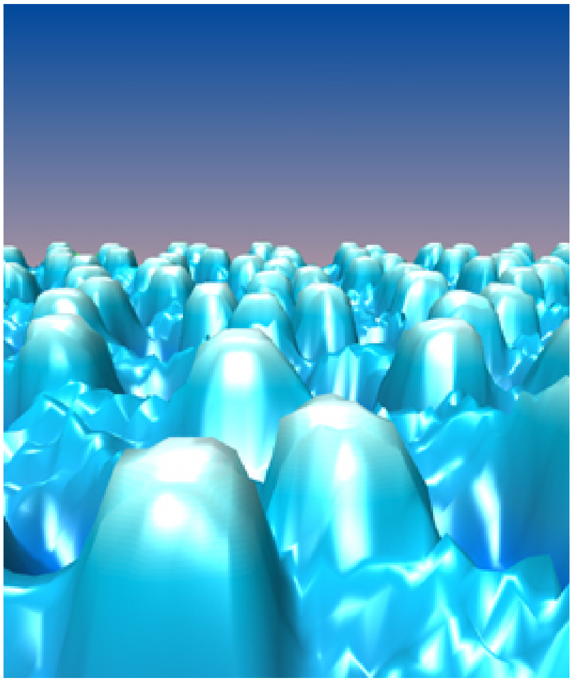
New method developed for exploring frustrated systems

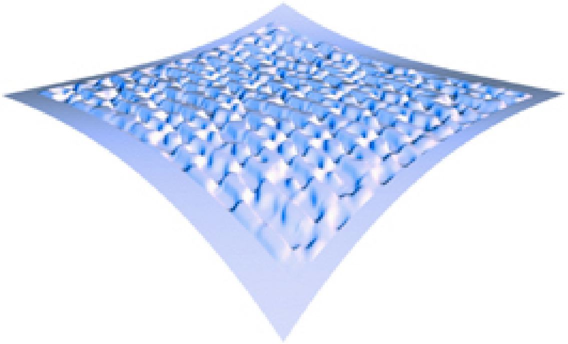
January 18 2006



Credit: William McConville and Ruifang Wang, Penn State

A new method for exploring the secrets of Mother Nature's frustrations has been developed by a team of physicists lead by Penn State University professors Peter Schiffer, Vincent Crespi, and Nitin Samarth. The research, which will be published this week in the journal *Nature*, is is an important contribution to the study of complex interacting systems, and it also could contribute to technologies for advanced magnetic-recording devices.

"We all would prefer to have less personal experience with frustration, but the state of frustration also is an important factor in the way many systems in nature work," explains Schiffer, who is a professor of physics at Penn State. "Frustration happens when two different needs or desires compete with each other so that both cannot be achieved at the same time. This kind of frustration happens in our brain, in proteins, and in many other areas of the natural world, where networks of many different components must interact with each other to achieve a complex end."



Credit: William McConville and Ruifang Wang, Penn State

Schiffer explains, for example, that neural networks, which allow the brain to function, and protein molecules, which allow living matter to function, consist of thousands to millions of interacting components, and that a crucial element of these interactions is that they often are "frustrated." "When two different and competing signals are sent in the brain, the brain needs to choose which signal will dominate in order to take a particular action," Schiffer says. "Frustration happens even in a simple substance such as ice, which consists of only hydrogen and oxygen atoms, because there are competing forces on the hydrogen atoms pushing them between different positions relative to their neighboring oxygen atoms," he explains.

Understanding the consequences of frustration in an extremely complex system like the brain is very difficult, so there is a great deal of research interest in studying simpler frustrated systems, like ice, in order to obtain a basic understanding of the nature of frustration. One group of such systems are materials in which some of the individual atoms have "magnetic moments," meaning that each atoms is like a tiny bar magnet or compass needle. If a material has these atoms arranged in certain ways, the interactions among groups of magnetic atoms compete with each other, which leads to a state of frustration. These "frustrated magnetic materials" are perhaps the cleanest systems in which frustration can be studied and have been the subject of intense research.

"The direction along which the magnetic moment of these magnetic atoms is pointed is determined by interactions with the other magnetic atoms in the material," Schiffer explains; "however, it has been almost impossible to look at the magnetic states of individual atoms, and existing chemical-synthesis techniques do not permit the strength of the interactions within these materials to be easily tuned." As a result, physicists have been able to study only the collective behavior of a group of frustrated magnetic atoms--not the specific behavior of the individual atoms.

Now, Schiffer and his colleagues have developed a new method to study the subtleties of frustration, which involves using "electron beam lithography" to build a magnetically frustrated material by sculpting arrays of hundreds of thousands of microscopic bar magnets, each only a few millionths of an inch in size. The samples were fabricated at the Penn State Nanofabrication Facility by Penn State graduate student Ruifang Wang. "Rather than relying on chemically synthesized materials whose magnetic atoms are pre-arranged, we decided to make our own frustrated system," Samarth says. "We tailored our system to mimic the magnetic structure of a specific set of materials that we wished to study, in which the frustrated magnetic atoms are arranged so that they behave in a manner exactly analogous to the hydrogen atoms in ice. Ruifang put in a truly heroic effort in getting the experiment to work." This set of materials is called "spin ice" since "spin" is another way of denoting the magnetism of an individual atom.

Because the systems made by Schiffer and his colleagues were created intentionally with a particular size and arrangement of individual magnets, the researchers were able to arrange the system so that the interactions between the magnets were frustrated in the same manner as in spin-ice materials. "Using a special microscope, we could see the direction in which each magnetic moment was pointing in this artificial spin ice, something which is impossible with either chemically synthesized frustrated magnetic materials or with ordinary ice," Schiffer says. "We also could change the spacing of the arrays, which allows us to tune the strength of the frustrated interactions."

The researchers say this work is an important step forward in the study of the nature of frustration in large networks. "Using such fabricated arrays, it now is possible to engineer frustrated systems to alter the strength of interactions, the geometry of the lattice, the type and number of defects, and other properties that impact the nature of frustration," Schiffer explains. These systems also allow scientists to probe the state of individual elements within a frustrated system. The interacting magnets also are relevant to modern magnetic-recording technology, which relies on increasingly tiny magnetic structures in order to fit more and more information onto smaller and smaller hard drives.

Source: Penn State

Citation: New method developed for exploring frustrated systems (2006, January 18) retrieved 18 April 2024 from https://phys.org/news/2006-01-method-exploring-frustrated.html