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BARRIERS TO FLUX ENTRY AND EXIT IN SEMI-REVERSIBLE TYPE II SUPERCONDUCTORS

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Résumé.- Un échantillon refroidi dans un champ constant montre, après qu'un pulse de chaleur ait induit une expulsion de flux, une barrière qui s'oppose à la sortie de tourbillons comparable à celle qui s'oppose à leur entrée.

Abstract.- A sample cooled in a static H exhibits, after heat pulse induced flux expulsion, a barrier against flux exit comparable to that opposing flux entry.

INTRODUCTION.- The possibility that the surface barrier can be exploited to increase the current carrying capacity and reduce A.C. losses and may influence the stability of hysteretic type II superconductors when $H_{c1} < H_o < H_{c2}$ has renewed the interest in this feature /1,2/ A.C. measurements in a constant bias field H_o /3/ and observations where the sense of a swept field is reversed /4/ cannot separate the contributions of the barrier to entry and exit of flux but measure the sum of these. Data obtained where H is increased after colling from T_c in a static H_o have been taken to measure the barrier to flux entry only and as showing that the barrier to flux exit is negligible /5/. We report on observations of heat pulse induced flux expulsion which show that the barrier to flux exit is in a critical state during the initial cooling /6/. We describe a technique for unmasking and identifying the two barriers and present evidence that they are comparable.

EXPERIMENTAL PROCEDURE AND RESULTS.- The behaviour we describe has been encountered in solid cylinders of $Pb_{0.84}In_{0.16}$ and $Nb_{0.25}Ta_{0.75}$ in a magnetic field parallel to the cylinder axis. We present data only for the PbIn sample of 8 cm length and 0.25 cm diam. An energy pulse of time constant $\tau = R_H C \approx 10^{-4}$s is provided by discharging a condenser C through two hair-pin shaped heaters ($R_H \approx 20\,\Omega$ each) electrically connected in parallel and placed directly on the specimen and along its axis as shown in figure 1(a) A second non-inductively wound single layer manganin wire heater coil intimately embraces the sample and hair-pin heaters. When a suitable steady current flowing in the latter heater is interrupted., the sample cools from T_c, to the 4.2 K bath temperature.

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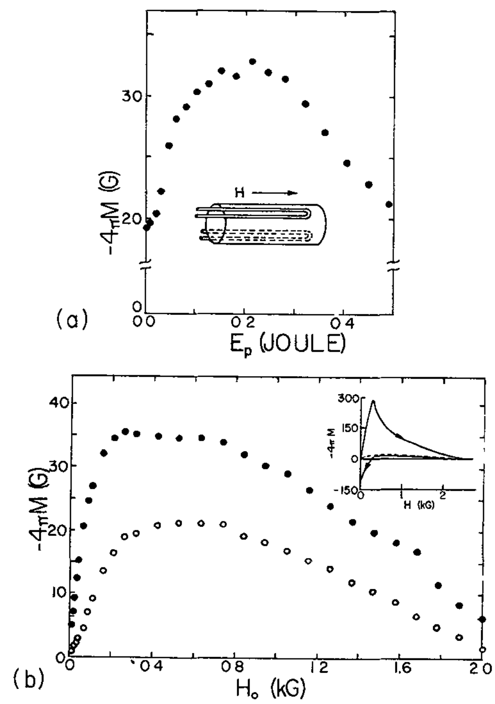

Fig.1:(a)Diamagnetic magnetization after application of heat spike of energy E_p.Sample cooled from to 4.2 K in H_o = 180 G before each pulse.
(b) Diamagnetic magnetization after cooling from T_c to 4.2.K in stationary H_o(open circles) and after subsequent application of optimum heat spike (full circles). Inset : Magnetization curves at 4.2 K Dashed lin is "Meissner" effect.

The expulsion of flux occuring during cooling from T_c to 4.2.K in a chosen stationary applied field H_o, is monitored with a balanced pick up coil These data are displayed in figure 1(b) (open circles). The pick up coil also detects expulsion of flux caused by the subsequent application of a heat spick (pulse). In figure 1(a) we show typical variations of the diamagnetic moment ensuing from application of a heat spike vs.the energy of the discharge. We stress that the sample is cooled from

T_c to 4.2 K before each measurement (each heat spike treatment). We note that the diamagnetic moment can be appreciably enhanced by this tehcnique, augmenting by a factor of $\gtrsim 5$ at low fields. The maximum diamagnetic moment achevied by application of an optimum heat pulse is presented vs. H_o in figure 1 (b) (full circles).

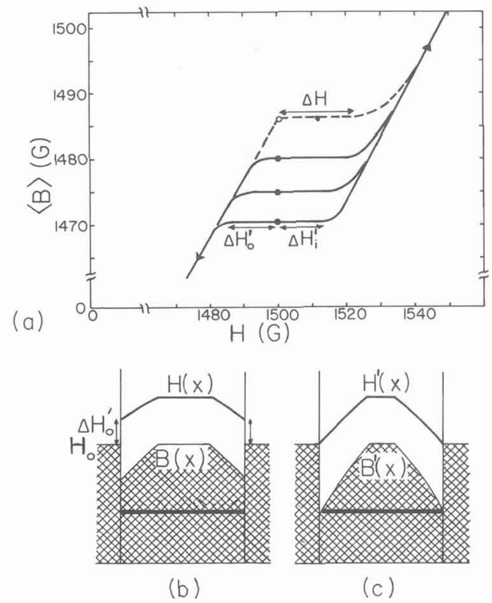

Fig. 2 : (a) Average magnetic induction <B> as H is lowered or raised from H_o = 1500 G after cooling from T_c to 4.2 K No heat spike (top curve), less than optimum (intermediate curves) and optimum heat spike (lowest curve) applied after cooling before varying H.
(b) Profile of B and H after cooling. Horizontal line indicates B profile in sample with no barrier and no bulk pinning.
(c) Profiles of B and H when heat spike raises surface T to T_c thereby destroying $\Delta H'_o$, the barrier to flux exit but leaving T = 4.2 K in bulk.

The barriers to flux entry or exit are measured by monitoring <B> as the applied field is either raised or lowered from H_o. The changes in magnetic behaviour induced by the heat spike treatment are especially dramatic in the range of intermediate to high fields and typical curves are displayed in fifure 2(a). When a heat pulse has been applied after cooling from T_c and the diamagnetic moment thereby augmented , the sample exhibits an opposition to exit as well as to entry of flux. These barriers are seen to be comparable when the optimum heat pulse level is utilized (lowermost curve of figure 2(a)).

DISCUSSION.- The "effective" barriers to flux entry or exit at T_f(4.2 K in our case) can be unmasked by the heat spike treatment. These barriers are observed to be comparable when the heat pulse technique induced the largest additional expulsion of flux (lowest <B> , hence largest diamagnetic moment) before H is varied after cooling in the chosen H_o.

In type II superconductors, the magnetic induction B is in equilibrium with $H/H_{c2}(T)$ and may vary spatially in hysteretic materials. As a sample cools from T_c, flux should be expelled since $B_{eq}<H_o<H_{c2}$ (T). This flux expulsion can be opposed by a surface barrier and bulk pinning. Consequently for flux expulsion to occur as T is lowered, the flux retaining barrier $\Delta H_o(T)$ must be surmounted hence be in a critical state. This is shown schematically in figure 2(b). If this situation prevails until T_f is reached, a subsequent decrease of H from H_o will cause flux to leave the sample leading to the illusion that there is no barrier present against flux exit. If instead, H is increased from H_o, flux entry will be opposed until, by Faraday-Lenz laws of induction, the paramagnetically circulating (flux retaining) surface current I_{so} is extinguished and an irreversible critical diamagnetic (field shielding) surface current I_{si} is generated. Consequenly $\Delta H = \mu_o\,(|I_{so}|+|I_{si}|) = \Delta H'_o + \Delta H'_i$.

Considering an infinite slab, thickness x = X and H_o// to the surfaces, we take that, after cooling, B (x) is in equilibrium with

$$H(x) = H_o + \mu_o I_{so} + \mu_o \int^{x} j_c(x')\,dx' \qquad (1)$$

where 0< x < X/2. The B(x) and H(x) profiles are sketched in figure 2 (b). Here $\mu_o = 4\pi/10$ and j_c is bulk critical current density. Application of a heat spike can 'ideally" raise the surface temperature to T_c leaving the temperature of the bulk unperturbed. In this ideal limit, $I_{so}(T) \to o$ and $H(x) \to H'(x) = H_o + \mu_o \int_o^x j_c\,(x')\,dx'$. The B profile drops to a new configuration B'(x) in equilibrium with H' (x) as shown in figure 2 (c). Intermediate configuration of B and H will occur depending on the degree of quenching of I_{so} and heat diffusion into the bulk. The essential feature is that when the temperature returns to T_f, the barrier to flux exit is no longer in a critical state and may be fully available to oppose exit of flux when H is subsequently lowered from H_o. Conversely and again in the ideal limit, an increase in H from H_o now needs to overcome only the true barrier $\Delta H'_i = \mu_o I_{si}$ to flux entry in order that vortices enter and <B > increase.

References

/1/ Bussière,J.F., IEEE Trans.Magn. Mag-13 (1977) 131

/2/ Kim,S., Howard,R.E. and Beasley,M.R.,J.Appl. Phys. 49 (1978) 731

/3/ Bussière,J.F. and Suenaga,M.,J.Appl. Phys.47 (1976) 707

/4/ Leblanc,M.A.R.,and Griffiths, D.J., Phys.Lett: 21 (1966) 150

/5/ Bussière,J.F., Phys.Lett.58A (1976) 343

/6/ Leblanc,M.A.R., Griffiths,D.J. and Belanger,B.C. Phys. Rev. Lett. 18 (1967) 844