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TURBULENCE IN AQUEOUS GLUCOSE SOLUTIONS INDUCED BY MAGNETIC FIELD

The turbulent motion induced by a magnetic field in aqueous glucose solutions has been studied. Changes in the motion occurring owing to variations in the magnetic field induction and the solution concentration are analyzed. The dependence of the turbulent motion synchronization degree on the magnetic induction is found to be nonmonotonic. The minimum in this dependence is found to be connected with the emergence of unstable fluctuation modes. The following growth of the synchronization degree is explained by a strengthening of the hydrodynamic interaction between anisotropic clusters. Higher solution concentrations are found to reduce the synchronization degree. This fact is a consequence of the mutual compensation of perturbations created by different clusters.

Keywords: aqueous glucose solution, magnetic field, turbulence, synchronization degree.

1. Introduction

Since the magnetic methods of medical examination and disease treatment become more widespread in medicine, the problem of the magnetic field influence on the structure and properties of liquids attracts interest in the physics of liquids. At present, a significant body of experimental data was accumulated on this subject [1]. At the same time, any physical interpretation of those experimental data is practically absent.

In our previous work [1], it was found that the application of a dc magnetic field induces a turbulent motion in the aqueous solution. This work is a continuation of the previous one. Here, we tried to answer the question: "How do the solution concentration and the magnetic field induction affect the turbulent motion?"

2. Experimental Data

Light scattering in aqueous glucose solutions under the action of a dc magnetic field was studied. The experimental installation and technique were described in work [2] in detail.

The relative intensity of light scattering $\xi = I/I_0$ was measured, where I is the scattering intensity at the time moment t, and I_0 the scattering intensity at the beginning of measurements ($t = 0$). Solutions with the concentrations $C = 5\%$ and 40% were studied at the following values of the magnetic field induction: $B = 0.13$, 0.16, 0.25, 0.43, and 3.2 mT. A typical dependence $\xi(t)$ is depicted in Fig. 1, *a*. Figure 1, *b* demonstrates the corresponding dependence $B(t)$.

It is evident from Fig. 1, *a* that, before the magnetic field had been switched on, the scattering intensity was constant within the measurement error. However, after the magnetic field was switched on (see Fig. 1, *b*), the scattering intensity demonstrated substantial fluctuations, the magnitude of which considerably exceeded the experiment error. The character of the dependence $\xi(t)$ in all other examined cases did not change essentially. All dependences demonstrated considerable fluctuations arising at the moment of the magnetic field switching on.

3. Discussion

What factor is responsible for the emergence of the observed fluctuations? In work [1], it was shown that the magnetic field affects the behavior of the solution owing to the presence of anisotropic clusters in the solution. Under the action of the magnetic field, the clusters begin to move and try to orient themselves in the magnetic field direction. This motion gives rise to the appearance of fluxes in the liquid that surrounds the clusters. The fluxes influence the motion of other clusters. As a result, there emerges an interaction between the clusters, which is called the hydrodynamic interaction. This interaction hinders clusters' aspiration to orientation. Under the action of two factors – the orienting magnetic field and the disorienting hydrodynamic interaction – the motion of clusters transforms into self-oscillations.

The self-oscillations of clusters may become unstable, which gives rise to the emergence of their turbulent motion. It is known [3] that the stability can be lost in two ways. One of them consists in the formation of unstable oscillation modes with incommensurate frequencies. Owing to the imposing of those modes, there arises a quasiperiodic (multiperiodic) motion. If the mode number exceeds a certain threshold, the character of the motion becomes chaotic, inherent to the turbulent motion. This is the turbulization scenario proposed by L.D. Landau [3]. It is also called the theory of weak turbulence or the theory of quasiperiodic stochasticity [4].

The other way includes the appearance of oscillation modes with doubled periods. The motion of particles, which arose after the magnetic field is switched on, manifested itself in our experiment in the form of dielectric permittivity fluctuations. At first, as was already mentioned, there emerged a periodic motion (self-oscillations of clusters). Here, we dealt with anisotropy fluctuations. Later, the creation of new oscillation modes and their imposing made it impossible to ascribe a certain type of dielectric permittivity fluctuations to a separate mode. Each of them gave

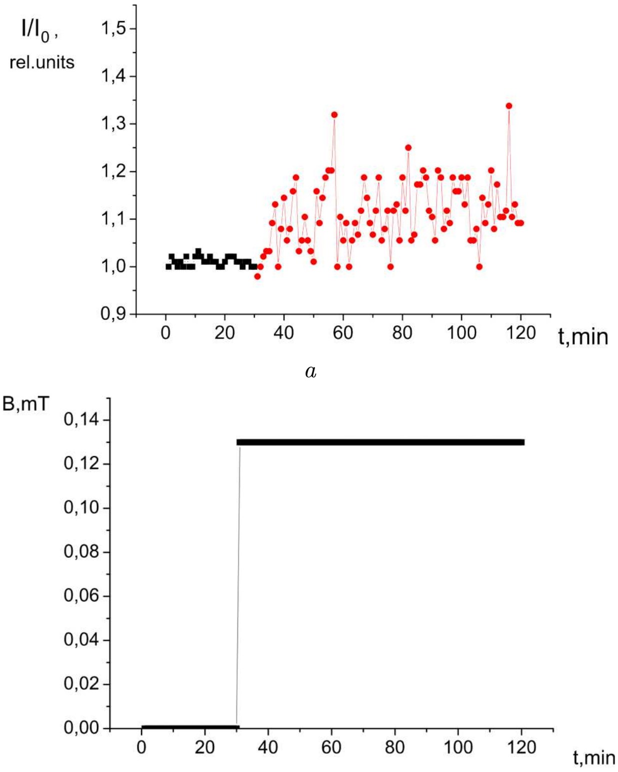

Fig. 1. Relative intensity of light scattering (a) and the external magnetic field induction (b) as functions of the time

a contribution to the anisotropy, concentration, and density fluctuations.

Every oscillation mode corresponded to a definite spatially periodic dependence of the dielectric permittivity. Therefore, the observed light scattering was a result of the imposing of several such dependences, the "dielectric-permittivity waves".

Two ways of turbulence emergence were mentioned above. In order to found, which of them was realized in our case, we calculated the Fourier transforms of the dependences $\xi(t)$. In Fig. 2, a, the Fourier transform $\xi_\omega(\omega)$ of the dependence $\xi(t)$ shown in Fig. 1, a is depicted. For the sake of comparison, Fig. 2, b illustrates the Fourier transform in the case where the turbulization had occurred following the doubled-period scenario. One can see from Fig. 2 that the Fourier transform of the dependence $\xi(t)$ obtained in our experiment has nothing to do with the doubled-period pattern. Accordingly, we have nothing to do but to draw a conclusion that L.D. Landau's scenario was

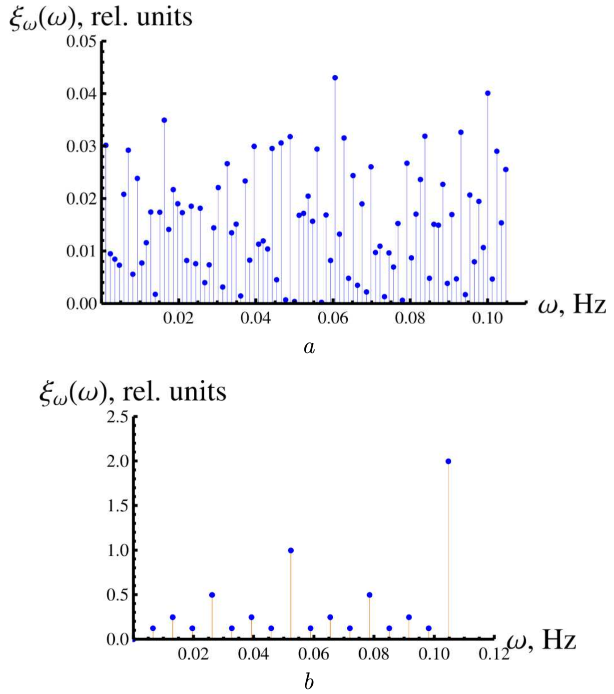

Fig. 2. Fourier transform of the dependence $\xi(t)$ measured at the magnetic field with an induction of 0.13 mT (*a*) and the Fourier transform in the case of doubled-period scenario (*b*)

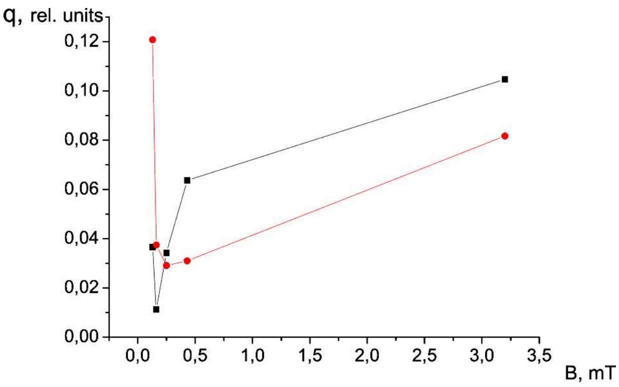

Fig. 3. Dependences of the synchronization degree q on the magnetic field induction B for 5% (squares) and 40% (circles) aqueous glucose solutions

realized in our case. The same conclusion is valid for the Fourier transforms of all other $\xi(t)$-dependences obtained by us.

As was already mentioned above, according to L.D. Landau's scenario, the dependence $\xi(t)$ is a multiperiodic function, which is a sum of elementary oscillation modes. Let m be the number of those modes. It is known [4] that, in order to characterize the state of turbulent motion, the notion of synchronization is introduced. The state of complete synchronization corresponds to a periodic motion, when all elementary modes have an identical frequency. For this state, $m = 1$. When m increases, the oscillations of separate modes become less and less correlated. In this case, it is accepted to say [4] that the degree of their synchronization decreases, i.e. their gradual desynchronization takes place. At $m \to \infty$, a complete desynchronization is realized, when there is no correlation between elementary modes. Hence, the quantity $1/m$ plays the role of synchronization degree: if the synchronization is complete, this quantity equals 1, and at a complete desynchronization its value equals zero.

Let us introduce into consideration the effective synchronization degree q by the formula

$$q = \frac{\xi_{\omega m}}{\sum\limits_i \xi_\omega(\omega_i)}, \qquad (1)$$

where $\xi_{\omega m}$ is the maximum value of ξ_ω. The possibility of using formula (1) follows from the fact that it is valid in both limiting cases, $m = 1$ and $m \to \infty$. In both of them, the q-value coincides with the corresponding $1/m$-value. Really, in the state of complete synchronization, i.e. when $m = 1$, the sum in formula (1) contains only one term; all other terms equal zero, so that $q = 1$ in this case. In the state of complete desynchronization, i.e. as $m \to \infty$ (actually, at the values $m \gg 1$), all terms of the sum in formula (1) become almost identical, and we obtain the equality $q = 1/m$.

By applying formula (1) to the dependences $\xi_\omega(\omega)$, the synchronization degrees for the turbulent motions corresponding to various magnetic field inductions and solution concentrations were calculated. The results of calculations are depicted in Fig. 3. Let us emphasize three following features in the behavior of synchronization degree described by the plots in Fig. 3:

(i) the dependence $q(B)$ has a minimum at a certain value $B = B_m$;

(ii) the rate dq/dB at $B > B_m$ decreases, when the solution concentration increases;

(iii) at the synchronization, modes with higher frequencies survive.

The quasiperiodic mode is known to be unstable [3]. Owing to the interaction between modes, this mode disappears for a while, generating a new periodic motion. As we see, this synchronization is not associated with the action of external factors, but follows from the nature of weak (quasiperiodic) turbulence. At the same time, the synchronization observed in our experiment has another origin: this is the action of an external factor (a magnetic field) that induces it. It is reasonable to call the synchronization of this kind induced or stimulated by a magnetic field.

In the framework of the model proposed in work [1], the emergence of turbulence is associated with the hydrodynamic interaction. In the absence of the latter, the turbulence does not exist. Therefore, the action of the magnetic field was reduced only to the rotation of anisotropic clusters, i.e. their orientation in the field direction. It is owing to the hydrodynamic interaction that the motion of clusters obtains the oscillatory character. The lower the frequency of oscillations, the closer the oscillation motion, by its characteristics, to the rotation (for the latter, the frequency can be considered equal to zero). Therefore, when high-frequency modes begin to dominate in the quasiperiodic regime, it should be recognized that the hydrodynamic interaction between anisotropic clusters becomes stronger in this case. In other words, in the framework of the adopted model, the stimulated synchronization should be considered as a consequence of the strengthening of the hydrodynamic interaction.

Let us analyze the peculiarities in the behavior of synchronization degree, which were mentioned above, in connection with possible variations of the hydrodynamic interaction. From this viewpoint, the observed growth of q with B at $B > B_m$ testifies to a more intensive hydrodynamic interaction. This conclusion, in our opinion, looks quite reasonable, because the growth of the induction B increases the value of the external angular momentum, with which the field acts on the cluster, and, accordingly, even more excites the liquid surrounding it.

The minimum in the dependence $q(B)$ testifies to a weakening of the hydrodynamic interaction. Let us recall that, simultaneously with the synchronization, the process of formation of new unstable modes takes place. Therefore, we may assume that the prevalence of the latter process gives rise to the observed weakening of the hydrodynamic interaction: the appearance of a new mode makes the primary perturbation of the medium induced by the action of an external angular momentum weaker.

Finally, in the framework of the adopted model, the observed general recession of the synchronization degree q with a growth of the solute concentration can be explained by the fact that the number of clusters increases at that, and the perturbations generated by the motion of various clusters are mutually imposed. Those perturbations become partially compensated. At the same time, as the number of clusters increases, the probability of this compensation also increases, which brings about a reduction of q.

4. Conclusions

The emergence of a turbulent motion in the aqueous glucose solution under the action of a magnetic field is accompanied by the synchronization of this motion. This synchronization is stimulated, because the synchronization degree depends on the magnetic field induction.

The dependence of the synchronization degree q on the magnetic induction B has a non-monotonic character: a minimum is observed at a certain value $B = B_m$. The growth of the synchronization degree at $B > B_m$ is stimulated by the strengthening of the hydrodynamic interaction between the clusters. The observed minimum takes place owing to the generation of unstable oscillation modes in the solution.

The synchronization degree decreases, as the concentration grows. This behavior is associated with the mutual compensation of perturbations generated by the motion of various clusters.

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ТУРБУЛЕНТНІСТЬ У ВОДНИХ РОЗЧИНАХ ГЛЮКОЗИ, ВИКЛИКАНА МАГНІТНИМ ПОЛЕМ

Р е з ю м е

Досліджується турбулентний рух у водному розчині глюкози, спричинений магнітним полем. Вивчаються зміни, що відбуваються із цим рухом, внаслідок зміни значень індукції магнітного поля та концентрації розчину. Встановлено, що залежність ступеня синхронізації турбулентного руху від магнітної індукції є немонотонною функцією. Наявність мінімуму у цієї функції пов'язується із виникненням нестійких коливних мод. Наступне зростання ступеня синхронізації пояснюється посиленням гідродинамічної взаємодії між анізотропними кластерами. Встановлено, що збільшення концентрації розчину зменшує ступінь синхронізації. Цей факт є наслідком взаємної компенсації збурень, які створені різними кластерами.