Magnetic Ordering & Superconductivity in Co Doped $BaFe_2As_2$

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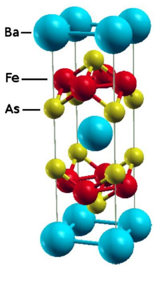
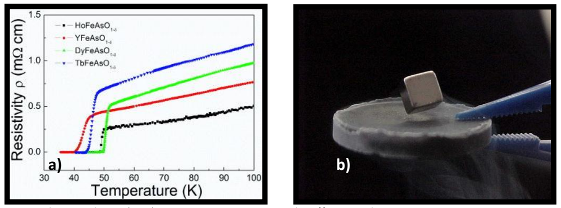


Fig. 1: Unit Cell of $BaFe_2As_2$.
A.F. Kemper *et al.* Phys. Rev. B. **80**, 104511 (2009)

Superconductivity is a phenomenon that has greatly intrigued condensed matter physicists since its discovery 100 years ago. Of particular interest are the high T_c superconductors, since they could greatly influence electronics and power distribution through a resistance of zero at high temperatures. A new class of high T_c superconductors was recently discovered, igniting much more research in the field: the Fe-pnictides. This includes the AFe_2As_2 (A = Ca, Sr, Ba) series, known as the 122 series [1].

This project investigates the magnetic ordering and superconducting properties of $BaFe_2As_2$, at 4 different amounts of Co doping (0%, 4.7%, 7.4% and 7.7%) through ^{57}Fe Mössbauer spectroscopy and susceptibility analysis.

Samples were provided by Canfield in AMES lab, grown in flux.



Jie Yang *et al.*, New J. Phys. **11** (2009) 02005
http://www.wondermagnet.com

Fig 2: Superconductors exhibit several interesting characteristics. At low temperatures, below T_c, they have a resistance of 0Ω (a). Furthermore, they are diamagnetic, meaning they expel magnetic flux through the Meissner effect (b).

Mössbauer Spectroscopy? What's That?

Mössbauer spectroscopy is an experimental technique, used to probe nuclear interactions. It works by emitting gamma rays at a sample, and measuring the absorption pattern.

A radiation source is mounted on a moving drive, producing a Doppler effect to modify the energy of the emitted gammas. At resonant energies of the source, more gammas are absorbed, providing information about the energy states of the sample.

For this experiment, the radiation source was 57-Co.

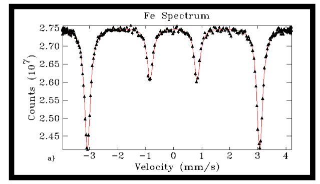


Fig 3: Fe spectrum, from 57-Fe Mössbauer spectroscopy

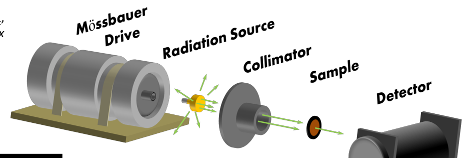


Fig 4: Standard setup of a Mössbauer spectrometer.

The 3 primary nuclear interactions measured by Mössbauer spectroscopy are:

1. Isomer Shift: energy shift due to charge density of the electrons and nucleus
2. Quadrupole Splitting: interaction between nucleus and electric field gradient
3. Hyperfine Field: interaction between nucleus and magnetic field

Magnetic Ordering Transition

^{57}Fe Mössbauer spectroscopy was used to investigate the magnetic transition. At low temperatures, $BaFe_2As_2$ orders antiferromagnetically. As the temperature is increased, it undergoes a magnetic ordering transition to become paramagnetic [2]. This can be clearly observed through Mössbauer spectroscopy, since the hyperfine field goes to 0T and the spectrum collapses to a single line [3]. However, this transition is suppressed with an increase in Co doping [4].

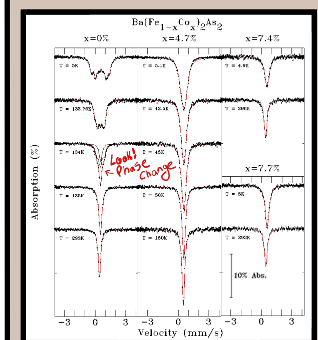


Fig 5: Mössbauer spectra demonstrating the magnetic ordering transition temperature. In the undoped and 4.7% Co doped spectra, the lines collapse to a central peak. In the x=7.4%, 7.7% spectra, there is no difference between base and room temperature, indicating no change. In order to fit the transition of the undoped sample, two subspectra were used.

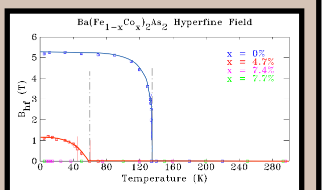


Fig 6: A change in magnetic ordering is marked by a collapse in the hyperfine field. This transition is clearly seen in the undoped and 4.7% Co doped samples. However, since Co doping suppresses this transition, the x = 7.4%, 7.7% samples have B_{hf} = 0T for all temperatures.

Phase Diagram

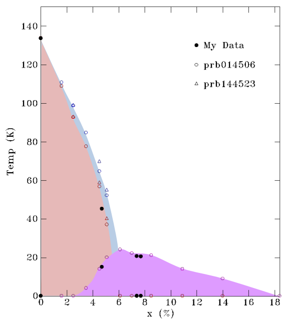
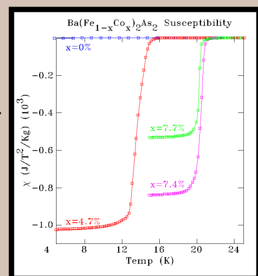


Fig 7: Phase diagram showing the various transition temperatures of $BaFe_2As_2$ at different Co doping [1][4][6]. Pink region indicates orthorhombic structure and antiferromagnetic order. Blue is also orthorhombic structure but with paramagnetic order, and white is tetragonal structure with paramagnetic order. Purple region is superconducting zone.

Superconducting Transition

A superconductor expels magnetic flux by aligning its moments opposite that of an externally applied field. Therefore, in order to determine the superconducting temperature, the magnetization was measured in response to an externally applied field. A susceptibility plot was made, through the use of a Quantum Design Physical Property Measurement System (Quantum Design PPMS). Susceptibility (χ) indicates the degree of magnetization of a substance in response to a magnetic field [5].

Fig 8: Susceptibility vs. Temperature of various Co doped samples. These measurements were made through the use of a Quantum Design Physical Property Measurement System, with a frequency of 377Hz and a field of 1mT.



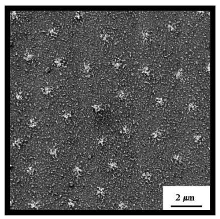


Fig 9: Vortices induced in MgB_2 crystals by a magnetic field.
L. Ya. Vinnikov Phys. Rev. B. **67**, 09512 (2003)

Fun Fact

At low fields, magnetic flux only penetrates a small distance, λ, in superconductors. However., if the applied field is greater than a critical field, then vortices form, surrounded by superconducting regions, through which the flux can pass.

In Field Mössbauer Spectroscopy

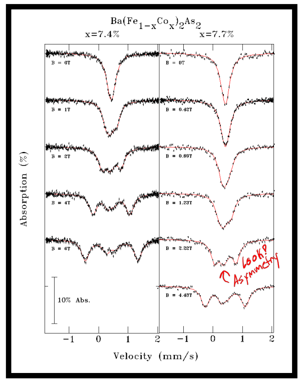


Fig 10: ^{57}Fe Mössbauer spectroscopy at 5K at various applied fields. The splitting in the spectrum is due to the hyperfine field. There is also an asymmetry in the central peaks, resulting from a quadrupole splitting

The effect of an externally applied field was investigated on the 7.4% and 7.7% Co doped samples. The hyperfine field increases linearly with an increasing applied field. Furthermore, a quadrupole splitting appears, indicating a distortion in the electric field gradient.

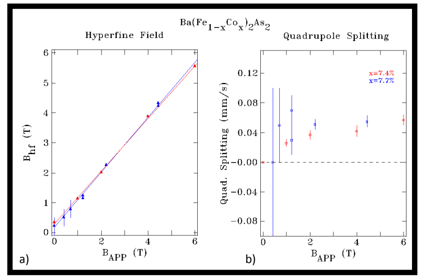


Fig 11: Along with increasing the hyperfine field of the sample, the applied magnetic field also introduces a quadrupole splitting. The splitting was determined by plotting two subspectra, and the difference is equivalent to the quadrupole splitting.

Conclusion

Through the use of Mössbauer spectroscopy and susceptibility measurements, the magnetic ordering and superconducting transition temperature of undoped, 4.7%, 7.4% and 7.7% Co doped $BaFe_2As_2$ were determined.

Furthermore, an applied magnetic field induces a quadrupole splitting, indicating a distortion in the electric field gradient. This project could be furthered by an investigation of this distortion.

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[6] P.C. Canfield *et al.*, Pys. Rev. B **80**, 060501 (2009)