoelectric phenomena in biological fluids can affect the activation of biochemical processes in the body of animals.

Keywords: thermoEMF, electrical conductivity, colloidal solutions, blood plasma.

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Introduction

Principles of emerging thermosensitivity in living organisms, temperature control mechanisms in warm-blooded animals, including man are studied in a set of publications [1,2]. Study of the influence of biopotentials on life support processes is of high interest both from the point of view of practical medicine and from the point of view of fundamental biophysics [3]. There are publications where biological fluids are studied, primarily animal blood [4], to investigate chemical composition, its association with normal life support processes, physical methods are discussed, primarily, chemical and optical diagnostics by blood variables [5,6].

Previously, authors of [7] put forward a hypothesis of influence of thermoelectric processes taking place in biological fluids on temperature control processes. The hypothesis was put forward on the basis of the study of thermoelectric properties of solutions simulating human blood.

The human blood simulating solutions included: Ringer's solution [8] simulating ion composition of human blood serum, serum albumin distilled water solution simulating colloid blood subsystem and their mixtures. According to the experiments, thermoelectric EMF of Ringer's solutions and their mixtures with serum albumin has unusual thermoelectric properties. In the temperature range up to 33°C, thermo-emf factor is equal to zero and above this temperature $\alpha = -16 \pm 6\,\mu$V/K.

At the same time, the experiments in [8] did not address the essential blood subsystem of living organisms — blood count subsystem which imparts suspension properties and is equal to 40−50% of human blood weight and 30−45% in animals [9,10]. And in the remaining 50−60% falling on blood serum, 90% is taken by water. Therefore, in quantitative relationship, red blood cells make prevailing contribution to blood composition of living bodies. [11] reported that if one subsystem prevails over another in mixtures of colloid solutions with ion electrolytes in quantitative ratio, this subsystem will make the main contribution to thermoelectric EMF of the mixture.

According to the foregoing, the purpose of the research is to investigate the red blood cell subsystem contribution into the final thermoelectric EMF of blood of living organisms.

1. Experimental results and discussion

To measure thermoelectric EMF in animal blood samples, experimental unit based on U-shaped tube described in [8] was used.

2. Study of thermoelectric properties of animal blood

Measurements of thermoelectric effect on animal blood samples (pigs, nutria) were first carried out herein. Influence of blood composition change due to dilution with distilled water, Ringer's water on thermoelectric factor was studied.

Fresh, max. 24 h from collection, cooled pig and nutria blood was used as samples. Large coagulate fractions were removed from the samples by mechanical filtration before the measurement.

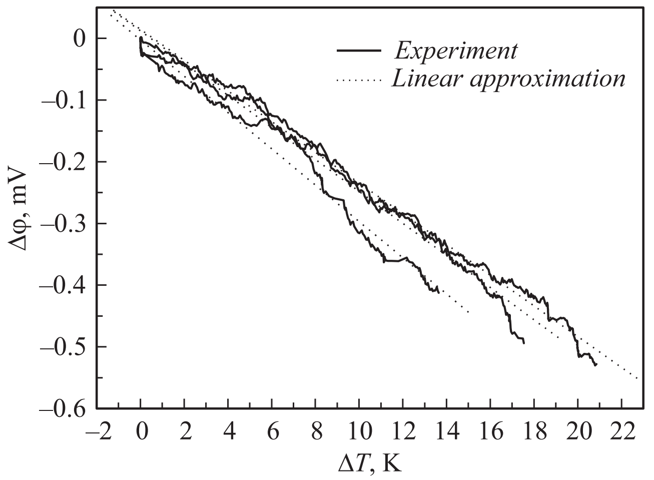

Figure 1. Dependence of thermoelectric potential difference on temperature difference for pig blood samples. Colder area temperature is equal to 18°C.

Composition of warm-blooded animals blood, primarily pigs, is close to that of human blood. Ion composition of blood serum is mainly defined by sodium, potassium and calcium cations as wells as chlorine anions. Their content in human blood serum is as follows: 135–155 mmol/l (Na^+), 3.6–5.0 mmol/l (K^+), 2.25–2.75 mmol/l (Ca^{2+}), 97–108 mmol/l (Cl^-) [9]. Difference with pig blood serum composition is negligible: 180 mmol/l (Na^+), 7 mmol/l (K^+), 3 mmol/l (Ca^{2+}), 100 mmol/l (Cl^-) [10]. Ion content in adult nutria blood serum is: 126 mmol/l (Na^+), 7.5 mmol/l (K^+), 115 mmol/l (Cl^-) [12].

Pig blood was chosen as the first test object simulating human blood. Measurement of thermoelectric potentials was carried out in conditions when the temperature of colder part was unchanged and was equal to 18°C. The opposite blood sample area was heated up to 40°C, which makes it possible to prevent red blood cell degradation due to denaturation of proteins. Thus, such experiment configuration simulates warm-blooded living organism functioning conditions to a great extent.

Figure 1 shows dependences of thermoelectric EMF of three pig blood samples on temperature difference between the heated and cold areas. Thermo-emf coefficient $\alpha = -26.6 \pm 4\,\mu$V/K was calculated by the linear approximation method. The specified value exceeds the previously measured thermo-emf coefficient of Ringer's solution by a factor of 1.5. In addition,the nature of dependence changes: if in Ringer's solution, thermo-emf coefficient depended on temperature to a large extent, blood samples show steady change in thermoelectric potential difference with temperature difference growth.

The obtained data on the influence of serum concentration on its thermoelectric properties indicate prevailing contribution of colloid components of red blood cells.

In order to reduce systematic error, a set of measurements was carried out both in the temperature growth area (tube heating) and in the temperature reduction area (tube cooldown after furnace shutdown). Difference in measured values α did not exceed 10%.

Similar measurements were carried out on nutria blood samples. Experimental results are shown in the form of thermo-emf dependences on temperature difference in Figure 2. Thermo-emf coefficient $\alpha = -28 \pm 4\,\mu$V/K.

[13] shows that the thermo-emf coefficient $\alpha = \Delta\varphi/\Delta T$, until high concentration gradients are formed in the solution, is defined by additive contributions of separate charged particles, each of them is proportional to the product of mobilities u_i and transfer heat Q_i:

$$\alpha \propto -\sum_i \frac{u_i Q_i}{T z_i}.$$

where z_i is the electrical charge of a particle of type i in electron charge units. Analysis of the foregoing data on the chemical composition of animal blood serum shows that the ratio of potassium ion concentration to sodium ion concentration is maximum for nutria blood and is about 1 : 17, and for pig blood does not exceed 1 : 26. In order to define the influence of potassium ions on the thermo-emf coefficient of blood, measurements on simulated samples were carried out: Ringer's medical solution and its modifications with increased potassium ion content.

Ion composition of Ringer's medical solution is isotonic to human blood serum. Industrially produced solution contains nonorganic salts — 8.60 g/l NaCl, 0.30 g/l KCl and 0.33 g/l $CaCl_2$ and additives — sodium hydroxide, hydrochloric acid. Thus, the ratio of potassium ion concentrations to sodium ion concentration is equal to 1 : 37. Thermo-emf coefficient of Ringer's solution was changed by us earlier [7] and was equal to $\alpha = -16 \pm 6\,\mu$V/K. Addition of 0.1 g/l

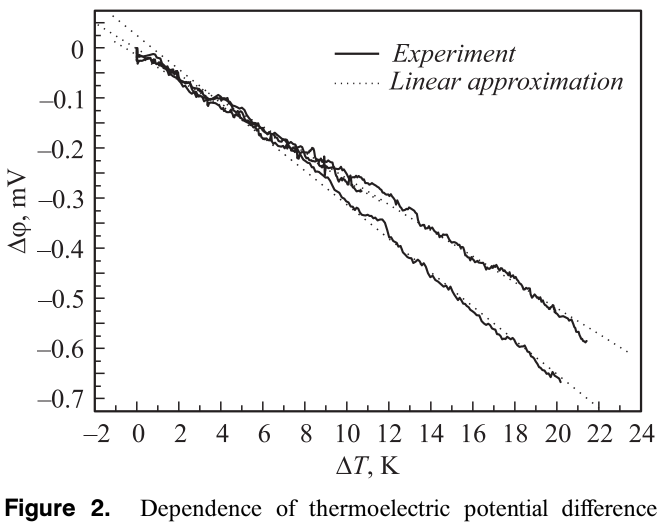

Figure 2. Dependence of thermoelectric potential difference on temperature difference for nutria blood samples. Colder area temperature is equal to 18°C.

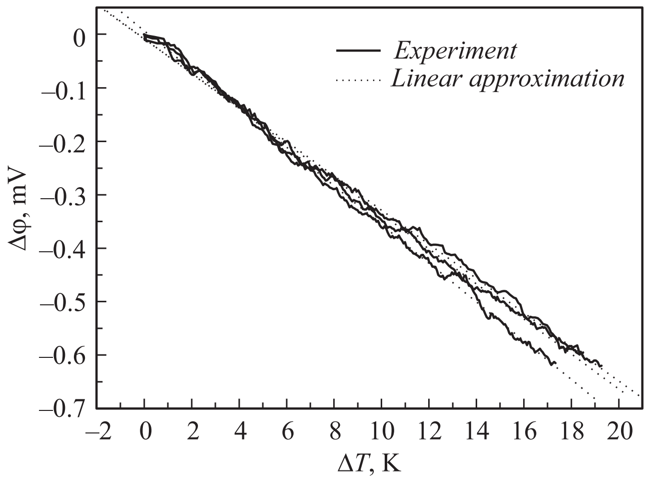

Figure 3. Dependence of thermoelectric potential difference on temperature difference for pig blood samples diluted by distilled water in ratio 70 : 40.

potassium chloride solution reduced α to $10\,\mu$V/K, and a concentration of 0.3 g/l virtually reduced this value to zero (lower than $5\,\mu$V/K).

Thus, potassium ion concentration having significant impact on biochemical processes in living organisms [9] also influences thermoelectric potentials appearing in blood under temperature gradients.

3. Study of conductivity of blood colloid subsystem

Colloid solutions such as animal and human blood are well studied in terms of chemical analysis, there is comprehensive information on conductivity of these objects [13]. Conductometry methods were used to obtain absolute conductivity values and assessment of contribution of individual subsystems to electric charge transfer processes in blood.

Medium conductivity coefficient σ is defined by additive contributions of all types of charged particles and depends on their mobility u_i [14]

$$\sigma = F \sum_i |z_i| c_i u_i,$$

where F is Faraday constant, z_i is the electric charge of particle in electron charge units, c_i is the volumetric concentration of particles of type i.

According to [9], conductivity of whole blood is to 70% defined by salts present in serum (mainly sodium chloride), to 25% by serum proteins and only to 5% by blood cells. No systematized data on thermoelectric properties of blood is available in literature.

In order to define the contribution of red blood cell subsystem into the final thermoelectric EMF, measurements were continued on blood samples modified with addition of distilled water. Ratio of mass components of whole blood to distilled water was 70 : 40 (Figure 3). This proportion was used both for nutria blood and pig blood. Directly before the measurement, the obtained solutions were subjected to mixing to retain compound homogeneity.

In addition to the study of thermoelectric EMF, the specified diluted pig and nutria blood samples were used for measurements of conductivity coefficient. The measurements were carried out using Mettler Toledo S30 laboratory conductometer. For this, conductivity was recorded on heated and cold ends of U-shaped tube.

Summary data on conductivity for various pig and nutria whole blood temperature as well as for their aqueous solutions in Table 1.

According to the measurements, the conductivity coefficient of solutions is proportionally lower than the conductivity coefficient of initial blood samples. This is associated with reduced ion concentration in plasma giving, as it has been already said, the main contribution to the electric charge transfer mechanism.

Conductivities of heated areas in blood samples exceed conductivities for cold tube ends. The specified ratio is satisfied both for initial pig and nutria samples and for aqueous solutions. And conductivity of pig and nutria whole blood is increased, respectively, by 3.0% per 1°C and 2.5% per 1°C, which agrees with human blood data: approx. 2.1% per 1°C [9]. Temperature coefficient of conductivity of aqueous solutions of pi and nutria blood is a little bit lower than for whole blood: respectively, 2.5 and 2% per 1°C. The specified dependence of conductivity of diluted electrolytes on temperature agrees with [15].

Summary thermo-emf coefficients for pig and nutria whole blood as well as for their aqueous solutions are listed in Table 2.

The analysis of obtained results indicates that dilution of colloid solution leads to the increase in thermo-emf coefficient. This dependence was obtained both for pig blood and nutria blood.

Conclusion

Thus, the experimental study of thermoelectric properties of animal (pigs and nutria) blood allows to make the following conclusions.

1. Dependence of thermoelectric potentials on temperature in animal blood samples as opposed to Ringer's medical solution is monotonic, and thermoelectric EMF by absolute value is 1.5 times higher and is equal to $\alpha = -26.6 \pm 4\,\mu$V/K for pig blood and $= -28 \pm 4\,\mu$V/K for nutria blood.

2. Dependence of thermoelectric differences of potentials on temperature is defined mainly by red blood cells and, to a lesser extent, by ion component of blood serum.

3. Animal blood conductivity and temperature dependence almost coincide with known data for human blood and are defined by the ion component.

Table 1. Conductivity measurements in pig and nutria blood as well as in aqueous solution at 20 and 40°C

№	Substance	σ, μS/cm		Relative error, %
		$T = 20^\circ$C	$T = 40^\circ$C	
1	Pig blood	39.9	64.8	±5
2	Pig blood diluted with distilled water in the ratio of 70 : 40	28.7	44.8	±5
3	Nutria blood	41.5	62.8	±5
4	Nutria blood diluted with distilled water in the ratio of 70 : 40	31.0	42.7	±5

Note. Dilution was carried out with distilled water in the ratio of 70 : 40; confidence probability for all measurements 0.95.

Table 2. Measurements of thermoelectric EMF of pig and nutria blood as well as water solutions

Item №	Substance	α, μV/K	$\pm\alpha$, μV/K	Relative error, %
1	Pig blood	−26.6	4	±15
2	Pig blood diluted with distilled water in the ratio of 70 : 40	−33.7	2	±6
3	Nutria blood	−28.0	4	±14
4	Nutria blood diluted with distilled water in the ratio of 70 : 40	−31.2	4	±13

Note. Dilution was carried out with distilled water in the ratio of 70 : 40; confidence probability for all measurements 0.95.

Potentials formed as a result of thermoelectric effect probably may influence biochemical processes in body, in particular may be one of the physical mechanisms which determine temperature control.

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Compliance with ethical standards

All applicable international, national, and/or institutional guidelines for animal care and management were observed.

This research does not include any studies involving humans as objects.

Conflict of interest

The authors declare that they have no conflict of interest.

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