

## **Osmium doping of $\text{UAl}_2$**

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### **Abstract**

Samples of  $\text{UAl}_2$  and  $\text{UAl}_{1.6}\text{Os}_{0.4}$  were made and analyzed using x-ray diffraction and magnetic susceptibility measurements. The results of these measurements indicate that the replacement of aluminum with osmium decreases the effective mass of electrons in this system, suggesting that spin fluctuations are being suppressed.

## Introduction

In 1975, Trainor *et al.* presented research indicating the presence of spin fluctuations in the system  $\text{UAl}_2$  [1]. Spin fluctuations in a substance are the result of magnetic spins fluctuating in and out of alignment. These fluctuations interact with electrons such that, in a sense, they “slow down” the movement of electrons resulting in an effective electron mass (indicated by  $m_e^*$ ) greater than the normal “bare” (or non-interacting) electron rest mass,  $m_e$ . This larger effective mass influences the properties of the substance. Particularly, we are interested in the specific heat (specific heat at  $T = 0$  is given by  $\gamma$ ) and the magnetic susceptibility ( $\chi$ ) of our samples. These properties are directly proportional to  $m_e^*$ , and therefore to the spin fluctuation behavior of the system. Therefore, we can draw conclusions pertaining to the spin fluctuations of the sample based on our observations of  $\chi$  and  $\gamma$ .

Our project involved replacing a small amount of aluminum in the  $\text{UAl}_2$  system with osmium. This process, called “doping,” changes the properties of the sample. For this particular project, we replaced 20% of the aluminum to form  $\text{UAl}_{1.6}\text{Os}_{0.4}$ . Our plan was to measure  $\chi$  in the doped sample and compare it to the  $\chi$  of our pure sample. These measurements would indicate how the osmium in the compound was affecting the spin fluctuations of the system. Measurements of the specific heat  $\gamma$  are planned for the future.

## Procedure

We began by making the desired samples in the lab. We calculated and weighed out the correct masses of each metal using simple stoichiometry and an accurate balance. Then, using an Edmund Bühler arc-melter, we melted each compound several times in an

oxygen-free, argon atmosphere. We made each sample, successfully keeping the mass loss due to melting below 0.2%. However, we did encounter a few of obstacles in the process of making the samples. Our first  $UAl_2$  sample “exploded” on the second melt attempt. The “explosion” was simply the sample shattering into many pieces upon being heated rapidly by the plasma arc in the arc-melter. To counter this problem, we slowly warmed the bead by bringing the arc slowly toward the sample until it melted. Despite employing this technique, our second sample exploded again, this time on the third melt. However, x-ray analysis of the sample revealed it had formed the proper structure before exploding. In addition, during the first attempt at doping the aluminum, we had difficulty getting the osmium to mix in. Upon breaking the sample open, we discovered a small bead of osmium which had not melted and mixed with the other metals. We tried several techniques to get the osmium to melt before we were successful. When we melted the sample with high heat to melt the osmium, we encountered high mass loss due to aluminum’s high vapor pressure. Finally, we melted just the uranium and osmium together several times at high heat to mix them thoroughly. This was possible because both uranium and osmium have relatively low vapor pressures. Then, we melted the aluminum into our  $UO_{0.4}$  mixture. After going through this procedure, the final product still had a very small osmium bead in the center. However, this unmixed osmium was only about 3mg in mass. The loss of 3mg of osmium would not significantly affect our results.

We put each sample through several procedures. First, after breaking the sample into pieces, we took about 200-300mg of the sample and ground it into a fine powder using a mortar and pestle. We then glued the powder to a glass x-ray slide. After the glue on each slide dried, we took x-ray diffraction data at the Major Analytical and Instrumentation

Center (MAIC) at the University of Florida. We used these x-ray data to confirm we had made a satisfactory sample. If some of the elements had not mixed into the lattice properly, the diffraction pattern would have indicated a second phase. The data were also useful to calculate the size of the sample's cubic lattice structure. Using the peaks of the diffraction pattern, our Unitcell computer program calculated the lattice parameter of each sample. The lattice parameters allowed us to track what was happening to the size of the structure of the sample as we doped it.

Next, we put each sample in the Superconducting Quantum Interference Device (SQUID) to measure magnetic susceptibility. These  $\chi$  data gave us an indication of how the magnetism of the sample reacts to an applied magnetic field. Because the susceptibility data are related to  $m_e^*$ , this step was an integral part of the project. We measured the susceptibility of both samples over a temperature range of 2-300K.

We stored both samples in the lab so they are available for specific heat and resistivity measurements in the future.

## Results

First, our x-ray diffraction data, shown in Fig. 1, indicate we produced samples of adequate quality. Both patterns are clean and free of too much background "noise." Fig. 2 shows the lattice parameters of  $UAl_2$ ,  $UAl_{1.6}Os_{0.4}$ , and  $UOs_2$ . The literature-value lattice parameters for  $UAl_2$  and  $UOs_2$  come from Lam *et al.* [2] and Heal and Williams [3], respectively. The data show that the lattice structure of the osmium doped sample is smaller than that of  $UAl_2$ . This shrinking of the lattice is influential in the suppression of spin fluctuations, as the U-U interatomic spacing is moved away from the Hill limit. The

Hill limit ( $3.5 \text{ \AA}$ ) is the value above which f-f orbital overlap, without hybridization, ceases.

Our  $\chi$  data in Fig. 3 clearly show the susceptibility of  $\text{UAl}_{1.6}\text{Os}_{0.4}$  is lower than that of pure  $\text{UAl}_2$ . Because  $\chi$  is directly proportional to  $m_e^*$ , the decrease in  $\chi$  indicates the osmium doping has decreased  $m_e^*$  by suppressing spin fluctuations.

## **Conclusion**

This research indicates that the doping of  $\text{UAl}_2$  with osmium suppresses the spin fluctuations of the system. Because of the proportionality of  $\chi$  and  $\gamma$  to  $m_e^*$ , the lower  $\chi$  values of  $\text{UAl}_{1.6}\text{Os}_{0.4}$  indicate a lower  $m_e^*$ , and therefore suppressed spin fluctuations. This conclusion could be reinforced with specific heat data, which we were unable to obtain due to the brief duration of the program. We would predict the specific heat value  $\gamma$  ( $=142 \text{ mJ/mole-K}^2$  in [1] pure  $\text{UAl}_2$ ) to be lower in the doped sample.

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## References

- [1] R. J. Trainor, M. B. Brodsky, and H. B. Culbert, Phys. Rev. Lett. **34**, 1019 (1975).
- [2] D. J. Lam, J. B. Darby, Jr., J. W. Downey, and L. J. Norton, J. Nucl. Mater. **22**, 22 (1967).
- [3] T. J. Heal and G. I. Williams, Acta Crystallogr. **8**, 494 (1955).

## Figures

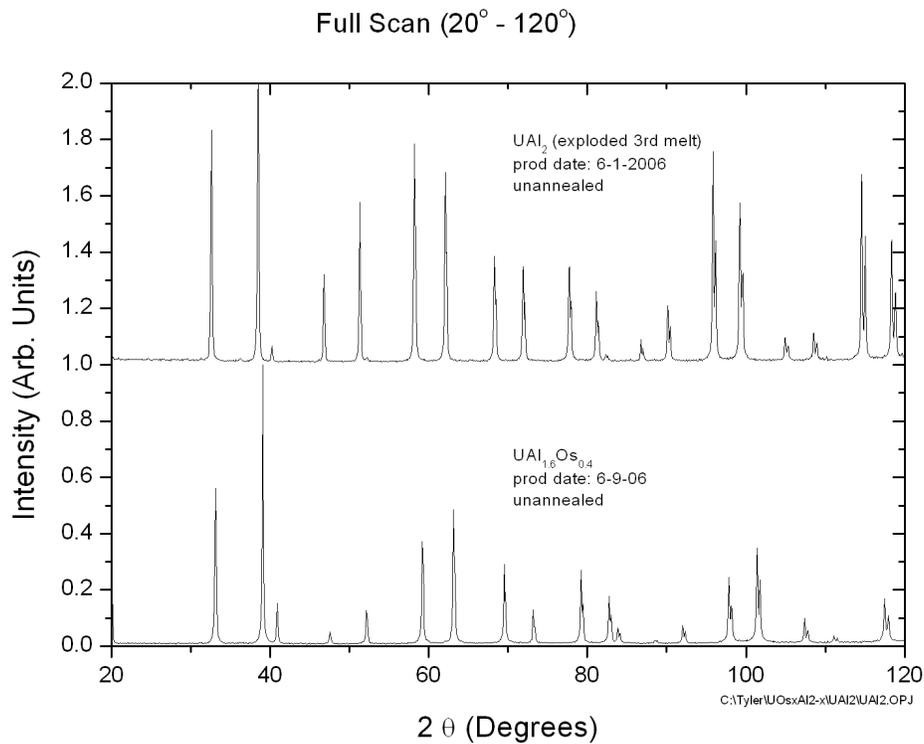


Fig 1. Comparison of x-ray diffraction patterns for UAl<sub>2</sub> and UAl<sub>1.6</sub>Os<sub>0.4</sub>

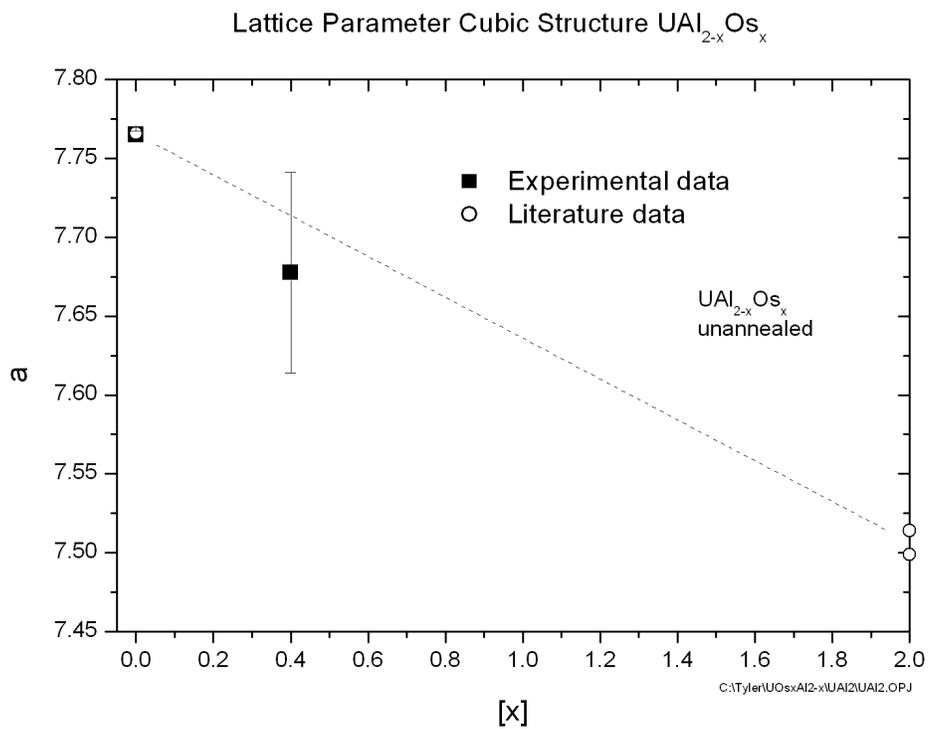


Fig. 2 Lattice parameters of  $UAl_{2-x}Os_x$

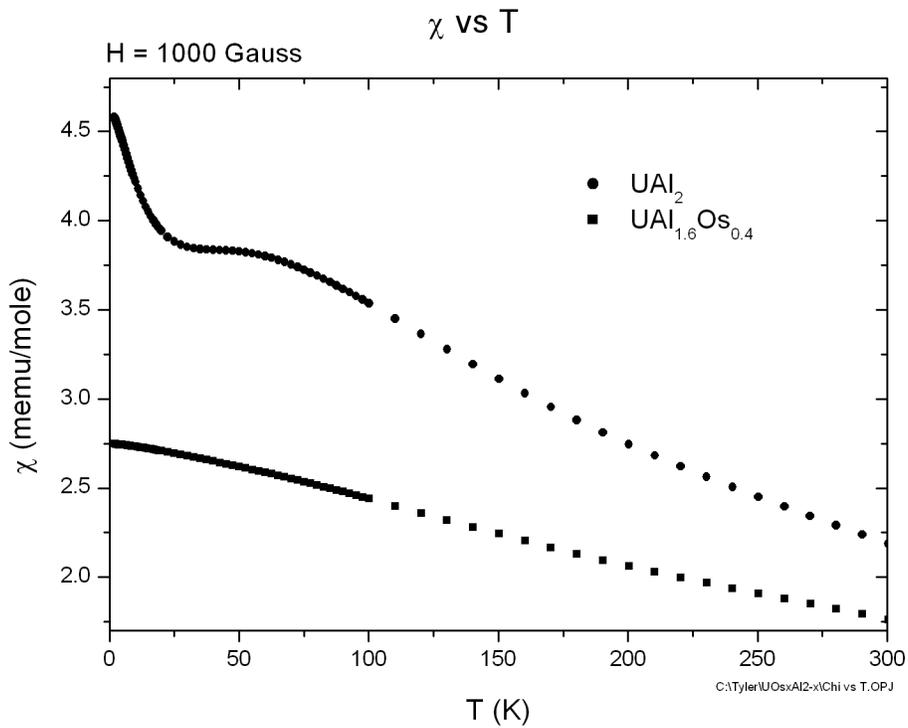


Fig. 3. Comparison of magnetic susceptibility for  $UAl_2$  and  $UAl_{1.6}Os_{0.4}$