Two-Dimensional Superconductivity in a Bulk Single-Crystal

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Introduction
Recently, extremely high superconducting upper-critical fields were observed in ultra-thin single-crystals of transition-metal dichalcogenides for magnetic fields applied along a planar direction [1, 2]. This was attributed to strong spin-orbit coupling and to the Ising configuration of the orbital moments in single or few atomic layers of these compounds, which leads to singlet pairing among carriers having their spins locked along their angular momentum. Such a strong coupling is expected to renormalize the Clogston limit, and to lead to an anomalous temperature dependence for the upper critical fields in the neighborhood of $T_c$, that is $H_{c2} \propto (1-T/T_c)^{1/2}$.

Experimental
In successive runs that involved measurements in resistive magnets and in the millikelvin facility we extracted the upper critical fields of $\text{Nb}_3\text{Pd}_x\text{Se}_7$ with $x \sim 0.81$, with a $T_c$ of $\sim 3.5$ K finding that it displays behavior akin to the one displayed by thin atomic layers of transition metal dichalcogenides namely the square root dependence of $H_{c2}$.

Results and Discussion

![Graph](image)

Fig.1  (a) Phase boundary between superconducting and metallic states for magnetic fields applied along all three main crystallographic axes of $\text{Ta}_4\text{Pd}_3\text{Te}_{16}$. The upper critical fields are linearly dependent in $T$ for all three crystallographic orientations showing no sign of saturation. For fields applied along the $b$-axis, $H_{bc2}(T \to 0 \text{ K})$ surpasses the weak coupling Pauli limiting value $H_b = 1.84 \times T_c \approx 8.5$ T. (b) Superconducting anisotropy $\gamma = H_{bc2}/H_{a'c2}$, where both variables correspond to fields where the resistivity reaches 90 \% of its value in the metallic state. (c) Superconducting phase diagram for $\text{Nb}_3\text{Pd}_x\text{Se}_7$ single-crystals having a middle point resistive transition at $T_c \approx 3.5$ K. Notice, the much larger values of $H_{c2}$ relative to the Ta compound, as well as its anomalous phase-boundary for fields along the $b$-axis. Magenta line corresponds to a fit to the expression $H_{bc2} \propto (1-t)^{1/2}$ where $t = T/T_c$, which describes a nearly two-dimensional superconductor in the vicinity of $T_c$. (c) Superconductivity anisotropy $\gamma$ for $\text{Nb}_3\text{Pd}_x\text{Se}_7$. (d) The superconductivity anisotropy for $\text{Nb}_3\text{Pd}_x\text{Se}_7$ between the $b$-axis and the $a$-axis. From Ref. [3]

Conclusions
Although $\text{Ta}_4\text{Pd}_3\text{Te}_{16}$ behaves as an orbital limited superconductor over the entire temperature range, $\text{Nb}_3\text{Pd}_x\text{Se}_7$ behaves as a two-dimensional Pauli-limited superconductor. This indicates that the superconducting planes are decoupled due to very small coherence lengths. The reason for this decoupling remains to be understood.

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References