# On the Superconducting Phases of $UTe_2$


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**Abstract**

The anomalous triple point discovered in superconducting $UTe_2$ may indicate a gauge invariance breaking in the high-pressure phase, manifesting as Bose condensation of bound states of eight or even more electrons.


On the $P, T$ diagram of $UTe_2$, three lines of continuous phase transitions between the normal phase $n$ and two distinct superconducting phases, $s_1$ and $s_2$, meet at a single point (Fig.a) [1]. To our knowledge, such a point has not been observed in other systems, although a tetracritical point, as predicted by Landau in 1937 (Fig.b) does exist. A satisfactory explanation for this discovery is still lacking [2]. In this note, we point out that a natural extension of the concept of gauge invariance breaking may facilitate such an explanation.

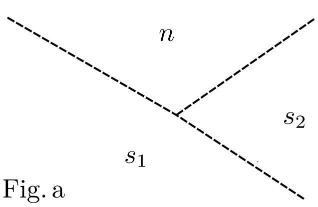


Fig. a

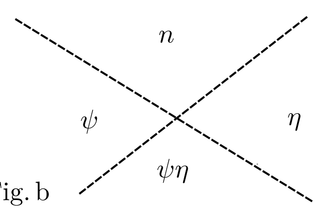


Fig. b

It was recently found [3] that the magnetic flux quantum in superconducting $CsV_3Sb_5$ changes with increasing temperature, taking the values $h/(2ek)$, where $k = 1, 2, 3$. This has been interpreted as evidence for the formation of $2k$-electron condensates. From a phenomenological perspective, arbitrary values of $k$ are clearly allowed.

Let us consider, within Landau theory of continuous transitions, a tetracritical point (Fig.b) in a superconductor. Assuming zero quasimomentum condensates in $UTe_2$, we restrict our consideration to its crystal class $\boldsymbol{D}_{2h}$. Let $\psi$ correspond to a $2k$-electron condensate and $\eta$ to a $2mk$-electron condensate, where $m > 1$. In addition to the usual Ginzburg-Landau terms:

$$(at + vp)|\psi|^2 + A|\psi|^4 + (bt - wp)|\eta|^2 + B|\eta|^4, \tag{1}$$

where $p$ and $t$ are deviations of pressure and temperature from the intersection, it is necessary to include cross terms — biquadratic and Indenbom-type [4]:

$$C|\psi|^2|\eta|^2 + I(\psi^{*m}\eta + \psi^m\eta^*). \tag{2}$$

The latter is allowed if $\eta$ transforms according to the unit representation of the crystal class for even $m$, or according to the same representation as $\psi$ for odd $m$. In this case, $\eta$ is induced by $\psi$ as an improper parameter [4], and the transition line $n|\eta$ terminates at the intersection point, which thus becomes a triple point. For $m = 2$, however, the Indenbom's invariant is cubic in $\psi, \eta$ at the intersection itself, and superconductivity emerges discontinuously at higher temperature. In the case $m = 3$, it is also cubic in $\psi$ on the line $\eta|\psi\eta$. Only for $m > 3$ does this scenario agree with the anomalous phase diagram of $UTe_2$. Note that Indenbom's invariant, though small here, is linear in $\eta$ and acts as a conjugate field, thus leading to the disappearance of one branch from the phase diagram.

It is easy to see that the phases $s_1$ and $s_2$ described here are nonmagnetic and preserve the crystal symmetry of the $n$ phase. The biquadratic term leads to a kink between the $n|s_1$ and $s_2|s_1$ lines, but available experimental accuracy does not even allow identification of the constant $C$ sign.

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