# High magnetic field facilities in Latin America

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# Abstract

The EC supported a network (under the Framework 5 ALFA Programme) designated HIFIELD (Project number II0147FI) and entitled: "Measurement methods involving high magnetic fields for advanced and novel materials". As a result, high field facilities were initiated, constructed or extended at the following laboratories in Latin America: Univ. Cordoba (Argentina), CES, Merida (Venezuela), CIMAV, Chihuahua (Mexico), Univ. Federal de Rio de Janeiro (Brazil).

# Aims of the Project

Prior to the start of the present ALFA project, with the exception of the "Centro de Estudios de Semiconductores", Departamento de Fisica, Universidad de Los Andes, Merida, Venezuela, where a 30 T system already existed, no other high field facility had been installed in Latin America. In order to improve this situation a network was established by the following partners:

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2) J.M. Broto, LNCMP. Toulouse, France (LNCMP).

3) H.A. Davies, M. Univ. Sheffield, U.K. (US).

4) J.P. Sinnecker, Univ. Federal de Rio de Janeiro, Brazil (UFRJ).

5) E. Estevez-Rams, Univ. Havana, Cuba (UH).

6) V. Sagredo, J. Gonzalez (CES), Univ. de los Andes, Merida, Venezuela (ULA).



7) H. Bertorello, Univ. Cordoba, Argentina (UC).

8) J. Matutes, Centro de Investigación en Materiales Avanzados; Chihuahua, Mexico (CIMAV) (IM).

The network, which was sponsored by the EC under the Framework 5 ALFA Programme with the name HIFIELD (Project number II0147FI) and entitled: "Measurement methods involving high magnetic fields for advanced and novel materials", was established with the following aims:

a) To initiate the construction and development of local high field systems; to exchange knowledge and to support the high field technology within the groups;

b) To improve and extend the measurement techniques in pulsed high magnetic fields;

c) To exchange materials which are of interest for investigations in high magnetic fields;

d) To provide training for members (students, post docs. and young scientists) of the partner laboratories;

d) To provide guidance in the development of measurement methods for characterizing magnetic materials, especially in high fields.

The network activities began in November 2002 and finished in November 2005, the project period being 36 months. The experiences and experimental results were exchanged at five specially organized workshops. However, the most exciting outcome of the network was that local high field centres were initiated. The results presented in



the present paper will summarize the technical status of these high field facilities in Latin America.

## High field facilities in Latin America

High field facility in Venezuela: As mentioned already, the high field facility at the "Centro de Estudios de Semiconductores", Departamento de Fisica, Universidad de Los Andes, Merida existed already, before the start of the ALFA project. It was developed in cooperation with the LNCMP in Toulouse. It consists of a capacitance battery having a stored energy of 0.6 MJ (30 condensors rated at 750 µF with Vmax = 8000 V). It allows the generation of a maximum field of 30 T (pulse duration 2.5 s, using a crowbar circuit) in a bore of 25 mm. The system facilitates experiments between 1.2 and 300 K. The main experimental techniques available are: magneto-transport (DC), magnetization measurements, magneto-optics: photolumininescence, photoconductivity, spectral range VIS-NIR. Specialised knowledge exists in the field of high-pressure experiments where investigations up to 30 GPa are possible. The development and exchange of knowledge in this area was also an important objective. Fig.1 shows, as one example, of magnetization measurement at T = 4.2 K on the compound Ag<sub>2</sub>FeGeSe<sub>4</sub> which presents an antiferromagnetic behavior with a Néel temperature of around 240 K. The magnetization measurements under high magnetic field exhibit a spin-flop (SF) phase transition.





Fig.1. Magnetization measurement at T = 4.2K of Ag<sub>2</sub>Fe<sub>1,z</sub>Cd<sub>z</sub>GeSe<sub>4</sub>

High field facility in Mexico: At CIMAV in Chihuahua a condensor battery, with C = 17 mF and a maximum charging voltage of 2500 V, was initially set up. With this battery, a field up to 20 T in a bore of 25 mm could be produced. Within the ALFA project a stronger pulse magnet was constructed by P. Frings (LNCMP Toulouse), which allows a maximum field of 28 T in a bore of 13.5 mm. The range of the pulse duration is between 10 ms (rise time) and more than 50 ms (using a crowbar circuit?). The behavior of this pulse magnet is shown in Fig.2. The pulsed field facility is used especially for the investigation of magneto-electric materials, which is a particular research topic at CIMAV.





High field facility in Brasil: At the Univ. of Rio de Janeiro a condensor battery with C =0.4 mF and a maximum charging voltage of 10000 V (stored energy 20 kJ) was built, the first pulse magnet being designed at T.U.Vienna, within the ALFA project. This magnet has an inner bore of 19 mm and consists of two coils within one magnet. The theoretical maximum field of the inner magnet is 24 T (at 2000 V; T = 77 K), with a pulse duration of 10 ms (sine half wave); the total coil delivers 19.5 T (at 2000 V; T = 77 K), with a pulse duration of 23 ms (sine half wave). The maximum available field depends on the inductivity and the time constant of the system.

Fig.3 shows the measured field versus time profiles obtained for the inner magnet using the condensor battery at T.U.Vienna. To test this magnet, SPD measurements of the anisotropy field HA [1] for BaFe<sub>12</sub>O<sub>19</sub> (see Fig.4) with increasing and decreasing field (see arrows) were performed. The amplitude of the peak at  $H_A$ depends on the field sweep rate dH/dt. Additionally, dynamic hysteresis measurements



on  $Gd(Co,Cu)_5$  were made. These measurements confirmed that the magnet performed in accordance with the specifications.



Fig.3 Field versus time profile of the inner part of the pulse magnet.



High field facility in Argentina: At the Univ. of Cordoba a condensor battery, with C = 14 mF and a maximum charging voltage of 3000 V, is under construction. Within the ALFA project the first pulse magnet was designed at T.U. Vienna. This magnet has an inner bore of 36 mm and attains a maximum field of 29 T (at 77 K), with a pulse duration of 20 ms. The magnet will also be operated at room temperature, at which a maximum field of 24 T should be possible. A self-made two-channel 12 bit analog-digital measuring system was also developed and constructed.

### New measuring facilities

Also within this ALFA project, the following new measuring facilities were developped:

a) Local measurement of the magnetization on the surface of permanent magnets using planar pick-up coils [2]. Using this technique, local inhomogeneities in



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permanent magnets, as well as eddy current distributions, can be detected. This development was a cooperation between Univ. of Havana and T.U.Vienna.

b) Development of a new method of determining the magnetic viscosity from pulsed field measurements, using different pulse durations. The viscosity coefficient is calculated from the dependence of the coercivity obtained by using different field sweep rates dH/dt. This method was tested on a set of Sm(Co,Cu)<sub>5</sub> samples [3]. This development was a cooperation between Univ. of Havana and T.U.Vienna.

c) Development of a new method of determining the magnetic viscosity in hard magnetic materials after pulse magnetizing [4]. In this case, the permanent magnet is first pulse magnetized and, afterwards, the time dependence of the local stray field is measured using a set of balanced Hall probes. The signal is measured using a lock-in technique. Initial tests showed good agreement between this method and the standard technique for determining the viscosity coefficient in static fields. This development was also a cooperation between Univ. of Havana and T.U.Vienna.

d) Development of a new measuring technique to determine the magneto-electric coefficient from measurements in pulsed fields. In this technique, the voltage due to the magneto-electric effect is measured directly during the application of a field pulse [5]. This development was a cooperation between CIMAV (Mexico) and T.U.Vienna.

e) Development of a pressure cell (hydrostatic pressure up to 15 kbar) for measuring the pressure dependence of magnetic parameters in hard magnetic materials. With this pressure cell, which is made of MP35N steel, the pressure dependence of the anisotropy field for barium ferrite (BaFe<sub>12</sub>O<sub>19</sub>) was measured using



the SPD method, for the first time. This pressure cell was developed at T.U.Vienna; similarly, a diamond anvil cell was developed as a cooperation between LNCMP (Toulouse) and the CES (Merida, Venezuela).

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