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Possibilities and Limitations Concerning the Generation of Megaoersted Fields

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(16. IV. 68)

Abstract. A brief review of the actual state of very high magnetic field research is given, with particular attention to the results obtained in Frascati.

1. Historical Note on Very High Magnetic Fields

Various methods for the generation of high magnetic fields have been developed in the last 50 years. Whereas fields in the range of 100000 Oe have been generated for the needs of solid state physicists, the interest of scientists in the production of higher

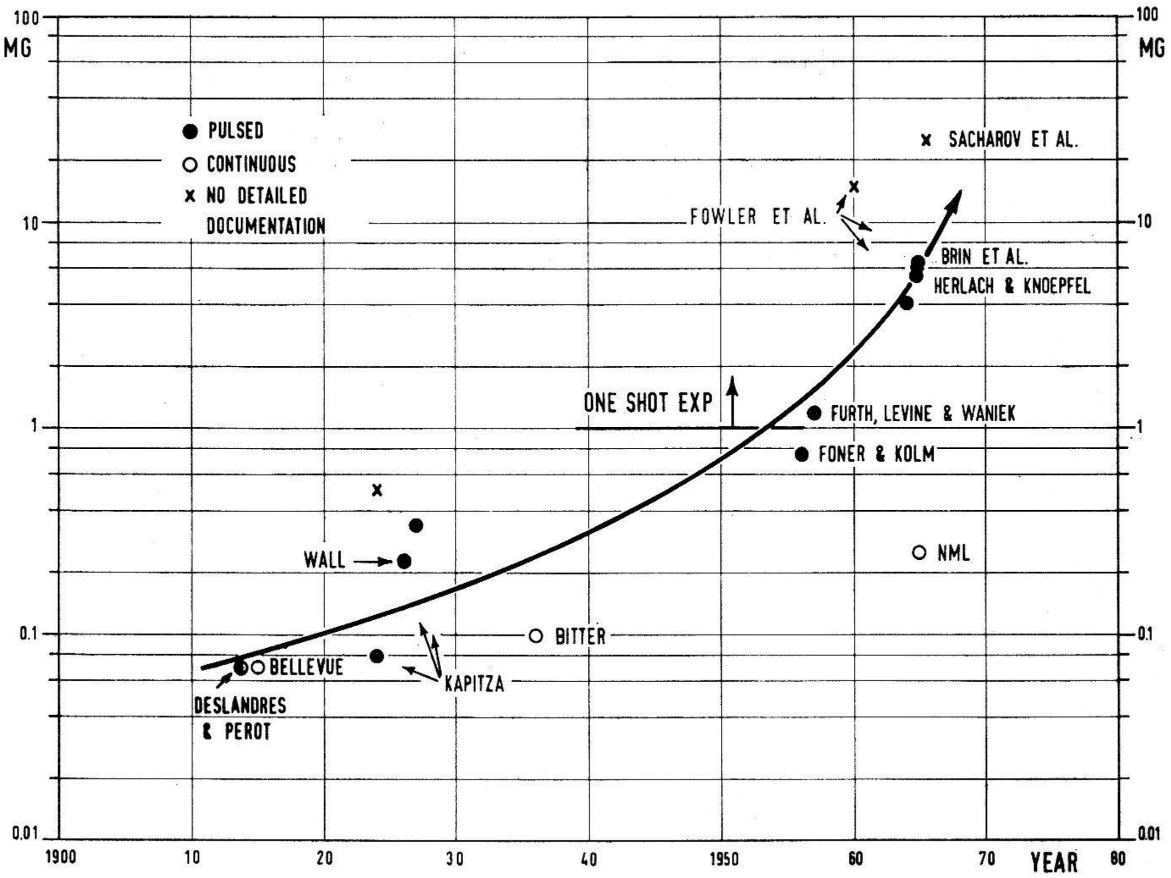

Figure 1

Very high magnetic field history.

fields has been stimulated for a large part by the arduous experimental and technical problems connected with the fields themselves. This is particularly true for fields in the megaoersted range, where complicated magnetohydrodynamic problems play an important and often determining role.

In Figure 1 we have sketched the history of high magnetic fields. It starts in practice with the quasi-stationary fields generated by Deslandres and Pérot at the 'Au Bon Marché' in Paris in 1914 [1], touches upon the pioneering work of Kapitza [2] and Bitter [3] and ends with the suprahigh fields obtained recently with the explosive driven flux compression devices [6], a method first used by Fowler et al. [4]. One would be tempted (as has been done for other domains of physics!) to extrapolate the magnetic growth-line to the future: it is left to the imagination of the reader to guess the values which will be reached in 1980.

In doing so, one should not ignore, however, the physical problems related to such extreme magnetic fields, which make it extremely difficult, if not impossible, to generate with classical means (i.e. excluding nuclear explosives) fields in excess of 20 MOe. This is also shown by the uncertainty about the maximum fields claimed, which lie, according to different authors, somewhere between 6 and 25 MOe [5].

2. Effects Limiting the Generation of Suprahigh Magnetic Fields

Consider the single-turn solenoid coupled to a pulsed current source (e.g. capacitor bank) of Figure 2. The oscillograms show [18] that initially the current-field relation is linear; from about 0.5 MOe the field increases less rapidly than the current and at

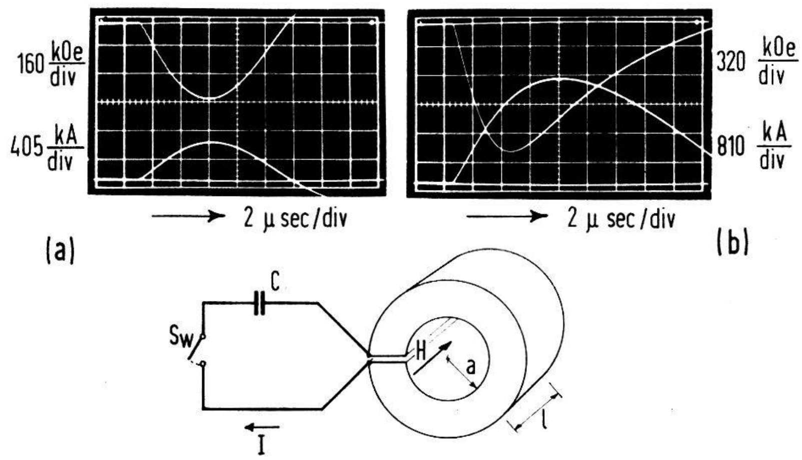

Figure 2

Results of a copper single-turn solenoid coupled to a capacitor bank (Ref. [18]). In oscillogram (a) the field-current relationship is still linear; at higher capacitor bank energies (200 kJ, 15 kV) the field maximum is attained before the current maximum (b).

1.4 MOe attains its maximum value, though the current still augments. This non-linear behaviour depends mainly on three effects, which all tend to increase the apparent diameter of the coil:

a) the enhanced magnetic diffusion, due to the high temperature (i.e. low conductivity) of the inner surface layers;

b) the compression of the conductor and the consequent expansion of the bore, as a result of the large magnetic pressure;
c) the axial ejection of metal, due to the same reason as the previous effect.

With systems as shown in Figure 2 fields up to 2.5 MOe have been generated [12, 13]: according to what has been said, this clearly requires extremely short discharge times.

Fields in excess of 5 MOe can be generated only by using the imploding flux compression device (Fig. 3). The difficulties to be overcome remain fundamentally the same, but are expressed in a somewhat different form [7]. In fact here the energy

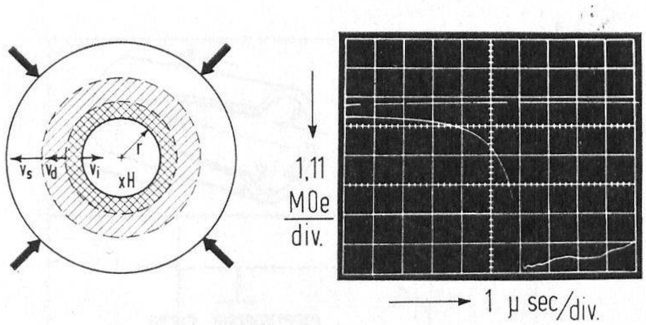

Figure 3

Implosion of a cylindrical conductor compressing a trapped flux. The velocity distribution in the metal is rather complicated since in addition to the centripedal cylindrical flow one has an outgoing shock (v_s). Towards the end of implosion the inner surface is disturbed by violent instabilities. The oscillogram documents a field of 6.1 MOe.

reservoir with which the field is built up, is represented by the kinetic energy of the imploding 'liner'. Due to the high pressure, corresponding to the generated fields, an outward moving shock wave is set up. It is clear, therefore, that only part of the total kinetic energy of the imploding mass can be converted into the maximum magnetic field. It can be shown [10] that this field is given approximately by the relation

$$\frac{H^2_{max}}{8\,\pi} \simeq \varrho\, v^2\,,$$

where ϱ and v are respectively the initial density and velocity of the compressing conductor. For $v = 1$ cm/μsec, which is about the highest velocity obtainable with chemical explosives, and $\varrho_{Cu} = 8.9$ g/cm³ we find: $H_{max} \simeq 15$ MOe. The flux loss due to anomalous magnetic field diffusion is less severe, since in principle it can be compensated by increasing the initial magnetic flux in the device.

3. Application of Very High Magnetic Fields in Experimental Physics

The possibilities of and the interest in the application of very high fields in solid state physics have been discussed elsewhere [8, 14]. As an example of experiments performed with explosive driven megaoersted generators we may mention two magneto-optical measurements: Faraday rotation in quartz probes [9] and Zeeman splitting of Na D-line up to 5 MOe [16].

Also of interest is the application of very high magnetic fields in plasma physics [11] particularly in connection with very large explosive driven current generators [17].

A new application possibility concerns the physics of high energy density [15]. A particular aspect is represented by the extreme temperatures obtained in connection with suprahigh magnetic fields. The surface temperature θ_s of a conductor subjected to a field pulse H is, for example [15],

$$c_v \, \theta_s \simeq \frac{H^2}{8 \pi}$$

where c_v is the specific heat of the metal: at $H = 15$ MOe we obtain for copper a surface temperature of the order of 100000 °K.

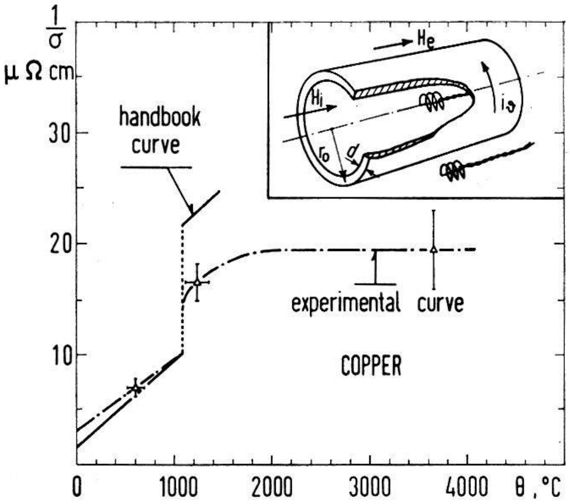

Figure 4

The resistivity of copper as a function of temperature; the insert shows the probe system used ($r_0 = 0.2$ cm, $l = 3$ cm).

As an example consider the diffusion of a very high field through a thin hollow conductor as shown in the insert of Figure 4. From Faraday's induction law we obtain after some transformations and assuming the current density in the conductor constant (Gaussian units: c velocity of light)

$$H_i + 2 \pi r_0 d \, \frac{\sigma}{c^2} \, \frac{dH_i}{dt} = H_e \, .$$

The temperature increase is defined by Joule's law which can be written in the form

$$c_v \, \theta = \int_0^t \frac{j_\vartheta^2}{\sigma} \, dt = \frac{r_0}{8 \pi d} \int_0^{Hi} (H_e - H_i) \, dH_i \, ,$$

where $j_\vartheta = c \, (H_i - H_e)/4 \pi d$ is the current density. By measuring the internal and external magnetic field (H_i and H_e respectively) we can deduce therefore the temperature dependence of the electrical conductivity σ. In Figure 4 we give the result obtained by placing a copper probe in an explosive-generated field of 1.7 MOe.

In conclusion we can say that very high magnetic fields up to the currently produced 5–10 MOe open new and interesting possibilities in experimental physics, which go beyond most of the classical schemes used in the last 50 years.

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Etude de la cinétique de luminescence de CsI par des méthodes d'électronique nucléaire

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I. Introduction

A l'époque (1940–47) où l'un d'entre nous (J. R.) a profité de la présence stimulante à l'Institut de Physique de l'EPF du Prof. G. BUSCH, physique nucléaire et physique du solide y coexistaient en relations étroites. Depuis lors, marqué par cette influence, il s'est appliqué à développer à Neuchâtel des recherches en physique des cristaux pouvant bénéficier de méthodes de la physique nucléaire et tirant parti d'un programme orienté dans les deux domaines.