

Hysteresis of Magnetic Moment of Superconducting Nb and Ta Cylinders

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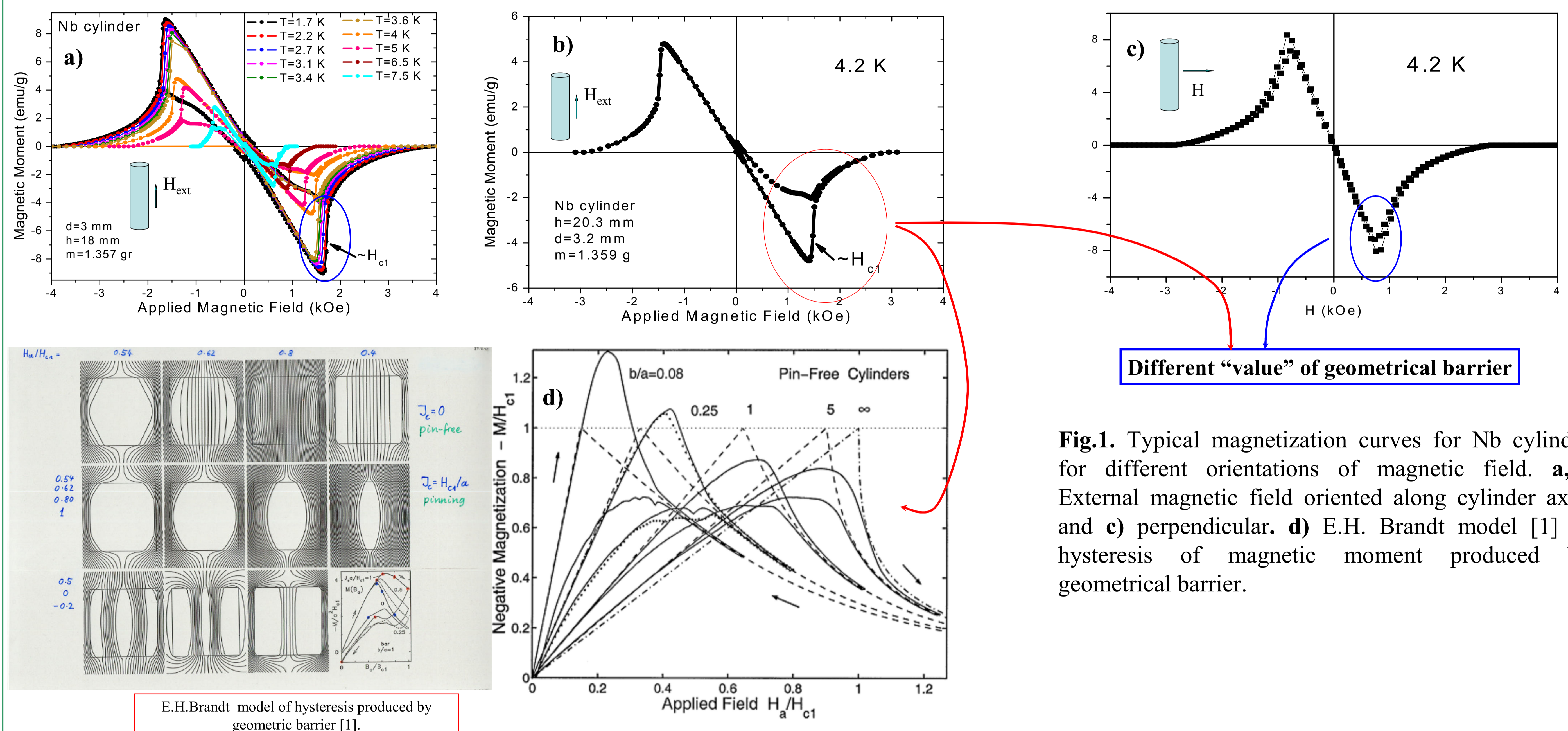
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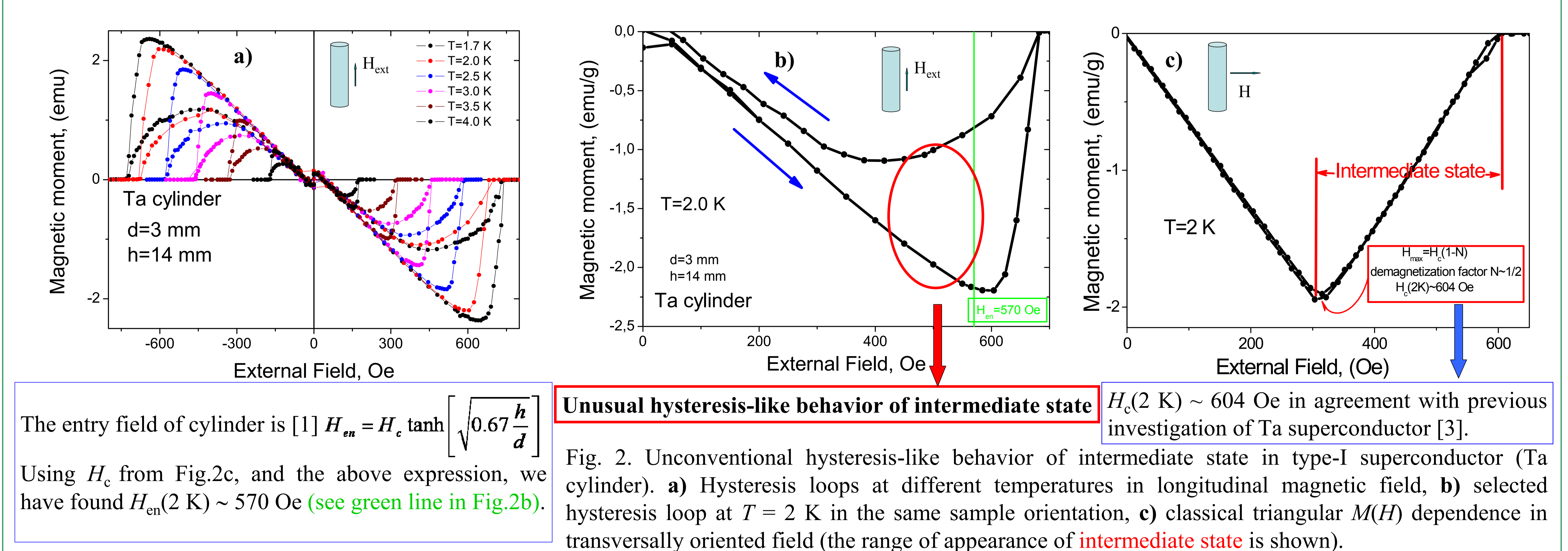
Motivation Magnetic irreversibility of flux penetration was experimentally investigated in superconducting Nb ($\kappa=\lambda/\xi=1.28$, λ - depth of penetration, ξ - coherent length) and Ta ($\kappa=\lambda/\xi=0.38$) cylinders. Magnetic moment measurement shows strongly irreversible behavior at remagnetization in the magnetic fields $H_{c1g} < H \leq H_{c2}$, where H_{c1g} is the magnetic field of magnetic flux entrance, and H_{c2} is the second critical field. All specimen shapes (apart from ellipsoid) exhibit magnetic irreversibility due to a geometric barrier for flux penetration [1]. This is true for both type-I [2] and type-II [3, 4] superconductors. The role of geometric barrier, surface barrier and pinning in magnetic irreversibility of flux penetration into superconducting cylinders Nb and Ta were discussed taking into account results of investigation in [5,6]. Here, we compare the irreversible magnetization loops of cylinders for two orientations of magnetic field: parallel and perpendicular to the axis. Temperature dependencies of different characteristic fields (H_{c1g} , H_{c1} , H_{c2}) were investigated.

Experiment, Samples. Magnetization of *high-purity* Nb ($\rho_{300}/\rho_{10} \sim 1500$) and Ta cylinders (LTSC) (with the ratios of height/diameter $(h/d)_{Nb}=6.3$ $(h/d)_{Ta}=4.3$; $d=3.2\text{mm}$) was studied using the Squid magnetometer with external magnetic field oriented along cylinder axis and Foner's VSM with external magnetic field oriented perpendicular to cylinder axis. **Samples were annealed during 2 hours at $T = 2300^\circ\text{C}$ in order to lower the pinning.** Magnetization curves for different orientations of magnetic field for Nb cylinder are shown in Fig.1. In perpendicular orientation hysteresis of magnetic moment is practically absent (Fig.1b). This denotes a pin-free sample (without volume pinning center).

Nb cylinder (type-II superconductor)



Ta cylinder (type-I superconductor)



The entry field of cylinder is [1] $H_{en} = H_c \tanh \left[\sqrt{0.67} \frac{h}{d} \right]$
Using H_c from Fig.2c, and the above expression, we have found $H_{en}(2\text{ K}) \sim 570\text{ Oe}$ (see green line in Fig.2b).

Unusual hysteresis-like behavior of intermediate state $H_{c2}(2\text{ K}) \sim 604\text{ Oe}$ in agreement with previous investigation of Ta superconductor [3].

References

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Conclusions

Nb pinning free Type-II Sc: 1. The cylinder has a significant irreversibility in classical geometry, when the field is parallel to the cylinder axis. Moreover, it is greater than in the perpendicular geometry. 2. The first penetration field into Nb sample is considerably lower than the maximum determined by the magnetic moment of the first critical field H_{c1} .

Irreversibility of magnetic moment and low value of H_{c1} in good agreement with the E.H. Brandt model [1] and with the theoretical calculations based on the role of the geometric barrier.

Ta pinning free Type-I Sc: Classical reversible behavior of magnetic properties was observed in perpendicular geometry. *But astonishing, strongly irreversible behavior of intermediate state of type-I superconductor was present in parallel orientation. This nature of hysteresis is not clear.*