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Elucidation of Amorphization of Flux Line Lattice in $Yb_3Rh_4Sn_{13}$

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The characteristic details of the path dependence in the in-phase ac susceptibility data are elucidated via provision of an external stimulus and the process of thermal cyclings across the multiple steps comprising the peak effect (PE) phenomenon in a single crystal of $Yb_3Rh_4Sn_{13}$.

The vortex phase diagram in $Yb_3Rh_4Sn_{13}$ (T_c~7.6 K) is similar to those in UPd_3Al_3 and $CeRu_2$ as determined from the study of the peak effect (PE) in current density J_c. In these systems, the presence of an apparent tricritical point, where the $H_{c2}(T)$ line and peak effect (PE) curve $H_p(T)$ appear to meet, has often been cited as an evidence for the nucleation of a novel superconducting phase [1] at the onset of PE. In contrast to this scenario, Banerjee et al [2] had recently elucidated the fracturing of flux line lattice (FLL) across the PE region in single crystals of $CeRu_2$ and 2H-$NbSe_2$. We have explored the latter notion in the same single crystal of $Yb_3Rh_4Sn_{13}$ in which vortex phase diagram had been reported earlier [3]. We report here that the PE in $Yb_3Rh_4Sn_{13}$ comprises novel facets associated with triggering of amorphisation of FLL in multiple steps (two or more).

The data on the PE have been obtained via temperature dependent in phase ac susceptibility ($\chi'(T)$) measurements. Figure 1 shows a comparison of $\chi'(T)$ (f=211 Hz, h_{ac}=0.6 Oe (r.m.s.)) for the vortex states obtained in zero field cooled (ZFC) and field cooled (FC) modes at 8 kOe. In a $\chi'(T)$ measurement, the PE manifests as an anomalous dip as T increases. χ' could be related to J_c and the correlation volume V_c of FLL via $\chi' \sim -1 + \alpha h_{ac}/J_c$ and $HJ_c = (n_p f_p^2/V_c)^{1/2}$, where α is sample size and geometry dependent factor, n_p is density of pins and f_p represents the elementary pinning interaction. It is interesting to note that the anomalous variation in J_c (or V_c) across the PE region in Fig. 1 comprises a rich structure from T_{pl1} to T_p. Such a structure did not get revealed in the earlier measurements[3] presumably due to a limitation in resolution and stability of temperature(see the complete χ' curve in the inset of Fig. 1). The differences in ZFC and FC responses ceases near the temperature T_p, above which the diamagnetic χ' rapidly moves towards its normal state value, thereby signaling the collapse of J_c in response to a collapse of the elementary pinning force f_p[4]. The locus of $T_p(H)$ is considered to bifurcate the (H,T) phase space into regions of pronounced metastability and the absence of it. The lower J_c ZFC state is more ordered (i.e., smaller V_c) than the higher J_c FC state and above T_p, the vortex array is disordered in equilibrium [2].

Cooling the sample in field amounts to an attempt to supercool the disorder present near T_p. This could become more apparent by examining the $\chi'(T)$ data (see Fig.2) obtained while cooling down from temperatures lying in different pockets of the PE regime. The continuous and dotted curves in Fig. 2 correspond to $\chi'(T)$ data in ZFC and FC warm-up runs. Note that on cooling down from $T_I(<T_{pl1})$, $\chi'(T)$ retraces its path (see filled circle data points). But, on cooling down from $T_{II}(T_{pl1}<T_{II}<T_{pl2})$ and $T_{III}(T_{pl2}<T_{III}<T_{pl3})$, the $\chi'(T)$ data fail to retrace the ZFC curve across T_{pl1}. However, the cool down response eventually merges into the ZFC $\chi'(T)$ curve. This is a newer feature, not evident in the earlier measurements in $NbSe_2$, $CeRu_2$ and

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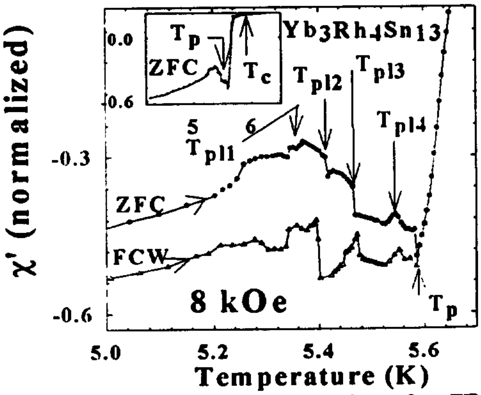

Figure 1: $\chi'(T)$ plots in $Yb_3Rh_4Sn_{13}$ for ZFC and FCW FLL. The compressed plot in inset does not reveal detailed structure evident in the main panel.

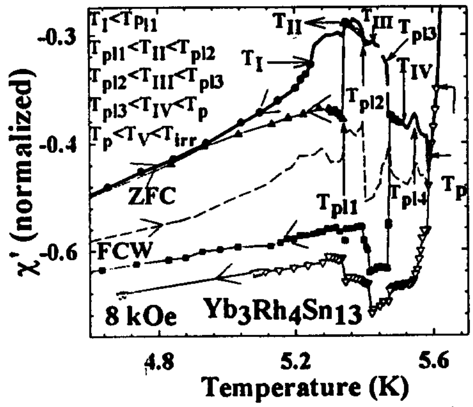

Figure 2: $\chi'(T)$ curves obtained while decreasing T from T_I, T_{II}, T_{III}, T_{IV} and T_V. The solid and dotted lines represent the ZFC and FCW behavior.

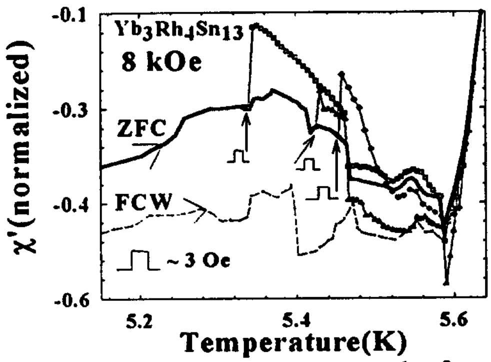

Figure 3: $\chi'(T)$ responses observed after short exposure to ac pulses (3 Oe(r.m.s.)).

$Ca_3Rh_4Sn_{13}$, where a cool down across the onset (T_{pl}) of PE led to generation of a FC like disordered phase [2]. The irreversible behavior across T_{pl1} in the present sample though continues to favor the claim of T_{pl1} as the location of a first order transition [4]. Proceeding further, note that on cooling down from T_{IV} ($T_{pl3}<T_{IV}<T_p$) and $T_V(>T_p)$, one ends up producing disordered FC like states while crossing T_{pl3} and T_p respectively. It can be seen that T_{pl3} and T_p mark the positions of sharp jumps in ZFC $\chi'(T)$ curve. The data in Fig. 2 thus vividly elucidate the whithering away of the order in FLL in multiple steps.

It is known that the PE does not reveal itself in (isofield) temperature scans during dc magnetization measurements as there is no driving force to trigger the disordering process while crossing the PE regime. In $\chi'(T)$ measurements, the ac field provides the necessary driving field. Banerjee et at [5] had shown that prior to arrival of the PE region, an imposition of a large ac field (even for a very short duration) acts as a healing force to transform the metastable disordered state to its ordered configuration. presumably by driving out the dislocations in FLL. Figure 3 provides a glimpse into the observed novel behavior when h_{ac} of 3 Oe (r.m.s.) is momentarily (~1 sec) pulsed at temperatures just before T_{pl1}, just after T_{pl2} and just before T_{pl3}. In each case, it leads to production of a more ordered (as evidenced by lesser diamagnetic $\chi'(T)$ values) vortex array. These ordered states could skip the (effective pinning induced [4]) fracturing transitions located at T_{pl2} and T_{pl3}, during the warm-up cycle. However, the occurrence of PE phenomenon across T_p does not get suppressed. In fact, the PE peak gets sharper as the order in FLL improves.

To summarize, the specific details of fracturing are governed by the competition and interplay between interaction amongst vortices and disordering effects of pinning centers and thermal fluctuations. A kind of dislocations that invade the sample at T_{pl1} gets eliminated as the sample is cooled. whereas others cannot be driven out unless an external stimulus is provided at $T<T_{pl1}$ [5].

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