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THE BIOSCOPE SYSTEM – TESTING AND VALIDATING A NOVEL SENSOR FOR AQUEOUS SOLUTIONS

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A novel device called the Bioscope System is investigated for feasibility as sensor for chemicals in aqueous solutions. Thereby a sample is probed by a pulsed voltage and electrical properties of that sample are measured. These electrical properties can be considered as a sum parameter of the sample in terms of conductivity and permittivity. It is demonstrated that the Bioscope System can indeed measure differences between different substances in aqueous solution and between different concentrations of the same substance in aqueous solution. A qualitative explanation is provided. Possible improvements of the system are suggested.

Keywords: aqueous solutions, electromagnetic waves, impedance, permittivity, sensor.

Introduction

The Bioscope is a novel measuring device invented in 2006 by a Swiss company. According to the manufacturer [1], the Bioscope System can be used to test a wide range of samples and it is sensitive to minor changes in materials such as liquids, water in particular, living matter (e.g. plants, animals, cells) and organic materials like proteins and biomolecules. Within the scope of this study we tried to find out whether the measurement principle of the Bioscope System would be feasible to distinguish between different concentrations of organic and inorganic components in aqueous solution.

The main constituents of the Bioscope are an analog signal generator, a signal transducer probe and a detector circuit. The system is connected to a laptop which acts as power supply, recording and analyzing unit. The Bioscope System has been tested to distinguish different processing stages of various fruit and vegetable juices, such as described in [2].

Methods similar to the one described here have been used in food quality measurements (e.g. [3] and papers quoted therein) in a different frequency range; and also for medical applications such as the investigation of tissue properties [4].The method can be compared to the measurement technique presented by [5], which describes electrical impedance spectroscopy on piezoelectric materials and ultrasound transducers. This method allowed for rapid impedance measurement for a range of frequencies using a short pulse.

The Bioscope System generates a low frequency square wave signal, which is coupled capacitively to a small transducer needle. This needle is immersed in the sample and acts as an unipolar probe in contrast to usually used coaxial probes [6, 7] A detection circuit monitors the voltage on the needle. Changes in the detected signals are a reflection of changes in the sample's electric properties. Thus a combination of dielectric permittivity and conductivity are the sampleproperties being probed. The detection circuit detects the time that the measured voltage is above a certain threshold and outputs a DC voltage describing the load that the sample represents.

There are several ways to display the resultant signal. Actually, monitoring this signal over time would suffice. The manufacturer chose to use a computer to display this result by using a DC-to-Pulse-width modulator (PWM) connected to a soundcard and audio analyzing software (Fig. 1). The resultant signal is Fourier transformed, and the amplitudes of the constituent frequencies are analysed.

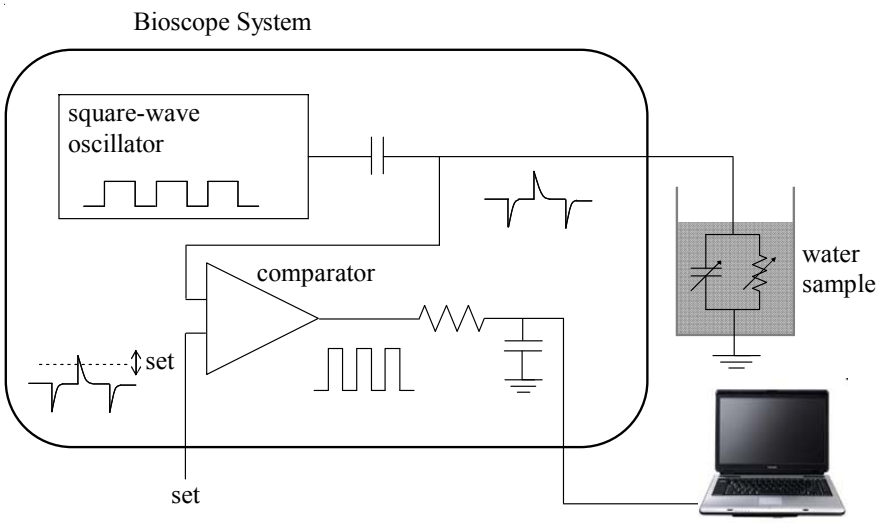

Fig. 1. Block diagram of the Bioscope and the shape of the signal at the different components.

Fig. 1 shows the block-schematic of the Bioscope System and provides insight into the processing of the signal through the system's different components. The oscillator generates a square-wave with a duty cycle of 50 %, which is differentiated by the capacitor. The resulting sharp pulse is the signal that reaches the sample through the transducer probe. The sample is represented by both its resistance *R* and its capacitance *C* joined in parallel. Depending on the dielectric properties and the conductivity of the sample, it acts as resistive and capacitive load.

The pulse height of the output signal is related to those properties and is compared with a reference "set" level, and the time that the signal is above this level is measured. The "set" level can be considered a "zero-adjust" setting with an optimal set-point creating an output signal about halfway the total output scale. When the signal is time averaged by an averaging circuit (which is accomplished here by the capacitor and resistor with an RC time constant of approximately 0.1 seconds), a voltage is obtained which is a measure for the load represented by the sample. In the remaining circuit (which is not shown here) the voltage is again transformed into a pulse width modulated signal in order to make it readable by a sound card. This signal is fast Fourier transformed and the groundharmonic of the FFT-spectra is used for evaluation. In the device, the 'measurement frequency' can be adjusted between 60 Hz and 5 kHz. This frequency represents the pulse repetition rate. This setting should be of minor influence on the results because the actual measurement is already done in a single pulse

Theoretical aspects

In the Fig. 2 below a schematic representation of the square wave generator (V1), the differentiating capacitor (C1) and the load described above (see Fig. 1) are represented by the couple C2 and R1. Measuring the voltage across the load gives information about this load. In the Bioscope circuit the signal is fed into an electronic comparator. When its input signal is greater than a certain set-level the output is "high" and otherwise it is "low".

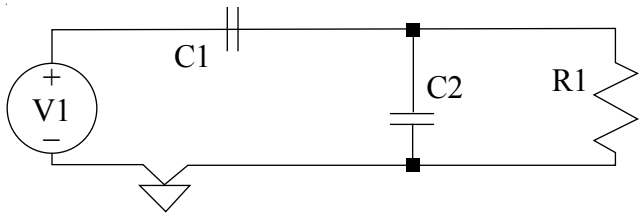

Fig. 2. Schematic representation of the Bioscope measurement principle. V1– square wave generator, C1– differentiating capacitor, C2 and R1– capacitor and resistor simulating the load.

In the following example a single pulse is considered. The pulse generator (V1) is set to a square wave of initial 0 (Volts) and after a short time it rises to the "high" level. The response of the voltage across the load with different loads is then observed. In Fig. 3, *a* the effect of a change in load resistance is shown; while on the Fig. 3, *b* the effect of a changing load capacitance is shown. When the signals are compared with a certain "set" level both the load resistance and the load capacitance have influence on the output of the comparator. It cannot be determined whether a change in the output of the comparator is due to a change in resistance, capacitance or both, though.

Thus, the system works by applying a pulse shaped measurement signal, the load is determined by measuring the voltage at the measurement node. In practice the pulse decay time for the system when loaded with a water sample to a few percent is less than a hundred microseconds.

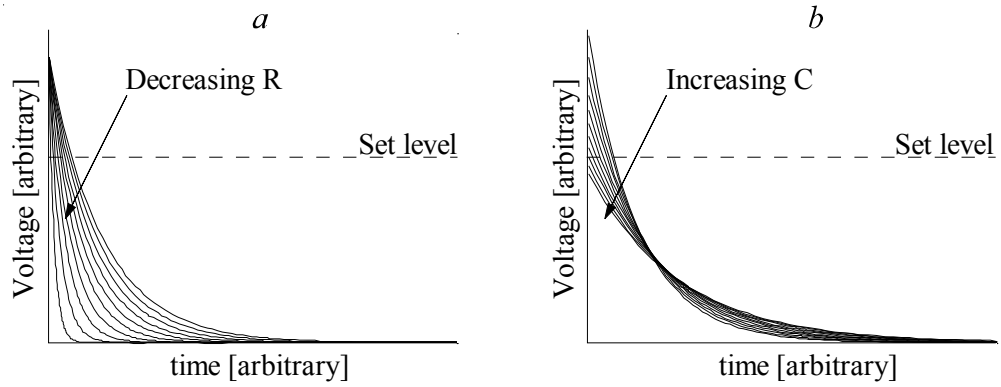

Fig. 3. The effect of a change in resistance (a); the effect of a change in capacitance (b).

At a pulse repetition rate of 111 Hz the time between pulses is about a hundred times longer than the pulse time. Therefore it can be assumed that separate pulses do not influence each other, thus the pulse repetition rate probably does not play an important role in the measurement procedure.

Permittivity is a property, which represents the interaction of materials with electromagnetic energy. These properties are commonly represented by a complex number, the so-called relative complex permittivity

$$\varepsilon^* = \varepsilon' - i\varepsilon'', \qquad (1)$$

where ε' – the dielectric constant, ε'' – the loss factor and i – the imaginary unit. The loss factor is associated with the energy dissipation in the material, and the capability of energy storage in the material is related to the dielectric constant.

A classical method to determine the relative electric permittivity of a liquid makes use of capacitance measurements where the space between parallel-plane plates of an electrical capacitive cell is filled with material to be tested. The Bioscope System is similar: a capacitor is formed with the monopolar probe being one plate and the grounded faraday cage being the second plate. Nevertheless, the fact that the Bioscope uses a monopolar probe and a pulsed measurement signal differs from established methods [8]. Although it is regarded a one electrode system by the manufacturer, the other electrode is actually the surrounding ground, the Faraday cage with a grounding plate below the sample. Everything in between, the water sample and the glass beaker and the air space, has influence on the measurement result. If everything else but the solution is kept constant, it is possible to compare two aqueous solutions whereby just one electrode is inside the sample, making the system appear like a single electrode system. The difference of this versus a normal two electrode system is a more strongly inhomogeneous field around the needle.

Experimental

The measurements were taken with a Bioscope System at room temperature 20°C. All experiments were carried out in a Faraday cage to shield the system and to provide a stable measurement environment. The water samples were measured in 500 ml glass beakers which contained 450.0 ± 1 ml of the sample. The signal was recorded using "FFT-properties " audio software. After signal analysis the amplitudes of the ground frequency of the FFT spectrum of the PWM signal were divided by the reference amplitudes (Milli-Q water if not stated otherwise), and these relative amplitudes were compared. For simplicity, these are referred to as "relative amplitudes" or "Bioscope amplitudes" from here on.

All measurements were taken at a pulse-repetition rate of 111 Hz, which is a standard setting of the Bioscope System [1]. During the measurements the laptop was powered by battery instead of the power supply in order to minimize crosstalk from the mains grid.

Results and discussion

In order to investigate the response of the signal due to different chemical substances, 1 mM aqueous solutions of NaCl, ethanol, saccharose, dimethylsulfoxide (DMSO), $CdCl_2$ and $CuSO_4$ were tested. The amplitudes of aqueous solutions of NaCl, ethanol, saccharose, DMSO,$CdCl_2$ and $CuSO_4$ are illustrated in Fig. 4. The $CdCl_2$ solution shows the biggest differences compared to Milli-Q water. The amplitudes of the salt solutions are significantly lower in comparison to Milli-Q water, DMSO, saccharose and ethanol solutions. No

significant differences between the amplitudes of DMSO, saccharose and ethanol could be observed. The differences in the amplitude of saccharose and ethanol were significant compared to Milli-Q water.

In general the amplitude of the ionic salts is much lower than the one of the three non ionic substances. This is probably due to the conductivity of these solutions which is much higher in case of the salts compared to the non ionic substances. No significant differences between the salt solutions were observed although these solutions show significant differences in their conductivity (Tabl. 1). The theoretical conductivities were calculated using the program OLI Analyzer Studio 3.1.

Table 1. Calculated and measured conductivity of different aqueous solutions and the corresponding Bioscope Amplitudes

Substance [mM]	Milli-Q	$CuSO_4$	NaCl	DMSO	Saccharose	Ethanol	$CdCl_2$
Calculated conductivity [μS/cm]	0.06	217	110	0.04	0.04	0.04	0.04
Measured conductivity [μS/cm]	0.90	168	127	1.10	1.00	0.80	207
Bioscope amplitude	1.000	0.794	0.787	1.048	1.033	1.049	0.743

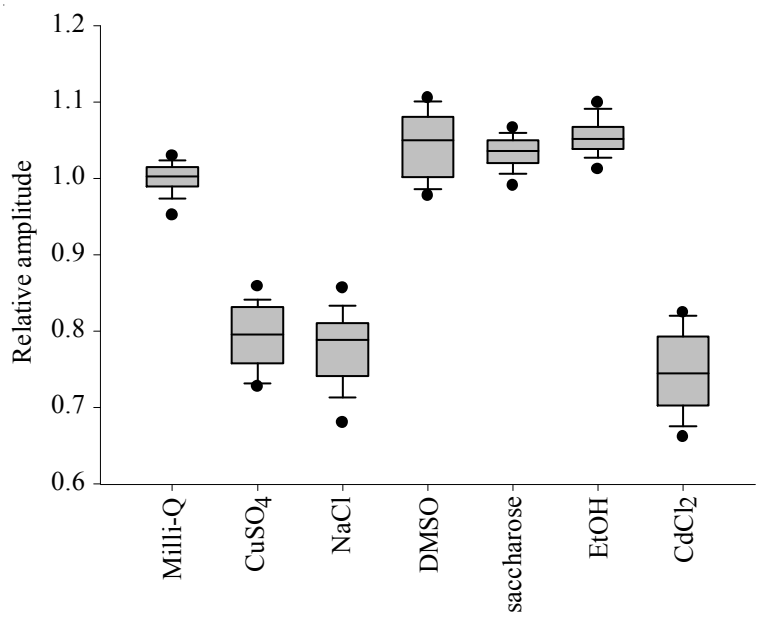

Fig. 4. Bioscope amplitudes of Milli-Q water, 1 mM aqueous solutions of $CuSO_4$, NaCl, DMSO, saccharose, ethanol and $CdCl_2$..

Fig. 5 shows the results of a concentration series of NaCl from 1 mM to 0.1 μM, the corresponding conductivities are listed in Tabl. 2. For this concentration series a 1 mM solution of NaCl was diluted tenfold for each dilution step. Furthermore different concentrations of saccharose were measured. The results of these measurements are shown in Fig. 6, and corresponding conductivities are listed in Tabl.3. The response of the Bioscope signal at different concentrations of $CuSO_4$ from 1 mM to 0.1 μM is shown in Fig. 7. This result show an unexpected progression since at very low concentrations the amplitude of the signal is increasing and not converging to the Milli-Q signal. The conductivities for the concentration series of $CuSO_4$ are given inTabl. 4.

Table 2. Calculated and measured conductivity of NaCl solutions and the corresponding Bioscope amplitudes

NaCl [mM]	0	0.0001	0.001	0.01	0.1	1	17.1
Calculated conductivity [μS/cm]	0.06	0.05	0.2	1.2	11.3	110	1771
Measured conductivity [μS/cm]	1.0	1.0	1.0	2.3	13.4	127	1820
Bioscope amplitude	1.000	1.021	0.996	0.951	0.934	0.913	0.927

Naturally, all solutions had conductivities above or equal 0.8 μS/cm due to the saturation with ambient CO_2 [9]. Measured conductivities above this value are in reasonable agreement with calculated values; for higher concentrations (1mM and above), the deviations are somewhat larger due to the increasing non-ideality of these solutions.

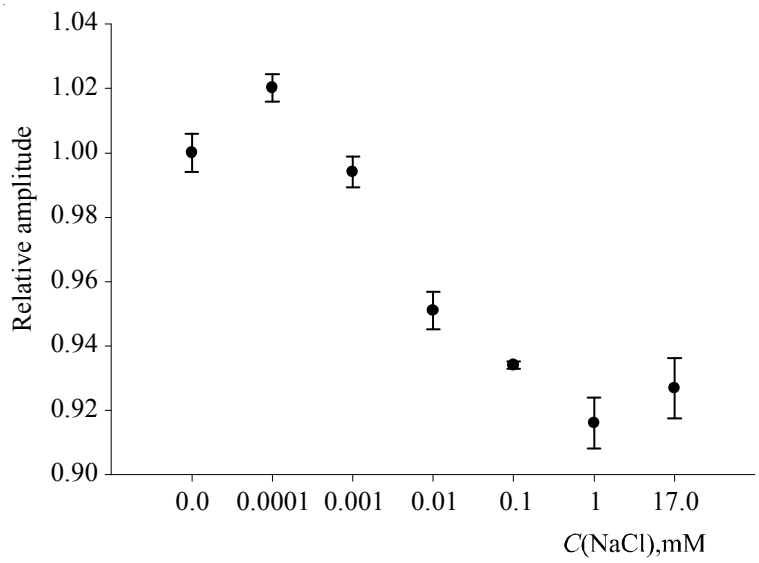

Fig. 5. Bioscope amplitudes of different NaCl concentrations.

Table 3. Calculated and measured conductivity of saccharose solutions and the corresponding Bioscope amplitudes

Saccharose [mM]	0	0.01	0.10	1.00	3.00
Calculated conductivity [μS/cm]	0.06	0.04	0.04	0.04	0.04
Measured conductivity [μS/cm]	0.9	1.1	1.2	1.0	1.0
Bioscope amplitude	1.000	0.989	0.972	1.001	0.993

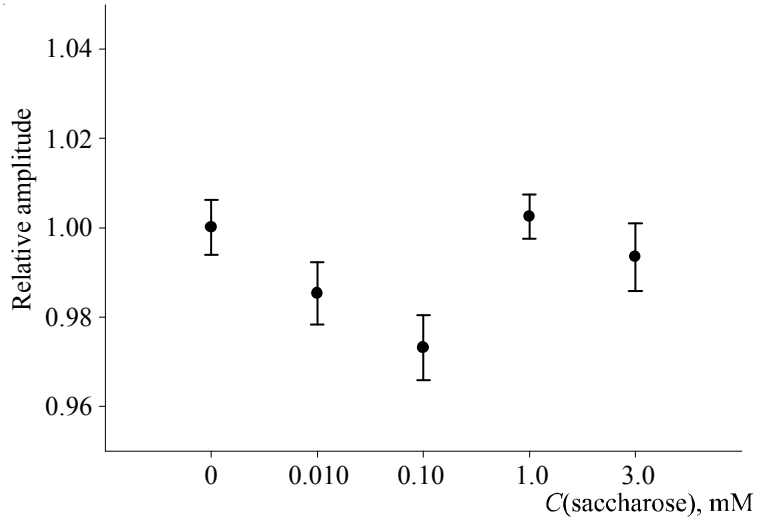

Fig. 6. Bisocope amplitudes of different saccharose concentrations.

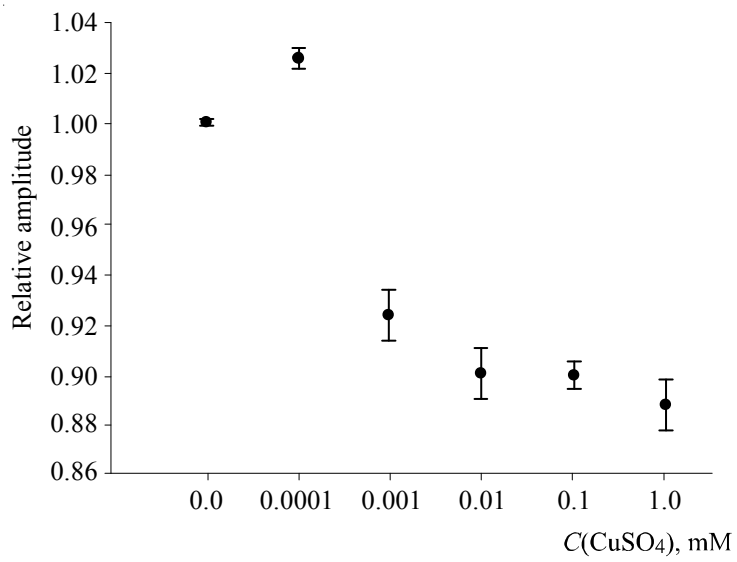

Fig. 7. Bioscope amplitudes of $CuSO_4$ solutions in a concentration range from 0.1μ M to 1mM.

Table. 4. Calculated and measured conductivity of $CuSO_4$ solutions and the corresponding Bioscope amplitudes

$CuSO_4$ [mM]	0	0.0001	0.001	0.01	0.1	1
Calculated conductivity [μS/cm]	0.06	0.07	0.03	2.3	21.2	168
Measured conductivity [μS/cm]	0.9	0.8	1.7	3.5	25.6	219
Bioscope amplitude	1.000	1.023	0.924	0.910	0.903	0.895

Furthermore, the influence of temperature on Milli-Q water was investigated as shown in Fig. 8. The temperature influence is significant for large temperature differences (> 40°C) but is considered insignificant for the measurement results as the temperature was kept constant at 20 ±1°C.

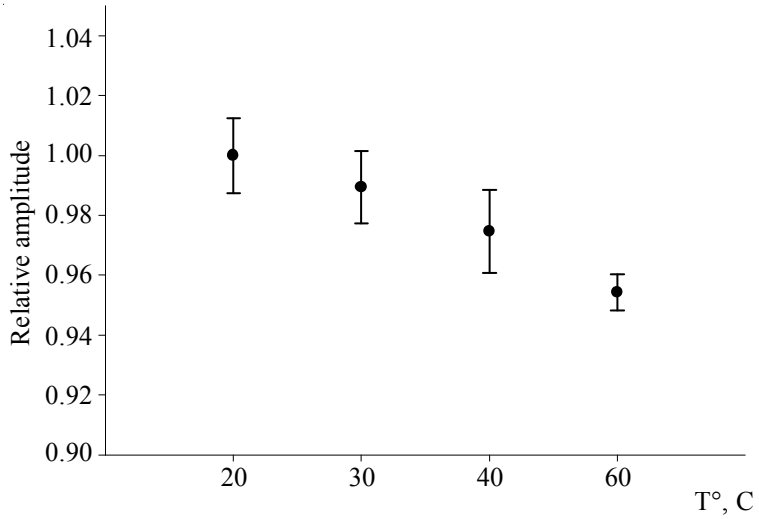

Fig. 8. Bisocope amplitudes of Milli-Q water at different temperatures (in relation to 20°C).

The Bioscope System shows a different response signal for different substances in aqueous solution (see Fig. 4) and also for different concentrations of the same substance in aqueous solution (see Fig. 5 – 7). These output difference can be attributed to changes in the electrical properties of the aqueous solutions, caused by changes in the chemistry and physics of the aqueous solutions. Different concentrations cause changes in the conductivity, electric and magnetic permeability. The conductivity and electric permittivity are comprised within the electrical load the system is probed (see Fig. 1). A possible explanation considers the water dipole. Due to their electric properties, water molecules will orientate- and thus oscillate- to an alternating electromagnetic field. The mobility of the water molecules depends on solutes and their hydration properties, respectively. Therefore even low concentrations of solutes could

affect (di-)electric properties (permittivity and conductivity). Since the Bioscope responds to small changes in electric properties, the device is a sensitive instrument for small concentration differences (see Fig. 5 – 7).

In course of the investigations we found out that the amplitude is also somewhat depending on the USB power output. Although rated 5V DC, the USB voltage is not always exactly at 5V but can vary, depending on the computer and the computer activity, between 4.75 and 5.25 Volt [10]. A change in this voltage has effect on the output signal and should be as stable as possible in time. An independently regulated supply – instead of using the USB power output in order to improve signal stability is recommended. Furthermore we suggest the laptop used for the measurement to be properly grounded or battery operated, since we found significant variation in the signal when the Laptop was powered by the AC grid.

Conclusions

The Bioscope System is able to measure significant differences between 1 mM aqueous solutionsof NaCl, ethanol, saccharose, DMSO, $CdCl_2$ and $CuSO_4$. The differences in the signal measured by the Bioscope System are attributed to changes in the electric load that the solution is to the circuit.

We suggest that this system can be used as a simple and rapid sensor for various analyticapplications. We furthermore suggest improvement of the device by making it less dependent on the power supply voltage. For further analytical applications and future commercial use, derivation of a theoretical model is considered of importance.

Summarizing we conclude that the Bioscope System is a smart measuring device which has potential to be used in various applications, e.g. in quality control where it could quickly detect variations in aqueous solutions.

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Резюме. Изучено новое устройство Bioscope System для возможного использования в качестве сенсора химических веществ в водных растворах. Посредством сенсора образец зондируется пульсирующим напряжением и измеряются его электрические свойства, которые могут рассматриваться как суммарный параметр в выражении электропроводности и электрической емкости. Продемонстрировано, что Bioscope System может действительно измерять различия между разными веществами и разными концентрациями одних и тех же веществ в водном растворе. Предлагаются возможные усовершенствования системы.

Резюме. Вивчено нове облаштування Bioscope System для можливого використання як сенсора хімічних речовин у водних розчинах. За допомогою сенсора зразок зондується пульсуючою напругою і вимірюються його електричні властивості, які можуть розглядатися як сумарний параметр у вираженні електропровідності і електричної місткості. Продемонстровано, що Bioscope System може дійсно вимірювати відмінності між різними речовинами і різними концентраціями одних і тих же речовин у водному розчині. Пропонуються можливі удосконалення системи.

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