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Magnetic neutron scattering studies on the Fe-based superconductor system $Fe_{1+y}Te_{1-x}Se_x$

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ABSTRACT

I present a brief overview on the interplay between magnetism and superconductivity in one of the Fe-based superconductor systems, $Fe_{1+y}Te_{1-x}Se_x$, where the research of our group has centered. The parent compound $Fe_{1+y}Te$ is an antiferromagnet; with Se doping, antiferromagnetic order is suppressed, followed by the appearance of superconductivity; optimal superconductivity is achieved when $x \sim 50\%$, with a superconducting temperature T_c of ~15 K. The parent compound has an in-plane magnetic ordering wave vector around (0.5, 0) (using the tetragonal notation with two Fe atoms per cell). When Se concentration increases, the spectral weight appears to be shifted to the wave vector around (0.5, 0.5), accompanying the optimization of superconductivity. A neutron-spin resonance has been observed around (0.5, 0.5) below T_c, and is suppressed, along with superconductivity, by an external magnetic field. Taking these evidences into account, it is concluded that magnetism and superconductivity in this system couple to each other closely—while the static magnetic order around (0.5, 0) competes with superconductivity, the spin excitations around (0.5, 0.5) may be an important ingredient for it. I will also discuss the nature of magnetism and substitution effects of 3*d* transition metals.

1. Introduction

1.1. A brief overview

The quest for an alternative superconducting mechanism was soon initiated after the discovery of high-temperature superconductivity in the lamellar copper-oxide materials [1–3], which posed a

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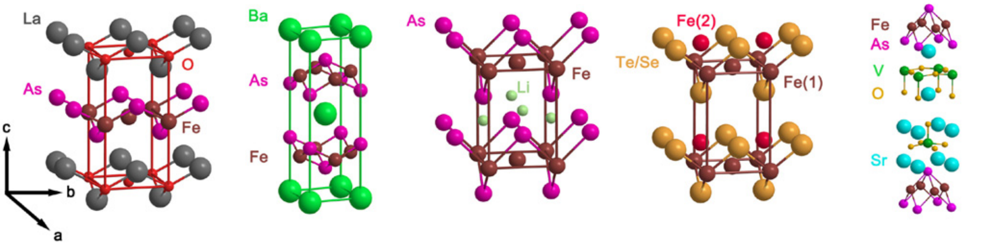

Fig. 1. Schematic crystal structures for the 1111, 122, 111, 11, and 21 311 type Fe-based superconductors.

great challenge to BCS theory [4], the many-body theory developed by Bardeen, Cooper, and Schrieffer that successfully explained conventional superconductivity [4]. The key concept is that electrons form pairs aided by the electron–phonon interactions, and the pairs condense at the superconducting temperature T_c. In the cuprate superconductors, electron–phonon coupling is not sufficient to induce superconductivity with such high T_cs [5,6]. In these materials, superconductivity develops from electronically doping a Mott insulator, and is in close proximity to the antiferromagnetic phase [5–9]. Thus, it is very promising that one may eventually work out the high-T_c mechanism by studying the interplay between magnetism and superconductivity.

Research on this subject gained substantial momentum in 2008 with the discovery of superconductivity in compounds that contain Fe instead of Cu (termed "Fe-based superconductors") [10,11]. The field was initially excited by the discovery of superconductivity in $LaFeAsO_{1-x}F_x$ (labeled 1111 based on the elemental ratios in the chemical formula of the parent material) with $T_c = 26$ K by Hosono's group [11], following the group's earlier report of superconductivity in $LaFePO_{1-x}F_x$ with $T_c \sim 5$ K [10]. Soon after the initial discovery, the scientific community witnessed a burst of new Fe-based superconductors. So far, besides the 1111 system, other five major families of Fe-based superconductors have been discovered, typified by $BaFe_2As_2$ (122) [12–15], LiFeAs (111) [16–22], $Fe_{1+y}Te_{1-x}Se_x$ (11) [23–27], Sr_2VO_3FeAs (21311) [28,29], and $A_xFe_{2-y}Se_2$ (A = alkaline elements) [30–34]. The crystal structures for the five families are shown in Fig. 1 (The $A_xFe_{2-y}Se_2$ compounds are isostructural to the 122) [10,20,35–38]. They are all tetragonal at room temperature, and have layered structures. The current record of T_c in the bulk materials is 56 K in $Gd_{1-x}Th_xFeAsO$ [39,40]. This makes the Fe-based superconductors second only to cuprates in T_c, and for this reason they are often considered as another class of high-temperature superconductors. Comparing the differences and similarities between the two classes may help find the common ground underlying the high T_c in these superconductors.

The distinct properties of the parent compound set the Fe-based superconductors apart from the copper oxides. The undoped cuprates are Mott insulators, which are predicted by band theory to be metallic but turn out to be insulating because the otherwise itinerant electrons are localized due to the large Coulomb repulsion [5,6]. In the Fe-based superconductors, their parent compounds are metallic [41]. This naturally leads to a different starting point, and a weak-coupling theory is often more favorable [42,43]. Furthermore, unlike cuprates where only a single Cu 3d band is involved, four or five Fe 3d orbitals are involved in the multiple bands that cross the Fermi level [43]. This in some cases can complicate the interpretations [44]. Despite the differences, these two classes of high-temperature superconductors share surprisingly similar phase diagrams [45]. With very few exceptions in the Fe-based superconductors, the parent compounds exhibit long-range antiferromagnetic order, which is suppressed with doping, and superconductivity appears above a certain doping level [36–38,46–64], resembling the phase diagrams of the cuprate superconductors [5–9]. Such a similarity immediately leads to the speculation that the pairing mechanism may be the same, with magnetic excitations replacing phonons in the electron pairing interactions [41–43,65–68]. However, because of the multiband nature of the superconductivity, orbital excitations have also been proposed as possible contributors to the pairing mechanism [44,69,70]. Although a consensus on the high-T_c mechanism has not been reached so far, it is generally believed that studying the magnetic correlations has and will continue to yield important results that are critical in understanding the high-T_c superconductivity.