

## Magnetic properties of the covalent chain antiferromagnet RbFeSe<sub>2</sub>

Z. Seidov,<sup>1,2</sup> H.-A. Krug von Nidda,<sup>1,\*</sup> V. Tsurkan,<sup>1,3</sup> I. G. Filippova,<sup>3</sup> A. Günther,<sup>1</sup> T. P. Gavrilova,<sup>4</sup> F. G. Vagizov,<sup>5</sup>  
A. G. Kiiamov,<sup>5</sup> L. R. Tagirov,<sup>4,5</sup> and A. Loidl<sup>1</sup>

<sup>1</sup>*Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, 86135 Augsburg, Germany*

<sup>2</sup>*Institute of Physics, Azerbaijan National Academy of Sciences, AZ-1143 Baku, Azerbaijan*

<sup>3</sup>*Institute of Applied Physics, Academy of Sciences of Moldova, MD-20208 Chisinau, Moldova*

<sup>4</sup>*E. K. Zavoisky Physical-Technical Institute, Russian Academy of Sciences, 420029 Kazan, Russia*

<sup>5</sup>*Institute of Physics, Kazan Federal University, 420008 Kazan, Russia*

(Received 30 May 2016; revised manuscript received 1 September 2016; published 13 October 2016)

Single crystals of the ternary iron selenide RbFeSe<sub>2</sub> have been investigated by means of x-ray diffraction, magnetic susceptibility, magnetization, and specific-heat measurements as well as by Mössbauer spectroscopy. Built up from linear chains of edge-sharing FeSe<sub>4</sub> tetrahedra, RbFeSe<sub>2</sub> represents a quasi-one-dimensional antiferromagnet. Below  $T_N = 248$  K three-dimensional antiferromagnetic collinear magnetic order sets in, with the magnetic moments oriented perpendicularly to the chain direction. The hyperfine fields determined from our Mössbauer studies reveal strongly reduced magnetic moments. The high-temperature susceptibility data of RbFeSe<sub>2</sub> suggest a one-dimensional metallic character along the chains.

DOI: 10.1103/PhysRevB.94.134414

### I. INTRODUCTION

The recent discovery of iron-based superconductors [1–4] has stimulated high interest and enormous scientific activities in the field of iron-pnictide and -chalcogenide materials. Notably, all iron-based superconductors exhibit some structural similarity. From the initially discovered LaFeAsO<sub>1-x</sub>F<sub>x</sub> to recently reported K<sub>x</sub>Fe<sub>2-y</sub>Se<sub>2</sub> and (Tl,K)Fe<sub>2-x</sub>Se<sub>2</sub>, two-dimensional (2D) layers of FePn or FeCh (Pn = pnictogens, Ch = chalcogens) tetrahedra are the common structural units [5–9]. The mechanism of superconductivity and its relation to the crystal structure in these systems is still under debate. In particular, the question concerning localization or delocalization of the magnetic moments of iron deserves intense consideration. Therefore, in order to achieve deeper insight into the nature of superconductivity, the study of materials containing similar building blocks related to these systems is of significant interest. In this respect, it is important to note that currently pressure-induced superconductivity has been discovered even in the 1D spin-ladder compound BaFe<sub>2</sub>S<sub>3</sub> consisting of FeS<sub>4</sub> tetrahedra as well [10].

Systematic structural investigations of ternary metal chalcogenides A<sub>x</sub>Fe<sub>y</sub>X<sub>z</sub> (A = alkali metal, Tl; X = S, Se) have revealed a variety of distinct compositions with tetrahedral [FeX<sub>4</sub>] structural units, i.e., A<sub>5</sub>FeX<sub>4</sub>, AFe<sub>2</sub>X<sub>2</sub>, AFe<sub>2</sub>X<sub>3</sub>, A<sub>3</sub>FeX<sub>3</sub>, AFeX<sub>2</sub>, and A<sub>3</sub>Fe<sub>2</sub>S<sub>4</sub> [11–19]. The chalcogenide crystals Na<sub>5</sub>FeS<sub>4</sub>, A<sub>3</sub>FeX<sub>3</sub> (A = Na, Cs; X = S, Se), and AFeX<sub>2</sub> (A = K, Cs; X = S, Se) consist of discrete tetrahedral [FeS<sub>4</sub>]<sup>5-</sup> complexes [14], edge-linked double tetrahedral [Fe<sub>2</sub>X<sub>6</sub>]<sup>6-</sup> complexes [15,20,21], or one-dimensional  ${}^1_{\infty}$ [FeX<sub>4/2</sub>]<sup>-</sup> chains [15,22,23], respectively. Magnetic susceptibility measurements revealed a systematic reduction of the local iron-spin moment  $S = 5/2$  of discrete tetrahedra down to  $S = 3/2$  in double-tetrahedral complex and towards  $S = 1/2$  in chain compounds [14,15,20–24].

In this work we concentrate on RbFeSe<sub>2</sub> chalcogenide, which belongs to the group of one-dimensional compounds AFeX<sub>2</sub> consisting of linear chains of edge-sharing [FeX<sub>4</sub>] tetrahedra along the *c* direction separated by Rb atoms (see Fig. 1). Concerning the question about the relation of superconductivity and magnetism, these linear chain compounds serve as useful model systems, because the small Fe-Fe intrachain separation gives rise to strong covalence effects and is expected to promote spin reduction and charge-carrier delocalization on the verge to 1D metallic behavior.

The crystallographic and magnetic data for AFeX<sub>2</sub> (A = K, Rb, Cs, Tl; X = S, Se) are collected in Table I. In their magnetic properties, the iron compounds can be divided into three groups as follows (see references in Tiwary and Vasudevan [24], Seidov *et al.* [25], Asgerov *et al.* [26], Nishi and Ito [27,28], Welz *et al.* [29–32], and Bronger and Müller [15,22]):

(1) monoclinic TlFeS<sub>2</sub>, TlFeSe<sub>2</sub>, KFeSe<sub>2</sub>, and RbFeSe<sub>2</sub> with the magnetic moments ordered perpendicular to the chains;

(2) orthorhombic CsFeS<sub>2</sub> with no magnetic order down to the structural transition at  $T_{\text{struc}} = 70$  K (below  $T_{\text{struc}}$  with orientation of the magnetic moments approximately along the chain direction); and

(3) monoclinic KFeS<sub>2</sub>, RbFeS<sub>2</sub> with the ordered moments slightly tilted from the chain axis.

All these compounds involve formally trivalent iron with a half-filled 3*d* electronic shell. The ordered magnetic moment, far below the ionic high-spin value of  $5\mu_B$ , indicates a considerable 3*d* delocalization, which has been attributed to intimate Fe contact resulting from the in-chain Fe distance, not much exceeding the Fe-Fe distance (2.48 Å) of metallic iron. Hence, a certain degree of itinerancy along the chains and concomitant one-dimensional metallic behavior can be expected.

In this article we present x-ray diffraction, magnetization, specific-heat, and Mössbauer experiments on single-crystalline RbFeSe<sub>2</sub>. The comparison of our results with those of related 1D and 2D iron chalcogenides and pnictides is

\*hans-albrecht.krug@physik.uni-augsburg.de