Available online at www.sciencedirect.com

ScienceDirect

C. R. Physique 9 (2008) 681–682

COMPTES RENDUS PHYSIQUE

http://france.elsevier.com/direct/COMREN/

The dynamo effect/L'effet dynamo

Foreword

The existence of the Earth's magnetic field was already known from the Greeks, since Aristoteles and his students, in their "*Promenades*" were using magnetized stones, old ancestors of our compass. However, its origin has been subjected to questions until recent times. In 1600, two thousands years after Aristoteles, the British physicist William Gilbert suggested that the Earth was carrying a big magnet in its interior. In 1840, Gauss showed that, the source of this magnetic field is indeed in the centre of our planet. Since the beginning of the 20th century, it is recognized that the temperature of the Earth core is much too high to explain such a magnetization. At about the same time, it was realized that other astrophysical objects such as the Sun and many stars also exhibit a magnetic field. The true origin of this magnetic field, the one generally accepted nowadays, is based on the dynamo effect, a mechanism initially proposed by Sir Joseph Larmor in 1919 for the Sun. It was then accepted that this dynamo action should also be valid in the case of the Earth, whose core is essentially made of molten iron, driven in a motion of natural convection, as well as in the case of other planets like Jupiter. Initially, the origin of buoyancy, the driving force, was supposed to be the heat generated by the residual radioactivity. Today, most scientists agree that the presence of a solute, due to the continuous release of light elements by the solidification of the inner core, should be the most relevant source of the density variations, which result in this convective fluid motion. In the presence of the magnetic field, this motion induces an electric current looping through the electrically conducting Earth core, which, in turn, self-sustains the magnetic field. Then, the origin of this magnetic field should not be magnetic, as assumed by Gilbert, but *magnetohydrodynamic*. In the case of the Sun, made of ionized gases, the mechanism should also have a similar origin, although the main characteristics are strongly different. There exist also planets, such as Mars, which have no magnetic field, although they may have carried one in the past.

It seems, indeed, that all the astrophysical objects, which exhibit a magnetic field, have an important part of their body under a fluid state, either a liquid core as the Earth, or an ionized gas as the Sun, which is driven in motion by buoyancy and can therefore be a candidate to the dynamo effect. It is however clear, when one is looking at key orders of magnitudes, that the different dynamos can follow different leading mechanisms. In some of them, as it is the case in the Earth, which are rapidly rotating bodies, the fluid flow is highly organized by the Coriolis force. In others, such as the Sun, the turbulent character of the fluid motion seems to be predominant upon the influence of the Coriolis force. This suggests that there should not be a unique model for the existence of planetary and stellar magnetic fields, but, on the contrary, that the different classes of astrophysical bodies have their specific way to self-sustain a magnetic field.

Then, beyond the physical intuition of the dynamo effect, many questions remain absolutely open and are the basis of important research programs since the second half of the 20th century. The main ideas on the conditions required for a dynamo action were raised by eminent theoreticians, namely Cowling, Ponomarenko, Bullard, Parker, Moffatt, Roberts and our fellow member Philippe Nozières. They demonstrated that two ingredients are necessary. First, the typical transit time of the fluid must be much smaller than the time of the magnetic diffusion, or the ohmic losses. If this condition is not satisfied, any initial magnetism is damped out and suppressed during the magnetic diffusion time. The ratio of these two time scales, named the *magnetic Reynolds number*, must then be large enough, but it remains difficult to determine the threshold. Second, the system must possess *a sufficient dissymmetry*, so that the electromotive forces within the fluid do not exactly cancel. In the case of rapidly rotating bodies, like the Earth, it is postulated that the Coriolis force is the key ingredient to insure this dissymmetry. To satisfy that condition in laboratory experiments, a quite special organization of the flow is privileged, such that the velocity field has a strong enough helicity.

1631-0705/$ – see front matter
doi:10.1016/j.crhy.2008.07.010

During the years 2000–2002, two such dynamos were experimented, both in duct flows highly organized by the geometry of helical ducts, in Riga and in Karlsruhe. Then, the first experimental dynamo in a finite volume of fluid in a highly turbulent regime has been achieved in Cadarache, France, in 2006, by our colleagues François Daviaud, Stephan Fauve and Jean-François Pinton. It is currently known as *the VKS dynamo*, where the acronym VKS refers to "von Kármán sodium", since the fluid motion is forced to be a classic von Kármán flow between two contra-rotating disks in a finite cylinder full of liquid sodium. Many scientists of the magnetohydrodynamics (MHD) community do consider this experiment as one of the most remarkable achievements in their specialty. This success deserved that a meeting of the Academy of sciences was dedicated to the presentation of this experiment and of its specific merits. The meeting took place in Paris, on May 29, 2007, around presentations made by those researchers. However, since the reference to the case of the Earth was unavoidable, it was thought that another experiment of magneto-convection in a rotating sphere full of liquid sodium, now in progress in Grenoble in the Henri-Claude Nataf group, be also presented. Our fellow member Philippe Nozières was invited to introduce the subject, its challenges and its central properties, on the basis of ideas that he had initially proposed in 1976. And our fellow member Jean-Louis le Mouël accepted to point more precisely the case of the Earth magnetic field in order to illustrate the still quite open challenges before a good understanding of its main features.

At the invitation of our fellow member Guy Laval, editor-in-chief of the series Comptes rendus Physique, it has been decided to prepare and publish a special issue of this journal, dedicated to the dynamo effect, under the responsibility of Jean-François Pinton and myself, acting as invited editors. The authors of presentations on 29 May 2007, were asked to submit the material of their presentations. Several other complementary papers were also invited, either by the authors of the Riga and Karlsruhe experimental dynamos, or by famous experts in closely connected topics, such as the state of the art in the numerical modelling of the VKS dynamo, the solar dynamo, or the apparently antagonistic role of turbulence on the dynamo effect. It is expected that this special issue, printed before the end of this decade during which the understanding and the knowledge of this phenomenon have made a unique jump forward, will be a useful reference for further advances.

René Moreau
Laboratoire SIMAP, Groupe EPM,
INPG-ENSEEG,
BP 75,
1340, rue de la Piscine,
38402 Saint Martin d'Hères cedex,
France
E-mail addresses: rene.moreau@simap.grenoble-inp.fr, r.j.moreau@orange.fr

Available online 29 August 2008