Physics/Summer

Abstract:
At low enough temperatures, certain materials, called superconductors, experience zero resistivity and are able to transport current with no subsequent loss of energy. This phenomenon has incredible applications in the fields of electrical engineering, medical science and could revolutionize our energy industry. There are a number of superconductor families, one of which is Barium Iron Arsenide ($BaFe_2As_2$) which becomes superconducting by either hole or electron doping. Partial substitution of Ba with K, or Fe with Ni/Co change electron population of the conducting band in the parent compound. The mechanism of a subsequent effect on carrier coupling is still debated in literature. This correlation can be observed by examining hole or electron injection effects produced by crystalline surface treatment in oxygen and alcohol vapors. The electron donation/stripping will result in a higher or lower electron density that will manifests itself as an Isomer Shift of the Mossbauer spectrum.

Description of Research:

Superconductivity is the phenomenon of exactly zero resistance and the expulsion of the magnetic field from within the solid. It was discovered in 1911 by Heike Kamerlingh Onnes and has been the focus of many scientists for decades for its many unusual properties. A superconductor can transport current across any distance without losing any of it to resistance while normal copper wires waste about 10% of power in transporting electricity. Superconductors also have very unique magnetic properties. Japan has built their first Maglev Train (Magnetically levitating Train) which now holds the world record for fastest railed vehicle using superconducting magnets. Superconductors are also used in making MRI machines and other practical equipment.

There are various different superconducting families of materials. One family of superconductors Barium Iron Arsenide ($BaFe_2As_2$) has been discovered recently[1] and has attracted special interest of scientists. The compound contains Iron which normally destroys superconductivity in other materials. The parent compound is normal, but when doped with 5% Nickel it becomes superconducting. The reason behind this change to a superconducting state with doping is not fully understood[2], and is still debated by scientists. It is believed that the process of doping increases the electron population in the conduction band of the parent compound. This in turn allows for the electrons to pair up in what is called a Cooper pair. This formation of Cooper pairs is what makes a compound a superconductor[3]. It is the goal of this project to test whether the direct electron or hole donation of the doping process is indeed responsible for the transition to the superconducting state. This would narrow the possible explanations of the triggering mechanism for this phenomenon. If the direct electron or hole donation is not responsible for this transition, then it concludes that the doping process is invoking superconductivity in a different manner. Proposed experiment would provide crucial information for understanding the mechanism of this phenomenon.

The novelty of proposed method is in the pure chemical nature of electron population manipulation compared to atomic doping used before. This method has been performed and developed by Dr. Nath[4] a faculty member of the department of Chemistry at UNCA. We will bathe the compound in alcohol vapor (to donate electrons) or oxygen (to strip electrons). The alcohol molecules will attach itself to surface of the material and donate an electron to the crystal without changing its composition. The same will happen when the crystal is bathed in oxygen, but the oxygen will strip an electron instead. If it is the change in electron population in the conducting band that causes a transition to superconducting state, then both chemical and atomic doping methods should produce the same result.

A series of treatments at various temperatures is planned followed by spectroscopic analysis. To measure the change in electron population of the $BaFe_2As_2$ structure, we will be using Mossbauer Spectroscopy, which operates by measuring the resonant absorption of gamma rays in solids and is very sensitive to local electron density. Changing the electron population affects the resonant absorption of gamma rays and is registered as an Isomer Shift of the Mössbauer spectrum.

Energy-dispersive X-ray spectroscopy (EDX) will be performed on our sample to investigate whether our treatment could have altered the elemental composition of the $BaFe_2As_2$. By studying the emitted X-ray spectrum of a sample it is possible to identify its elemental composition. This test will be used to confirm that there hasn't been any chemical alteration to our sample such as oxidation due to the alcohol/oxygen treatment. X-ray Diffraction (XRD) will be used to identify the crystalline structure of the sample. Undesirable structural change could have occurred due to thermal treatment and would show up on X-ray diffractograms.

Finally, magnetic and transport properties of alcohol/oxygen treated samples will be compared to the doped samples of $BaFe_2As_2$. This part is performed in collaboration with research groups from the Applied Superconductivity Center, National High Magnetic Field Laboratory at Florida State University and the Institute of Physics, Chinese Academy of Sciences in Beijing who provide UNCA team with high quality initial samples of superconducting materials.

This project has a potential to shed light on the necessary conditions for inducing superconductivity in compounds. The goal of scientist for decades has been to find better materials that can become superconducting at higher temperature. Today the highest critical temperature (temperature at which a material becomes superconducting, T_c) of any superconductor is held by mercury barium calcium copper oxide with a T_c of 135 K (-216 Fahrenheit). It is the hope of scientists that a superconductor of higher T_c will be found and possibly even at the magic temperture of 300K (room temperature). Understanding details of the phenomenon makes it possible to predict the properties and thus design materials with all required special features.

Time period:
June 1 2012-July 31st 2012

Timeline:
Week 1: Setting up & lab Preparation

Week 2: Energy-dispersive X-ray spectroscopy (EDX) and X-ray Diffraction (XRD) on untreated samples.

Week 3&4: Alcohol/Oxygen Treatment of multiple samples.

Week 5&6: Mossbauer spectroscopy on samples

Week 7: EDX and XRD on treated samples

Week 8: Analysis and organization of data in preparation for publication.

Budget:

Object	Cost
Radioactive source Co^{57}	416$
Liquid nitrogen tank	78$
Helium cylinder	103$
Argon cylinder	89$
Ethanol	20$
High vacuum gauge	330$
Oxygen cylinder	98$
Nitrogen cylinder	77$
Total	1211$

Justification of budget:
The Nitrogen, Helium and Argon gases are used to prepare the oven in which the Oxygen and Ethanol treatment will take place. The Co^{57} and high vacuum gauge are need in the Mossbauer spectroscopy.

Additional Funding:

No additional funding is granted

Publication outlet:
We will develop an undergraduate thesis which I will present at the fall symposium. I will also apply to publish our body of work at Big South Undergraduate Research Symposium.

References:

1. Kamihara Y., Watanabe T., Hirano M., Hosono H., *J. Am. Chem. Soc*. **130**, 3296 (2008).
2. Stewart G. R., *Rev. Mod. Phys*. **83** 1589,(2011)
3. Mandrus D., Sefat A. S, McGuire M. A., Sales B. C., *Chemistry of Materials*., **22**, 715, (2010)
4. Nath A*., Acc. Chem*. Res. **17**, 90, (1984)