

## INFLUENCE OF PHASE TRANSITION OF NEAR MEMBRANE WATER ON GRAVITROPIC REACTION OF PLANTS IN DIFFERENT COMBINATION OF MAGNETIC AND ELECTRIC FIELDS

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**Abstract.** It was shown before that the effect of the combined magnetic field on the gravitropic reaction of plants' roots depended essentially on the initial orientation of roots and combined magnetic field and gravity vectors. Goal of the work fulfilled under the conditions of low level of magnetic and electric fields' noises, was, to summarize the experimental results obtained in this and our previous works and to understand the common mechanism of these differences. So the experiments of simultaneous action of static magnetic field and alternating electric field of different orientations relatively each other were observed. The gravitropic reaction of cross roots was investigated in static vertical magnetic field and alternating electric field of all possible different directions relatively the magnetic field and roots direction (3 variants). The alternating electric field was tuned to cyclotron frequency of  $\text{Ca}^{2+}$  ions in vertical magnetic field. The biological effect wasn't observed at all for the roots parallel to static magnetic field. The analogous investigation has been fulfilled for horizontal magnetic field. The alternating electric field was tuned to cyclotron frequency of  $\text{Ca}^{2+}$  ions in horizontal magnetic field. Six different types of relative directions of magnetic field, electric field and roots were investigated. The clear biological effect was obtained only for two cases from six, when the roots were not parallel to the magnetic field. The direction of roots relatively both static magnetic field and alternating electric field is very important. The effect may be explained by membrane breathing caused by alternating electric field because the alternating electric field created the alternating magnetic field. But other explanation is the phase transition in near membrane water and it is more likely. The effect caused by the rotation of ions around the domains in the vacuum layer. This explanation explained very well the results obtained both in combined magnetic field and in the static magnetic field combined with the alternating electric field.

**Key words:** static magnetic field, alternating electric field, gravitropic reaction, roots' direction, ion's cyclotron frequency, phase transition in water.

### INTRODUCTION

The investigation of combined magnetic field (CMF, static and parallel to it alternating magnetic field) influence on the plants roots gravitropic reaction have been studied in details before for different relative orientation of fields and roots initial direction [1-4]. It was shown that the biological effect depended essentially on the orientation of roots relatively the CMF [3]. It was shown also that the roots initial direction relatively  $B_{DC}$  and  $B_{AC}$  ( $B_{DC}$  and  $B_{AC}$  were inductances of static and alternating magnetic fields when they were not parallel to each other) were essential for the observation of negative gravitropic reaction presence and decreasing of gravitropic reaction [4]. The effect we obtained might be explained by our theory based on Liboff's hypothesis (the electric field of membrane was taken in consideration [5]) and our previous work [3, 4]. It was shown in [3, 4] that the breathing of the membrane caused by the changes of ions pressure on it was important only in the cases when the ions' direction of moving was not parallel either for  $B_{DC}$  or  $B_{AC}$ .

To confirm or deny our hypothesis we changed the alternating component of magnetic field by alternating electric field of different orientations. пааее

The first part of the work was devoted to the experiments in vertical static magnetic field.

### EXPERIMENTS IN VERTICAL STATIC MAGNETIC FIELD

- At first experiment the static magnetic field was directed parallel to the gravity vector, the alternating electric field was directed parallel to static magnetic field, roots were directed perpendicular to both two fields components and gravity vector.
- At second experiment the static magnetic field was directed parallel to the gravity vector, the alternating electric field was directed perpendicular to static magnetic one, roots were directed parallel to alternating electric field.
- At third experiment the static magnetic field was directed parallel to the gravity vector, the alternating electric field was directed perpendicular to static magnetic one, roots were directed perpendicular to both two field's components and gravity vector.

### Materials and methods.

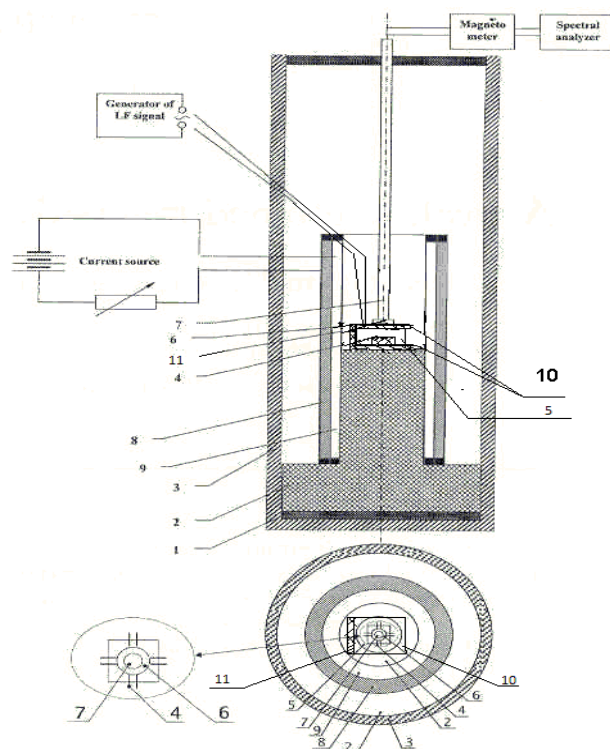
For the investigation a new initial part of the setting we used before was made. The previous setting of the investigation was described in details before [2, 3]. The only distinction was the possibility to obtain the electric field that was parallel or perpendicular to gravity vector. For the purpose the samples were located in capacitance between two non-magnetic planes (fig. 1, 2).

The only difference between figure 1 and figure 2 was the orientation of the electric field created by non-magnetic planes.

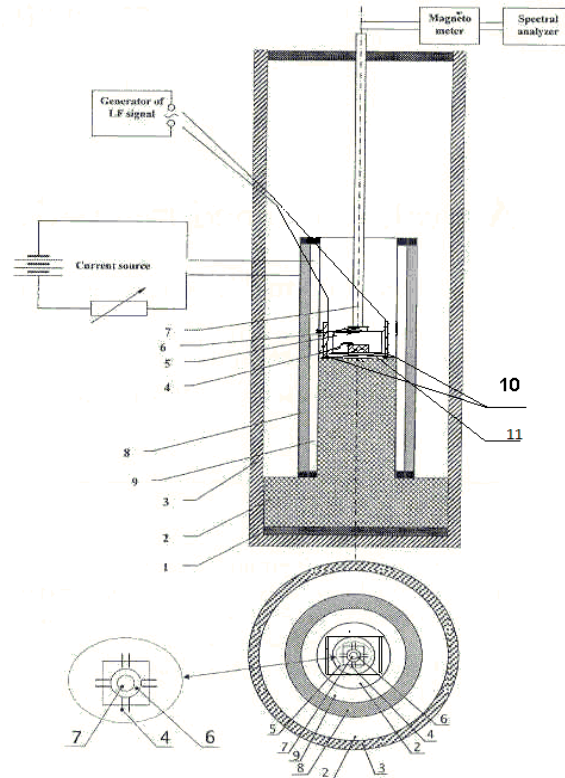
To decrease both the noise of the shield, and generated by solenoid we used the superconducting shield with warm volume inside. The inside part of the warm volume coincides with the inside part of  $\mu$ -metal shield represented on figures 1 and 2. The magnetic and electric noise  $1/f$  and Nyquist one were decreased by 100-1000 times. But the vibration noise and 50 Hz noise level decreased only by 20 – 100 times. The Shuman noise at 8 Hz was almost at the same level. So the level of Nyquist noise was at the order of 0.02 nT, at 50 Hz of the order 1-0.2 nT and at 8 Hz it was at the order of 1-2 nT. But we can decrease the magnetic noise of the generator of electric field only down to 5-10 nT.

### Results.

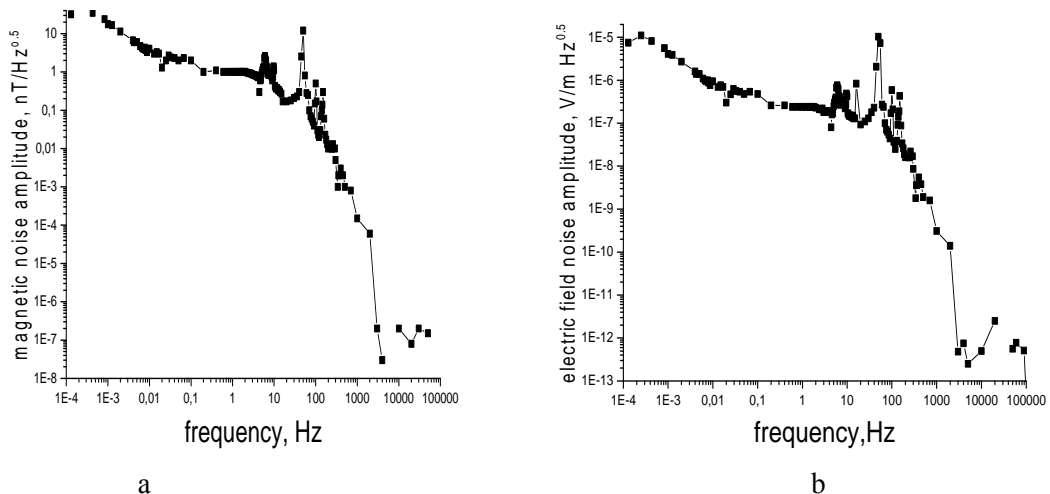
The results were obtained for the configuration of fields that were shown on figure 4 just as in [6]. As it is clear from figures 5 and 6 the gravitropic reaction velocity depended essentially on the direction of initial roots growing relatively the alternating electric field direction. It was revealed at the first and second experiments that the velocity of gravitropic reaction was decreased essentially while at the third experiment it didn't differ from the control experiment. We observed the biological effect only for the experiments when the amplitude of alternating electric field was 100 V/m and more. Any effect was observed at the amplitude of alternating electric field 10 V/m. We have to notice here that it is impossible to determine the exact value of amplitude of alternating electric field because of the wet environment of roots. The exact value depends on the humidity of the camera and the electric resistance of the root.



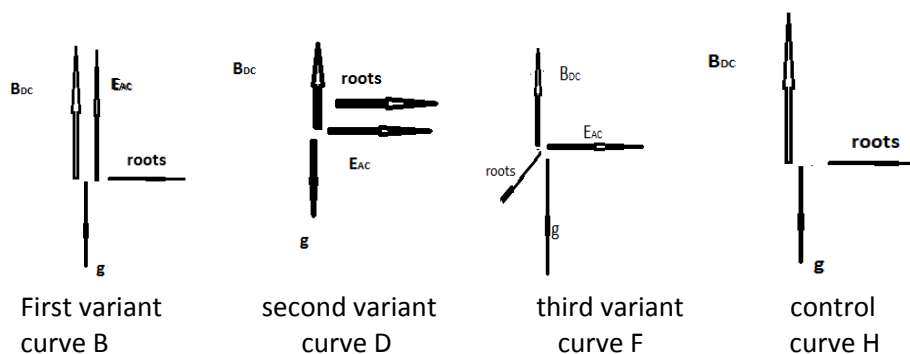
**Figure 1.** The damping rubber (1) supported the holder of dielectric material (2). The  $\mu$ -metal shield (3) surrounded the samples (4) that were mounted inside a moist chamber of non-magnetic plastic material (5) and solenoids (8, 9). The magnetic field was measured and controlled by sensor elements (fluxgate magnetometer or SQUID) (6) inside a holder (7). The solenoids (8, 9) had a cylindrical shape and comprised the system that generated the static magnetic field (9) [2, 3]. The new part: two flat plates from non-magnetic material (10) were sourced from LF generator. They were divided by dielectric plate (11). The enlarged central part of the top view showed the orientation of 4 pairs of roots (4), arranged around the magnetic field sensor (7). The coils of solenoids (8, 9) were the spaces between the circles in the bottom part. The space between the innermost circles was the holder of dielectric material (2)



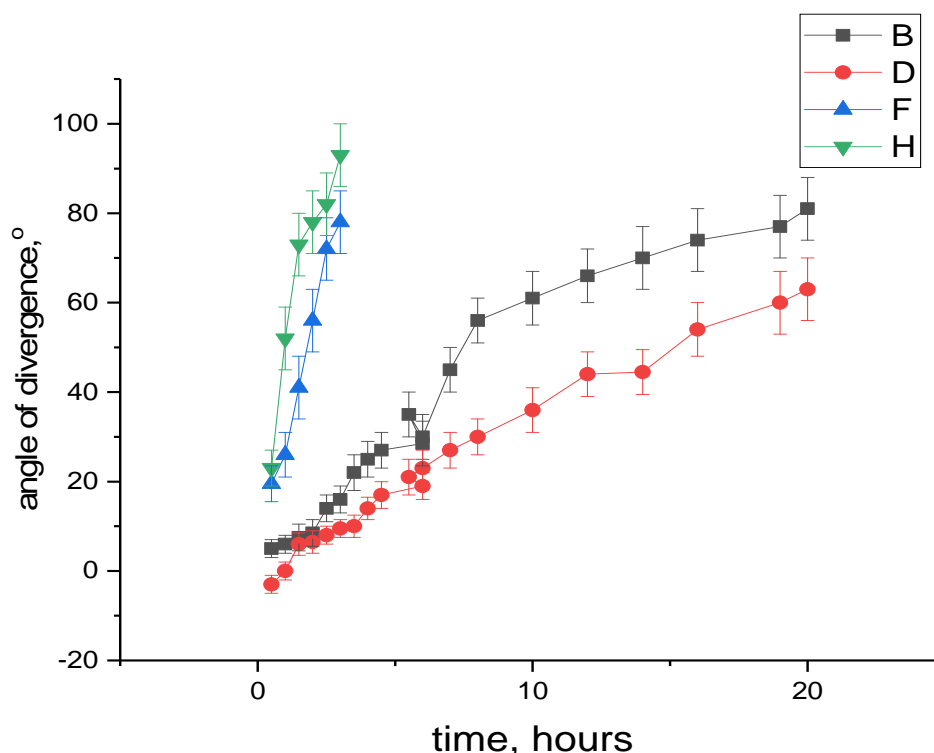
**Figure 2.** The damping rubber (1) supported the holder of dielectric material (2). The  $\mu$ -metal shield (3) surrounded the samples (4) that were mounted inside a moist chamber of non-magnetic plastic material (5) and solenoids (8, 9). The magnetic field was measured and controlled by sensor elements (fluxgate magnetometer or SQUID) (6) inside a holder (7). The solenoids (8, 9) had a cylindrical shape and comprised the system that generated the static magnetic field (9) [2, 3]. The new part: two flat plates from non-magnetic material (10) were sourced from LF generator. They were divided by dielectric plate (11). The enlarged central part of the top view shown the orientation of 4 pairs of roots (4), arranged around the magnetic field sensor (7). The coils of solenoids (8, 9) were the spaces between the circles in the bottom part. The space between the innermost circles was the holder of dielectric material (2)



**Figure 3.** The amplitudes of spectral densities of magnetic (a) and electric (b) fields' noises' dependencies on frequency ( $\mu$ -metal shield)



**Figure 4.** The value of static magnetic field induction was equal to  $8.65 \mu\text{T}$ , the frequency of alternate electric field was equal to  $6.85 \text{ Hz}$ , and the amplitude of electric field was equal to  $100 \text{ V/m}$ . Curves B, D, F and H correspond to the figure 5



**Figure 5.** The dependences of divergences of cress roots from the horizontal plane on time. Curve B corresponds to the first experiment (fig.4) curve D corresponds to the second experiment (fig.4), curve F relates to the third experiment (fig. 4) and curve H relates to the control experiment. The value of static magnetic field induction is equal to  $8.65 \mu\text{T}$ , the frequency of alternating electric field is equal to  $6.85 \text{ Hz}$ , and the amplitude of electric field is equal to  $100 \text{ V/m}$

### EXPERIMENTS IN HORIZONTAL STATIC MAGNETIC FIELD

The following experiments of roots location relatively the static horizontal magnetic field and alternating electric field were investigated. In all variants the static magnetic field with magnetic inductance  $B_{DC}$  was directed perpendicular to the gravity vector  $g$ .

In the first experiment the electric field was directed parallel to magnetic one and the roots were perpendicular to both of them.

In the 2-nd experiment the electric field was directed perpendicular to the magnetic one and parallel to the gravity vector  $g$ , the roots were perpendicular to both fields.

In the 3-d experiment the electric field was directed perpendicular to magnetic one and parallel to  $g$ , the roots were parallel to magnetic field.

In the 4-th experiment the electric field was directed parallel to magnetic one and roots were parallel to both of them.

In the 5-th experiment the electric field was directed perpendicular to both the magnetic field and  $g$  and the roots were parallel to magnetic field.

In the 6-th experiment the electric field was directed perpendicular to both the magnetic field and  $g$  and the roots were parallel to electric field  $B_{DC}$ .

#### New experimental setting.

To obtain the horizontal magnetic field it was necessary to turn the settings that had been drawn on figures 1 and 2 on the side by the same way as in the work [3]. Then the axes of the shield and the solenoid became horizontal. In that case the setting shown on fig. 1 created horizontal electric field and the setting shown on fig. 2 created vertical electric field. The direction of artificially created magnetic field was horizontal. The dependences of amplitude spectral density of magnetic field and electric fields noises on the frequency were similar to the dependencies shown on figure 3. But the amplitudes of spectral densities of magnetic and electric field's noises were approximately by seven times less. We have to notice here that we oriented the  $\mu$ -metal shield perpendicular to the direction of horizontal component of Earth's magnetic field. It allowed us to decrease the magnetic and electric noises essentially (by the order of 50 times)..

#### Results.

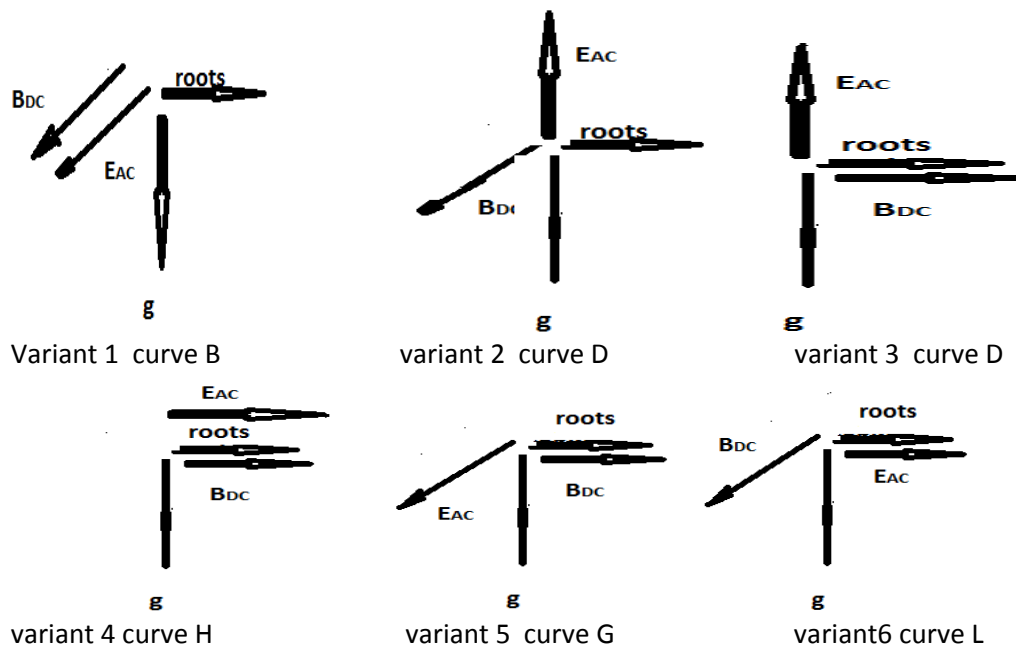
The results obtained were shown on figures 7 and 8.

It was clear from figures 5 and 7 that the main condition under which the gravitropic reaction inhibition was observed was the following. The roots needn't be parallel to the static magnetic field and had to be parallel to the alternating electric field.

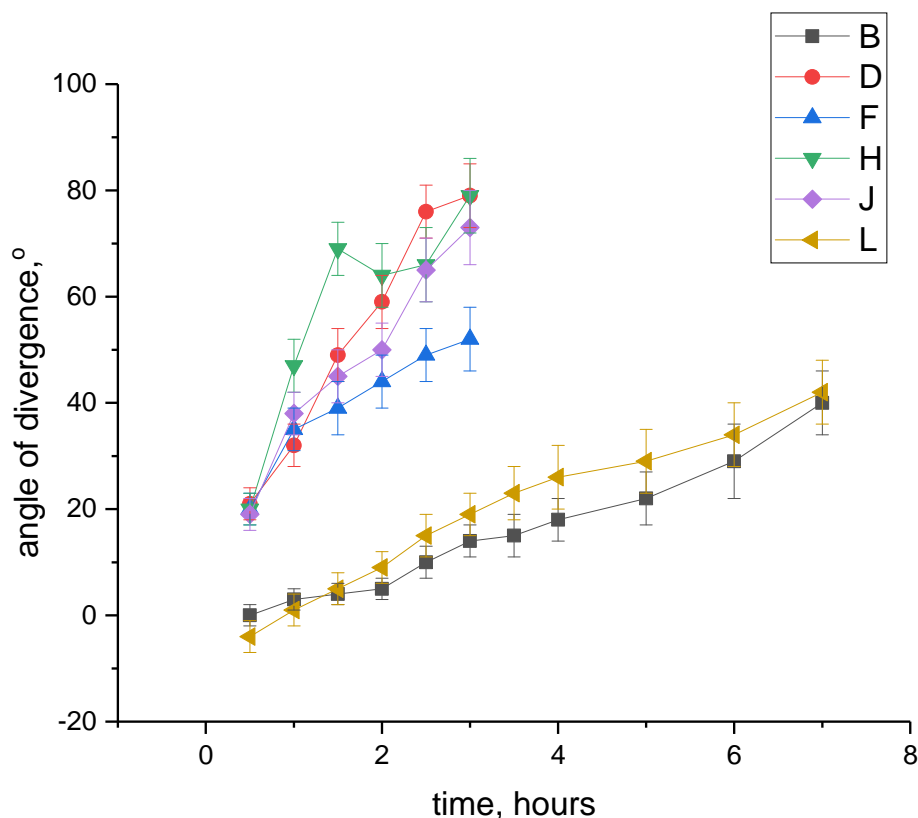
### DISCUSSION

The results obtained in this work confirm the results of our previous works [3, 4]. It was shown in the works [3, 4] that the biological effect on gravitropic reaction existed only in the cases when the roots direction was perpendicular to static or alternating magnetic fields or to both of them. In this work we showed that the same effect existed. The gravitropic reaction was sensitive to simultaneous action of static magnetic field and alternating electric one only when the roots direction didn't coincide neither with the direction to static magnetic field nor with the direction of alternating magnetic field created by alternating electric field. This result coincides well with the results of previous works [3-5] and confirmed the fact that the main direction of  $Ca^{2+}$  ions' moving was the moving along the roots. The results obtained in horizontal magnetic field confirmed the results obtained in vertical magnetic field.

The effect we obtained might be explained by our theory based on Liboff's hypothesis [5], that (the electric field of membrane had to be taken in consideration) as ours previous works. The alternating electric field created alternating pressure on membrane in the direction of the electric field and so the membrane began to breathe with the same frequency. The membrane breathing was important only in the cases when the ions direction of moving was not parallel either for  $B_{DC}$  or  $B_{AC}$ . Here  $B_{AC}$  is the alternating magnetic field created by alternating electric field.



**Figure 6.** Variants of experiments in horizontal static magnetic field combined with the alternative electric fields of different directions. In the down part of the scheme the curves corresponding to every variant was signed in the correlation with the figure 8



**Figure 7.** Dependence of cress roots angle of divergence from the horizontal place on time. Magnetic field was directed perpendicular to gravitational vector  $g$ . Curve B corresponded to the first experiment (the electric field was parallel to magnetic one and the roots were perpendicular to both of them); curve D corresponded to the second experiment (the electric field was perpendicular to the magnetic one and parallel to the gravity vector  $g$ , the roots were perpendicular to both fields); curve F corresponded to the third experiment the electric field was perpendicular to magnetic one and parallel to  $g$ , the roots were parallel to magnetic field); curve H corresponded to the fourth experiment (the electric field was parallel to magnetic one and roots were parallel to both of them); curve J related to the fifth experiment (the electric field was perpendicular to both the magnetic field and  $g$  and the roots were parallel to magnetic field); curve L related to the sixth experiment (the electric field was perpendicular to both the magnetic field and  $g$  and the roots were parallel to electric field). The value of static magnetic field induction was equal to  $8.65\mu\text{T}$ , the frequency of alternating electric field was equal to  $6.85\text{ Hz}$ , and the amplitude of electric field was equal to  $100\text{ V/m}$ .

We tried to estimate the amplitude of electric field necessary to observe the effect. The Maxwell equation is:

$$\text{Rot}E = -dB/dt. \quad (1)$$

So for the cell:

$$E2\pi a = 2\pi f B_{AC}. \quad (2)$$

Here  $E$  – the electric field value;  $f$  – the frequency of alternating electric field component. For plant cell with the  $a$  of the order of  $10\ \mu\text{m}$ ,  $f = 31.75\text{ Hz}$  and  $B_{AC} = 40\text{--}70\ \mu\text{T}$  we obtain for  $E_{AC}$  value of the order  $100\text{--}200\text{ V/m}$ . This value coincided very well with the value of acting  $E_{AC}$  in our experiment.

The more convincing conclusions that may be made from the experiments that are shown in this work are based on the last works of Liboff, Foletti and Marchettini [8–10]. All these works were devoted to the phase transition in the pure water in combined magnetic field [8], the presence of structured domains in the water and higher conductivity in the domains caused by the proton hopping between the domains [9], and the presence of the ‘vacuum’ region between the domains [10]. In our previous work [11] to explain the cyclotron resonance existence we regarded the rotation along the cell from the inner part of the cell. The only counterargument for existence of ion cyclotron resonance in that case was the small free path of ion at room temperature. In the case of domains the protons rotate around the domain in the vacuum layer of the order  $10\text{ nm}$ . So there are no obstacles for the ion cyclotron resonance existence.

The possibility of phase transition in water *in vivo* during the treatment at cyclotron frequency of  $\text{H}_3\text{O}^+$  was proved [12, 13]. Besides we have to underline here that we must take into account the generation of magnetic noise in wet seeds [14, 15]. The fact was confirmed by the last work of Liboff [16] and the values of generated noise level observed in [14–16] coincide between themselves. Moreover according to [8, 9, 14] it may be caused by the external magnetic field

noise. The external magnetic noise with the noise level 5-20 nT may create the magnetic noise in wet seeds up to 80 nT while the dry seeds don't change the noise level of the shield used [14]. All these facts prove the leading role of water in all biological processes.

Now we can investigate the substitution of alternating magnetic field by alternating electric field. In all cases when the roots are directed along the static magnetic field there was no biological effect (or it was very small and existed only at the beginning of the treatment). This fact showed that the  $\text{Ca}^{2+}$  ions moved in the direction that was parallel to the direction of static magnetic field.

#### **Vertical static magnetic field.**

In the case when the direction of alternating electric field coincided with the direction of root and so with the direction of  $\text{Ca}^{2+}$  ions moving the effect was maximal and we observed even the negative gravitropic reaction. This case was similar to the effect we had observed before in combined magnetic fields when both its components had been directed parallel to each other and gravitation vector. The alternating electric field modulated ions velocity's magnitude absolutely analogous the modulation of magnetic induction modulation (fig. 4. second variant).

The first variant in fig.4 corresponded to variant, when the alternating electric field was perpendicular to roots and static magnetic field. The experiment showed the essential inhibition of gravitropic reaction. In this variant the  $\text{Ca}^{2+}$  ions moved by the spiral. Its observation was limited by the dimension of the domain.

#### **Horizontal static magnetic field.**

The first variant in figure corresponded to the first variant of figure 4 and the sixth variant corresponded to the second variant of figure 4. The second variant in figure 6 corresponded to exit from domain region.

All other variants in figure 6 corresponded to the third variant of figure 4.

We have to notice here that in our experiment even remained magnetic field at the frequency 50 Hz in the 3-layered  $\mu$ -metal shield (at the level 20-50 nT) is enough to generate phase transitions in water. In our experiments only in superconducting shield it may be decreased by 1000 times. But in superconducting shield we cannot create horizontal magnetic field because of lack of dimensions in horizontal direction.

We have to notice here that while the gravitropic reaction is absent, the roots become thicker. The effect may be connected with water detained in roots.

## **CONCLUSIONS**

The direction of roots relatively both static magnetic field and alternating electric field is very important.

The effect may be explained by membrane breathing caused by alternating electric field. The alternating electric field created the alternating magnetic field. The results obtained in combined magnetic field coincided very well with the results obtained in magnetic field acting simultaneously with electric field.

The other explanation is the phase transition in near membrane water. The effect caused by the rotation of ions around the domains in the vacuum layer. This explanation explained very well the results obtained both in combined magnetic field and in the static magnetic field combined with the alternating electric field.

All results confirmed the directed moving of ions  $\text{Ca}^{2+}$  in the roots and the fact that all effects were connected with the ions moving.

The role of water is very important too. The existence of ion cyclotron resonance may be explained by phase transition in water. More other phase transition in water may be created by magnetic noise of the system.

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