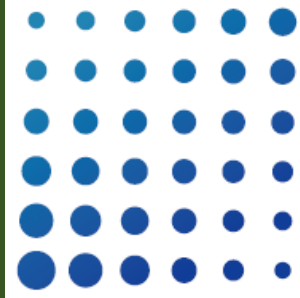

DCMP

Division of Condensed Matter Physics
Association of Asia Pacific Physical Societies

DCMP NEWSLETTER

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Division of Condensed Matter Physics
Association of Asia-Pacific Physical Societies

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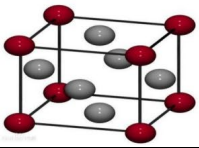

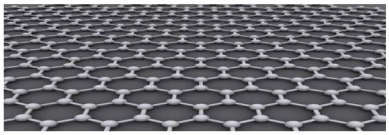

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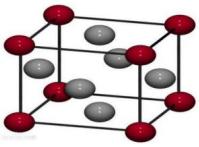
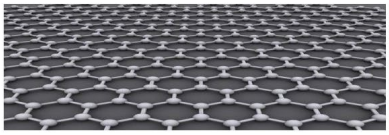




Large facilities/institute/organization reports

Report 1:

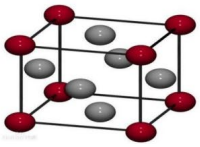
Status and perspectives of Condensed Matter Physics research in Australia

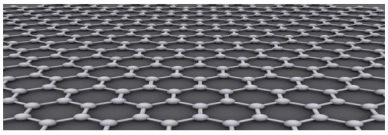
Australia's condensed matter physics research is recognised for its remarkable depth and breadth, driven by a strong desire to establish Australia as a major player on the global stage of cutting edge research. As a relatively small country with far fewer scientists compared to such giants as China and Japan, Australia manages to produce more than 2000 condensed matter journal articles per year (according to Scopus). This work attracts citation rates well above those of countries with much larger and better resourced research ecosystems. This is testament to the nation's commitment to investing in science and technology, as well as the innovative spirit and collaborative nature of its researchers. Here we consider some of the ingredients that are key to the success of condensed matter physics in Australia, both historically and into the future.

Modern condensed matter physics is an expensive business. It requires state-of-the-art equipment, usually housed in custom-built facilities, and often staffed by highly trained technicians. The Australian governments at state and federal levels have invested in large-scale infrastructure, such as the National Computational Infrastructure [1] and Pawsey Supercomputer [2] facilities, Microscopy Australia [3], the OPAL research reactor [4], the Australian Synchrotron [5] and the Australian National Nanofabrication Facility [6]. These facilities provide local opportunities for conducting condensed matter physics research within Australia – which is critical for addressing the challenge of geographical isolation from the rest of the world. Access to funding for some of these large-scale infrastructure projects is through the NCRIS funding scheme [7] designed for building national science infrastructure – typically for open facility access.

More generally, the Australian Research Council (ARC) is the primary funding body for research grants in Australia, providing support to researchers and institutions across a wide range of academic disciplines, including physics [8]. One scheme of the ARC which has been particularly pivotal for condensed matter physics is the Linkage Infrastructure, Equipment and Facilities (LIEF) [9] which provides funding to purchase and commission medium to large scale experimental facilities housed at Australian Universities. This scheme requires participation of multiple researchers across several Universities to apply as a consortium for new equipment. This has the effect of encouraging collaboration and creating a network of users for the resulting equipment.

The ARC infrastructure schemes have been particularly effective in providing Australian condensed matter physics researchers with state-of-the-art equipment. After the first experiments in Bose-Einstein Condensation were performed in the late 90s, within five years Australian researchers were applying for funding for optical traps and control lasers. As the field of quantum dots, and semiconductor nanostructures was developing the groundwork for the next generation of light emitting diodes, semiconductor lasers and other photonic devices, the ARC was funding ultra-fast lasers, lithography equipment and clean-room equipment. Over the last two decades, single electron electronics and quantum computing have become an enormous field of research, and in Australia the number of dilution refrigerators has risen from fewer than five to well over 50 at last count. Similarly, as the fields of graphene and two-dimensional materials took off in the late 2000s and into the 2010s, the ARC was funding glove-boxes, molecular beam





epitaxy systems and a wide variety of electron microscope and other characterisation tools.

The advantage of such funding schemes is that it provided a competitive process open to all Australian condensed matter academics, irrespective of which University they worked at or the financial situations within their departments. As a result, relatively junior faculty can develop their research programmes on the latest equipment while also collaborating with existing established researchers. In addition, due to the cross-disciplinary nature of a lot of condensed matter research, it helps build links to chemistry, mathematics, materials science, optics and photonics and other fields which benefit from high quality condensed matter research.

Developing a strong network of like-minded researchers is important in any field, and any part of the world. However in Australia with its long distances and sparse population – it is critical. Another strength of condensed matter in Australia is the regular conferences and workshops that bring the community together. The Australian Institute of Physics (AIP) this year will host the 50th anniversary of its National Congress. This event runs every second year and covers all of physics, including a significant representation from the condensed matter and materials (CMM) topical group [10]. Additionally, since 2017, the AIP has also hosted the AIP Summer Meetings in alternate years, to provide even more opportunities to strengthen collaborative ties nationally and present the most recent work.

The CMM topical group is almost as old as the AIP itself and has run the Annual Condensed Matter and Materials Meeting since 1977 [11,12]. This is a well known and loved event, particularly popular with students and junior academics being introduced to the condensed matter community in Australia. The 46th event was held in February 2024 at Charles Sturt University, Wagga Wagga, with the 47th already planned for February 2025.

Another key conference of the community is the International Conference on Nanoscience and Nanotechnology (ICONN) which, since the mid-2000s, has brought together not just condensed matter, but also optics, chemistry, materials and electronics under the umbrella of the Australian Nanotechnology Network. Similarly, since 2009, the Gordon Godfrey workshop on spins, topology and strong electron correlations has been hosted by the University of New South Wales to bring together these key topics of condensed matter physics.

Fig 1: ARC CoE FLEET workshop 2023 – a family friendly and inclusive workshop

A particularly pleasing development in the last decade is Australia's proactive approach to improving diversity and inclusion in condensed matter (a notoriously imbalanced field). Inclusive policies, stipulating required minimum numbers of women Plenary and Invited speakers, are now standard practice at conferences around Australia. Not only do these policies help ensure women are well represented, but they also provide support for attendees with disabilities and delegates with child-care responsibilities – by offering child-care options and family friendly events during conferences (Fig 1). Such measures help to ensure researchers who are parents, carers or face challenges in traditional academic settings, are given the opportunity to attend and present their research.

Equipment and networking is only part of the story. At the end of the day the researchers themselves need to be supported. The ARC also provides funding opportunities geared towards researchers at different stages of their careers. These include such programs as:

- Discovery Early Career Researcher Awards (DECRA) support early-career researchers in their first 5-7 years after PhD completion.

- Discovery Projects support researchers in all stages of their careers to undertake research projects.
- Linkage Projects supports collaborations between researchers and industry partners.
- Future Fellowships (for up to 15 years post PhD) and Laureate Fellowships (for well established, senior researchers) – for particularly innovative and high impact research projects.
- In more recent years, ARC Industry Fellowships provide an industry partnered version of DECRA, Future and Laureate Fellowships.

All these schemes have helped to build a strong and vibrant condensed matter research community across the country. Another strong contributor is that the Australian government also funds PhD student scholarships directly, rather than only through grants. This means talented students embarking on a research career can take their pick of research groups, which means a young and exciting field can grow quickly thanks to this pipeline of eager students.

Among its various funding programs, the ARC Centres of Excellence (CoE) program stands out as a flagship initiative that has had a profound impact on the Australian research landscape [9]. The CoE program was established in 1990 with the aim of supporting large-scale, collaborative research projects that tackle complex, multidisciplinary challenges of great national and global significance. These centres bring together teams of researchers from multiple institutions, often from different universities and research organizations located all around Australia, to work together on a shared research agenda. The program provides funding for typically seven years, with each centre receiving approximately $30-40 million AUD over this period (~ $21-27 million USD). The CoE budget is typically spent on a range of activities, including PhD student bursaries, early career researcher salaries (Fig 2), equipment, travel, and consumables.

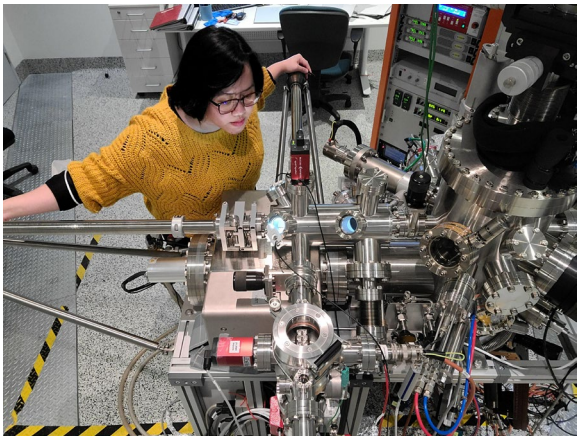


Fig 2: ARC funded postdoc Chi-Xuan Trang uses an MBE facility for sample preparation at Monash University.

One of the key strengths of the CoE program is its ability to foster collaboration, networking and knowledge transfer between researchers from different universities and disciplines – which is incredibly important in Australia with such large geographical distances between research institutions. This has led to the development of new research areas, the creation of new technologies, the training of future researchers and the spin-off of new manufacturing initiatives – all critical to growing Australia's scientific capacity. The centres have also driven the focus for creation of new research infrastructure and equipment, which has benefited not just the individual centre but also the broader research community.

Amongst the Centres of Excellence funded by the ARC, there have been six in which one can find significant areas of condensed matter research. One of the most visible is the ARC Centre of Excellence for Quantum Computation and Communication Technology (CQC^2T) [13] and its predecessor the Centre of Excellence for Quantum Computer Technology, which has been continually funded since 1999. This Centre currently involves over 160 researchers across several institutions and has been instrumental in developing both local expertise and training future generations. In particular, Australia is known world-wide for its research in silicon-based quantum computing which originated in this

centre.

The ARC Centre of Excellence for Engineered Quantum Systems (EQUS) [14] which was funded in 2011, is another Centre with considerable impact in condensed matter physics. The aim of the Centre is building quantum machines to harness the quantum world for future health, economy, environment and security of Australian society. Based at the University of Queensland, it also involves academics, researchers and students across five Australian Universities, along with partner Investigators representing six overseas countries and the Australian National Measurement Institute.

This strength in quantum technology research in Australia is well recognised [15, 16] and has resulted in a series of recent spin-outs, including Silicon Quantum Computing [17], Diraq [18], Quantum Brilliance [19] and Analogue Quantum Circuits [20]. All of these companies seek to commercialise condensed matter research developed within Australia for the growing quantum computing industry.

As a result of the success of quantum research in Australia, as well as these nascent commercialisation efforts, in April 2024 the Australian Federal Government announced the creation of the “Australian Centre for Quantum Growth”, a national centre to grow the quantum industry [21], namely quantum computing, communication, sensing and related technologies. With 2025 declared as the International Year of Quantum, it will be interesting to see how the quantum physics related research evolves in Australia and around the world.

Focusing more on “core” condensed matter research, the ARC Centre of Excellence in Future Low-Energy Electronics Technologies (FLEET) [22] was funded (2017-2024) to research low power methods of information processing. Over the lifetime of the centre, FLEET brought together over 400 researchers including more than 150 Research Fellows and Students from eight Australian and eleven international research institutions [23]. The research themes of the Centre were Topological Materials, Exciton Superfluids and Light-Transformed Materials through atomically thin materials and nano-device fabrication (Fig 3). Spin-offs from the research achievements in FLEET include 10 patents and three new companies including TQ Transistors [24] which was set up to license the IP of the topological transistor developed at FLEET in 2022.

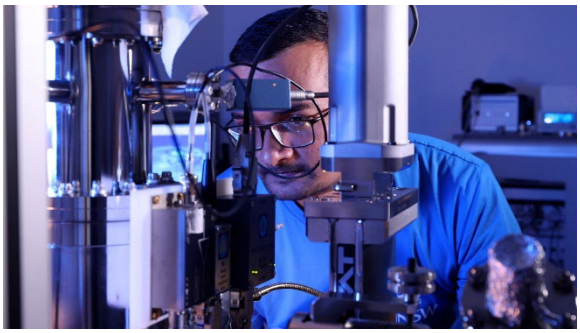
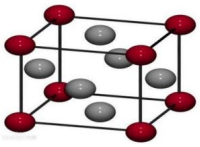
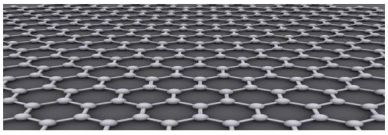


Fig 3: Pankaj Sharma from FLEET monitoring sample quality with the scanning tunneling microscope located at the University of New South Wales.

The most recent ARC Centre of Excellence involving aspects of condensed matter physics research is that for Carbon Science and Innovation [25], awarded initially in 2023 and with a budget of $35M to commence in March, 2024. The research engages investigators across seven Australian Universities and has three research programs: Advanced Carbon Catalysts; Carbon Catalysts for Renewable Energy with Zero Emissions; and Carbon Catalysts for Green Chemistry to Reduce Carbon Emissions.

The Centre of Excellence scheme has also supported a number of collaborations between condensed matter research and other areas of science. For example the ARC Centre of Excellence for Electromaterials Science [26] was funded from 2005 until 2021, and focused on electrochemistry and related topics including significant work in the physics of electromaterials. Also overlapping with chemistry, in 2017 the ARC Centre of Excellence in Exciton Science [27] brought together research groups working in photochemistry, photovoltaics and organic electronics. One of the Exciton Science Centre’s key research themes was solar energy generation, researching both augmentation for silicon photovoltaics and





potential replacement materials, for example perovskites. About one quarter of the Centres publications were in an area of condensed matter physics.

A number of other Centres of Excellence have focused on optics and photonics, which leveraged the condensed matter physics capabilities in Australia. These include the Centre for Quantum-Atom Optics (2003-2010) and the Centre for Ultrahigh Bandwidth Devices for Optical Systems (2003-2017). Most recently the ARC Centre of Excellence in Optical Microcombs for Breakthrough Science was funded in 2023 [28]. Lead out of RMIT University, this Centre builds on the legacy of high quality photonics research in Australia which depends on the latest advances in materials and characterisation.

These Centre's of Excellence certainly highlight the wide range of condensed matter physics research currently undertaken in Australia. Australia is also making significant contributions to other global challenges in condensed matter physcis. According to the Australian Academy of Science's 2020 report [29], Australia has a growing reputation for excellence in research areas such as superconductivity, quantum materials and nanomaterials. There are strong examples of research groups tackling these big issues in Australia:

- Quantum Materials: Developing a deeper understanding of quantum materials, such as topological insulators, superconductors, and superfluids, and finding ways to manipulate and control their properties.
- High-Temperature Superconductors: Finding a way to create superconductors that can operate at room temperature or higher, which would revolutionize energy transmission and storage.
- Spintronics: Developing spin-based electronics that can replace traditional charge-based electronics, which would enable more efficient and faster computing.
- Quantum Computing: Building scalable and reliable quantum computers that can solve complex problems that are currently unsolvable by classical computers.
- Topological Quantum Computation: Developing a robust and scalable method for topological quantum computation, which would enable fault-tolerant quantum computing.
- Nanomaterials: Understanding the behaviour of materials at the nanoscale and developing new materials with unique properties that can be used in applications such as energy storage, catalysis, and sensing.

These are just a few examples of the many research projects and initiatives that are currently contributing to the biggest global challenges in condensed matter physics in Australia. It will certainly be exciting to see what is next for Australian condensed matter physics research in the coming years.

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All images provided courtesy of FLEET.

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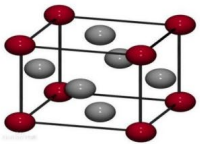

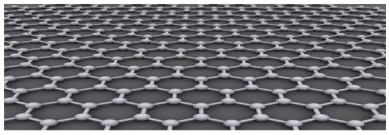

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Report 2: Korea Institute for Advanced Study (KIAS)

Author: Professor Kwon Park

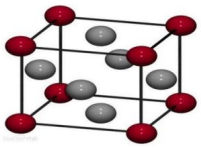
Korea Institute for Advanced Study (KIAS)

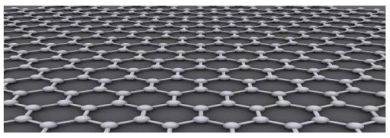
We would like to begin with a quick overview of KIAS. KIAS was established in 1996 by the Korean Government to promote excellence in basic science research. KIAS is situated on a 120,000-square-meter campus in Seoul, providing its members with a conducive environment for research. As Korea's premier institute for basic sciences, KIAS provides a platform for advanced learning and the active exploration of new ideas for both local and international scientists.

At KIAS, scientists from around the world collaborate on research, take sabbatical leave, and participate in various research activities. The institute also hosts a variety of meetings, seminars, workshops, and seasonal schools to fulfill its mission. The faculty and research staff at KIAS are diverse, representing different nationalities and backgrounds. KIAS aims to become a world-class research hub and welcomes opportunities to engage with research communities globally.

KIAS comprises three schools; the School of Mathematics, the School of Physics, and the School of Computational Sciences. Many resident scientists in the Schools of Physics and Computational Sciences study condensed matter physics. Specifically, there are three condensed matter theory groups at KIAS: one in the School of Physics and two in the School of Computational Sciences.

First of all, Professor Kwon Park leads the Quantum Many-Body Theory (QMBT) group in the School of Physics. The QMBT group focuses on various quantum many-body problems arising in strongly correlated electron systems such as high-temperature superconductivity, fractional quantum Hall





effects, topological matter, Floquet nonequilibrium steady states, quantum magnetism, and quantum computers.

In particular, Professor Park and collaborators in the QMBT group discovered that the projected BCS theory, which incorporates the resonating valence bond state proposed by P. W. Anderson, can unify antiferromagnetism and strongly correlated superconductivity. This could serve as a significant breakthrough in solving the mystery of high-temperature superconductivity. Also, it was discovered that the fractional topological order can be directly visualized in experiments by using the adiabatic connection between fractional Chern insulators and the Tao-Thouless state. The Tao-Thouless state is a charge density wave state that can be achieved in the thin torus limit of a topological insulator. This state can be created experimentally by transforming magic-angle twisted bilayer graphene (MATBG) or other 2D materials such as $MoTe_2$ into a nanotube.

Professor Park has been engaged in various activities to promote collaboration among the Asian Pacific Physical Societies. One of these initiatives is the organization of the IACS (Indian Association for Cultivation of Sciences)-APCTP (Asia-Pacific Center for Theoretical Physics)-KIAS Joint Conference on "Emergent Phenomena in Novel Oxide Materials and Low Dimensional Systems."

Secondly, Professor Young-Woo Son leads the Ab Initio Material Science (AIMS) group in the School of Computational Sciences. The main objective of the AIMS group at KIAS is to create computational methodologies and tools for calculating material properties at a fundamental level using atomistic first principles, or ab initio quantum mechanical calculations. These methods are then applied to gain insights into and predict material properties. A variety of different computational approaches have been developed and used, which require only atomic numbers and positions as input. The group has collaborated with various condensed matter experimental groups worldwide and has organized a series of important international and domestic conferences.

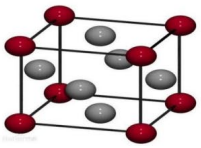
Below are a few accomplishments achieved by the AIMS group. (i) The group has developed a new ab initio computational method to efficiently and accurately compute various physical properties of correlated materials. While density functional theory (DFT) methods can be fast, they often sacrifice accuracy for speed, or they require significant resources to reach the desired level of accuracy. The group addressed this issue by devising a new method to simultaneously determine the self-consistent on-site and inter-site Hubbard interactions within conventional DFT methods. (ii) The group has developed a new computational method to reliably simulate large-scale atomistic motions incorporating electron-phonon interactions. (iii) Also, the group has collaborated with several research groups to study correlated excitons in charge transfer insulators, nontrivial lattice dynamics of twisted layered materials, and anomalous Raman scattering in layered materials.

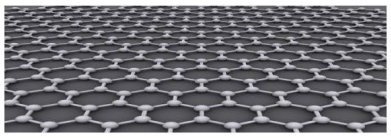
Finally, Professor Sangkook Choi leads the Computational Quantum Many-Body Theory (CQMBT) group in the School of Computational Sciences. The CQMBT group is committed to developing theories, algorithms, and software for both classical and quantum computers to explore the capabilities of correlated quantum materials. One of our main projects involves developing the ab initio fully self-consistent GW+EDMFT methodology for classical computers. This represents the first complete implementation of this technique based on first principles. On the quantum computing front, we have developed the quantum Zeno Monte Carlo algorithm, which demonstrates polynomial computational cost and device-noise resilience.

Professor Choi also serves as a consultant at Brookhaven National Lab in the USA. He is actively engaged in various committees, including the steering committee for the DMFT-QE symposium series at the Flatiron Institute and the organizing committee for the international conference on computational quantum many-body theory at KIAS.

To summarize, KIAS aims to become a global center for condensed matter physics theory, with a special focus on strongly correlated quantum many-body problems. We look forward to strengthening our partnerships with other condensed matter physics groups and communities in the Asia-Pacific region.

Photo: KIAS at night





Selected Contributions on condensed Matter Physics in the Asian Pacific Areas

Report 1:

Title: $CsCr_3Sb_5$: A chromium-based kagome superconductor with strong correlations*

Subtitle: *A new chromium-based kagome metal, CsCr3Sb5, was discovered, featuring with strong electron correlations, frustrated magnetism, and characteristic flat bands. Under moderately high pressure, a superconducting "dome" emerges at around the quantum critical point of the charge- and spin-density-wave orders.*

By Yi Liu and Guang-Han Cao

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Abstract: The discovery of vanadium-based kagome materials ACr_3Sb_5 (A=K,Rb,Cs) as well as their intriguing emergent phenomena calls for exploration of a correlated version of ACr_3Sb_5. Here we report on a chromium-based kagome metal, $CsCr_3Sb_5$, which hosts strong electron correlations, frustrated magnetism and characteristic flat bands. At ambient pressure, $CsCr_3Sb_5$ undergoes a concurrent structural and magnetic phase transition at 55 K with a stripe-like $4a_0$ structural modulation. Upon applying pressure, the charge- and spin-density-wave orders are gradually suppressed, and superconductivity with the highest superconducting transition temperature of 6.4 K appears at the quantum critical point where the normal state exhibits a non-Fermi-liquid behavior. The work offers an unprecedented platform for investigating superconductivity in correlated kagome systems.

1. Background

Materials with two-dimensional kagome lattices are featured with geometric frustration and characteristic electronic structures, from which various intriguing quantum states may emerge [1]. The vanadium-based kagome materials ACr_3Sb_5 [2] present many interesting phenomena such as electronic topology, superconductivity, and unconventional charge density wave [3]. Nevertheless, this class of materials are most likely phonon-mediated conventional superconductors, in line with the nonmagnetic nature and relatively weak electron correlations [3,4]. Correlated magnetic kagome materials, on the other hand, generally bear robust magnetism hampering the appearance of superconductivity. Historically, exotic superconductivity was expected from theoretical investigations [5-8], yet the experimental realization is hard to achieve. Below we report a new chromium-based kagome material, $CsCr_3Sb_5$, which uniquely hosts strong electron correlations, frustrated magnetism at ambient pressure, and unconventional superconductivity nearby a quantum critical point (QCP) at $P_c \approx 4$ GPa.

2. Correlations, magnetism, and structural modulations of $CsCr_3Sb_5$

$CsCr_3Sb_5$ is structurally analogus to CsV_3Sb_5, which crystallizes in a hexagonal lattice with the space group of *P*6/*mmm*. Cr atoms form a two-dimensional (2D) kagome net with Sb1 atoms located at the center of the hexagons (Fig. 1a). The in-plane resistivity $\rho_{ab}(T)$ is nearly temperature-independent above 150 K with an absolute

value of resistivity of 1.4 mΩ cm (Fig. 1b). The resistivity anisotropy ρ_c/ρ_{ab} is as high as ~60, indicating a quasi-2D transport property.

The low-T specific-heat data (top inset of Fig. 1c) show a large electronic specific-heat coefficient, γ_{exp} = 105(1) mJ K^{-1} mol^{-1}, four times larger than that of CsV_3Sb_5 or that of the DFT calculation, suggesting strong electron correlations. Notably, there appears a phase transition at T_N = 55 K, at which the resistivity and magnetic susceptibility (Fig. 1d,e) consistently show an anomaly.

Local-moment magnetism is manifested by the magnetic susceptibility data as well as the nuclear magnetic resonance (NMR) measurement. The Curie-Weiss (CW) fit of the high-temperature susceptibility data yields an effective magnetic moment of μ_{eff} = 1.26 ± 0.12 μ_B/Cr and large values of paramagnetic CW temperatures θ_{CW}. The magnetic frustration index, $f = |\theta_{CW}|/T_N \approx 6$-7, suggests significant magnetic frustrations that commonly exist in a magnetic kagome lattice. The phase transition at 55 K is identified as an antiferromagnetic (AFM) spin-density-wave (SDW) ordering, because of the splitting of NMR line at low temperature (Fig. 1f). Nevertheless, the spectral line is severely broadened, implying that the magnetic structure should be somewhat complex. Indeed, a recent theoretical study [9] suggests a complicated altermagnetic order as the ground state for $CsCr_3Sb_5$.

The low-temperature x-ray diffractions indicate a monoclinic distortion and a structural modulation with a single **Q** vector (1/4, 0, 0) based on a pseudo-hexagonal lattice below 55 K. The structural modulation suggests a charge-density-wave (CDW) instability. Therefore, the ground state likely possesses a concurrent intertwined DW order, in which charge, spin, and lattice degrees of freedom couple together.

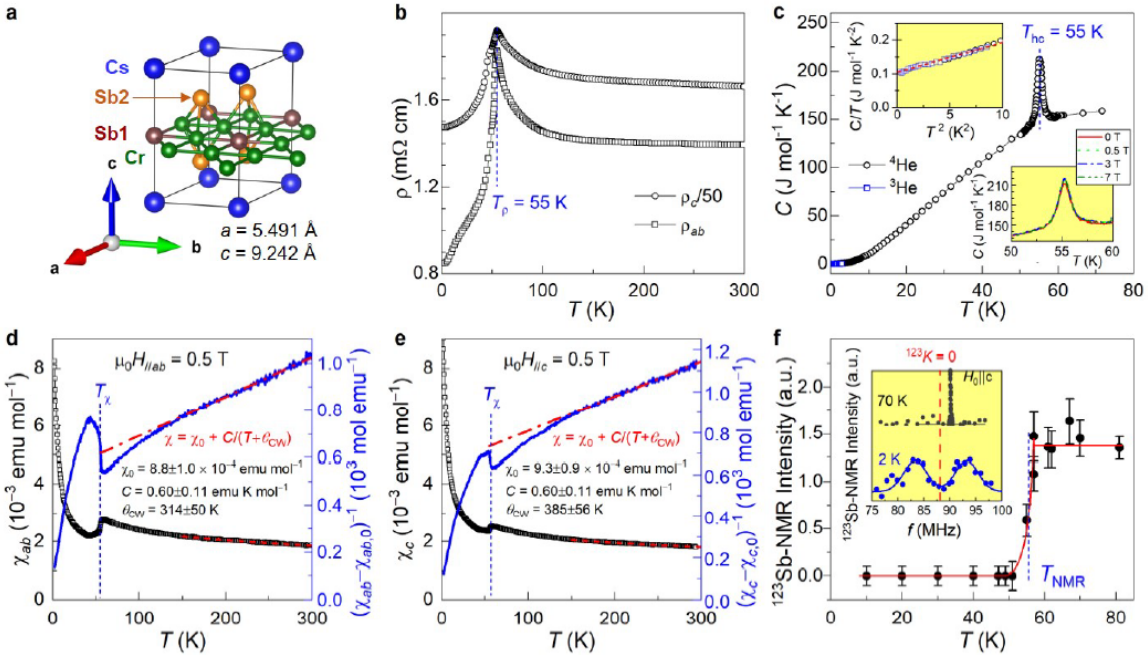


Fig. 1. Crystal structure (**a**) and physical properties of $CsCr_3Sb_5$. **b**, In-plane and out-of-plane resistivity as functions of temperature T. **c**, Temperature dependence of specific heat. **d,e**, Temperature dependence of magnetic susceptibility with magnetic field parallel (**d**) and perpendicular (**e**) to the *ab* plane, respectively. **f**, Temperature dependence of ^{123}Sb-NMR signal.

3. Superconductivity under pressure

Figure 2a shows the $\rho(T)$ data of $CsCr_3Sb_5$ under various pressures up to 12 GPa. One sees that the resistivity decreases monotonically with pressure, and the metallicity is steadily enhanced. At P > 1 GPa, the resistivity peak evolves into two anomalies at T_1 and T_2, respectively. There is a remarkable resistivity jump at T_1, implying a CDW ordering because the latter

generally opens an energy gap. Comparatively, the anomaly at T_2 is rather mild, which is putatively attributed to an SDW ordering. With increasing pressure, both T_1 and T_2 decrease monotonically, and superconductivity gradually emerges for $P >$ 3.6 GPa. Details of the data can be seen in Ref. [10].

The electronic $P - T$ phase diagram for $CsCr_3Sb_5$ is presented in Fig. 2b. At ambient pressure, there is a CDW/SDW-like ordering at 55 K. When the applied pressure exceeds 1 GPa, it evolves into two successive transitions, probably associated with CDW and SDW orderings, respectively. Both the DW-like transition temperatures, T_1 and T_2, are suppressed gradually before going to absolute zero. The critical pressure at $T_2 \rightarrow 0$ is extrapolated to be $P_c \approx 4$ GPa where T_c and the upper crtical field $H_{c2}(0)$ achieve their maximal values. In addition, there is a narrow region of 3.6 GPa < P < 4.1 GPa, in which superconductivity coexists with the DW orders. All these results resemble those of iron-based superconductors and some other unconventional superconductors, pointing to quantum criticality in the present system. As is known, one of the most important hallmarks of quantum criticality is a non-Fermi-liquid behavior, which is indeed observed for $P_c \approx 4$ GPa from the normal-state resistivity just above T_c. In addition, the large effective electronic mass, derived from the resistivity data [10], suggests unconventional superconductivity in pressurized $CsCr_3Sb_5$, because the T_c/T_F (T_F is the Fermi temperature) values estimated just lie in the unconventional-superconductor region covering cuprates, iron-based pnictides/chalcogenides, and heavy-fermion materials.

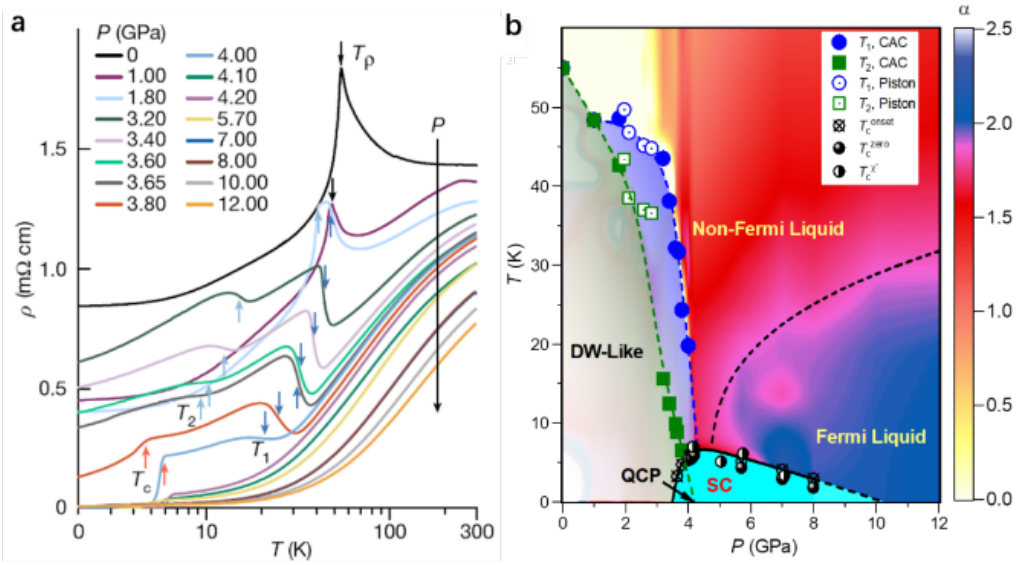
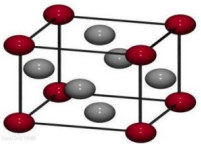
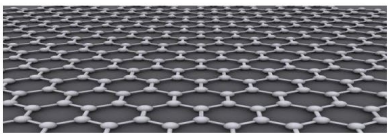


Fig. 2. Superconductivity emerging from density-wave-like orders in $CsCr_3Sb_5$. **a**, $\rho(T)$ curves under high pressures. The blue, olive, and red arrows mark CDW-like, SDW-like, and superconducting transitions at T_1, T_2, and T_c, respectively. **b**, The electronic $P - T$ phase diagram. DW, QCP, and SC denote density-wave, quantum critical point, and superconductivity, respectively.

4. Outlook

Unconventional superconductivity typically emerges from a spin- and/or charge-ordered state in a correlated electron system, as exemplified in cuprates, iron-based pnictides/chalcogenides, and heavy-fermion materials. Here $CsCr_3Sb_5$ possesses similarities with the known unconventional superconductors in terms of electron correlations, evolution of superconductivity, intertwined orders, and the T_c/T_F value in particular. This possible realization of unconventional superconductivity in the chromium-based correlated kagome metal supplies a unique example, which may shed light on the mechanism of unconventional superconductivity from a distinct perspective.





There are a lot of issues open for the future studies. For instance, further confirmation of unconventional superconductivity in pressurized $CsCr_3Sb_5$ is important. It is also appealing to reveal the superconducting pairing symmetry. For these purposes, experimental explorations for the ambient-pressure superconductivity via chemical doping/substitutions and/or gate-voltage regulation are highly deserved. The nature of the phase transition, especially the form of magnetic structure, as well as its evolution under pressure, is of special interest given its intimate relationship with the possible USC.

* This work was in collaboration with Prof. Jin-Guang Cheng's group and Prof. Rui Zhou's Group. Thanks are also due to all other co-authors of Ref. [10].

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Report 2:

Title: Bulk superconductivity in trilayer nickelate $La_4Ni_3O_{10-\delta}$ single crystals under pressure

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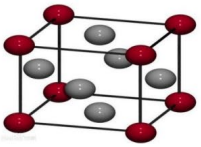
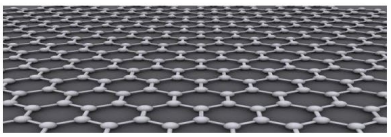
Abstract: Exploring new high-temperature superconductors is a key area in condensed matter physics. Recently, our study demonstrates that applying pressure to trilayer nickelate $La_4Ni_3O_{10-\delta}$ single crystals suppresses spin and charge orders, inducing superconductivity with a maximum critical temperature of about 30 K at 69.0 GPa. DC susceptibility measurements show a significant diamagnetic response below this temperature, confirming bulk superconductivity with over 80% volume fraction. In its normal state, the material exhibits "strange metal" behavior with linear temperature-dependent resistance up to 300 K. The observed layer-dependent superconductivity suggests a distinct interlayer coupling in nickelates, differentiating them from cuprates. These results offer new insights into superconductivity mechanisms and present a novel material system for further exploration of high-temperature superconductivity and related phenomena.

The mechanism behind high-temperature superconductors remains largely elusive despite decades of intensive research [1, 2]. Discovering new high-temperature superconducting materials beyond cuprates is essential for unraveling this underlying mechanism and holds significant potential for practical applications. In 2019, an intriguing development occurred when superconductivity was observed in "infinite-layer" nickelate thin films with a critical temperature (T_c) of ~15 K. In these materials, Ni^{1+} (d^9) forms square planar NiO_2 layers closely resembling Cu^{2+} (d^9) in cuprates [3]. More recently, signatures of superconductivity have also been observed in the Ruddlesden-Popper (RP) bilayer perovskite $La_3Ni_2O_7$ under high pressure,





achieving a T_c of approximately 80 K above 14 GPa [4].

In our recent work, we report the observation of bulk superconductivity in trilayer nickelate $La_4Ni_3O_{10-\delta}$ single crystals [5]. By using the high-pressure optical floating zone technique we have successfully synthesized high-quality $La_4Ni_3O_{10-\delta}$ single crystals with minimal oxygen vacancies (Fig. 1a and 1b). High-pressure X-ray diffraction measurements revealed a structural transition from *P2₁/a* to *I4/mmm* at pressures around 13-15 GPa, along with the tilting of the NiO_6 octahedra (Fig. 1c). We also conducted resistance and DC susceptibility measurements under hydrostatic high-pressure conditions in a diamond anvil cell with noble gas pressure media. Our results unequivocally demonstrate the bulk superconductivity of $La_4Ni_3O_{10-\delta}$ with a high superconducting volume fraction exceeding 80%. Thus, our work establishes a novel material platform for studying nickelate high-temperature superconductors.

The experimental evidence of superconductivity in $La_4Ni_3O_{10-\delta}$ come from two primary aspects. The first one is zero electrical resistance under pressure. The maximum superconducting critical temperature reaching about 30 K at a pressure of 69 GPa (Fig. 1d). This transition to zero resistance is a hallmark of superconductivity. The second evidence is the Meissner effect. We detected a strong diamagnetic response through DC susceptibility measurements (Fig. 1e). This indicates a Meissner effect that the material expels magnetic fields, another critical characteristic behavior of superconductors. The superconducting volume fraction exceeds 80%, confirming the bulk nature of the superconductivity in this compound.

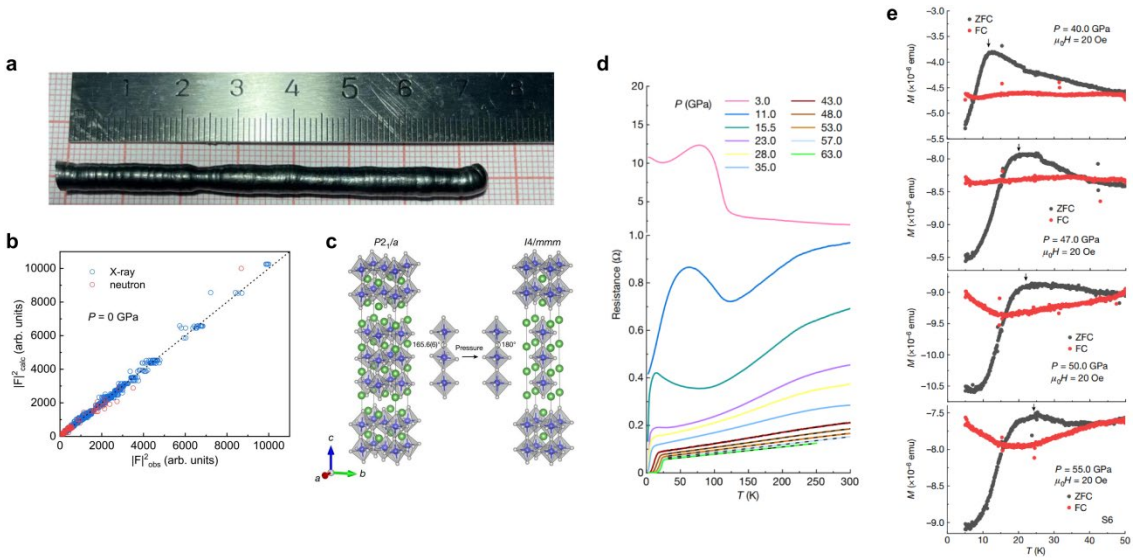


Figure 1. Bulk superconductivity in $La_4Ni_3O_{10-\delta}$. a, Photograph of $La_4Ni_3O_{10-\delta}$ single crystals. b, Neutron and X-ray diffraction refinements identified the composition as $La_4Ni_3O_{9.96(4)}$, pointing to minor oxygen deficiency. c, High-pressure X-ray diffraction measurements reveal a structural transition from *P2₁/a* to *I4/mmm*, along with tilting of the NiO6 octahedra. d, Electrical resistance measurements under high pressure demonstrate a clear superconducting transition in $La_4Ni_3O_{10-\delta}$. e, DC susceptibility measurements under hydrostatic high-pressure conditions further confirm the superconducting phase transition, with a superconducting volume fraction exceeding 80%.

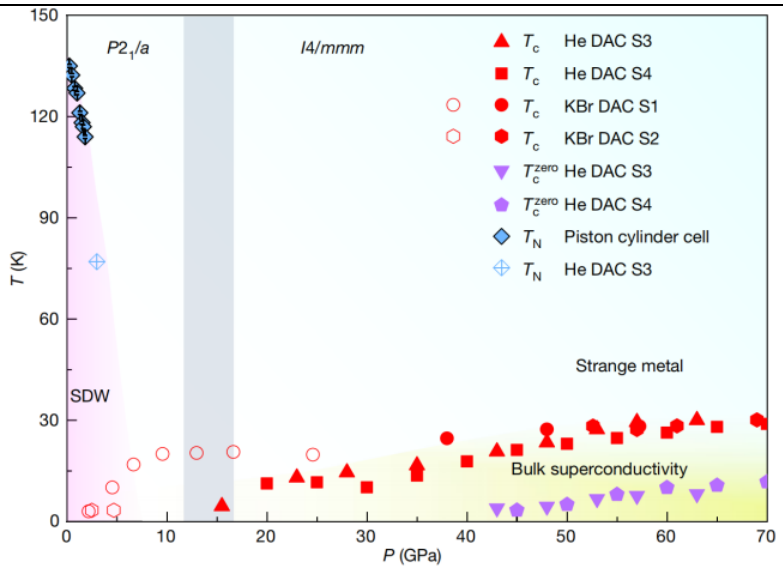


Figure 2. Phase diagram of $La_4Ni_3O_{10-\delta}$. As pressure increases, the spin density wave state is progressively suppressed, leading to the emergence of bulk superconductivity at pressures above approximately 40 GPa.

The high-pressure properties of $La_4Ni_3O_{10-\delta}$ provide valuable insights into its superconducting mechanism. As shown in Fig. 2, the phase diagram of $La_4Ni_3O_{10-\delta}$ reveals a progression through several distinct states, including spin/charge density waves, strange metal behavior, and superconductivity. Therefore, $La_4Ni_3O_{10-\delta}$ provides a new material platform to study the intricate interplay between these states. Moreover, the layer-dependent superconducting critical temperature (Tc) in nickelates, which differs from the behavior seen in cuprates, where T_c increases with the number of CuO_2 layers and peaks in trilayer cuprates [6-8], points to unique interlayer coupling and charge transfer mechanisms specific to nickelates. The trilayer structure of $La_4Ni_3O_{10-\delta}$ presents an excellent opportunity to explore the role of interlayer coupling in unconventional electron pairing, potentially offering deeper insights into the mechanisms driving high-temperature superconductivity.

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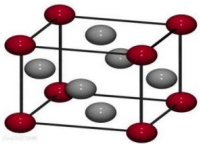

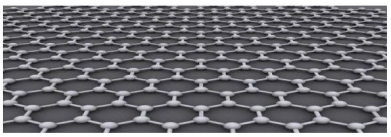

Report 3:

Title: Orbital Hall effect detection via magneto-optical Kerr effect

Subtitle: *Magneto-optical Kerr effect measurement on a Ti film indicates the orbital magnetic moment accumulation at the top and bottom surfaces of the film when an electrical current flows in the film, confirming the orbital Hall effect in Ti.*

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The orbital Hall effect [1] refers to the electrical generation of an orbital angular momentum current flowing in a direction transverse to an externally applied electric field. This effect was theoretically predicted [2-6] for various solids even without spin-orbit coupling, but did not receive much attention for a long time. A recent surge of interest in the orbital Hall effect is motivated by recently proposed methods [7,8] of its experimental detection. Here, we present a brief overview of recent developments in the orbital Hall effect, focusing on its detection [9] via the magneto-optical Kerr effect.

1. Electron orbital angular momentum in solids

According to Bohr's model of the hydrogen atom, an electron orbits the hydrogen nucleus and has orbital angular momentum. However, according to the Schrodinger equation, an electron wavefunction in solids, where atoms are regularly arranged, can differ significantly from that of an electron orbiting a single atom. In particular, in solids with both time-reversal symmetry and space-inversion symmetry, the energy eigenstates of electrons cannot have orbital angular momentum due to these symmetries. For this reason, it has long been assumed that electrons have no orbital angular momentum in solids with these symmetries.

A theoretical prediction [2] contradicting this common assumption was reported in 2005. It was predicted that electrons would acquire orbital angular momentum and flow perpendicular to the electric field when an electric field is applied to a hold-doped Si with the above two symmetries and a very weak spin-orbit coupling. The authors of Ref. [2] termed this phenomenon the orbital Hall effect. According to the papers by Japanese theoretical researchers published in 2008 [3] and 2009 [4], the orbital Hall effect occurs also in 4*d* and 5*d* transition metals. Contrary to the hole-doped Si, these metals have much stronger spin-orbit coupling, and it was also predicted [3,4] that the electron orbital angular momentum will be converted to the electron spin angular momentum, giving rise to the spin Hall effect. The orbital Hall effect was [5] theoretically predicted for other solids. In particular, the theoretical paper in 2018 predicted the orbital Hall effect to occur in many solid materials [6]. However, these theoretical predictions did not receive much attention initially, partly because it was unclear how to verify the orbital Hall effect experimentally and partly because the orbital Hall effect is inconsistent with the common assumption of the orbital quenching.

2. Experimental schemes to detect the orbital Hall effect

Experimental detection of orbital currents can proceed similarly to the experimental detection of spin currents. When a spin

current is injected into a ferromagnet, its magnetization direction changes. The torque that changes the magnetization direction due to the spin current injection is called spin torque. Therefore, the injected spin current can be estimated by measuring the spin torque.

According to the theoretical calculations [7,8], the magnetization direction of a ferromagnet should change even if an orbital current is injected into the ferromagnet instead of a spin current. The torque that changes the magnetization direction due to the orbital current injection is called orbital torque [7]. Then, one can estimate the injected orbital current by measuring the orbital torque. Based on this idea, several experiments have been performed [10-15], and orbital torques of significant magnitude have been reported.

However, in the case of the orbital torque, there are a few technical problems. The orbital current should transmit through the interface between an orbital-current-generating material and a ferromagnet to inject the orbital current into a ferromagnet. Unfortunately, the interface is often poorly characterized, and the orbital current transmission through the interface is poorly understood. For these reasons, the orbital current detection via the orbital torque measurement is indirect. A more direct detection scheme is needed, which does not involve an orbital current transmission through interfaces.

The most direct way to detect an orbital current without its transmission through interfaces is to perform an experiment analogous to the spin Hall effect detection without a spin current transmission through interfaces. To measure the spin Hall effect in GaAs, Kato et al. [16] probed the spin moment accumulated at the side surfaces of a GaAs sample using an optical method called the magneto-optical Kerr effect. When a linearly polarized light is reflected by a magnetized material, the linear polarization direction is tilted either clockwise or anticlockwise depending on whether the magnetic moment is pointing, say, up or down direction. This effect amounts to the magneto-optical Kerr effect and allows one to measure the magnetic moment at each point of the light reflection. Kato et al. used this method to map out the spatial profile of the spin magnetic moment generated by the spin Hall effect. They verified that the spin magnetic moments on the opposite side surfaces point in opposite directions, providing direct evidence of the spin Hall effect. In a similar way, to measure the orbital Hall effect that occurs in a specific material, one may probe the orbital magnetic moment at surfaces of the material generated by the orbital Hall current. This detection scheme does not involve any orbital current transmission through interfaces.

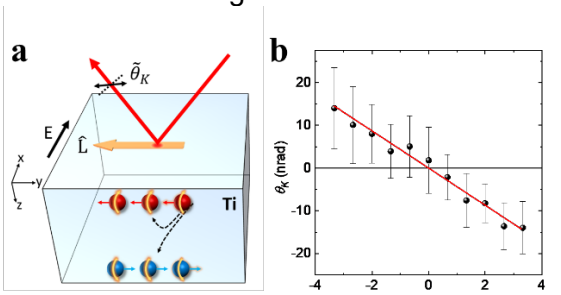
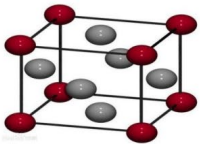
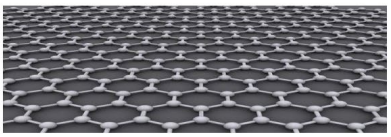


Fig. 1. (a) The magneto-optical Kerr effect arising from the orbital magnetic moment accumulated at the top and bottom surfaces of Ti thin film. (b) The Kerr rotation angle θ_K as a function of the current density j_c in a Ti film.

The joint research team of Sungkyunkwan University and Pohang University of Science and Technology in Korea performed this experiment on Ti and confirmed the orbital Hall effect in Ti through a detection scheme that does not involve any orbital-current transmission through interfaces [9]. Figure 1(a) shows the measurement scheme schematically, where a linearly polarized light (red line) is reflected from the center of the top surface of a Ti thin film. When an external electric field E is applied to the film, the orbital Hall effect is expected to generate the orbital magnetic moment accumulated near the top and bottom surfaces of the Ti film. Due to the magneto-optical Kerr effect, the linear polarization of the light is expected to change with the polarization angle change (or the Kerr angle) θ_K linearly proportional to the amount of the orbital magnetic moment. Figure 1(b) shows the Kerr rotation angle θ_K as a function of the current density j_c in a Ti





film. The linear proportionality between θ_K and j_c indicates that the measured θ_K is not a thermal artifact. Since the light penetrates into the film, the measured θ_K contains information on not only the orbital magnetic moment near the top surface but also the orbital magnetic moment near the bottom surface. To separate the two contributions to θ_K, the joint team then measured θ_K/j_c as a function of the Ti film thickness t_{Ti}. The dependence of θ_K/j_c on t_{Ti} allows one to extract the profile of the orbital magnetic moment along the film depth direction. This analysis verified that the orbital magnetic moment has opposite values at the top and bottom surfaces of the Ti film, confirming the orbital Hall effect.

3. Outlook

Recent theoretical [1-8] and experimental [9-15] reports indicate that an electron can carry in solids not only the spin angular momentum but also orbital angular momentum in diverse situations. This discovery is expected to advance our understanding of material properties. For example, in past studies on the spin-orbit coupling effect, the spin is regarded as a dynamic variable, whereas the orbital is often assumed to be a frozen environment rather than a dynamic degree of freedom. However, recent studies indicate that even if electron eigenstates do not have finite orbital angular momentum expectation values, the states will be deformed to carry a finite orbital angular momentum when an external electric field is applied. This implies that electron orbital angular momentum may play an important role in many nonequilibrium situations. Further studies are needed to uncover the full implication of the orbital angular momentum dynamics.

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Report 4:

Title: Bulk High-temperature Superconductivity Achieved in $La_2PrNi_2O_7$ under High Pressure

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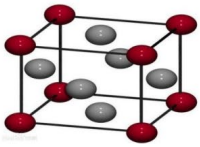
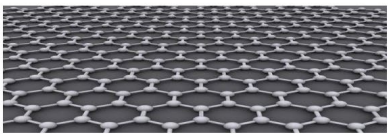
Abstract: By partially substituting La with smaller Pr in $La_3Ni_2O_{7-\delta}$, we successfully eliminate the competing Ruddlesden–Popper (R–P) phases and the inner apical oxygen vacancies in the bilayer nickelate $La_2PrNi_2O_7$. For the high-purity $La_2PrNi_2O_7$, bulk high-temperature superconductivity (HTSC) with appreciable superconducting shielding volume fraction f_{sc} was achieved in the high-pressure tetragonal phase. The observed optimal superconducting





transition temperatures T_c^{onset} = 82.5 K and T_c^{zero} = 60 K in $La_2PrNi_2O_7$ are the highest values among existing nickelate superconductors reported so far. These findings not only resolve the existing controversies but also provide directions for exploring bulk HTSC in the bilayer nickelates.

Introduction

Recently, signatures of high-temperature superconductivity (HTSC) with $T_c \approx$ 80K were discovered at pressures above 14 GPa in the crystals of $La_3Ni_2O_7$, which is the n = 2 member of the Ruddlesden-Popper (R-P) nickelates denoted as $La_{n+1}Ni_nO_{3n+1}$ (n = 1, 2, 3, …, ∞). This discovery has immediately attracted tremendous research interest as a new family of HTSC. However, subsequent studies revealed that the $La_3Ni_2O_7$ single crystals grown with optical-image floating-zone method under moderate oxygen pressure present some sample-quality issues such as the chemical inhomogeneity, oxygen vacancy, and the coexistence of minority monolayer (n = 1, 214) and trilayer (n = 3, 4310) R-P phases. These complications lead to significant sample-dependent behaviors of existing experiments and the absence of solid experimental evidence for bulk HTSC in the bilayer nickelate $La_3Ni_2O_7$. Thus, achieving bulk HTSC and identifying the exact phase at play are the most prominent tasks at present.

Stacking faults in $La_3Ni_2O_{7-\delta}$

In light of the challenges to obtain high-purity $La_3Ni_2O_7$ single crystals, we resorted to the polycrystalline samples of bilayer nickelates $La_{3-x}Pr_xNi_2O_{7-\delta}$, which can be prepared in a relatively large quantity with better controlled quality and reproducibility via wet-chemistry sol-gel method. Our recent study on $La_3Ni_2O_{7-\delta}$ polycrystalline samples shows that the (*h,k,0*) reflections in its neutron powder diffraction (NPD) pattern are resolution limited whereas those associated with *c*-axis display clear asymmetric Warren-like shapes, **Fig. 1a**, which are typically attributed to short-range orders or stacking faults along *c*-axis. To verify this, we performed high-angle annular dark-field (HAADF) scanning transmission electron microscopy (STEM) on the $La_3Ni_2O_{7-\delta}$ samples. Although the bilayer structure dominates in most images, we observe ubiquitous intergrowth of 327 with 4310 and 214 phases, **Fig. 1b.** To quantify the amount of stacking faults associated with the intergrowths, we resorted to nuclear quadrupole resonance (NQR) as a sensitive global probe to investigate local structure disorders of bulk samples. The NQR spectra demonstrated that the $La_3Ni_2O_{7-\delta}$ polycrystalline samples contain a considerable amount of 327/4310 and 327/214 interfaces, **the upper panel of Fig. 1c**.

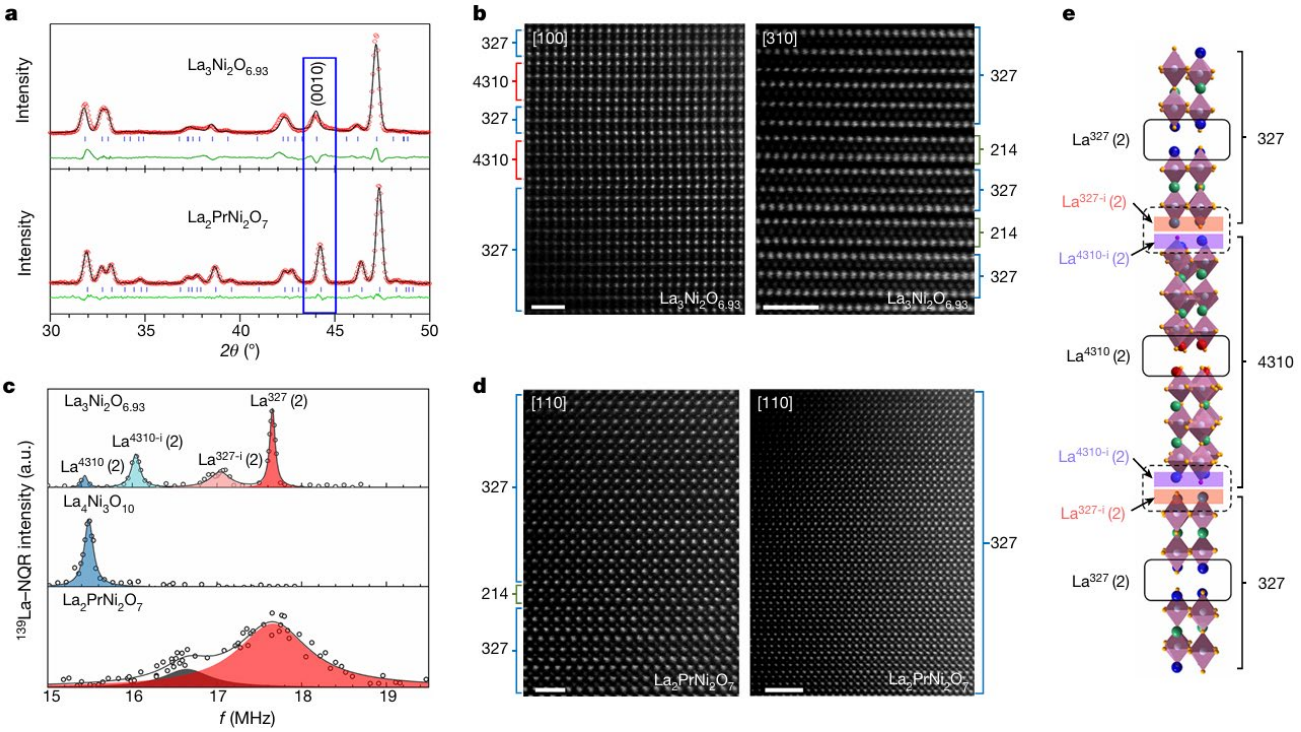


Fig.1 Characterizations on the micro-structures of $La_{3-x}Pr_xNi_2O_{7-\delta}$ (x = 0, 1) samples. (a) Rietveld refinements of the NPD patterns in the 2θ range between 30° and 50°, highlighting the distinct features of the (0 0 10) reflection. HAADF-STEM images illustrating the stacking of layers along *c*-axis for $La_3Ni_2O_{7-\delta}$ (b) and $La_2PrNi_2O_7$ (d) samples. (c) ^{139}La(2) NQR spectra around the frequency $3\nu_Q$ in $La_3Ni_2O_{7-\delta}$, $La_4Ni_3O_{10}$, and $La_2PrNi_2O_7$ samples at 188 K. (e) A schematic drawing of the structure illustrating different La^{4310}(2), La^{4310i}(2), La^{327i}(2), and La^{327}(2) sites with triple-layer-NiO_2 intercalated in normal double-layer NiO_2 plane.

$La_2PrNi_2O_{7-\delta}$ with improved phase purity

In contrast to $La_3Ni_2O_{7-\delta}$, the asymmetric Warren-like feature of (0 0 10) peak in the NPD pattern is hardly discernable for $La_2PrNi_2O_{7-\delta}$, the lower panel of **Fig. 1a**, signaling an obvious improvement of sample's quality. In accordance with the NPD results, the STEM images of La2PrNi2O7 show that the 327/4310 intergrowth can hardly be observed, and the 327/214 intergrowth is significantly reduced, **Fig. 1d**. The absence of 4310 phase was further verified by the NQR measurements. As shown in the lower panel of **Fig. 1c**, the resonance peaks for La^{4310}(2) and La^{4310i}(2) are absent, while a broad peak is observed at the La^{327}(2) position. The combined STEM and NQR results together with the NPD refinements unambiguously verified the improved phase purity with negligible oxygen vacancies in the $La_2PrNi_2O_7$ samples. The availability of nearly 327-phase-pure $La_2PrNi_2O_7$ samples provides an excellent opportunity to clarify the roles of the 327/4310 interfaces for pressure-induced HTSC.

Pressure-induced structural transition

For $La_3Ni_2O_{7-\delta}$, the emergence of HTSC is concomitant with the orthorhombic *Amam* to *Fmmm* structure transition under high pressure. A recent high-pressure study reveals that the sample adopts a tetragonal *I4/mmm* structure in the superconducting phase at low temperatures. It is interesting to examine

whether structural transition appears in $La_2PrNi_2O_7$ under high pressure. **Figure 2a** presents the synchrotron XRD (SXRD) patterns collected at room temperature under various pressures from 3.2 to 56 GPa. As can be seen from **Fig. 2b**, upon compression to 11.1 GPa, several adjacent peaks are merged, such as the (0 2 0) and (2 0 0) peaks at ~13.4°, (1 3 5) and (3 1 5) peaks at ~23.1°. This observation suggests pressure-induced structural transition towards a higher symmetry. Subsequent analyses revealed that the high-pressure phase can be better described using the $Sr_3Ti_2O_7$-type structural model with tetragonal *I4/mmm* space group **(Fig. 2d)**. Such an orthorhombic-*Amam* to tetragonal-*I4/mmm* structural transition is distinct from that observed in $La_3Ni_2O_7$ crystals whose high-pressure phase adopts the orthorhombic *Fmmm* symmetry at room temperature.

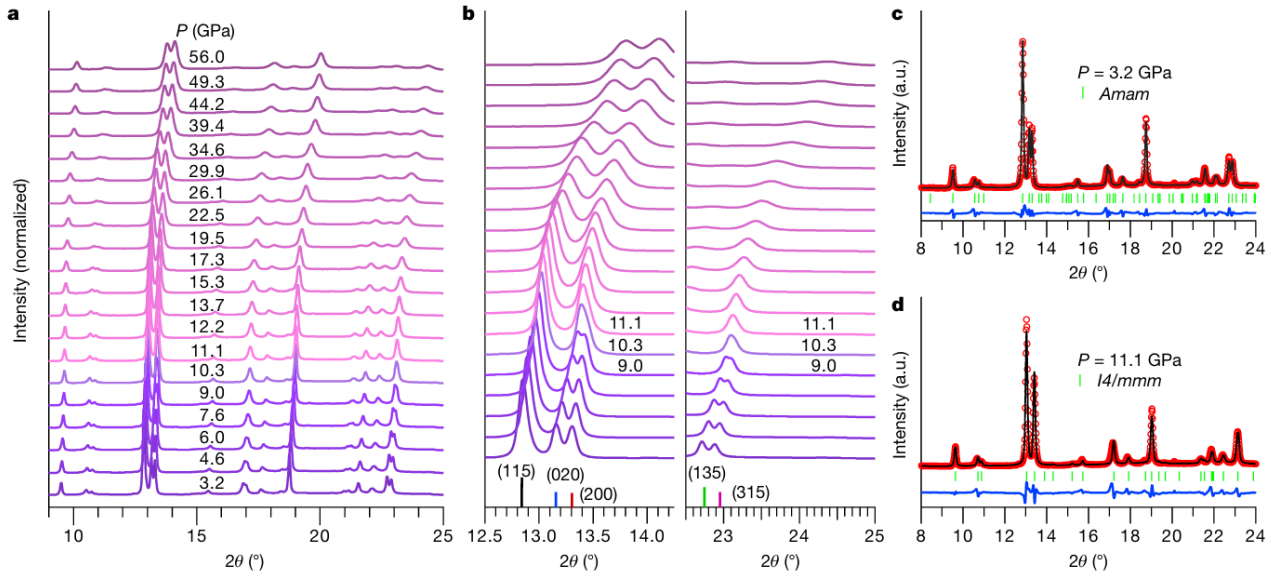


Fig.2 Pressure-induced structural transition in $La_2PrNi_2O_7$. (a, b) SXRD patterns of $La_2PrNi_2O_7$ powder samples under high pressure. (c, d) Refinement results of the SXRD patterns at 3.2 GPa using the space group *Amam* and at 11.1 GPa using the space group *I4/mmm*.

Evidence of bulk HTSC

To explore HTSC in the high-pressure tetragonal phase of $La_2PrNi_2O_7$, we measured the resistivity and ac magnetic susceptibility across multiple samples under various hydrostatic pressures up to 19-20 GPa. **Fig. 3a, b** present the typical $\rho(T)$ data of $La_2PrNi_2O_7$ under high pressure. Notably, $La_2PrNi_2O_7$ achieves a record-high $T_c^{zero} \approx 60$ K among known nickelate superconductors, which surpasses that of $La_3Ni_2O_{7-\delta}$ at similar pressures by approximately 20 K. This enhancement in superconducting performance demonstrate that the absence of 327/4310 interfaces are beneficial for achieving superior superconducting properties. This is further supported by the observations of clear diamagnetic signals in

Fig. 3c, which displays the $\chi'(T)$ of $La_2PrNi_2O_7$ sample together with a piece of FeSe single crystal as reference. Since FeSe undergoes a structural transition at ~10 GPa into a non-superconducting hexagonal phase, the observed diamagnetic signals in $\chi'(T)$ above 15 GPa are attributed exclusively to $La_2PrNi_2O_7$. The superconducting shielding volume fraction, f_{sc}, of $La_2PrNi_2O_7$ can be estimated by considering their volume ratio (~1:1.15) and comparing its diamagnetic response to that of FeSe at 9 GPa. The f_{sc} of $La_2PrNi_2O_7$ at 8 K is estimated to increase rapidly from ~5.3(5)% at 15 GPa to ~97(10)% at 19 GPa, unambiguously testified to a bulk nature of observed HTSC. These results provided the key evidence of bulk HTSC, including the zero resistance with high T_c^{onset} = 82.5K and T_c^{zero} = 60K and the clear diamagnetic response with a superconducting shielding volume fraction of 97%.

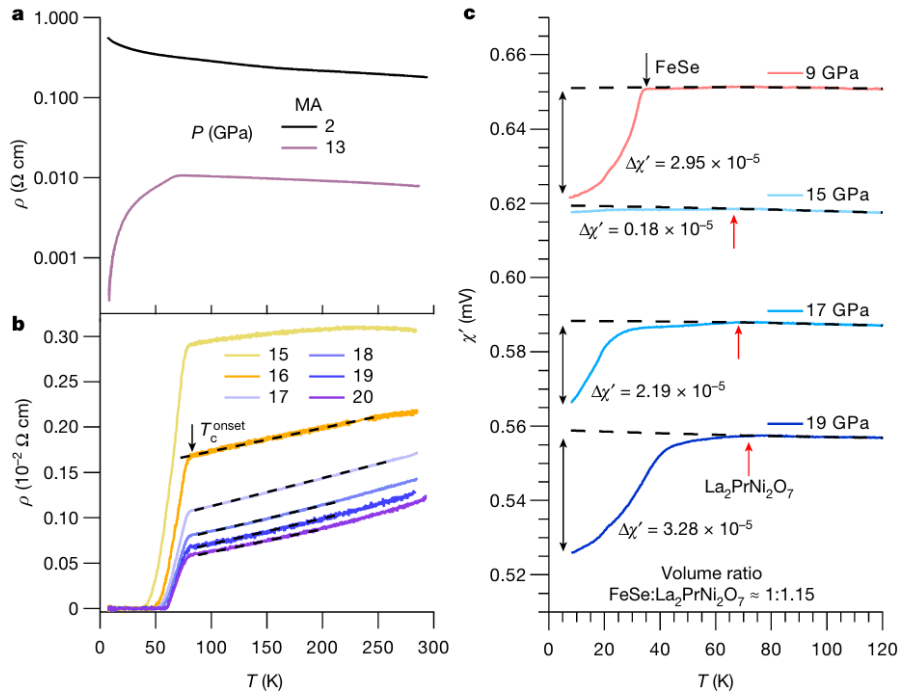


Fig.3 Pressure-induced HTSC in $La_2PrNi_2O_7$. (a, b) $\rho(T)$ of $La_2PrNi_2O_7$ samples under various hydrostatic pressures up to 20 GPa measured in multianvil (MA) apparatus. (c) $\chi'(T)$ of $La_2PrNi_2O_7$ samples under various pressures up to 19 GPa measured with MA.

T-P phase diagram

Figure 4 presents the *T-P* phase diagram of $La_2PrNi_2O_7$, depicting explicitly the emergence of HTSC in concomitant with the structural transition, similar to $La_3Ni_2O_{7-\delta}$. Notably, bulk HTSC occurs at pressures higher than $P_c \approx 11$ GPa for structural transition, with f_{sc}(8 K) increasing rapidly from ~5.3(5)% at 15 GPa to ~97(10)% at 19 GPa. These results indicate that the structural transition is a prerequisite to trigger superconductivity in the bilayer nickelates, while bulk HTSC requires higher pressure to further enhance the interlayer coupling between $3d_{z2}$ orbitals and to optimize the contribution of Ni-$3d_{z2}$ derived γ band near the Fermi level. The constructed *T-P* phase diagram also reveals a close relationship between strange-metal-like behavior and HTSC in the $La_2PrNi_2O_7$

samples.

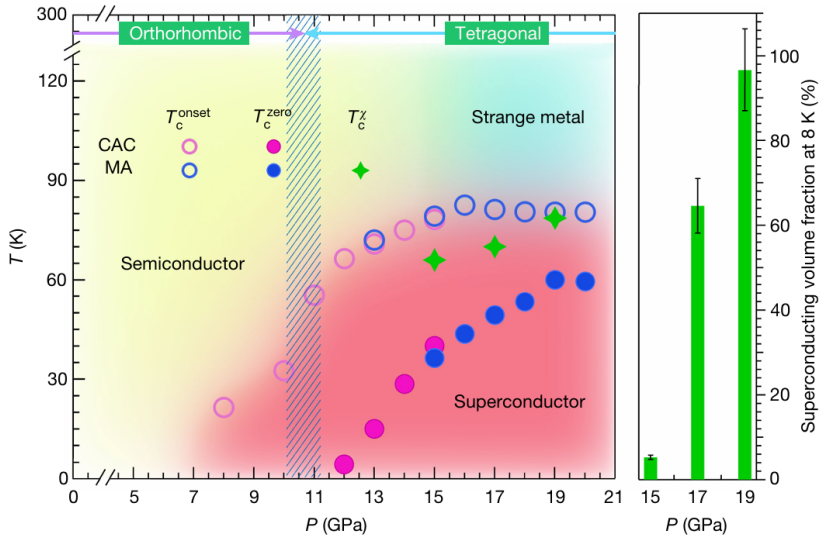


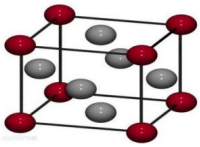
Fig.4 The *T-P* phase diagram of $La_2PrNi_2O_7$.

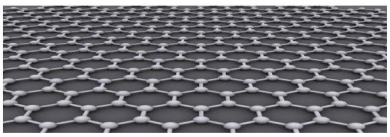
Conclusion

Our results provide critical experimental evidence for bulk HTSC in the pressurized $La_2PrNi_2O_7$, confirming the bilayer R-P phase as the source of HTSC and revealing the intergrowths of 327/4310 and 327/214 phases as detrimental factors for bulk HTSC in $La_3Ni_2O_{7-\delta}$. This work not only resolves the existing controversies but also highlights pathways for further exploration of bulk HTSC in bilayer nickelates, providing valuable guidance for the optimization and synthesis of nickel-based high-temperature superconductors.

Reference

[1] "Bulk high-temperature superconductivity in pressurized tetragonal $La_2PrNi_2O_7$", Ningning Wang, Gang Wang, Xiaoling Shen, Jun Hou, Jun Luo, Xiaoping Ma, Huaixin Yang, Lifen Shi, Jie Dou, Jie Feng, Jie Yang, Yunqing Shi, Zhian Ren, Hanming Ma, Pengtao Yang, Ziyi Liu, Yue Liu, Hua Zhang, Xiaoli Dong, Yuxin Wang, Kun Jiang, Jiangping Hu, Shoko Nagasaki, Kentaro Kitagawa, Stuart Calder, Jiaqiang Yan, Jianping Sun, Bosen Wang, Rui Zhou, Yoshiya Uwatoko & Jinguang Cheng, *Nature* **634**, 579–584 (2024).





Recent Academic Exchanges and Activities in the Asian Pacific Areas

Report 1: SECUF-2024

The 3rd Conference on Physics under Synergetic Extreme Conditions and the accompanied Summer School of SECUF, together briefed as SECUF-2024, was successfully held in Beijing, China from July 19th to July 22nd. The detailed information is given at

(http://secuf2024.cpsjournals.cn/detail.php?m=174&id=1745&t=3349).

The SECUF series of annual conferences and summer schools was first launched in 2022, for promoting academic exchange and collaboration on cutting-edge research in condensed matter physics and material science under synergetic extreme conditions. It is based on a newly accomplished user facility - Synergetic Extreme Condition User Facility (SECUF) which is located in Huairou, Beijing and is now opening to academic and industrial users in China and world-wide. Previously, SECUF-2022 (online) and SECUF-2023 (onsite) were successfully organized, with the participation of hundreds of invited speakers and a large audience.

The conference consists of two parts. The first part is a Summer School, which delivers tutorial lectures on fundamental knowledge of researches under extreme physical conditions, together with the introduction of the experimental conditions available in SECUF. The second part is a Conference containing one plenary session and five parallel sessions, for exchanging newest research progresses under extreme physical conditions.

Plenary Session: The conference on physics under synergetic extreme conditions.

Session 1: Emergent quantum materials and phenomena under high pressure extreme conditions.

Session 2: Physical properties under synergetic extreme conditions.

Session 3: Quantum transport in low dimensional materials and quantum devices at ultralow temperatures.

Session 4: Ultrafast physics and technology.

Session 5: High-pressure and high-temperature large-volume press techniques and applications.

The SECUF-2024 not only provides an important opportunity for scientific researchers to present their work, but also offer an excellent stage for scientific enterprises from various fields to promote their latest scientific research equipment.

Group Photo of SECUF-2024

Report 2: The Conference of Condensed Matter Physics (CCMP) 2024

On August 5th, 2024, the Conference of Condensed Matter Physics 2024 (CCMP2024) (http://ccmp2024.ioply.cn/) commenced in Liyang City, Jiangsu Province. This significant event has drawn extensive attention from the academic community.

The Conference of Condensed Matter Physics (CCMP) evolved from the annual conference series "International Conference on Condensed Matter Theory and Computational Materials," which began in 2002. In 2015, the Organizing Committee decided to expand the conference's scope and scale to reflect the latest developments in condensed matter physics by adding new

sessions that cover a broader range of topics. Consequently, the conference was renamed the Conference of Condensed Matter Physics (CCMP). The conference aims to provide a platform for cooperation and exchanges in interdisciplinary research in the field of condensed matter physics, and continuously promote international academic exchanges in China.

This year, more than 800 high-level experts, young and middle-aged leading talents from both at home and abroad were invited to the CCMP2024. They gathered together to jointly discuss the latest developments in the field and promote relevant international cooperation and exchanges. During the conference, experts and scholars actively engaged in in-depth discussions, sharing their latest research findings and insights.

The conference includes plenary session: new frontiers in condensed matter physics, session 1: Superconductivity and magnetism, session 2: computational and material physics, session 3: non-equilibrium and statistical physics and session 4: low-dimensional systems and topological physics.

The successful holding of the CCMP2024 will surely promote the further development of condensed matter physics and have a positive impact on related fields. The conference will be routinely organized every year, mostly during summer. It is expected that more breakthroughs and innovations will emerge in this field in the future.

Report 3: The 2nd China National Conference on Vortex Matter in Superconductors

The 2nd National Conference on Vortex Matter in Superconductors was successfully held from August 2nd to 6th in Weihai city, China. The conference was initiated by Professor Hai-Hu Wen from Nanjing University and Professor Zhixiang Shi from Southeast University and was hosted by Southeast University. The conference was

attended by more than 80 experts, scholars, and students, with 31 significant talks which were divided into four thematic sessions, namely:(i) Vortex dynamics and vortex phase diagram; (ii) Vortex image and vortex structure; (iii) Vortex pinning and related applications;(iv) Superconductivity mechanism related to vortex physics.

The conference aims to promote the development of the research of superconducting vortex physics, while addressing the recent hot research topics in the field of superconductivity, facilitating academic exchanges, and fostering the growth of young talents.

The relaxed atmosphere of the conference allowed participants to engage in extensive discussions on topics such as vortex structure and lattice observations, vortex phase transitions, vortex dynamics and transport, vortex pinning and the critical current density, superconductivity mechanism related to vortex physics, and superconducting electronics. As a result, three young researchers were awarded for their contributions.

The organizing committee provided a convenient platform for communication, with the hope that the conference would encourage further collaboration and research in the field of vortex matter in superconductors.

Group Photo of the 2nd China National Conference on Vortex Matter in Superconductors