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Physics

PROBING OF A MIXED AQUEOUS SODIUM CHLORIDE AND GLUCOSE SOLUTION WITH THE USE OF A THERMOELASTIC OPTICAL INDICATOR MICROSCOPE

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In the article, we present a report on the observation of microwave absorption of sodium chloride (NaCl) and glucose aqueous solution of various concentrations using a thermoelastic optical indicator microscope (TEOIM). The non-invasive sensing technology of TEOIM offers a great advantage over other detection technologies. With the help of TECIM, the change in the distribution of the microwave field was visualized depending on the concentration of NaCl and glucose in the range of 8–14 *GHz*. This article shows the investigation results for various concentrations of NaCl (0–2.5%) and presents the behavior of average microwave near-field intensity for glucose (varied in the range of 0–10%) and NaCl (fixed at 0.9%) complex aqueous solutions.

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***Keywords*:** sodium chloride, glucose, microwave, near-field distribution.

Introduction. Sodium Chloride (NaCl) is an essential compound in the human body. It is used to absorb and transport nutrients, maintain proper fluid balance, contract and relax muscles, etc. [1, 2]. The human body needs NaCl to function, but too little or too much concentration can be detrimental to human health. 0.9% NaCl solutions are widely used in medicine, food industry, chemistry and other areas. There is a wide spread need for high sensitive and reliable sensors for investigation of NaCl mixture solutions. NaCl solutions have unique electrical and biological properties. Sensitive detection of NaCl concentration changes will become a useful tool for researchers [3–5].

NaCl and glucose solutions are commonly used for infusion into human body as a source of energy, as well as to maintain and replace body fluids [6–8]. NaCl

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and glucose solutions at various concentrations of glucose can be used alone or in combination with another injectable nutritional supplement in patients who are unable to eat by themselves. In the NaCl and glucose solution, each of the components has its functions. Glucose provides energy and nourishes the body, while NaCl corrects NaCl imbalances and helps prevent dehydration. In this biological solution, the concentration of NaCl is 0.9%, which is the optimal percentage for the human body, but there are different concentrations for glucose depending on the patient. The normal concentration of glucose in human blood ranges from 70–140 mg/dL (0.07–0.14%). An incorrect concentration of glucose in the blood can harm a person. In this regard, there is a need for non-invasive investigation of these solutions.

Currently, many of systems for studying NaCl and glucose solutions are invasive, which has its drawbacks [9–11]. It is important to have non-invasive investigation method for NaCl and glucose testing that is both sensitive and efficient.

In this study, NaCl and glucose solutions were examined using a thermoelastic optical indicator microscope (TEOIM) [12]. TEOIM provides a non-invasive study of aqueous solutions under the influence of a microwave field. In this article, an aqueous solution of NaCl was monitored at various concentrations, volumes, and mixed with glucose at various concentrations. The studies were carried out with microwave radiation in the range of 8–14 GHz with a power of 2 W.

Description of the Experiment. Fig. 1 shows the experimental scheme of TEOIM [13]. An optical indicator (OI) is a glass with a nanometer-thick layer absorber of the magnetic component of radiated microwave field. The incoming light is first linearly polarized by a liner polarizer then it is modulated into a right or left circularly polarized wave by a $\lambda/4$ plate. After passing through the indicator, the wave changes its polarization from circular to elliptical due to thermoelastic deformations.

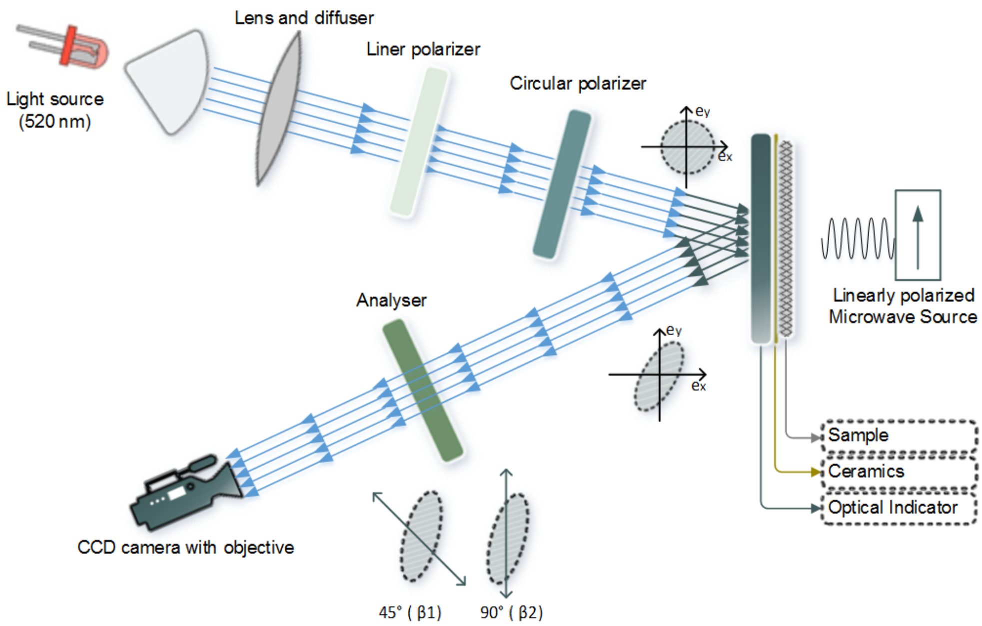

Fig. 1. Schematic diagram of the TEOIM.

Microwave radiation affects the sample and then, due to the properties of the indicator, is selectively absorbed in the OI. As a result of absorption, heat dissipation occurs in the absorption layer, which propagates through the thermoelastic medium and is causing thermomechanical stresses. When circularly polarized light falls on an environment with mechanical stress, the reflection from relief changes its polarization from circular to elliptical. As the CCD camera monitors the linear refraction of the OI, it makes it possible to record the mechanical stress in the OI. The elliptically polarized light reflected from the OI, passes through 90° or 45° oriented analyzer and is recorded by a CCD camera. As a result of the camera monitoring, the change in linear refraction in the optical indicator due to the samples' properties is recorded.

Since the heat source corresponding to the projected object is distributed in the finite range, the heat distribution of the source can be written as [13]:

$$q = C\left(2\frac{\partial^2 \beta_2}{\partial x \partial y} + \frac{\partial^2 \beta_1}{\partial x^2} - \frac{\partial^2 \beta_1}{\partial y^2}\right), \tag{1}$$

where q is the heat source distribution, β_1 and β_2 in the indicator are sliding voltages of normal and tangential components, and c is a constant depending on the wavelength of the incident light and OI properties. An synthesizer sweeper R&S SMA100B was used as a microwave source. Generated signal was amplified with Mini-Circuits ZVE-3W$-$183+ (0–35 dBm) and after amplification the signal was transmitted via Pasternak WR-90 coaxial to waveguide adapter.

Here we report the measurement of NaCl and glucose concentration in aqueous solution using TEOIM. The samples were plastic tubes with an inner diameter of 0.8 *mm*, filled with NaCl or/and glucose solution and placed in front of the microwave source at a distance of 10 *mm*. During the experiment, tubes of larger and smaller diameters were used (as an imitation of a human vein), but the most sensitive result was obtained for a 0.8 *mm* diameter tube, which was used in measurements as a container for aqueous solutions. The concentrations of NaCl were measured in the range of 0–2.5% with a concentration step of 0.5%, and glucose concentrations were measured in the range of 5–10% (by 1%, 2%, 5% and 10% steps).

Results and Discussion. Fig. 2 shows the measured dependence of the average signal intensity on the frequency (8–14 *GHz*) for the background field (free field) and 0.9% NaCl aqueous solution. The frequency behavior shows increasing trend both for deionized (DI) water and 0.9% NaCl solution. The change in intensity during the frequency sweep shows that the peak values and the largest difference between the measured DI water and NaCl solution were obtained at frequencies of 11 *GHz* and 13 *GHz*. Since used Pasternak WR-90 waveguide has an operating range of 8.2–12.4 *GHz* operating range, the operating frequency of 11 *GHz* was chosen for all measurements as correct operation frequency with highest sensitivity.

During the experiment with the TEOIM, we visualized the microwave near-field distribution of samples at a frequency of 11 *GHz*. Fig. 3 shows the microwave near-field distribution for (a) DI water and for NaCl and glucose mixed aqueous solutions. The concentration for NaCl was fixed at 0.9%, while the concentration of glucose in the mixture solutions varied from 0 to 10%. As can be see from Fig. 3, when the glucose concentration increased, the intensity of the microwave near-field in the central part of the tube decreased. Such a change in intensity is due to a decrease in the number of free dipoles in solution with an increase in glucose concentration.

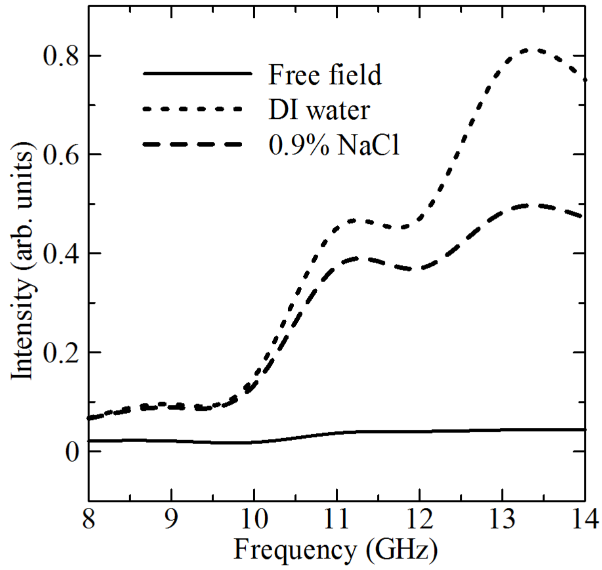

Fig. 2. The measured dependence of the average intensity on the microwave exposure frequency without a sample, i.e. background signal (free field), with DI water, and 0.9% aqueous solutions of NaCl in a plastic tube with a diameter of 0.8 *mm*.

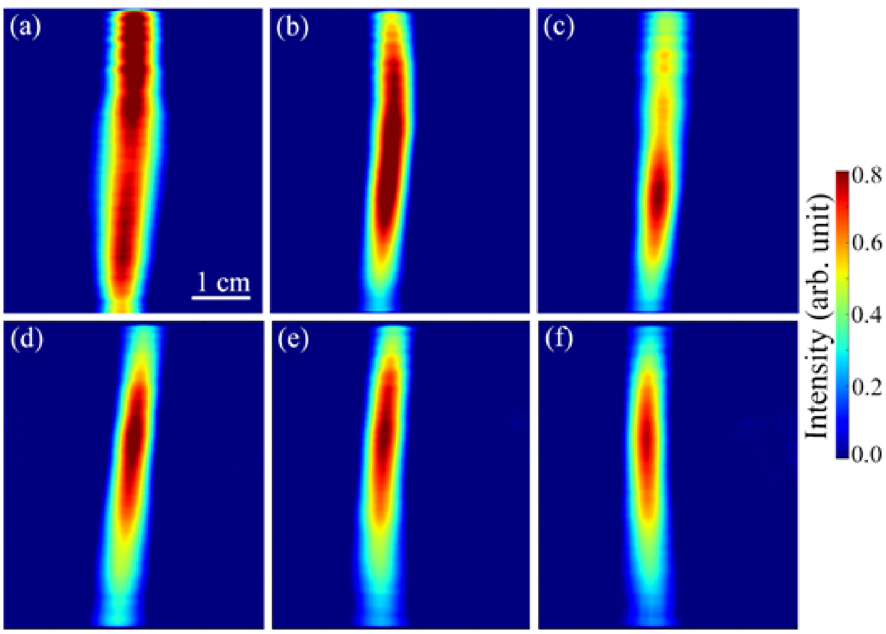

Fig. 3. Microwave near-field distribution for sample filled with (a) DI water and with NaCl and glucose mixture aqueous solution at 11 *GHz*. The concentration of NaCl was fixed at 0.9% and the concentration of glucose varied (b) 0%, (c) 1%, (d) 2%, (e) 5% and (f) 10%.

Fig. 4 shows the average microwave near-field intensity of glucose and NaCl (inset to Fig. 4) mixture aqueous solution for various concentrations of glucose and NaCl at a frequency of 11 *GHz*. A change in concentration leads to a change in the physical parameters of the solution, in particular, to a change in the complex dielectric permittivity. As the solute concentration increases, the signal value decreases almost linearly for both glucose and NaCl.

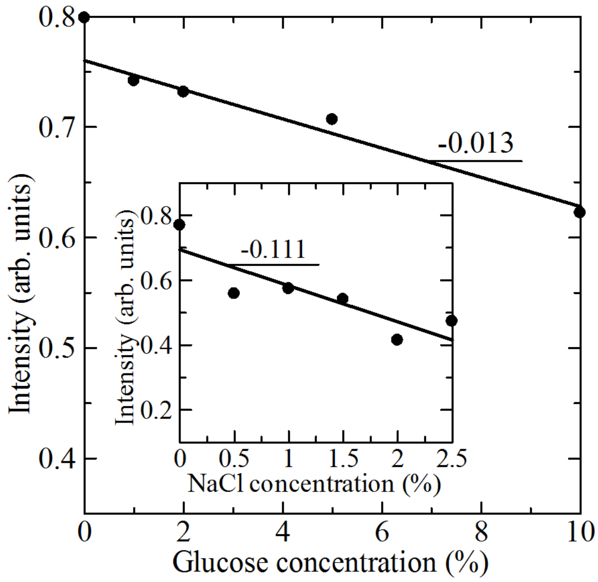

Fig. 4. Averaged microwave near-field intensity depending on the glucose concentration in aqueous solutions ranging from 0–10% at 11 *GHz*. Inset shows the average microwave near-field intensity vs. NaCl concentration in aqueous solutions ranging from 0–2.5% at 11 *GHz*. Solid line shows the linear fitting of the experimental data.

The obtained results show that the decrease in intensity associated with a change in concentration is greater for NaCl solution than for glucose: $-0.111\%^{-1}$ vs. $-0.013\%^{-1}$, or about 8.5 times. This effect is explained by the fact that glucose and NaCl have different mechanisms of dissolution in the liquid. Judging by the chemical properties, NaCl forms stronger molecular bonds with water than glucose, and, therefore, the decrease in intensity is more pronounced [14, 15]. As a result, an aqueous solution of NaCl has a higher electrical conductivity (i.e., a larger imaginary part of the complex permittivity) than an aqueous solution of glucose; hence, stronger interaction with incident microwaves. The dependence in Fig. 4 shows the sensitivity of the system and confirms that TEOIM is a useful method for determining the concentration of dissolved components in complex solutions.

Conclusion. The TEOIM visualization technique was used to study the microwave near-field distribution of NaCl and glucose mixture aqueous solutions. The concentrations of NaCl and glucose mixture aqueous solutions were determined at a frequency of 11 *GHz*. The intensity of the microwave near-field decreased with an increase in the concentration of glucose in an aqueous solution of a mixture of

NaCl and a mixture of glucose. The concentration of NaCl varied from 0 to 2.5% and glucose concentration varied from 0 to 10% with measurement sensitivity of $-0.111\%^{-1}$ and $-0.013\%^{-1}$ for NaCl and glucose, respectively. This new method is applicable as a non-invasive research method, which is a good approach to study the electromagnetic properties of various aqueous solutions, as well as to determine the change in the concentration of various substances in these solutions.

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Բ. Ժ. ՄԻՆԱՍՅԱՆ

ՆԱՏՐԻՈՒՄԻ ՔԼՈՐԻԴԻ ԵՎ ԳԼՅՈՒԿՈԶԻ ԽԱՌՆՈՒՐԴԱՅԻՆ ՋՐԱՅԻՆ ԼՈՒԾՈՒՅԹԻ ՀԵՏԱԶՈՏՈՒԹՅՈՒՆԸ ՋԵՐՄԱԱՌԱՁԳԱԿԱՆ ՕՊՏԻԿԱԿԱՆ ԻՆԴԻԿԱՏՈՐՈՎ ՄԱՆՐԱԴԻՏԱԿԻ ՕԳՆՈՒԹՅԱՄԲ

Դիտարկվել է նատրիումի քլորիդի (NaCl) և գլյուկոզի ջրային լուծույթի միկրոալիքային կլանումը տարբեր խտությունների դեպքում՝ օգտագործելով ջերմաառաձգական օպտիկական ինդիկատորով մանրադիտակը (ՋԱՕԻՄ): ՋԱՕԻՄ չներթափանցող սենսորային տեխնոլոգիան ունի մեծ առավելություն դետեկտման մյուս տեխնոլոգիաների նկատմամբ: ՋԱՕԻՄ-ի օգնությամբ իրականացվել է $8-14$ GHz տիրույթում միկրոալիքային դաշտի բաշխվածության փոփոխության արտապատկերում կախված նատրիումի քլորիդի և գլյուկոզի խտությունների փոփոխությունից: Հոդվածում ցույց են տրված NaCl-ի տարբեր խտությունների $(0-2,5\%)$ համար հետազոտության արդյունքները և ներկայացված է միկրոալիքային մոտակա-դաշտի միջինացված ինտենսիվության վարքը գլյուկոզի (փոփոխվել է $0-10\%$-ից) և NaCl-ի (ֆիքսված է $0,9\%$) բարդ ջրային լուծույթի համար:

Б. Ж. МИНАСЯН

ИССЛЕДОВАНИЕ СМЕШАННОГО ВОДНОГО РАСТВОРА ХЛОРИДА НАТРИЯ И ГЛЮКОЗЫ С ИСПОЛЬЗОВАНИЕМ ТЕРМОУПРУГОГО ОПТИЧЕСКОГО ИНДИКАТОРНОГО МИКРОСКОПА

В статье представлен отчет о наблюдении микроволнового поглощения водного раствора хлорида натрия (NaCl) и глюкозы в различных концентрациях с помощью термоупругого оптического индикаторного микроскопа (ТУОИМ). Неинвазивная сенсорная технология ТУОИМ дает большое преимущество по сравнению с другими технологиями обнаружения. С помощью ТУОИМ визуализировалось изменение распределения микроволнового поля в диапазоне $8-14$ *GHz* в зависимости от изменения концентрации NaCl и глюкозы. В статье показаны результаты исследования для различных концентраций NaCl $(0-2,5\%)$ и представлено поведение усредненной интенсивности микроволнового ближнего поля для сложного водного раствора глюкозы (варьируется в диапазоне $0-10\%$) и NaCl (фиксируется на уровне $0,9\%$).