Electromagnetically Induced Fluid Streaming as a Possible Mechanism of the Biomagnetic Orientation of Organisms

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The results show that both the direction and the intensity of the geomagnetic field can be sensed within the chamber of a Zeiss Cytopherometer. This suggests that electromagnetically induced fluid streaming might play a role in the perception of the geomagnetic field by organisms, although it is not clear at present in which organ the perception occurs. A basic requirement for such an organ would be an anisotropy of cells or cellular structures. The nervous system with its parallel axons, or specific cells associated with the nervous system, could thus be possible locations of the sensitivity towards magnetic fields.

Investigations on plants [1] and on animals [2, 3] have shown that they are able to sense the direction of the magnetic field of the earth. Several models concerning the nature of this mechanism have been developed [3], but as yet they remain unproven. It has so far not been possible to locate this sense in a particular organ [4]. Recently, M. J. M. Leask published a new hypothesis [5]. He attributes the mechanism to radicals which appear during the visual process in the retina. However this theory does not provide an explanation for the ability of certain organisms, *e. g.* bees [6] to orient in the dark.

We want to discuss a different mechanism as a possible explanation for biomagnetic orientation. It is based on a fluid stream which is caused by simultaneous perpendicular magnetic and electric fields in an electrolyte. The streaming was initially observed when crossed electric and magnetic fields of relatively low intensity (5 V/cm and 50×10^{-5} T) were sent through a solution of 0.145 M NaCl electrolyte [7]. The aim of the present study was to determine whether the streaming was strong enough to be sensitive to the direction of the earth's magnetic field.

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We used the chamber of an analytical cell electrophoresis apparatus (Cytopherometer, Zeiss) to demonstrate the electromagnetically induced streaming of the electrolyte. Within the chamber (Fig. 1) the electrical field and the current density is highest at the inlet (a), decreases rapidly as the chamber enlarges (b), and is lowest and homogeneous in the centre of the chamber (c). The ions of the electrolyte migrate under the action of the electric field. If a homogeneous magnetic field (B) is applied perpendicular to the electric field, the resulting Lorentz force ($F = q[v\,x\,B]$; q = charge, v = ion velocity in the electric field) on the ions is greater at the inlet than at the centre of the chamber because the velocity of the ions is greatest at the inlet and lowest at the centre.

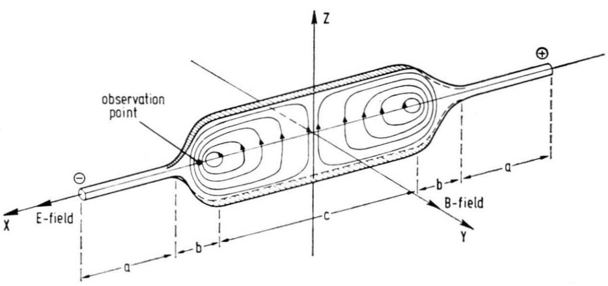

Fig. 1. The streaming of the fluid in the chamber of a Zeiss cytopherometer under the influence of crossed electric (E) and magnetic (B) fields.

The resulting pressure gradient produces a streaming of the fluid, as indicated by the circles in Fig. 1. The chamber was immersed in a 0 °C waterbath to prevent thermal convection during the experiments. The velocity of suspended particles used as an indicator for the fluid streaming, was observed with a microscope. After each measurement of the velocity in one direction the electric field was reversed to obtain the particle velocity in the opposite direction. 120 such velocity (v_1) measurements, with the chamber oriented vertically to or parallel with the direction of the geomagnetic field B_1 (Fig. 1), were averaged and compared with the particle velocities (v_2) in an artificial magnetic field (B_2) as a reference. The field B_2 was made about 100 times greater than the geomagnetic field in order to avoid any significant influence of the earth's magnetic field on the reference measurements. The strength of the geomagnetic field B_1 was calculated from the averaged particle velocities v_1 and v_2 and from the corresponding electrical currents I_1 and I_2 through the electrolyte:

$$B_1 = \frac{v_1 I_2 B_2}{v_2 I_1} . \quad (1)$$

We used human erythrocytes as particles. Their natural charge was mainly removed by treatment with neuraminidase [vibro comma (cholerae), Behringwerke, Marburg, Germany] in order to minimise the electrophoretic movement of the cells. The erythrocytes were then fixed with 2% glutardialdehyde and stored until needed. The electrolyte in the chamber consisted of a solution containing 1 M $CuSO_4$ and 0.5 M Na_2SO_4. The electrodes were made of Cu wire. This combination was chosen because (1) less heat was produced for a given electrical current density in the electrolyte as compared to a physiological saline solution and (2) no gas was produced at the electrodes to disturb the system. The measurements were made with a current of 50 mA which corresponds to a maximum current density of 1590 mA/cm^2 in the inlet and a minimum current density of 500 mA/cm^2 in the central part of the chamber.

The geomagnetic field in our laboratory had a maximum value of $0.40 \pm 0.01 \times 10^{-4}$ T (measured by a fluxgate magnetometer; Förster, Reutlingen, Germany) at an inclination of $46.5 \pm 0.7°$ and a declination of $-1°$. With our chamber oriented such that the geomagnetic field vector was parallel to the y-axis of the chamber (Fig. 1) a fluid stream in the direction of the z-axis was observed. The geomagnetic field strength, calculated from the velocity measurements using Eqn (1) was found to be $(0.46 \pm 0.05) \times 10^{-4}$ T. When the chamber was turned such that the geomagnetic field was parallel to the z-axis, no deflection of the erythrocytes along the z-axis was observed. The calculated intensity of the geomagnetic field exceeds the value measured with the magnetometer by 13%.

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