TT 24: Transport: Weyl Semimetals

Time: Tuesday 9:30–13:00 Location: H18

Invited Talk TT 24.1 Tue 9:30 H18

Detecting Weyl fermions in condensed matter — •Titus Neupert — Princeton Center for Theoretical Science, Princeton University, Princeton, New Jersey 08544, USA

Weyl semimetals are three-dimensional materials with topologically protected degeneracy points in the band structure. Even though this material class was envisioned several decades ago and anticipated in many theoretical studies, it took until the beginning of this year to find the first Weyl semimetal TaAs. In this talk, I will give an overview over the characteristic properties of Weyl semimetals, and more broadly three-dimensional topological semimetals. I will then discuss recent experiments that probe the physics of Weyl semimetals. For example, angle resolved photoemission spectroscopy measurements evidence the topological surface states, so-called Fermi arcs. Magnetotransport measurements detect a characteristic negative magnetoresistance associated with a nonconservation of the chiral charge of excitations near the Weyl points. This effect has a beautiful correspondence to the chiral anomaly studied in high-energy physics.

TT 24.2 Tue 10:00 H18

ARPES study of possible new Weyl semimetals — •Erik Haubold[1], Yevhen Kushnirenko[1], Alexander Fedorov[1], Seunghyun Khim[1], Sabine Wurmehl[1,2], Dmitriy Efremov[1], Timur Kim[3], Moritz Hoersch[3], Bernd Büchner[1,2], and Sergey Borisenko[1] — [1]IFW Dresden, Institut für Festkörperforschung, Postfach 270116, 01171 Dresden — [2]Institut für Festkörperphysik, TU Dresden, 01062 Dresden — [3]Diamond Light Source, Harwell Campus, Didcot OX11 0DE, United Kingdom

Development of modern electronics struggles with the ongoing decrease of the structural size. New approaches, for example spintronic devices, could solve these problems as they utilize intrinsic properties of the materials like the spin. The most promising materials for these applications are topological insulators and (Weyl-) semimetals as they possess unique surface and bulk properties which could enable direct spin manipulation. The goal of this contribution is to find new materials belonging to the group of Weyl semimetals. Weyl semimetals host the electrons which behave as Weyl Fermions — non-degenerate versions of Dirac fermions. To check for the presence of these states we use angle-resolved photoemission spectroscopy at synchrotrons, as it directly resolves the 3D electronic structure of the materials and therefore gives direct insight into their electronic structure. One of the materials to be studied is $TaIrTe_4$, which is a similar compound to the already proposed WTe_2. This choice is supported by band structure calculations indicating the possible presence of Weyl fermions in this compound.

TT 24.3 Tue 10:15 H18

Anisotropic density fluctuations, plasmons, and Friedel oscillations in nodal line semimetal — •Jun Won Rhim[1] and Yong Baek Kim[2] — [1]Max-Planck Institute for the Physics of Complex Systems — [2]Department of Physics and Center for Quantum Materials, University of Toronto, Toronto, Ontario M5S 1A7, Canada

Motivated by recent experimental efforts on three-dimensional semimetals, we investigate the static and dynamic density response of the nodal line semimetal by computing the polarizability for both undoped and doped cases. The nodal line semimetal in the absence of doping is characterized by a ring-shape zero energy contour in momentum space, which may be considered as a collection of Dirac points. In the doped case, the Fermi surface has a torus shape and two independent processes of the momentum transfer contribute to the singular features of the polarizability even though we only have a single Fermi surface. In the static limit, there exist two independent singularities in the second derivative of the static polarizability. This results in the highly anisotropic Friedel oscillations which show the angle-dependent algebraic power law and the beat phenomena in the oscillatory electron density near a charged impurity. Furthermore, the dynamical polarizability has two singular lines along $\hbar\omega = \gamma p$ and $\hbar\omega = \gamma p \sin\eta$, where η is the angle between the external momentum $\vec{p}$ and the plane where the nodal ring lies. From the dynamical polarizability, we obtain the plasmon modes in the doped case, which show anisotropic dispersions and angle-dependent plasma frequencies.

TT 24.4 Tue 10:30 H18

Superconductivity in Weyl Semimetal Candidate $MoTe_2$ — •Yanpeng Qi[1], Pavel Naumov[1], Mazhar Ali[2], Catherine Rajamathi[1], Oleg Barkalov[1], Michael Hanfland[3], Shu-Chun Wu[1], Chandra Shekhar[1], Yan Sun[1], Vicky Süss[1], Marcus Schmidt[1], Ulrich Schwarz[1], Eckhard Pippel[4], Peter Werner[4], Reinald Hillebrand[4], Tobias Förster[5], Erik Kampert[5], Walter Schnelle[1], Stuart Parkin[4], Robert Cava[2], Claudia Felser[1], Binghai Yan[1,6], and Sergey Medvedev[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Department of Chemistry, Princeton University, Princeton, USA — [3]European Synchrotron Radiation Facility, Grenoble, France — [4]Max Planck Institute of Microstructure Physics,Halle, Germany — [5]Dresden High Magnetic Field Laboratory,Dresden, Germany — [6]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

In this work, we investigate the sister compound of WTe_2, $MoTe_2$, which is also predicted to be a Weyl semimetal and a quantum spin Hall insulator in bulk and monolayer form, respectively. We find that $MoTe_2$ exhibits superconductivity with a resistive transition temperature T_c of 0.1 K. The application of a small pressure is shown to dramatically enhance the T_c, with a maximum value of 8.2 K being obtained at 11.7 GPa (a more than 80-fold increase in Tc). This yields a dome-shaped superconducting phase diagram. Further explorations into the nature of the superconductivity in this system may provide insights into the interplay between superconductivity and topological physics.

TT 24.5 Tue 10:45 H18

Bulk Fermi Surface Topology of the Weyl Semimetal Tantalumarsenide — •Marcel Naumann[1], Frank Arnold[1], Shu-Chun Wu[1], Yan Sun[1], Marcus Peter Schmidt[1], Horst Borrmann[1], Claudia Felser[1], Binghai Yan[1,2], and Elena Hassinger[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Max Planck Institute for Physics of Complex Systems, 01187 Dresden, Germany

Tantalumarsenide is a member of the non-centrosymmetric monopnictides which are putative Weyl semimetals. We have reconstructed the Fermi surface topology of TaAs by angular dependent Shubnikov-de Haas and de Haas-van Alphen measurements of a high quality single crystal and ab initio density-functional theory bandstructure calculations. By fitting the experimental angular dependence of the quantum oscillation frequencies to the calculated DFT bandstructure, we were able to reconstruct the entire Fermi surface and identify individual electron and hole pocket orbits in our measurements. We find that the Fermi surface consists of eight distinct pockets along each nodal ring, three pairs of topologically non-trivial electron Weyl-pockets and two trivial hole-pockets. Their effective charge carrier masses and scattering times have been determined by temperature and magnetic field dependencies of the quantum oscillation amplitude. Unlike the other members of the non-centrosymmetric monopnictides, TaAs is the first Weyl metal candidate were the Fermi energy is sufficiently close to both Weyl points to generate separate Weyl pockets with different chiralities.

TT 24.6 Tue 11:00 H18

Low energy electronic scattering processes in the topological Weyl semimetal TaAs — •Silvia Müllner[1], Peter Lemmens[1], Vladimir Gnezdilov[1,2], Raman Sankar[3], and Fangcheng Chou[3] — [1]IPKM, TU-BS, Braunschweig — [2]ILTPE NAS, Ukraine — [3]CCMS, National Taiwan Univ., Taipei, Taiwan

The topological Weyl semimetal TaAs shows Weyl points as well as topological surface states (Fermi arcs) intimately related to symmetry and strong spin orbit interaction. We find evidence for a low energy maximum in the scattering intensity that is compatible with electronic correlations in a collision dominated regime. We compare our observations with topological insulators.

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15 min. break

TT 24.7 Tue 11:30 H18

Apparent negative magnetoresistance without independent Weyl pockets in the Weyl semimetal TaP — •Elena Hassinger[1], Frank Arnold[1], Marcel Naumann[1], Shu-Chun Wu[1], Yan Sun[1], Ricardo Donizeth dos Reis[1], Mukkattu O. Ajeesh[1], Chandra Shekhar[1], Nitesh Kumar[1], Marcus Schmidt[1], Adolfo Grushin[2], Jens Bardarson[2], Michael Baenitz[1], Horst Borrmann[1], Michael Nicklas[1], Claudia Felser[1], and Binghai Yan[1,2] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Max Planck Institute for Physics of Complex Systems, Dresden, Germany

In the recently discovered Weyl semimetals, an unconventional negative longitudinal magnetoresistance is expected due to a phenomenon called chiral anomaly. An open question is, how close the Fermi energy needs to be to the Weyl nodes, in order to detect this phenomenon. This question can only be adressed by knowing the electronic bandstructure, i.e. the position of the Fermi energy, and the intrinsic longitudinal magnetoresistance precisely. Here, we report the detailed Fermi surface topology of the Weyl semimetal TaP determined via angle-resolved quantum oscillation spectra combined with bandstructure calculations. The Fermi surface consists of an electron and a hole banana without independent pockets around the Weyl points. Although the absence of independent Fermi surface pockets around the Weyl points means that no chiral anomaly is expected, we detect a negative longitudinal magnetoresistance. We discuss possible origins.

TT 24.8 Tue 11:45 H18

Magnetic resonance as a local probe for linear bands in the Weyl semimetals NbP and TaP — •Michael Baenitz, Hiroshi Yasuoka, Mayukh Majumder, Chandra Shekhar, Binghai Yan, Claudia Felser, and Markus Schmidt — MPI for Chemical Physics of Solids, 01187 Dresden, Germany

Some compensated d-electron semimetals, for example the monophosphites NbP and TaP, with non centrosymmetric structure and with sizable spin orbit coupling (SOC) form a new class of material: the Weyl semimetals (WSM). A unique linear crossing of valence- and conduction- band in a single point in reciprocal space defines the so called Weyl point where the fermion mass vanishes theoretically. In real materials the Fermi level E_F does not exactly match the Weyl node and as a consequence residual very light fermions are found. Due to the SOC these Weyl fermions have a chirality (handedness) on their linear dispersive ($E \propto k$) bands and frequently a linear density of states (DOS) at the Fermi level E_F. We use NMR as a probe for this linear d-electron bands. The shift provides the s- and d- electron contributions to the DOS at E_F, whereas the spin lattice relaxation is governed by low energy excitations around E_F. ^{31}P (I = 1/2) - Fourier - transform - and ^{95}Nb (I = 9/2) - broadline - sweep - NMR studies are performed. We investigated powder samples as well as single crystals on both systems. The angular dependence of the ^{95}Nb- and ^{31}P - NMR lines is discussed.

TT 24.9 Tue 12:00 H18

Fermi-surface topology of the Weyl semimetal NbP — •J. Klotz[1,2], Shu-Chun Wu[3], Chandra Shekhar[3], Yan Sun[3], Marcus Schmidt[3], Michael Nicklas[3], Michael Baenitz[3], M. Uhlarz[1], J. Wosnitza[1,2], Claudia Felser[3], and Binghai Yan[3,4] — [1]Hochfeld-Magnetlabor (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Institut für Festkörperphysik, TU Dresden, Germany — [3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [4]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The recent discovery of Weyl semimetals in transition-metal monopnictides revealed an exotic topological matter. Weyl semimetals feature band crossings with massless dispersions in their bulk band structure, termed Weyl points. Here, we present a Fermi-surface study on the Weyl semimetal NbP that combines both experimental data and band-structure calculations. We employed torque magnetometry in order to measure the angular dependence of the de Haas-van Alphen effect in a 12 T / 350 mK system. The excellent agreement between measured and calculated quantum-oscillation frequencies evidences the existence of two electron and two hole pockets and allows to locate the position of the Weyl points with respect to the Fermi energy.

TT 24.10 Tue 12:15 H18

Visualizing the chiral anomaly in Dirac and Weyl semimetals with photoemissspectroscopy — •Jan Behrends[1], Adolfo G Grushin[3], Teemu Ojanen[2], and Jens H Bardarson[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Low Temperature Laboratory, Department of Applied Physics, Aalto University, FI-00076 AALTO, Finland — [3]Department of Physics, University of California, Berkeley, CA 94720, USA

Quantum anomalies are the breaking of a classical symmetry by quantum fluctuations. They dictate how physical systems of diverse nature, ranging from fundamental particles to crystalline materials, respond topologically to external perturbations, insensitive to local details. In the solid state, it fundamentally affects the properties of topological Weyl and Dirac semimetals, recently realized experimentally.

In this work we propose that the most identifying consequence of the chiral anomaly, the charge density imbalance between fermions of different chirality induced by non-orthogonal electric and magnetic fields, can be directly observed in these materials with the existing technology of photoemission spectroscopy. With angle resolution, the chiral anomaly is identified by a characteristic note-shaped pattern of the emission spectra, originating from the imbalanced occupation of the bulk states and a previously unreported momentum dependent energy shift of the surface state Fermi arcs. Thereby, our work provides essential theoretical input to foster the direct visualization of the chiral anomaly in condensed matter.

TT 24.11 Tue 12:30 H18

Unconventional superconductivity in YPtBi and related topological semimetals — •Markus Meinert — Center for Spinelectronic Materials and Devices, Bielefeld University, Germany

YPtBi, a topological semimetal with very low carrier density, was recently found to be superconducting below $T_c = 0.77$ K. In the conventional theory, the nearly vanishing density of states around the Fermi level would imply a vanishing electron-phonon coupling and would therefore not allow for superconductivity. Based on relativistic density functional theory calculations of the electron-phonon coupling in YPtBi it is found that carrier concentrations of more than 10^{21} cm^{-3} are required to explain the observed critical temperature with the conventional pairing mechanism, which is several orders of magnitude larger than experimentally observed. It is very likely that an unconventional pairing mechanism is responsible for the superconductivity in YPtBi and related topological semimetals with the Half-Heusler structure.

TT 24.12 Tue 12:45 H18

Three-dimensional Dirac semimetal films grown by molecular beam epitaxy — Debakanta Samal[1], •Hiroyuki Nakamura[1], and Hidenori Takagi[1,2,3] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Stuttgart, Germany — [3]Department of Physics, University of Tokyo, Japan

Antiperovskite compounds have recently been predicted to host bulk three-dimensional Dirac dispersion as well as surface states protected by crystal symmetry. We present fabrication of cubic antiperovskite Sr_3PbO films, which has six Dirac points along high-symmetry momentum axes. Films were grown epitaxially on $LaAlO_3$ substrates by molecular beam epitaxy and capped with polymer to facilitate ex-situ transport characterization. All of the films showed metallic temperature dependence. The Hall effect measurement suggests that the carrier type is hole, with density between 10^{19} - 10^{20} cm^{-3}. We will describe our ongoing effort to tune the Fermi energy close to the Dirac point, as well as detail of the low temperature magnetotransport.