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Editorial

New Spin on Metal-Insulator Transitions

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Metal-insulator transitions (MITs) constitute a core subject of fundamental condensed-matter research. The localization of conduction electrons has been observed in a large variety of materials and gives rise to intriguing quantum phenomena such as unconventional superconductivity and exotic magnetism. Nearby an MIT, minuscule changes of interaction strength via chemical substitution, doping, physical pressure or even disorder can trigger spectacular resistivity changes from zero in a superconductor to infinity in an insulator near T = 0. While approaching an insulating state from the conducting side, deviations from Fermi-liquid transport in bad and strange metals are the rule rather than the exception, discussed in terms of spatial inhomogeneity and quantum criticality. Moreover, charge localization upon MITs has a crucial impact on the magnetic degrees of freedom that are studied for the possible realization of a quantum spin liquid.

Solving the challenges of correlated electron systems and the emergent phenomena around MITs has attracted much interest. As the drosophila of electron–electron interactions, the Mott MIT receives particular attention as it can be studied using the Hubbard model. On the experimental side, the topic has been recently promoted by the advent of twisted Moiré bilayer systems; however, true bulk materials, such as organic charge-transfer salts, fullerides and transition-metal oxides, remain indispensable for elucidating macroscopic quantum phases such as unconventional superconductivity and frustrated magnetism. Various novel methods have become available lately to tune and map the complex evolution of the metallic and insulating phases at cryogenic temperatures, including uniaxial strain and imaging techniques such as near-field microscopy. The controlled variation of disorder has also been utilized to study Griffiths phases and Anderson-type MITs.

Investigating MITs requires minute control of the relevant tuning parameters, such as the electronic bandwidth and band filling. While doping is the preferential tool in oxides, such as superconducting nickelates that are impacted by topotactic hydrogen [1], pressure tuning is the method of choice for organic charge-transfer salts. Kawasugi et al. achieved simultaneous control of band filling and bandwidth via in situ strain and gate tuning on κ-(BEDT-TTF)$_2X$ crystals [2]. Another powerful tuning method is partial chemical substitution, as applied in κ-type systems [3] and quasi one-dimensional (TMTTF)$_2X$ [4]. In the latter case, the Fabre salts with quarter-filled bands exhibit textbook-like charge-ordered states driven by inter-site Coulomb interactions, which also give rise to unconventional superconductivity in β''-(BEDT-TTF)$_2X$, as reviewed by Ihara and Imajo [5]. Such layered organic superconductors are well suited to study the Fulde–Ferrell–Larkin–Ovchinnikov (FFLO) state [6,7]. On the theoretical side, Riedl and coworkers review generalized models of κ-systems [8], while Tan et al. assessed universal aspects of Mott criticality [9]. Disorder and Anderson localization are studied using cluster methods [10,11] and experiments on BEDO-TTF crystals [12]. A useful tool to systematically investigate and compare all these phenomena is the database for crystalline organic conductors and superconductors provided by Ganter et al. [13]. The interplay of charge and spin degrees of freedom, prominently seen in manganites [14], is considered important in dimerized organic Mott systems, where dielectric anomalies have been controversially discussed [15]. In geometrically frustrated systems, the charge order can transform into a charge glass [16] and magnetic order can transform into a quantum spin liquid. Regarding the latter scenario, R. Kato et al. discuss discrepancies of thermal transport measurements on β'-EtMe$_3$Sb[Pd(dmit)$_2$]$_2$ [17].

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Taupin and Paschen inspect the controversies of condensed-matter research, namely the topic of whether heavy Fermion systems exhibit 'Planckian dissipation' [18].

This Special Issue provides a glimpse into the latest progress in answering the existing questions around MITs, including various topics of solid-state physics.

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