Synthesis and Magnetic Properties of the Actinide Impurity (Uranium) Doped CaB_6 & YCo_2

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Abstract:

This summer project focuses on the role of actinide impurities, specifically uranium, on YCo2 and CaB6. Small control uranium dopings were used to investigate the change in the magnetic properties depending on the atomic percent of the dopings. Uranium is a large atom and replaces Yttrium or Calcium ions in the lattice structure, the small dopings will create a gradual change, if any, in the transitions of these materials. YCo2 was doped with 0.01 atomic percent uranium and grown using an arc-melting technique. Four samples of CaB6 were grown with varying small dopings of uranium and employed an aluminum flux growth technique. CaB6 with no doping has shown no ferromagnetic ordering above 2 K, the doped samples suggest there to be a magnetic transition around 67 K. YCo2 has a transition from paramagnetic to ferromagnetic state around 90 T which is to be explored using pulsed fields. The doped sample of YCo2 upon measurement is ferromagnetic at low fields and temperature from 6K to 70K and further investigation will lead to finding the effect the doping on the sample in high fields.

Flux Growth of CaB_6

Growth Procedure

The ratio of the components were measured and weighed out. Then placed in the crucible with aluminum flux to excess, and sealed under vacuum in a quartz tube. The furnace went up to 1425 C and stayed there for 72 hours. Once slowly cooled down to 900 C, the crucibles are taken out and run in the centrifuge.

Sample #	Composition	Atomic %
320	$Ca_{0.980}U_{0.020}B_6$	2.0%
319	$Ca_{0.990}U_{0.010}B_6$	1.0%
318	$Ca_{0.995}U_{0.005}B_6$	0.5%
317	$Ca_{0.999}U_{0.001}B_6$	0.1%

Rose Torch-Propane/Oxygen *Crucibles sealed in quartz tubes* *Tube furnaces*

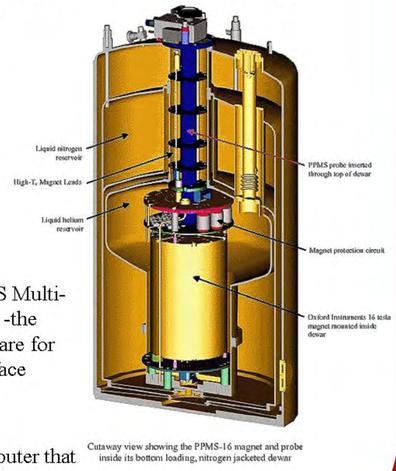
Etching and Annealing Techniques

Etching the crystals in hydrochloric acid allows the separation of the crystals from the excess aluminum flux. The separated crystals are wrapped in tantalum foil and heated up to 900 C for around 60 hr. This process allows the crystal lattice to release any stress or impurities that may have been contained.

PPMS (Physical Properties Measurement System)

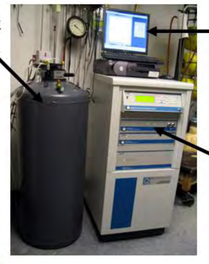
The PPMS was used to measure all the samples. Field sweeps ran from -12 T to 12 T and temperature sweeps from 6 K to 300 K.

VSM(Vibrating Sample Magnetometer) This is one of the options offered by the PPMS system. This particular option moves your sample vertically within the bore of the magnet. As the sample moves vertically the magnetic moment of the material is measured by the pick up coil.



Cutaway view showing the PPMS-16 magnet and probe inside its bottom loading, nitrogen jacketed dewar

Magnet

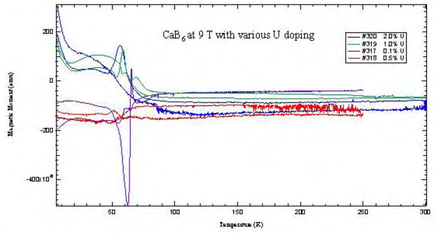


PPMS Multi-View -the software for interface

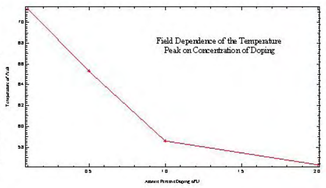
Computer that runs the magnet

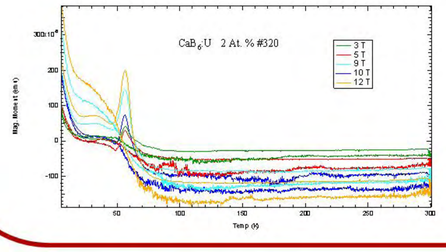
CaB_6 Results

Considering the graphs below it is concluded that the magnetization due to the transition is field dependent and temperature independent.

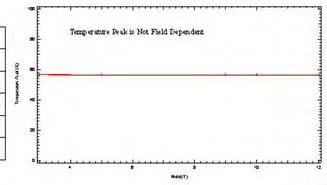


Temp. at Peak	Atomic Percent Doping
No Peak	0%
56.3 K	2.0%
58.6 K	1.0%
65.3 K	0.5%
71.3 K	0.1%



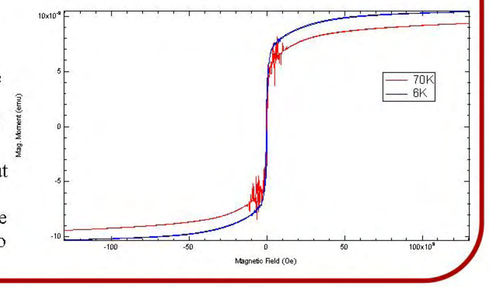


Temp. at Peak (K)	Field (T)
56.12	12
56.36	10
56.32	9
56.37	5
56.58	3



$Y_{0.9999}U_{0.0001}Co_2$ Magnetic Properties

The graph to the right indicates a ferromagnetic trend. YCo_2 has a metamagnetic transition around 90 T. The data collection was conducted using the PPMS. It is clear that the magnetization quickly saturates due to the steep slope, which is an indication of ferromagnetism. The saturation can be explained through the aligning of the electron spins, once they are all aligned the magnetization cannot get any larger, thus the flatting out of the graph. This is the preliminary study which is followed by running the sample in the Single Turn Pulse magnet because it is able to reach the fields necessary to see the metamagnetic transition.



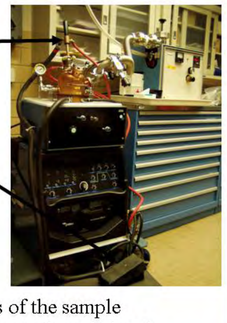
Arc Melting $Y_{0.9999}U_{0.0001}Co_2$

The Arc Furnace consists of a water-cooled copper Bell Jar hinged from a fixed baseplate. The electrode (stinger) shaft penetrates down through the Bell Jar top. The hearth is water-cooled copper with interchangeable top surfaces. The viewing piece is provided for observation inside the Bell Jar. There is a vacuum pump attached to produce a dry environment and then back filled with argon.

Viewing Piece

Hearth

Hoses for water cooling



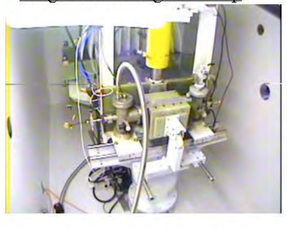
Stinger

Foot pedal that controls the current

After calculating and weighing out the components of the sample they were placed in the hearth. The chamber was purged, sealed and backfilled with argon. Next, the pieces were melted, to ensure homogeneity the piece was flipped and re-melted about 6 times.

Single Turn Pulsed Magnet

Single Turn Magnet Setup



The single turn magnet is used to get extreme magnetic fields for nanoseconds. The single turn magnet can get up to 300 T, which is about **6 million times greater than the earth's magnetic field**. This magnet will be used on the $Y_{0.9999}U_{0.0001}Co_2$ sample to find the critical field where the samples goes from being paramagnetic to ferromagnetic. This data will be compared to the undoped sample's metamagnetic transition whose critical field occurs around 90 T.

Capacitor Bank

S.T. Tank

Capacitors

Before Shot

After Shot

Magnet Pulse

Conclusion

The goal of this project was to investigate the role of actinide impurity (uranium) on YCo_2 and CaB_6 and there was found be a field dependency in the transition of CaB_6 and the effect on the YCo_2 showed a ferromagnetic trend at 70 K and 6 K. This process did provide the experience of learning different ways to grow, dope and characterize crystals. The study of the these samples is not complete and further investigation in what type of transition is being observed in the CaB_6 and running the YCo_2 sample in the pulse fields is to follow.

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