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THE FROZEN DISPERSE SYSTEMS WITH FRUCTOSE IMPURITY ELECTRO-PHYSICAL PROPERTIES FREQUENCY DISPERSION RESEARCH

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ABSTRACT

Temperature and concentration dependences of electro-physical properties are investigated at various frequencies in the range from 25 Hz till 1 MHz. The difference between Debye frequency dispersions is revealed. For explanation is offered the new model that is based on the frequency dependence of relaxation time. Influence of the temperature and concentration impurity are revealed. Function $\tau = \tau_0 \cdot \omega^{-\beta}$ satisfactorily describes frequency dispersion of relaxation time.

Keywords: Debye frequency dispersion, ice, the electro-physical properties.

INTRODUCTION

In works [1-4] has been noted that for some proton and number of ionic conductors frequency dispersion of specific electric conductivity differs from Debye and is described by sedate dependence $\sigma(\omega) \sim \omega^{\alpha}$. Value α, as a rule, less than 1. Let's notice that the similar is observed for threefold connections AB_2X_4, where A - element of transitional group of metals, B -III group elements and X - VI group elements, for example $FeGaInS_4$ [5]. Similar dependence, by [6], it is observed for nanoscale *nc*-Si films with value $\alpha = 0.74$.

The proton semiconductor in a particular case is ice. For single-crystal samples of ice Debye frequency dispersion of electro-physical properties [7-9] with four types of relaxation oscillators [5]:

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_S - \varepsilon_\infty}{1 + j\omega\tau_\varepsilon} \tag{1}$$

$$\sigma = \sigma_\infty - \frac{\sigma_\infty - \sigma_S}{1 + j\omega\tau_\sigma} \tag{2}$$

Let's notice that by [10] relaxation times for σ and ε are various, which is confirmed by our researches [11].

Unlike single-crystal ice, another situation is observed in the frozen moisture containing disperse environments. N. Maeno with employees has conducted researches of frequency dependences of frozen clay at a humidity of 11% and various temperatures from -15 to -100 °C. The analysis of these results has shown that $\alpha \approx 0.67$ and decreases with increase in temperature.

Observed deviations from Debye frequency dispersion of electro-physical properties number of authors [12],[13],[3] explain with not Debye mechanism of distribution of relaxer Cole-Cole, Davidson-Cole and Havriliak-Negami.However, such approach suffers from formalism as the called distributions have no the formulated physical mechanisms.

Another and already acceptable approach to the explanation of dependencies $\sigma(\omega) \sim \omega^{\alpha}$ is based on recognition of the role of percolation processes in conductivity of the disorder solid bodies. In works [14-15] is defined task solution about dependence $\sigma(\omega)$.The equation $\ln\tilde{\sigma} = \left(\frac{j\tilde{\omega}}{\tilde{\sigma}}\right)^{d_f/2}$ is decisive, where d_f– fractal dimension, $\tilde{\sigma} = \frac{\sigma'(\omega) + j\omega''}{\sigma(0)}$, $\tilde{\omega} = \frac{\varepsilon_0(\varepsilon_S - \varepsilon_\infty)}{\sigma(0)} \cdot \omega$. Kononov with employees [16] were succeeded to solve the equation under some simplifying conditions and at $\omega \to 0$ to receive the answer:

$$\sigma(\omega) - \sigma(0) = (\sigma_0)^{\left(1 - d_f/2\right)} \cdot \cos\left(\frac{\pi}{4} \cdot d_f\right) (\varepsilon_0 \Delta\varepsilon\omega)^{d_f/2} \tag{3}$$

However, the physical mechanism influence of the fractal dimension effect on frequency dependence remains not formulated.

In the real work, another approach to an explanation of observed deviations from Debye formulas for the description of frequency dependences of electro-physical properties is offered. It is supposed that the mechanism of the phenomenon remains Debye, Debye's formulas (1) and (2) are right, but the time of relaxation depends on the frequency of the electric field. Physically it is possible if except phonon relaxation there are other mechanisms, for example, connected with dispersion on static defects of crystal structure. This approach is illustrated by the example of electro-physical properties of the frozen disperse environment on the basis of quartz powder with fructose impurity.

RESEARCH TECHNIQUE

Experiment assumed research of temperature and frequency dependences of dielectric permeability and specific electric conductivity. For measurements were used LCR meter E7-20, range of frequencies 25 Hz - 1 MHz, the range of temperature change 170 – 290 K. The measuring cell represented the flat condenser S = 50 × 50 mm и d = 2 mm. As objects of research samples of the moisture containing disperse environment on the basis of powder of fine-grained quartz with fructose impurity acted (C = 0; 10^{-2}; 10^{-3}; 10^{-4}; 10^{-5}; 10^{-6} M).The humidity made 6 and 12%.

On the basis of direct measurements of capacity, good quality and conductivity values of components of complex dielectric permeability $\varepsilon = \varepsilon' - j\varepsilon''$ and specific electric conductivity paid off.

Experimental results are presentedin Figure-1 and Figure-2.

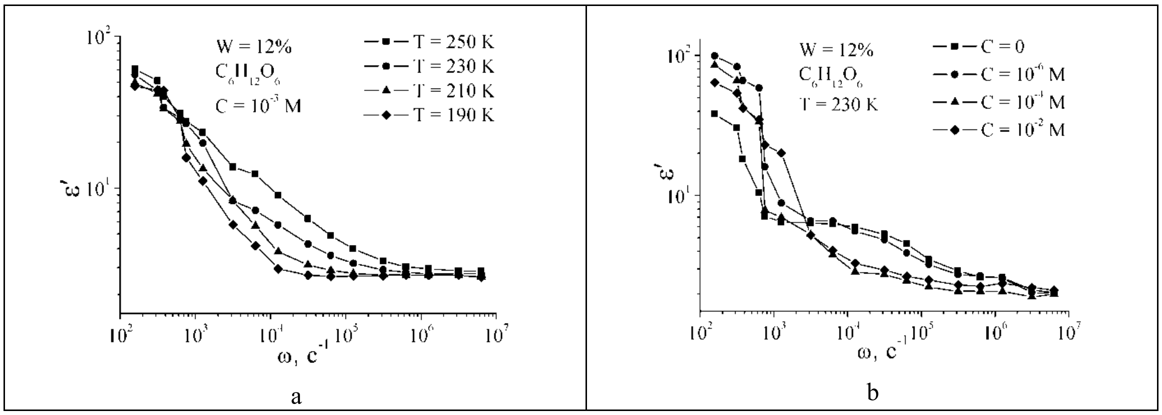

Figure-1. Frequency dispersion of dielectric permeability at different temperatures (a) and concentration of fructose (b).

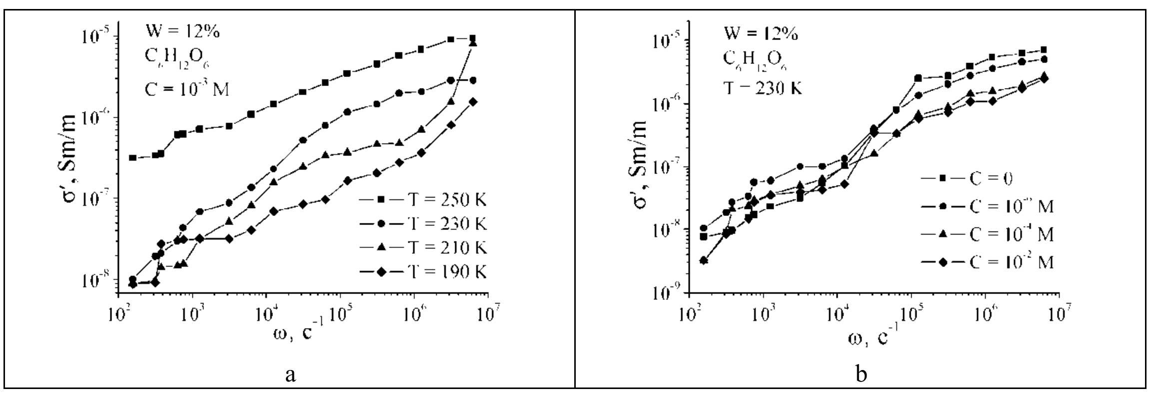

Figure-2. Frequency dispersion of specific electric conductivity at different temperatures (a) and concentration of fructose (b).

ANALYSIS OF RESULTS

Considering research problem - establishment of frequency dependence of time of relaxation on the basis of hypothesis of performance of formulas of Debye, from known formulas of Debye frequency dispersion.

$$\varepsilon' = \varepsilon_\infty + \frac{\varepsilon_S - \varepsilon_\infty}{1 + \left(\omega\tau_\varepsilon\right)^2} \tag{4}$$

$$\sigma' = \sigma_\infty - \frac{\sigma_\infty - \sigma_S}{1 + \left(\omega\tau_\sigma\right)^2} \tag{5}$$

we found

$$\tau_\varepsilon(\omega) = \frac{1}{\omega}\sqrt{\frac{\varepsilon_S - \varepsilon'}{\varepsilon' - \varepsilon_\infty}} \tag{6}$$

$$\tau_\sigma(\omega) = \frac{1}{\omega}\sqrt{\frac{\sigma' - \sigma_S}{\sigma_\infty - \sigma'}} \tag{7}$$

Results of calculations of times of relaxation are presentedin Figure-3 and Figure-4.

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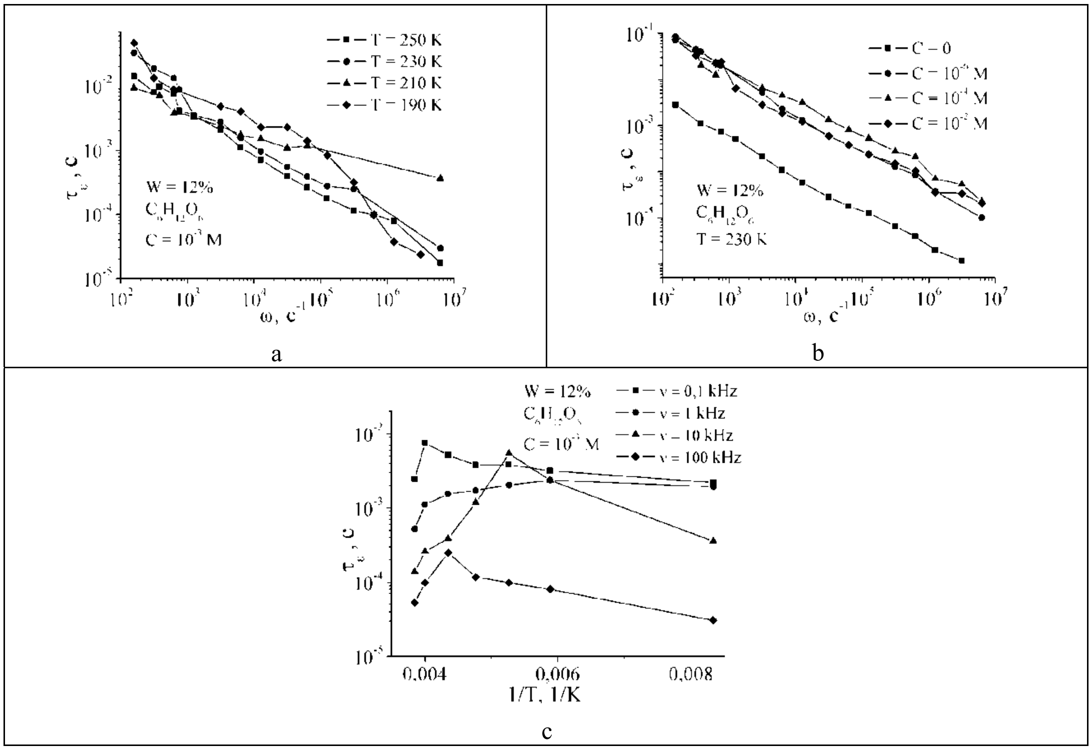

Figure-3. Dependence of time of relaxation of dielectric permeability of water-containing disperse system W = 12% with impurity of fructose a) from frequency at different temperatures, b) from frequency at different concentration of impurity, c) from temperature with different frequencies.

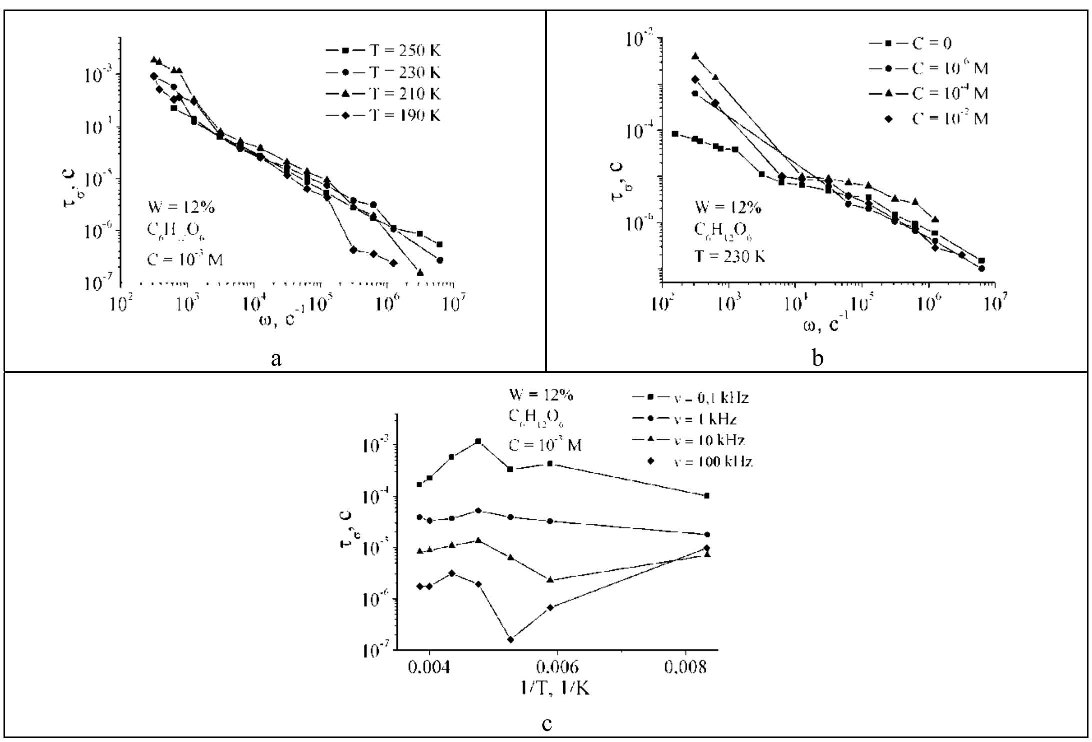

Figure-4. Dependence of time of relaxation of specific electric conductivity of water-containing disperse system W = 12% with impurity of fructose a) from frequency at different temperatures, b) from frequency at different concentration of impurity, c) from temperature with different frequencies.

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Static parameters ε_S and σ_S can be found from polynomial representations $\varepsilon'(\omega)$ and $\sigma'(\omega)$ at $\omega \rightarrow 0$. High-frequency parameters ε_∞ and σ_∞ are from polynomial representations $\varepsilon'(1/\omega)$ and $\sigma'(1/\omega)$ at $1/\omega \rightarrow 0$.
The analysis of graphic dependencies shows:

- $\tau_\varepsilon > \tau_\sigma$ on one - two orders(Figure-3a, Figure-4a);
- small influence on the time of relaxation of concentration of impurity(Figure-3b, Figure-4b);
- relaxation time τ_ε at C ≠ 0 it is more than C = 0that testifies to the delay of carriers impurity molecules (Figure-3b);
- at the increase in temperature to 250 K there is an area of temperatures when τ_ε decreases with reduction1/T, thus theenergy of activation of relaxation makes ΔE_τ = 0.35 eV(Figure-3c).

Frequency dependence of time of relaxation can be approximated by these date dependence of look $\tau = \tau_0 \cdot \omega^{-\beta}$. Values of coefficients τ and β for relaxation times τ_ε and τ_σ, and also valuesαin reliance $\sigma(\omega) \sim \omega^\alpha$ are provided in Table-1.

The analysis of the results given in the table allows drawing the following conclusions:

- temperature increase leads to decrease as$\tau_{0\varepsilon}$, and$\tau_{0\sigma}$;
- temperature increase leads to decreaseβ_ε and β_σ;
- increase of concentration of impurity increases$\tau_{0\varepsilon}$ and $\tau_{0\sigma}$;
- increase of concentration of impurity increasesβ_ε also reduces, though it is insignificant, β_σ;

Table-1. Values of parametersτ_0 and β for relaxation times $\tau_\varepsilon$and τ_σ and parameterα for sample with fructose impurity humidity W = 12%.

C, M	***T, K***	$\tau = \tau_{0\varepsilon} \cdot \omega^{-\beta}$		$\tau = \tau_{0\sigma} \cdot \omega^{-\beta}$		$\sigma(\omega) \sim \omega^\alpha$
		$\tau_{0\varepsilon}$	β_ε	$\tau_{0\sigma}$	β_σ	α
0	250	0,001	0,512	0,09	0,74	0,73
	230	0,0015	0,55	0,118	0,78	0,78
	210	0,0031	0,63	0,127	0,79	0,68
	190	0,0057	0,68	0,112	0,79	0,56
	170	0,01	0,8	0,49	0,93	0,49
10^{-5}	250	0,0018	0,544	0,56	0,68	0,63
	230	0,0019	0,54	0,166	0,57	0,72
	210	0,031	0,73	0,27	0,59	0,58
	190	0,034	0,77	0,132	0,46	0,43
	170	0,086	0,90	0,32	0,60	0,39
10^{-3}	250	0,0142	0,66	0,172	0,57	0,341
	230	0,0171	0,68	0,197	0,56	0,5
	210	0,065	0,80	0,36	0,59	0,36
	190	0,187	0,95	2,02	0,74	0,35
	170	0,22	0,97	1,84	0,77	0,23
10^{-2}	250	0,0098	0,68	0,61	0,67	0,377
	230	0,0036	0,64	0,51	0,64	0,32
	210	0,043	0,86	0,57	0,64	0,26
	190	0,077	0,95	4,7	0,84	0,25
	170	0,087	0,94	6,2	0,92	0,39

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According to [17] frequency dependences of dielectric permeability can be expressed through the relaxation time distribution function $f(\tau)$, the static ε_S and the high-frequency ε_∞ dielectric permeability by means of the 1 sort Fredholm integrated equations .

$$\varepsilon' - \varepsilon_\infty = (\varepsilon_S - \varepsilon_\infty)\int_0^\infty \frac{f(\tau)d\tau}{1+(\omega\tau)^2} \tag{8}$$

Having taken as example data ε', ε_S and ε_∞ at T = 230 K for water-containing disperse system with fructose mixture C = 10^{-3} M at humidity of sample W = 12 % we have solved the return problem of finding $f(\tau)$ (Figure 5) and have received the following expression

$$f(\tau) = 632.6\cdot\tau^{0.075} + 0.0346\cdot\tau^{-1,3} \tag{9}$$

This function can meet normalization condition if

$$588.5\cdot\tau^{1.075}\,|_0^{\tau_{GR}} - 0.115\cdot\tau^{-0.3}\,|_{\tau_{GR}}^{\infty} = 1 \tag{10}$$

The value $\tau_{GR} = 4.1\cdot10^{-3}$ c and corresponds to $\omega_{GR} = 0.0074\cdot\tau^{-1.688} = 79$ c^{-1}. τ_{GR} and ω_{GR} – time of relaxation and the circular frequency corresponding to the transition from one function of distribution to another. It is transition indicator from low-frequency area to high-frequency.

Let's note that in lack of impurity at T = 250 K $\alpha = d_f/2 = 0.71$, that is $d_f = 1.42$. But then it is physically unclear, why C = 10^{-2} M and W = 12 % $d_f = 2\alpha$ becomes 0.754, that is fractal dimension falls almost twice. Besides, also temperature dependence is unclear d_f form 0.98 at190 K to 1.42 at 250 K at W = 12 % and C = 0).

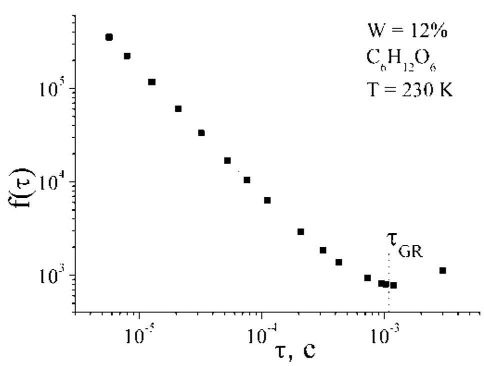

Figure 5. Dependence f(τ) for water-containing disperse system at W = 12 % and T = 230 K with fructose impurity C = 10^{-3} M.

CONCLUSIONS

In the conclusion, we will note the possible reasons resulting in dependence $\tau(\omega)$. First of all, with the frequency of electric field ν the number of collisions with static defects has to make 2ν. In this case the ratio would be carried out $\tau \sim 1/\omega$. But business is complicated by influence of other factors: probability of tunnel transition through defect, influence of the phonon mechanism of dispersion, ratio between amplitude of shift of charge and average distance between defects, the extent of polycrystalline. Told assumes development of the theory of dispersion of carriers at the hopping conductivity taking place in ice in water-containing disperse system.

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