



On the Superconducting Phases of UTe_2

V. I. Marchenko¹ · L. A. Melnikovsky^{1,2} 

Received: 2 July 2026 / Accepted: 17 September 2026

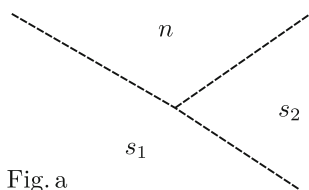
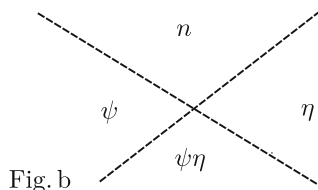
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2026

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.

Keywords Improper order parameter · Gauge symmetry breaking · Indenbom's invariant · Multiplet superconductivity · Ginzburg-Landau · Second order phase transitions

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.



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.

✉ L. A. Melnikovsky
lev.melnikovsky@weizmann.ac.il

¹ P.L. Kapitza Institute for Physical Problems, RAS, Moscow, Russia

² Weizmann Institute of Science, Rehovot, Israel

Let us first consider, within the Landau theory of continuous phase transitions, a tetracritical point (Fig. b) with two order parameters ψ and η . The free energy expansion contains a biquadratic term and has the form

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

where p and t are deviations of pressure and temperature from the intersection. The usual conditions for thermodynamic stability and continuous transitions are $A, B > 0$ and $C^2 < 4AB$. If ψ and η are superconducting order parameters corresponding to $2k$ - and $2mk$ -electron condensates, respectively, with $m > 1$, then the Ginzburg–Landau functional may also contain the Indenbom-type term [4]:

$$I(\psi^{*m}\eta + \psi^m\eta^*). \quad (2)$$

Assuming zero quasimomentum condensates in UTe_2 , we restrict our discussion to its crystal class D_{2h} . Indenbom's invariant (2) is allowed by symmetry if η transforms according to the unit representation of D_{2h} for even m , or according to the same representation as ψ for odd m . In this case, η is induced by ψ 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, Indenbom's invariant is cubic in ψ, η at the intersection itself, and superconductivity emerges discontinuously at a higher temperature. In the case of $m = 3$, it is also cubic in ψ on the line $\eta|\psi\eta$. Only for $m \geq 4$ does this scenario agree with the anomalous phase diagram of UTe_2 . Note that Indenbom's invariant, though small here, is linear in η and acts as a conjugate field; consequently, one phase boundary vanishes from the diagram.

It is easy to see that the phases s_1 (where $\psi \neq 0, \eta \neq 0$) and s_2 (where $\psi = 0, \eta \neq 0$) described here are nonmagnetic and preserve the crystal symmetry of the n phase ($\psi = 0, \eta = 0$). The biquadratic term produces a kink between the $n|s_1$ and $s_2|s_1$ lines, but the available experimental accuracy is insufficient to identify even the sign of the constant C .

We thank M. Elbaum, I.A. Fomin, E.I. Katz, and E.V. Surovtsev for helpful discussions.

Author Contributions Authors contributed equally

Data Availability No datasets were generated or analysed during the current study.

References

1. D. Braithwaite, M. Vališka, G. Knebel, G. Lapertot, J.-P. Brison, A. Pourret, M.E. Zhitomirsky, J. Flouquet, F. Honda, D. Aoki, Multiple superconducting phases in a nearly ferromagnetic system. *Commun. Phys.* **2**, 147 (2019). <https://doi.org/10.1038/s42005-019-0248-z>
2. T. Vasina, D. Aoki, A. Miyake, G. Seyfarth, A. Pourret, C. Marcenat, M. Amano Patino, G. Lapertot, J. Flouquet, J.-P. Brison, D. Braithwaite, G. Knebel, Connecting high-field and high-pressure superconductivity in UTe_2 . *Phys. Rev. Lett.* **134**, 096501 (2025). <https://doi.org/10.1103/PhysRevLett.134.096501>

3. J. Ge, P. Wang, Y. Xing, Q. Yin, A. Wang, J. Shen, H. Lei, Z. Wang, J. Wang, Charge- $4e$ and charge- $6e$ flux quantization and higher charge superconductivity in kagome superconductor ring devices. *Phys. Rev. X* **14**, 021025 (2024). <https://doi.org/10.1103/physrevx.14.021025>
4. L.D. Landau, E.M. Lifshitz, *Electrodynamics of continuous media*, §20 (Pergamon Press, Oxford, 1984)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.