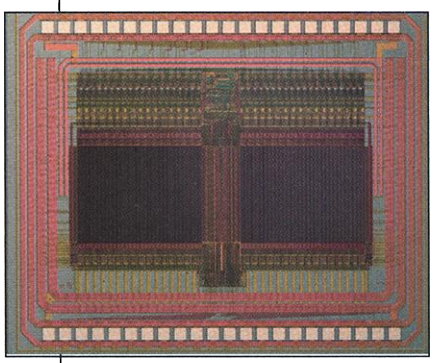
# The Attraction of Magnetism

As early as the 2nd century A.D., the Chinese found that unmagnetized iron ore became magnetized when brought close to naturally magnetized samples. Several centuries later, the observation that suspended magnetized rods always pointed in the same north-south direction led to what was probably the earliest application of magnets, as a navigational aid.

Understanding of how magnetism arises had to wait until the early 19th century, when the now-acknowledged giants of the field—Maxwell, Faraday, Oersted, Henry, and Ampere—recognized that the movement of charged electrical carriers produces a magnetic field. However, the explanation of "permanent" magnetism in materials such as lodestones had to wait until the 20th century and the quantum mechanical formulation of electron spin. Magnetic ordering arises through the alignment of unpaired electron spins on neighboring atoms through exchange interactions. Depending on the strength and sign of this interaction, spins can maintain a parallel ordering (ferromagnetism), an antiparallel ordering (antiferromagnetism), or align readily in an applied magnetic field (paramagnetism).



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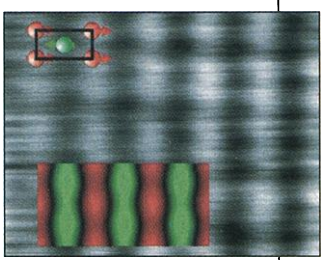
New materials and processing techniques have overcome the constraints inherent in naturally occurring magnetic materials. For example, strong, lightweight magnetic alloys have been developed for motors and generators. Current research efforts include the preparation of thin films for improved data storage, the exploitation of electron spin rather than charge for device switching ("spintronics"), and the development of new materials such as polymer-based magnets for lightweight and low-cost applications (see the report by Rajca *et al.*, p. 1503). In this special issue of *Science*, we look at some of the issues involved in characterizing magnetic systems, preparing new materials, and understanding the behavior of these complex new materials.

Although the patterns formed by scattered fine-iron filings provide a crude visualization of the magnetic field lines emanating from magnets, imaging complex magnetic structures on a finer scale requires more elaborate techniques. Freeman and Choi (p. 1484) provide an overview of the techniques that have been developed to probe and visualize magnetic ordering, from the macroscopic scale right down to the atomic scale.



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Alternate technologies will be required to address the so-called silicon roadblock some 10 or so years from now, when silicon-based electronics reaches its size limit. One such technology is based on controlling and manipulating the quantum mechanical spin of charge carriers with which information will be encoded. Wolf *et al.* (p. 1488) review this emergent field of spintronics and describe some of the problems (and advances) associated with materials preparation, device design, and the injection of spins into materials and their manipulation to perform logic operations.

The many-body aspect of magnetic systems makes the task of calculating a low-energy configuration of the spin ensemble a formidable one. Because a full quantum mechanical description is presently intractable, other mathematical models need to be developed so that a fuller understanding of such complex interactions can be realized. Bramwell and Gingras (p. 1495) review the theoretical understanding of a particular many-body magnetic system—the spin-frustrated magnet—the results of which may be applicable to other complex systems.

The richness of the theory developed to describe magnetic systems is on a par with that of other many-body interacting systems, such as the field of high-temperature superconductivity. But although the latter has yet to find its footing outside niche applications, the development of magnetic systems has largely kept pace with microelectronics, forming the workhorse of information technology. **–IAN S. OSBORNE**

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## REVIEWS



***See also Report on p. 1503.***

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