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ON THE PHASE DIAGRAM OF HIGH-T_c SUPERCONDUCTIVE GLASS MODEL

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The transition temperature T_c and isothermic magnetization are calculated as functions of applied magnetic field in the frame of the 2-D XY Josephson glass model. Three characteristic regions are shown to be distinguishable in the H-T plane: the diamagnetic region, region of superconducting glass and region of Josephson spin glass. The results are in quantitative agreement with experimental data and the results of numerical simulations for "new" superconductors.

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

О фазовой диаграмме в модели высокотемпературного сверхпроводящего стекла

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В двумерной XY модели джозефсоновских спинов вычислена зависимость температуры фазового перехода T_c и изотермической намагниченности от внешнего магнитного поля H при $0 \leq H < \infty$. Показано, что на плоскости (T, H) имеются три области, различающиеся характером зависимости T_c от H: диамагнитная область, область сверхпроводящего стекла и область джозефсоновского спинового стекла. Результаты качественно согласуются с данными экспериментов и численного моделирования для "новых" сверхпроводников.

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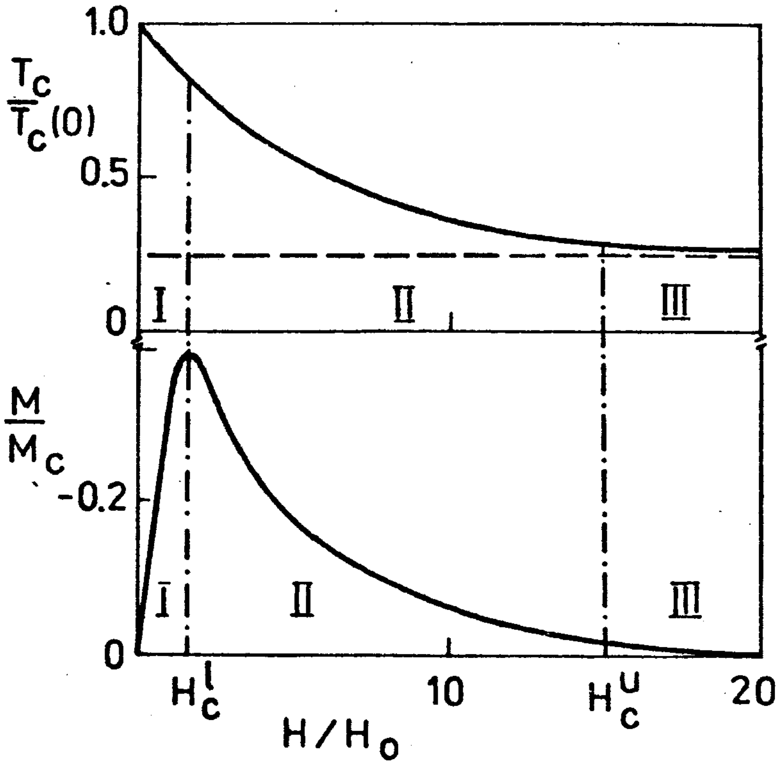
Many of the experimental results on the glassy behaviour of high-T_c superconductors can be explained in the 2-D disordered Josephson spin lattice model /1/. The phase diagram in the plane H-T was studied both numerically (up to fields $H \lesssim H_c^u$) /2/ and by analytical methods (for $H > H_c^u$) /3/. This paper presents the generalization to arbitrary magnetic fields. The obtained phase boundary $T_c(H)$ is shown in the upper part of the figure.



One may distinguish three characteristic regions in the field dependence of T_c.

I. $H < H_c^\ell$ (quasireversible diamagnetic region)

$$\frac{T_c(0) - T_c(H)}{T_c(0)} = \frac{2}{\sqrt{3}}\left(\frac{H}{H_0}\right)^2, \tag{1}$$

where

$$H_c = \frac{3}{4}H_0, \quad H_0 = \frac{\phi_0}{2S}, \quad T_c(0) = \frac{1}{2}JN,$$

and $S = \pi\sigma$ is a mean-square area of the superconducting cluster.

II. $H_c^u > H > H_c^\ell$ (region of superconductive glass: AT line)

$$\frac{T_c(0) - T_c(H)}{T_c(0)} = \sqrt[3]{\frac{6}{\sqrt{3}\cdot H_0^2}}\cdot H^{2/3}, \tag{2}$$

where $H_c^u = 15\,H_0$.

III. $H > H_c^u$ (region of Josephson spin glass: strong frustration)

$$T_c(H) = T_c(\infty)\left(1 + \frac{3NH_0^2}{2H^2}\right), \quad T_c(\infty) = \frac{1}{2} J\sqrt{N}. \tag{3}$$

The phase diagram obtained is consistent with [1] at $H \lesssim H_c^u$ and with [2] at $H > H_c^u$. The lower part of the picture shows the field dependence of the isothermal magnetization M. In the diamagnetic region (I) it has a linear character, in the SCG phase (II) the nonlinear effects become essential, and, at last, in the region of the JSG phase (III) the magnetization rapidly tends to zero (when $H \to H_c^u$) indicating the strong suppression of the superconducting transition temperature T_s in contrast with the glassy temperature $T_c(H)$ (see the figure).

The glassy transition, as is well-known, is connected with the dynamic transition from the ergodic to the nonergodic state. The nonergodicity parameter of the model $L_{ij} = \lim \overline{\langle S_i^*(t) S_j \rangle} \sim T(\chi_{FC} - \chi_{ZFC})$ is calculated, and its temperature dependence versus $T/T_c(H)$ is shown to have a universal character (a dynamic "temperature-field" scaling). The estimations for La ceramics [3] with $T_c(0) = 28K$, $H_0 = 0.05T$ give the mean value of the superconducting cluster area $S \simeq 0.02\,\mu^2$ and Josephson energy $J \simeq 3.5K$ in reasonable agreement with commonly used estimates. On the whole the experimental data for field-cooled and zero field-cooled measurements confirm the obtained phase diagram. Nevertheless, further experimental study of the magnetic field dependence of T_c under transition from the SCG phase to the JSG phase is of interest.

References

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