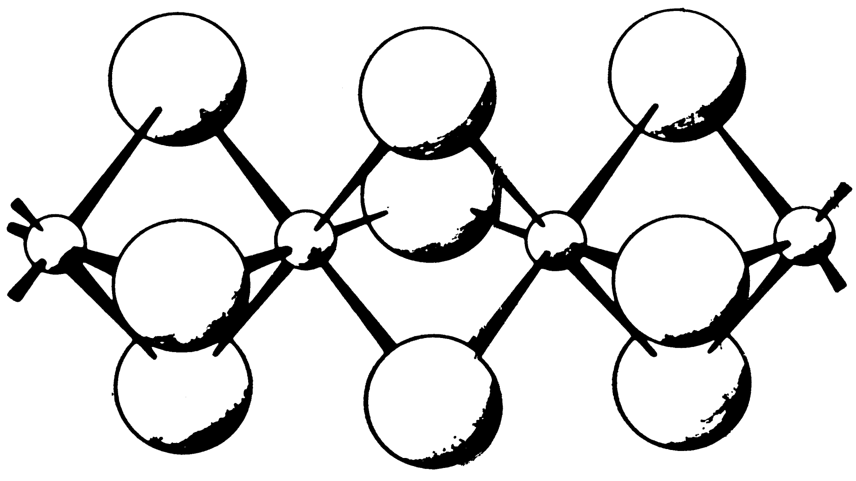
Testing magnetic theory

A new material is lending support to basic ideas



Structure of TMMC: Close to hypothetical case of one-dimensional magnetism.

The overall magnetic properties of a magnetic substance are determined by the way the magnetic fields of its atoms are aligned. If the fields—or, as physicists usually say, the spins, since the fields depend on the net result of all the rotary motions in the atom—are aligned at random, the substance is in a paramagnetic state. If the spins are all aligned in the same direction the state is called ferromagnetic. If the spins are ordered so that successive spins point in opposite directions—up-down, up-down, for example—the state is called antiferromagnetic.

The disordered paramagnetic state can pass into one of the ordered states when the temperature of the substance drops below a certain critical value. At this point the thermal motion of the atoms, which contributes to the disorder of their spins, becomes weaker than the magnetic forces, which tend to order the spins.

A good deal of the theoretical and experimental effort of specialists in magnetism is devoted to an understanding of so-called critical phenomena: what happens as the substance passes through the critical temperature and the atomic spins spontaneously align themselves. It appears that each atom interacts most strongly with its nearest neighbors to influence the direction of their spins but hardly at all with more distant atoms; theories start from this idea.

In the three-dimensional world of an actual solid, the nearest neighbors to any atom can be several, and lie in several directions. Deriving a theory to fit such a case, whether one tries to make it exact or only approximate, is very difficult. To attack the problem at a simpler level theorists have worked out theories for a hypothetical one-dimensional case in which each atom interacts only with its neighbors in one line and not to the side at all.

An actual substance that would behave according to a one-dimensional theory would have to have an unusual structure, some sort of built-in shielding in all but one dimension. Last week at the 16th Annual Conference on Magnetism and Magnetic Materials in Miami Beach, Dr. Michael T. Hutchings of the Atomic Energy Research Establishment at Harwell in England reported that he and Drs. Gen Shirane of Brookhaven National Laboratory, R. J. Birgeneau and R. Dingle of Bell Telephone Laboratories and S. L. Holt of the University of Wyoming had found a substance that behaves in nearly ideal accord with a theory of one-dimensional antiferromagnetism.

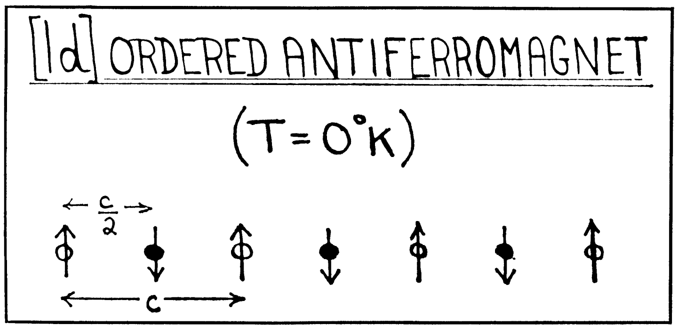
The substance is tetramethylammonium manganese chloride, $[(CH_3)_4N]MnCl_3$, called TMMC for short. In TMMC the manganese chloride ions, which are the magnetic elements, are in long chains. The chains are surrounded by tetramethylammonium ions in such a way that magnetic interactions between chains are virtually nil. The interactions go almost exclusively along the chains.

All theories of one-dimensional antiferromagnetism agree that there should be no actual antiferromagnetic order at temperatures above absolute zero. Some do predict order at absolute zero. Absolute zero cannot be reached exactly; what the experimenters observed was that the magnetic elements of TMMC show a tendency toward order at temperatures near zero, a tendency that would lead to antiferromagnetic order at absolute zero.

The observations were made by scattering beams of neutrons from the substance. Since neutrons also possess magnetic fields, the way in which they are scattered by the atoms of TMMC is influenced by the magnetic orientations of those atoms.

When they studied the changes in TMMC over time the experimenters found a surprise for theorists. Even though disordered, the magnetic state of TMMC changes its disorder in the way that ordered states change their order, and this wasn't supposed to happen. In a magnetically ordered substance, the spins periodically change direction. They do this in succession like falling dominoes, and the phenomenon has the appearance of a wave, called a spin wave, moving through the substance, turning over the spins. Spin waves appear in TMMC even when antiferromagnetic order does not exist. Theorists had not expected this result, but since they heard of it, they have managed to put it into the theory, Drs. F. B. McLean and Martin Blume of Brookhaven told the meeting.

Dr. Hutchings believes other one-dimensional substances will be found. One possibility, he suggests, is to replace manganese chloride with cobalt in a structure similar to TMMC. Study of these substances, he believes, will permit testing of theories and will indicate the direction future theoretical work must take. In particular they make it possible to find a value for the magnetic force between ions, a very important point. □



At absolute zero, successive spins of an antiferromagnetic substance would point in opposite directions.

Illustrations: Hutchings