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Thermoelectrokinetic phenomena in the convective plasma zone of the Sun and stars

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Abstract. The study shows that electromagnetic phenomena in the convective plasma zone of the Sun and stars and the local magnetic field near the Sun's surface are caused not only by the magnetohydrodynamic dynamo mechanism (Krause, Rädler 1980; Moffatt 1978; Morozov 2006), but also by the phenomena that have relatively recently become the focus of research, i. e., thermoelectrokinetic phenomena in the viscous electrically conductive medium in the presence of a temperature gradient (Grabov 2003; 2005a; 2005b; Prigogine, Nicolis 1977). The results of physical modelling and quantitative estimates show that thermoelectrokinetic currents can create primary magnetic fields of approximately B ≅ 103 Gs in the convective plasma zone of the Sun and stars.

Keywords: thermoelectrokinetic phenomena, viscous electrically conductive substance, plasma of the Sun, convective zone of the Sun, magnetic field near to a surface of the Sun

Introduction

Usually, electromagnetic processes in the convective plasma zone of the Sun and stars are described on the basis of the theory of magnetohydrodynamic dynamo (Krause, Rädler 1980; Moffatt 1978; Morozov 2006) (see Fig. 1 and Fig. 2). As the authors note (Krause, Rädler 1980), this theory is based on the equations of magnetic hydrodynamics: Maxwell's equations, the corresponding equations of the state and the Navier—Stokes equation. The most important value in the electrodynamics of medium fields is the average value of the electromotive force arising from the interaction of the velocity fluctuation and the magnetic field.

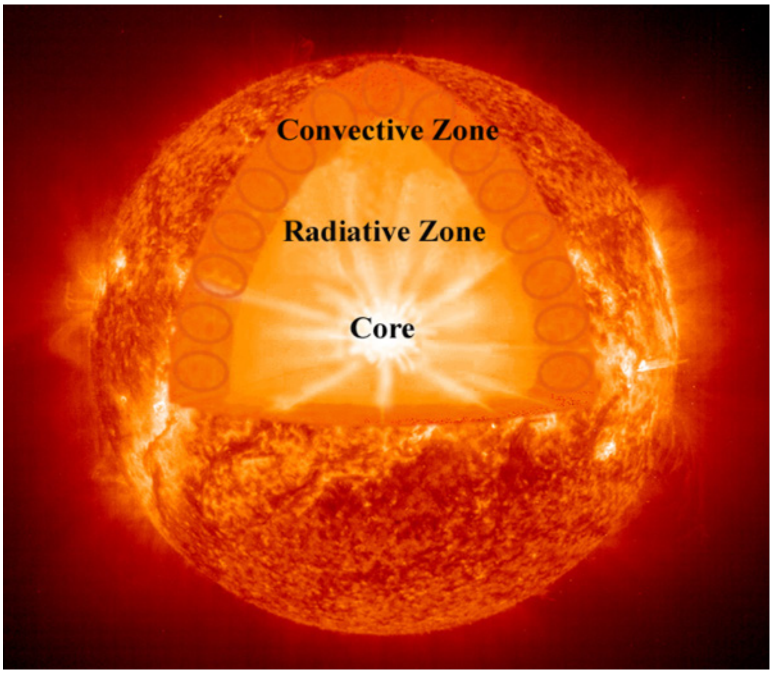

Fig. 1. Convective zone of the Sun

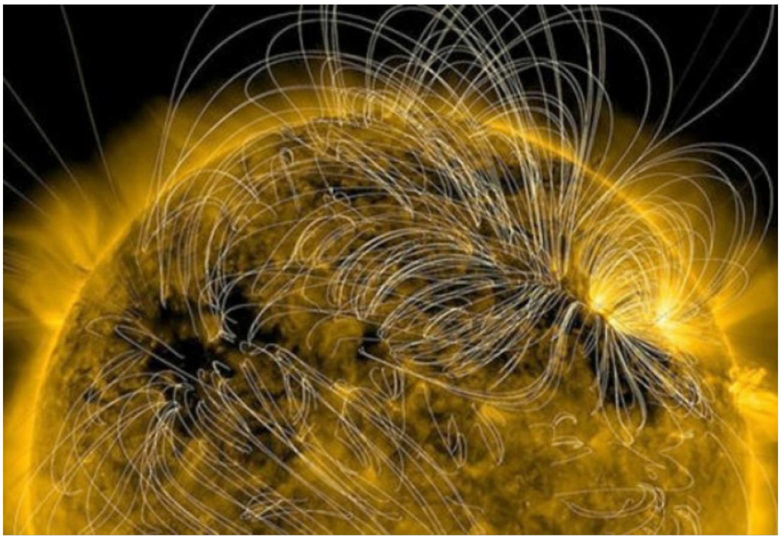

Fig. 2. Local magnetic field near to a surface of the Sun

The convective plasma zone of the Sun and stars is located in the gravitation field and the field of the radial temperature gradient. Along with that, the convective flow system itself is represented by convective dissipative structures such as Benard cells resulting from self-organisation in viscous media under conditions far from thermodynamic equilibrium (Ebeling 1976; Prigogine, Nicolis 1977).

On the other hand, it is known that in plasma, under the action of the temperature gradient and due to the differences in the intensity of thermodiffusion of electrons and ions, the thermoelectric field with the strength is formed (Kotel'nikov 2013).

$$E_t = \frac{3}{2}\left(\frac{k}{e}\right)\nabla T \qquad (1)$$

In the presence of inhomogeneity of the medium, the thermoelectric electromotive force is formed (Anatychuk 1998):

$$\varepsilon = \oint (E_t dl) \neq 0 \qquad (2)$$

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We will discuss the possibility of forming thermoelectric EMF in the convective plasma zone of the Sun and stars. It is obvious that this zone is located in the field of the radial temperature gradient in the state of existing closed thermokinetic vortices. Their model can be represented as a toroidal vessel filled with the viscous electrically conductive substance located in the field of parallel vectors of gravitational force and temperature gradient, as shown in Fig. 3.

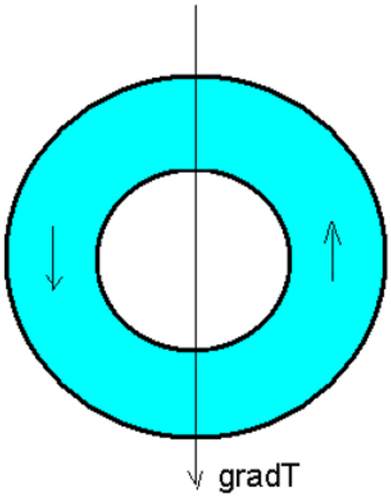


Fig. 3. Toroid as a vortex model convective cell

The theoretical analysis (Landa 2010) shows that if the Rayleigh number increases higher than the critical value, an ordered move, whose direction is determined by random factors, occurs in the vessel.

A further development of the toroid model (Fig. 3) is the transition to the open flow system in the form of a U-shaped tube through which a viscous electrically conductive liquid flows at the velocity V. It can be considered an analogue of the open semiconductor thermoelectric element, see Fig. 4.

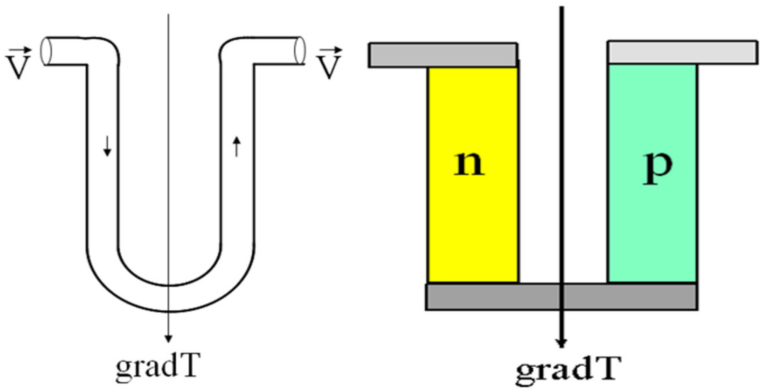
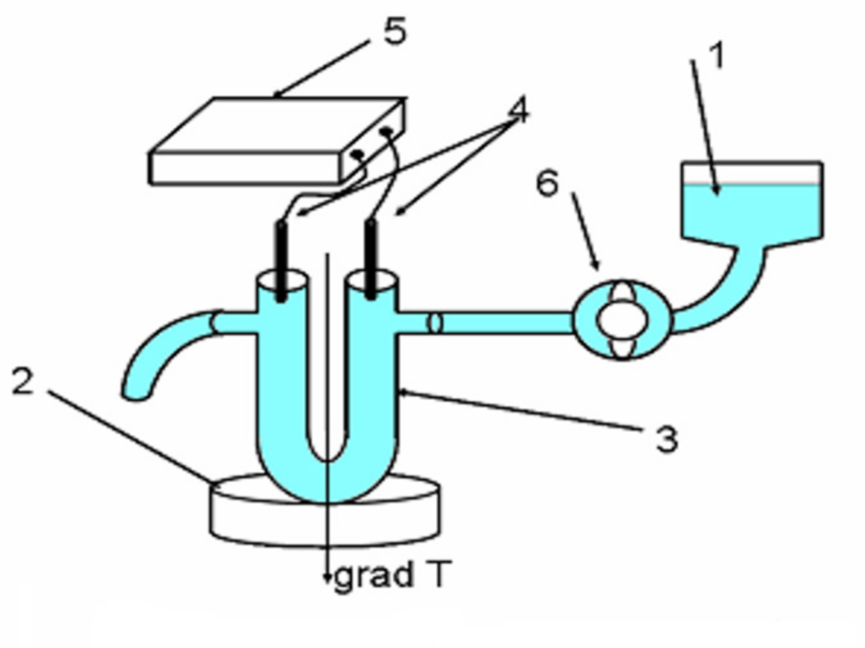


Fig. 4. The open flow system as an analog of a semiconductor thermoelectric element

The thermoelectric EMF in the viscous electrically conductive substance caused by this kinetic inhomogeneity was termed thermoelectrokinetic EMF (Grabov 2003; 2005a; 2005b; Grabov et al. 2010; 2017; Zaitsev et al. 2015). It belongs to the new group of thermoelectrokinetic phenomena that have become the focus of detailed experimental and theoretical research with the evidence taken from aqueous solutions of ionic compounds and electrolytes (Grabov et al. 2010; 2017; Zaitsev et al. 2015).

The experimental study of new thermoelectrokinetic phenomena

Experimental studies of thermoelectrokinetic EMF in liquid electrolytes was carried out using the equipment developed by (Grabov et al. 2010; 2017; Zaitsev et al. 2015) (see the layout in Fig. 5). Liquid electrolytes, aqueous solutions of ionic compounds, acids, alkalis and salts were used as a viscous electrically conductive medium. To get large values of thermoelectric EMF coefficients, the mobility of positive and negative ions in the solution should have significantly different values (Grabov et al. 2010; Zaitsev et al. 2015). These requirements are met, for example, by an aqueous solution of potassium hydroxide (KOH) with the mobility of K+ ions ($7.6 \times 10^{-8}\, m^2V^{-1}c^{-1}$) and OH- ($20.5 \times 10^{-8}\, m^2V^{-1}c^{-1}$) at 25 °C and the coefficient of thermoelectric EMF ε = −0.6 mV/K (Grabov et al. 2010; Zaitsev et al. 2015).



1—electrolyte, 2—heater, 3—U-shaped tube, 4—electrodes, 5—electrical measuring instrument, 6—peristaltic pump.

Fig. 5. Equipment for measuring thermoelectrokinetic EMF in liquid electrolytes

The thermoelectrokinetic EMF was measured between the points of entrance and exit of the electrolyte. The temperature was maintained the same throughout the experiment. In the presence of a temperature gradient and the absence of electrolyte flow, the EMF was close to zero, since the branches of the thermoelement were symmetrical. During electrolyte flow, the symmetry of the branches was violated, as a result, the EMF was measured and was found proportional to the temperature difference and the solution concentration. The dependence on electrolyte flow rate was linear at the initial stage, then it passed through a maximum with an EMF coefficient value approximately equal to 0.1 mV/K (Grabov et al. 2010; 2017; Zaitsev et al. 2015). This was due to a decrease in heat exchange and a temperature drop.

The experiments showed that the thermoelectrokinetic field strength and the thermoelectrokinetic EMF are proportional to the thermoelectric coefficient of the solution (α), temperature gradient (gradT) and the solution flow density (nv).

$$E = \beta(\alpha gradT)(nv) \tag{3}$$

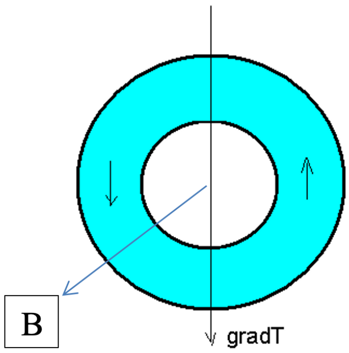
$$\varepsilon_{TEK} = \oint \beta(\alpha gradT)(nv)\,dl \tag{4}$$

At the fixed optimal electrolyte flow rate, the strength of the thermoelectrokinetic field is proportional to the temperature gradient (5) with the coefficient γ ≈ 0.1 mV/K for potassium hydroxide (KOH) (Grabov et al. 2010; Zaitsev et al. 2015).

 https://www.doi.org/10.33910/2687-153X-2022-3-2-75-80

$$E = -\beta\left(\alpha gradT\right)\left(nv\right) = -\gamma gradT \tag{5}$$

Let us apply the toroid model to the plasma convective vortex flow in the convective zone of the Sun (Grabov, Zaitsev, Kuznetsov 2012) (see Fig. 3). Let the external diameter of the convective zone of the Sun amount to about 10^4 km, a toroid cross-section dimeter to about 3×10^3 km, plasma conductivity equal $\sigma = 3 \times 10^3$ Ohm^{-1}m^{-1}, the average temperature value equal gradT = 10^{-2} K/m (Krause, Rädler 1980; Moffatt 1978; Morozov 2006) and the thermoelectrokinetic field strength coefficient equal the value obtained in the experiment with electrolytes γ = 0.1mV/K (Grabov et al. 2010; Zaitsev et al. 2015). Then, the magnitude of the magnetic induction vector in the toroid center, see Fig. 6, is 0.1 Tl, which is close in magnitude order to the experimentally observed results in the region of sunspots. This magnetic field can be considered as primary in plasma, as the dissipative substance which is transformed in magnetohydrodynamic processes and makes up a large range of observed values of magnetic field induction in the convective zone of the Sun. The magnetic field B ≅ (10 – 10^3) Gs is observed experimentally in sunspots (Krause, Rädler 1980; Moffatt 1978; Morozov 2006).



E = γ gradT
γ = (0,1 – 1) mV/K
E = γ gradT = 10^{-5} V/m
J = σE = 10^{-2} A/m^2
I = JS = J(πd^2/4) ≅10^{11} A
B = μ_0I/2πR ≅ 10^{-1} T ≅ 10^3 Gs

Fig. 6. Electric current and magnetic field of a single cell of the convective zone of the Sun

There is a reason to believe that thermoelectrokinetic phenomena can form in the viscous bowels of planets, their atmospheres and oceans.

Conclusions

The new class of phenomena in viscous electrically conductive media, called thermoelectrokinetic, has been experimentally discovered. These phenomena are cross kinetic phenomena of electric charge transfer in the presence of mass transfer and internal energy transfer.

Thermoelectrokinetic EMF and closed electric currents are formed in convective plasma cells in the convective zone of the Sun.

Approximate estimates show that the thermoelectrokinetic currents can create primary magnetic fields in the convective zone of the Sun which are transformed during the magnetohydrodynamic processes and make up a large range of the observed values of magnetic field induction.

Thermoelectrorinenic phenomena play a significant role in the evolution of the surrounding world.

Conflict of Interest

The authors declare that there is no conflict of interest, either existing or potential.

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