Scientists find metallic magnet with largest yet atomic displacement during thermal expansion

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(PhysOrg.com) -- Although most materials change shape in the presence of a magnetic field, the change is usually very small. In a new study, scientists have found that a certain magnet containing manganese experiences a change in the distance between two neighboring atoms of up to 2%, which is the largest ever found in a metallic magnet. Magnets with large magnetoelastic interactions - the mechanism that causes this change - play a crucial role in new materials that could be used in applications from sensors to refrigerants.

Alexander Barcza from the University of Cambridge and coauthors from ISIS and Imperial College London in the UK observed the giant magnetoelastic interactions in the material CoMnSi, which is a metallic antiferromagnet. The scientists also discovered that this magnet uses a new mechanism for achieving the large magnetoelastic effects, which involves competing exchange interactions among atoms.

“The usual mechanism [of magnetoelastic coupling], large spin-orbit coupling, is found mostly in rare earth-containing compounds, as the orbital angular momentum of rare earths is usually non-zero,” physicist Karl Sandeman of Imperial College London told *PhysOrg.com*. “So to be able to have a large magneto-elastic coupling in a transition metal-based system may be useful in terms of reducing the need to turn to rare earths for such effects. Rare earths, while not truly ‘rare,’ are already under increasing demand for their use in eco-friendly technologies that use batteries and permanent magnets."

The researchers could directly investigate this magnetoelastic effect on both the material's crystal and magnetic structure by using a technique called high-resolution neutron diffraction in combination with magnetic measurements. Their observations revealed that a change in applied magnetic field can cause the magnetism of the material to suddenly increase. This sudden increase in magnetism corresponds to a phase transition called metamagnetism.

The scientists showed that, in this case, the origin of the material's metamagnetism is a large magnetoelastic coupling among the material's atoms. The scientists observed what they describe as a "giant" change during heating of about 2% in the distances between manganese atoms. In addition, the researchers showed that the magnetoelastic coupling serves as a precursor to a metamagnetic tricritical point with enhanced shape change effects.

As the scientists explain, the large magnetoelastic coupling - and its resulting change in atomic separations - is driven by a competition between the exchange interactions of two different pairs of manganese atoms. Sandeman explained that, while the volume changes of the material are quite small overall, the shape change in certain directions is quite large. Specifically, textured materials show more shape change than other materials such as polycrystals, which tend to "average out" the changes.

"In a sense, competition is the theme here: the competition between different magnetic exchange leads to the presence of the magneto-elastic effect in the first place, as the system finds itself choosing between antiferromagnetic and ferromagnetic coupling of Mn atoms," Sandeman explained. "We also see a competition in the volume change, between the significant decrease in the length of one axis (the a-axis) with increasing temperature or magnetic field and the conventional, positive thermal expansion and swell in a magnetic field of the other two axes. The root of this is that, in zero field, the giant changes in Mn-Mn distances in our material compensate each other; and so the thermal expansion of the total volume of the material is actually quite small."

The discovery of a material with large atomic displacements during heating and shape changes in the presence of a magnetic field could have benefits in several areas, such as magnetic refrigerant materials and magnetostrictive materials, which respond to a change in magnetic field and can therefore be used as sensors or actuators. Plus, the researchers note that it should be possible to engineer materials of different compositions that have the same large magnetoelastic effects.

"The focus of my group is on magnetocaloric materials, which employ a magnetic field-driven change of state to provide a cooling effect," Sandeman said. "This is derived from a solid state transition such as a Curie point or, in this case, a metamagnetic transition, but is analagous to the evaporation of a volatile liquid to form a gas in a conventional gas compression fridge. Magnetic refrigerants often have bigger cooling effects if the magnetic change of state occurs in harmony with some change in the crystal lattice. Hence the interest in magneto-elastic interactions."

Sandeman is also the co-founder of a magnetic refrigeration company called Camfridge that is incorporating solid state magnetic refrigerants (different from those in this study) for gas-free, high-efficiency room-temperature cooling. The company also co-sponsored Alexander Barcza's research. In partnership with Whirlpool, Camfridge announced that it will display a working magnetic cooling prototype during the London 2012 Olympics. More information is available here.

More information: A. Barcza, et al. "Giant Magnetoelastic Coupling

in a Metallic Helical Metamagnet." *Physical Review Letters* 104, 247202 (2010). DOI:10.1103/PhysRevLett.104.247202