TT 9: Focus Session: Anomalous Quantum Oscillations

Quantum oscillation (QO) phenomena describe the periodic variation of thermodynamic and transport properties of materials as a function of magnetic field. Since their discovery almost a century ago, their observation has been taken as a definite sign for the presence of a Fermi surface (FS) in metals. The standard theory of Onsager connects the QO frequency with the momentum space area of FS orbits forming the basis of a well-established experimental procedure for determining the electronic structure of metals. However, recent developments have challenged this canonical description of QOs. New mechanisms have been proposed to explain anomalous QO observed in several materials ranging from twisted bilayer graphene to topological multifold-semimetals like CoSi and beyond. The proposed Focus Session aims to connect recent advances in the theoretical description of QO with specific experimental signatures in correlated metallic materials. The symposium will highlight the intimate connection between fluctuation contributions to QOs and the subtle experimental evidence for identifying the correct electronic structure.

Organizers: Johannes Knolle (TU Munich), Christian Pfleiderer (TU Munich)

Time: Monday 15:00–18:15 Location: H 0104

Invited Talk TT 9.1 Mon 15:00 H 0104

Unusual Magnetic Oscillations in Kagome Mott Insulators — •Lu Li — University of Michigan, Ann Arbor, MI 48109, US

The observations of the Landau Level quantizations in narrow-gapped correlated Kondo insulators raise intriguing questions on the origins [1]. However, none of the models suggest the phenomena existing in wide-gap insulators. Kagome lattice Mott insulator Herbertsmithite is a well-established Dirac fermion spin liquid candidate. Yet, our search for magnetic oscillations in Herbertsmithite yielded only a series of magnetic transitions [2], possibly due to the ion disorders on the Kagome lattice. This problem is resolved in the recently discovered sibling compound $YCu_3(OH)_{6.5}Br_{2.5}$ [3]. Using ultrasensitive magnetometry in 70 T intense fields, we observe both the 1/3-plateau and 1/9-plateau transitions. The magnetometry reveals strong oscillations in the magnetic torque. While the temperature dependence follows the Fermi liquid theory, the oscillations appear to be roughly periodic in the magnetic field B, opposite to the $1/B$ trend in conventional metals. Furthermore, a strong angular dependence is observed for the oscillation fields, which indicates the orbital effect. Separating orbital and Zeeman effect, we show that this magnetic oscillation pattern is consistent with a Dirac fermion existing near the 1/9 plateau, and the fermion's chemical potential is shifted by the Zeeman effect [4].

[1] Xiang, Li et al., Science 362, 65 (2018); Li et al., Nat. Rev. Phys. 2, 463 (2020); Xiang, Li et al., Nat. Phys. 17, 788 (2021).
[2] Asaba, Li et al., Phys. Rev. B 90, 064417(2014)
[3] Zeng et al., PRB 105, L121109 (2022)
[4] Zheng et al., arXiv:2310.07989 (2023)

Invited Talk TT 9.2 Mon 15:30 H 0104

Quantum oscillations in small-gap insulators — •Nigel Cooper — Cavendish Laboratory, University of Cambridge, United Kingdom

In recent years it has become understood that quantum oscillations of the magnetization as a function of magnetic field, long recognized as a phenomenon intrinsic to metals, can also manifest in insulating systems. Theory has shown that in certain narrow-gap band insulators, quantum oscillations can appear with a frequency set by the area traced out by the minimum gap in momentum space. I shall provide an overview of the theories of quantum oscillations in simple band insulators of this type, and discuss the relevance of these theories to experimental measurements on novel materials.

Invited Talk TT 9.3 Mon 16:00 H 0104

Quantum Oscillations of the Quasiparticle Lifetime in a Metal — •Nico Huber[1], Valentin Leeb[1,2], Andreas Bauer[1,4], Georg Benka[1], Johannes Knolle[1,2,3], Christian Pfleiderer[1,2,4], and Marc A. Wilde[1,4] — [1]Technical University of Munich (TUM) — [2]MCQST, Munich — [3]Blackett Laboratory, Imperial College London — [4]TUM Zentrum für QuantumEngineering (ZQE), Munich

The low-lying excitations of metals are remarkably well explained by effective single-particle theories. Yet, strong interactions are abundant in condensed matter systems. This raises the question for direct spectroscopic signatures of phenomena beyond effective single-particle behavior. Here, we report on such a signature in the quantum oscillations (QOs) of the topological semimetal CoSi [1]. Its surprisingly simple QO spectrum related to Fermi surface pockets around the R-point [2,3] allows us to identify a QO frequency which defies the standard description in two ways. First, the frequency corresponds to the difference of quasi-particle (QP) orbits of two bands although the composite orbit is semi-classically forbidden. Second, the oscillations exist up to 50 K - in contrast to its constituent frequencies, which already vanish above a few K. We show that our findings are in excellent agreement with QOs of the QP lifetime [4]. Since the only precondition for this effect is a non-linear coupling of two orbits, e.g., due to QP scattering on defects, such QOs of the QP lifetime are generic for any metal featuring Landau quantization.

[1] Huber *et al.*, Nature **621**, 276 (2023)
[2] Huber *et al.*, PRL **129**, 026401 (2022)
[3] Guo *et al.*, Nat. Phys. **18**, 813 (2022)
[4] Leeb, Knolle, PRB **108**, 054202 (2023)

15 min. break

Invited Talk TT 9.4 Mon 16:45 H 0104

Simplicity of quantum oscillations in CoSi from its hidden quasi-symmetry — •Philip J.W. Moll[1], Chunyu Guo[1], Lunhui Hu[2], Carsten Putzke[1], Jonas Diaz[3], Xiangwei Huang[3], Kaustuv Manna[4], Feng-Ren Fan[4], Yan Sun[4], Chandra Shekhar[4], Claudia Felser[4], Chaoxing Liu[2], and Andrei B Bernevig[5] — [1]MPI for the Structure & Dynamics of Matter — [2]The Pennsylvania State University — [3]EPFL — [4]MPI for Chemical Physics of Solids — [5]Princeton University

The crystal symmetry dictates the type of topological band structures it may host, hence it is the principle guiding the search for topological materials. Here we present a twist on this idea, materials in which approximate symmetries stabilize near-degeneracies of bands. Specifically, we coin quasi-symmetry as a term for an exact symmetry of a Hamiltonian to lower-order yet is broken by higher-order perturbation terms. This enforces finite but parametrically small gaps at low-symmetry k-points across the whole Brillouin zone, eliminating the need for fine-tuning as the sources of large Berry curvature will occur at any arbitrary chemical potentials. We demonstrate that in the eV-bandwidth semi-metal CoSi an internal quasi-symmetry stabilizes gaps below 2 meV on eight large near-degenerate planes (2D) [1]. These quasi-degeneracies connect continuously to thetrue, symmetry-protected topological ones in CoSi. Depending on spatial symmetry, these are easily gapped by weak strain which is evidenced by new magnetic breakdown orbits [2]. In contrast, the quasi-symmetry has no spatial character and thus is resilient to strain.

Invited Talk TT 9.5 Mon 17:15 H 0104

Quantum oscillations of superconducting iron-chalcogenides $FeSe_{1-x}S_x$ — •Amalia Coldea — Clarendon Laboratory, University of Oxford, Oxford, UK

Iron-chalcogenides superconductors display intertwined electronic nematic and spin-density wave phases and their role in superconducting pairing is difficult to assess. However, versatile tuning parameters, like applied pressure and chemical pressure [1,2], can be used to separate and explore their relative importance. I will present quantum oscillations studies in $FeSe_{1-x}S_x$ using magnetotransport and tunnel diode oscillator experiments tuned both by chemical and applied pressures [3,4,5,6]. I will discuss the evolution of the Fermi surface and the quasiparticle effective masses in the high-pressure phase of the tetragonal $FeSe_{1-x}S_x$ where superconductivity is enhanced. These findings will be compared with magnetotransport studies to understand the signatures of different competing phases with superconductivity [7].

[1] A. I. Coldea, Frontiers in Phys. 8, 594500 (2021)
[2] A. I. Coldea et al., npj Quantum Materials, 4, 2 (2019)
[3] P. Reiss et al, Nat. Phys. 16, 89 (2020)
[4] P. Reiss et al, Phys. Rev. Lett. 127, 246402 (2021)
[5] Z. Zajicek et al., A. I. Coldea, Phys. Rev. Res. 4, 043123 (2022)
[6] Z. Zajicek et al., A. I. Coldea, submitted (2023)
[7] P. Reiss et al., arXiv.2212.06824 (2022)

TT 9.6 Mon 17:45 H 0104

Interband scattering- and nematicity-induced quantum oscillation frequency in FeSe — •Valentin Leeb[1] and Johannes Knolle[1,2] — [1]Technical University of Munich, Germany — [2]Imperial College London, United Kingdom

Understanding the nematic phase observed in the iron-chalcogenide materials is crucial for describing their superconducting pairing. Experiments on $FeSe_{1-x}S_x$ showed that one of the slow Shubnikov–de Haas quantum oscillation frequencies disappears when tuning the material out of the nematic phase via chemical substitution or pressure, which has been interpreted as a Lifshitz transition [Coldea et al., npj Quant Mater 4, 2 (2019), Reiss et al., Nat. Phys. 16, 89-94 (2020)]. Here, we present a generic, alternative scenario for a nematicity-induced sharp quantum oscillation frequency which disappears in the tetragonal phase and is not connected to an underlying Fermi surface pocket. We show that different microscopic interband scattering mechanisms – for example, orbital-selective scattering – in conjunction with nematic order can give rise to this quantum oscillation frequency beyond the standard Onsager relation. We discuss implications for iron-chalcogenides and the interpretation of quantum oscillations in other correlated materials.

TT 9.7 Mon 18:00 H 0104

Interaction-induced quantum oscillations of the lifetime — •Przemyslaw Bieniek[1], Valentin Leeb[1], and Johannes Knolle[1,2] — [1]Technical University of Munich, Germany — [2]Imperial College London, United Kingdom

In the last few years, several deviations from the standard theory of quantum oscillations, as well as new theories, have been reported. Recently, it was demonstrated in CoSi that interband impurity scattering can lead to fundamentally new frequencies [Huber et al. Nature 2023; Leeb, Knolle PRB 2023]. Similar phenomena occur in 2D electron gases [Polyanovsky 1988]. However in all works, the effect of interactions was neglected completely. Here, we show that already simple Hubbard interactions lead to oscillations of the lifetime, eventually appearing as new quantum oscillation frequencies. We extend our analysis to more generic Coulomb interactions. Our results provide an alternative scenario for the microscopic scattering mechanism in CoSi.