The Physical Society of Japan Announces the Recipients of the 25th Outstanding Paper Award

In recognition of important achievements toward progress in physics, the Physical Society of Japan (JPS) annually selects outstanding papers from among original research articles published in the *Journal of the Physical Society of Japan, Progress of Theoretical Physics, Progress of Theoretical and Experimental Physics*, and *JPS Conference Proceedings*. The selection committee has chosen five papers for the 2020 award based on 18 nominations (for 18 papers) made by the editors of the JPS journals and representatives of the 19 divisions of the JPS.

The titles of the five selected papers, together with their citations, follow below.

Spin Chirality Ordering and Anomalous Hall Effect in the Ferromagnetic Kondo Lattice Model on a Triangular Lattice
J. Phys. Soc. Jpn. 79, 083711 (2010)
Authors: Yutaka Akagi and Yukitoshi Motome

The article addresses the question of ground-state properties of the Kondo lattice model on a triangular lattice, which is one of the lattice structures with geometrical frustration. An exciting possibility is that triads of spins on a triangle have an order of noncoplanar spin configuration, which results in scalar chirality. In the presence of scalar chirality, time-reversal symmetry and space inversion are broken. When itinerant electrons are coupled with a spin system with scalar chirality, the anomalous Hall effect is expected. The Hall coefficient of the ordered state is investigated based on the Kubo formula.

The Kondo lattice model on a triangular lattice was first investigated by I. Martin and C. D. Batista (Phys. Rev. Lett. 101, 156402 (2008)), wherein the ground state with scalar chirality was found at a filling of 3/4th of the conduction electrons along with the anomalous Hall effect. In the present paper, the authors investigated the ground states systematically up to unit cells with four sites for the whole range of filling of conduction electrons. As a consequence, a new stable ground state with scalar chirality was found at one quarter filling. The anomalous Hall effect was also confirmed at this filling. Thus, the systematic exploration for the states with scalar chirality was completed in the papers of Martin and Batista and the present authors. For these reasons, we conclude that the present paper deserves the Outstanding Paper Award of the Physical Society of Japan.

Extremely Large and Anisotropic Upper Critical Field and the Ferromagnetic Instability in UCoGe
J. Phys. Soc. Jpn. 78, 113709 (2009)
Authors: Dai Aoki, Tatsuma D. Matsuda, Valentin Taufour, Elena Hassinger, Georg Knebel, and Jacques Flouquet

Among the types of unconventional superconductivities, U-based superconductivities that coexist with ferromagnetism have attracted much attention as strong candidates for spin-triplet superconductors. The superconductivity of UGe_2, UIr, UCoGe, and URhGe, along with UTe_2 that was discovered last year, is assisted by the ferromagnetic phase. This link is regarded as strong evidence for non-unitary spin-triplet superconductivity, where a ferromagnetic fluctuation mediates the pairing. Experimental validation for the spin-triplet Cooper-pair

state is difficult in general, while the linkage between ferromagnetism and superconductivity in U-based materials occupies a significant position in this research area.

The authors of this paper conducted very carefully planned experiments under external magnetic fields on UCoGe single crystals and first pointed out that superconductivity in UCoGe is stabilized especially when the external field is very precisely applied along the b axis. An "S-shaped curve" is observed in the superconducting H-T phase diagram, featuring re-entrant behavior similar to that discovered in URhGe under high pressures. The authors further showed that Tc and the quasiparticle state are susceptible to the field orientation. Their findings made a significant impact on later studies for U-based superconductivity, for example, discoveries of a linkage between anisotropic ferromagnetic fluctuations and superconductivity in UCoGe, and re-entrant superconductivity in UTe_2. For these reasons, we conclude that this paper deserves the Outstanding Paper Award of the Physical Society of Japan.

Anisotropic Magnetoresistance Effects in Fe, Co, Ni, Fe_4N, and Half-Metallic Ferromagnet: A Systematic Analysis
J. Phys. Soc. Jpn. 81, 024705 (2012)
Authors: Satoshi Kokado, Masakiyo Tsunoda, Kikuo Harigaya, and Akimasa Sakuma

The anisotropic magnetoresistance (AMR) effect has been studied for the longest time among a number of magnetoresistance effects, and it has recently been actively studied as a fundamental phenomenon in the field of spintronics. In this paper, the authors theoretically studied the AMR effect that depends on the s-d scattering process from the conduction band to the localized d state in ferromagnetic transition metal materials. The s-d scattering process, for which only some of the contributions were considered in previous work, was fully incorporated in this paper, and the most general formula for the AMR ratio was derived. According to this paper, the AMR ratio is proportional to the product of the difference between the localized d-electron up and down spin density of states, and the difference between conduction s-electron up and down spin electrical conductivities at the Fermi level due to spin-orbit and exchange interactions. As a result, the relationship between the sign of the AMR ratio and the primary s-d scattering process that contributes to the AMR effect was clarified. A very practical theoretical formula has been obtained that applies to a wide range of magnetic materials, with properties such as strong ferromagnetism, weak ferromagnetism, and half metal. The most critical example is that screening in an experimental search for half metals has become possible because half metals have a negative AMR ratio. There are also many papers that can be used as starting points for subsequent theoretical studies, such as first-principle calculations. Considering the above points, this paper was recognized to have made an essential contribution to the physical understanding of electrical conductivity in ferromagnetic materials through theoretical research based on original ideas and, hence, deserves the Outstanding Paper Award of the Physical Society of Japan.

First-Principles Study of Magnetocrystalline Anisotropy and Magnetization in $NdFe_{12}$, $NdFe_{11}Ti$, and $NdFe_{11}TiN$
J. Phys. Soc. Jpn. 83, 043702 (2014)
Authors: Takashi Miyake, Kiyoyuki Terakura, Yosuke Harashima, Hiori Kino, and Shoji Ishibashi

The lack of heavy rare-earth elements doping in permanent magnets is a serious problem since the demand for permanent magnets utilized in, for instance, motors for electric vehicles increases every year. As a result, the authors theoretically studied the magnetic properties of ferromagnetic materials, including $NdFe_{12}$, to obtain guidelines for designing high-performance permanent magnets. They evaluated the crystal-field parameters at each Nd site by using first-principles calculations for estimating the magnetic anisotropy based on crystal-field theory. As a result, the authors found that the interstitial N atoms induce strong uniaxial magnetic anisotropy in $NdFe_{12}N$ and $NdFe_{11}TiN$. They also found that the hybridization between $2p$ orbitals of the interstitial N atoms and $3d$ orbitals in Fe atoms plays an important role in the enhancement of magnetization in these materials. Inspired by the theoretical results of this article, $NdFe_{12}N_x$ thin films, which show higher magnetic performances than $NdFe_{14}B$, have been successfully synthesized.

In conclusion, this article theoretically suggested a promising candidate for high-performance permanent magnets and significantly contributed to the researchers involved in the development of permanent magnets. For these reasons, we conclude that this article deserves the Outstanding Paper Award of the Physical Society of Japan.

Can we explain AMS-02 antiproton and positron excesses simultaneously by nearby supernovae without pulsars or dark matter?
Prog. Theor. Exp. Phys. 2016, 021E01 (2016)
Authors: Kazunori Kohri, Kunihito Ioka, Yutaka Fujita, and Ryo Yamazaki

In recent observations of cosmic rays, it has been reported that the anti-particle to particle ratio does not agree with that of the theoretical predictions. That is, clear excesses have been discovered in the fluxes of cosmic-ray positrons and antiprotons, compared to the predictions of standard astrophysical models. In addition to the many theoretical models that have been proposed to explain these excesses by groups in both the astrophysics and particle physics communities, the authors of this paper proposed a new theory of nearby old supernova remnants (SNRs), in which high-energy protons were accelerated to be the source for productions of both the observed positrons and antiprotons. They assumed that the SNRs were born approximately a hundred thousand years ago in molecular clouds located at around one hundred parsec from the solar system. The high-energy protons can scatter off background protons hadronically in the molecular clouds, producing both positrons and antiproton through a hadronic shower process involving scatterings and decays.

Near the solar system, we observe astronomically diffuse objects, which could be interpreted to be a mark of such old SNRs, and the authors also proposed a method to test their theory by observing anisotropy in direction for their propagation from sources in the future. It is impressive that their theoretical prediction of a possible antiproton excess reported in their earlier paper in 2009 agrees with the value observed in 2015 by the experiment module AMS-02 mounted on the International Space Station. This paper added additional physical interpretation of the observational data and theoretical discussion, making the entire work enormously influential in astrophysics and related fields, including particle physics. For these reasons, we conclude that this paper deserves the Outstanding Paper Award of the Physical Society of Japan.