tubules revealed "sliding" of mono-oriented chromosomes toward the spindle equator along other K-fibers through this lateral association, bringing the unattached sister kinetochore into range of microtubules from the distal pole (see the figure). Such excursions do not always result in capture, but they increase the probability that bipolar chromosome attachments can form.

The observed frequency of these chromosome movements suggested that sliding of unattached kinetochores along other K-fibers occurs commonly. In fact, under conditions (chemical inhibitors that perturb mitotic progression) that allowed congression and bi-orientation to be followed in a large population of chromosomes synchronously, Kapoor *et al*. observed that ~85% of kinetochores were paired such that one sister chromatid attached to a pole and the other laterally associated with a mature K-fiber from a different, bi-oriented chromosome that stretched toward the metaphase plate. This indicates the predominance of this congression mechanism to promote chromosome bi-orientation. By combining their chemical inhibitor–based assay with RNA interference, a technique capable of depleting a specific protein from cells, Kapoor *et al*. could investigate the factors behind kinetochore sliding along a lateral K-fiber. Their hunch was that the microtubule-based motor CENP-E, a member of the kinesin-7 family, was involved, because this protein localizes to the kinetochore during congression and moves with the correct polarity—toward microtubule "plus" ends that are uniformly oriented toward the metaphase plate in kinetochore fibers (*5*). Although kinetochores could still capture microtubules after CENP-E depletion, mono-oriented chromosomes that were not transported toward the metaphase plate accumulated at spindle poles. Thus, CENP-E is likely the motor responsible for gliding unattached sister kinetochores along neighboring K-fibers, helping mono-oriented chromosomes achieve congression before bi-orientation. These findings are the first to indicate bona fide kinetochore motility depending on CENP-E. Chromosome congression defects observed upon CENP-E inhibition were previously attributed to a role in microtubule capture and/or in maintaining kinetochore attachment to dynamic microtubules (*6*). CENP-E also contributes to a checkpoint signaling pathway that monitors kinetochore status (*7*), making it a central player in both the process and the fidelity of spindle function.

The spindle is a remarkable cellular machine, and the work by Kapoor *et al*. demonstrates that we are still uncovering its fundamental mechanisms. The findings explain why chromosome congression is a cooperative process, accelerating as more and more chromosomes gain bipolar attachments that can serve as tracks for mono-oriented chromosomes to congress. Once chromosomes are bi-oriented, they oscillate along the spindle axis as K-fiber microtubules coordinately polymerize and depolymerize at their plus ends. Although a large constellation of kinetochore proteins has been identified, it remains unclear which factors are operating at the dynamic kinetochore-microtubule interface, and how they are functioning. Combining state-of-the-art imaging, chemical biology, and molecular dissection is a great paradigm for elucidating the mechanistic principles of mitosis.

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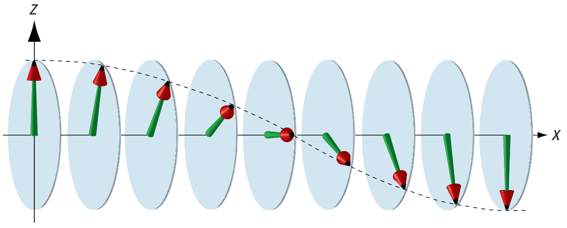
APPLIED PHYSICS

Helical Spin Order on the Move

Franco Nori and Akira Tonomura

In magnetic materials, electron spins are arranged in parallel, antiparallel or other regular configurations. Electron microscopy of certain of these materials reveals the details of atomic spins that appear to be arranged in a helix.

Magnetic materials can be thought of as assemblies of billions of miniature magnets called spins. These tiny microscopic magnets can be arranged in several possible configurations, depending on how the spins line up. When all the spins are aligned with each other, they form ferromagnets, examples of which can be found on most refrigerator doors. Here, the prefix "ferro" refers to iron, which is magnetic and naturally displays this kind of parallel-spin order. Another type of magnetic order is antiferromagnetic, in which nearby spins are oriented opposite to each other. Spin arrangements more complex than these can occur, however. An example is helical spin order (see the first figure). As its name suggests, this is a helix-like arrangement of the spins distributed along chains. Like a tiny magnetic corkscrew, the spin direction rotates around the axis of the helix (*1*). These microscopic arrangements of spins can be measured by techniques such as neutron scattering. Such methods, however, yield data in reciprocal space, which requires conversion to a real-space representation.



Spin order. Schematic diagram of a helical spin order.

As reported on page 359 of this issue, Uchida *et al.* (*2*) have taken the first steps to directly visualize helical spin order and especially its dynamics in real space. The spatiotemporal behavior of the magnetic spin order reported by Uchida *et al.* (*2*) is richer than expected from the averaged structure probed in the past via neutron scattering. In particular, the helical spin order exhibits a variety of magnetic defects similar to atomic dislocations in crystal lattices. By applying magnetic fields, the researchers (*2*) directly observed the deformation processes of the spin order, accompanied by nucleation, movement, and annihilation of magnetic defects.

To observe the helical ordering, Uchida *et al*. (*2*) bombarded the thin sample with electrons of sufficiently high energy to penetrate the interior of the sample. Electrons are sensitive to the magnetic fields produced by the spins. Thus, the deflection of their straight incident trajectories provides information about the spin arrangement inside the sample (see the second figure). Very fast electrons bombarding the sample are deflected by the Lorentz force: $\mathbf{F} = q\,(\mathbf{v} \times \mathbf{B})$. Here q and $\mathbf{v}$ are the electron charge and its velocity vector, and $\mathbf{B}$ is the magnetic induction vector. Only the $\mathbf{B}$ components perpendicular to the electron beam can cause deflection of the beam. The distribution of deflections, produced by magnetic structures, can be observed not in an in-focus electron micrograph but in a very defocused observation plane, since the deflection angle is extremely small. This technique, called Lorentz microscopy (*3*), has been used to directly observe magnetic domain structures in ferromagnetic materials. To be more precise, however, the incident parallel electrons have to

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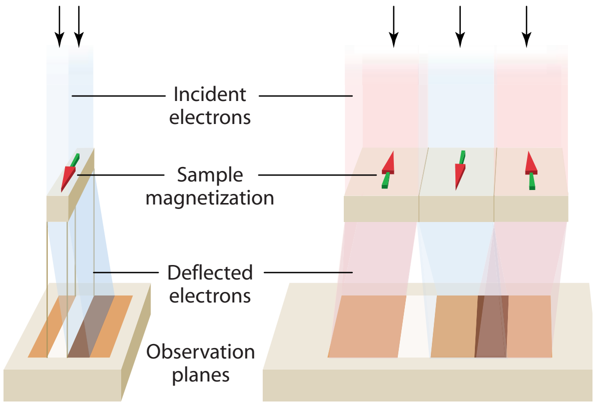
be regarded as a plane wave that interacts with the tiny magnetic fields inside the sample. In this representation, the phase of an electron wave is changed as it passes through a magnetic object, and the resulting phase changes, which cannot be directly observed, are transformed into observable intensity variations by image defocusing [see p. 151 in (*4*)].



Viewing magnetic order. Schematic diagram of how Lorentz microscopy can be used to observe magnetic structures in materials for (**left**) a single domain and (**right**) three domains. The incident electrons from the top are deflected by the sample magnetization, forming dark regions (bombarded by more electrons) and lighter regions (with fewer incident electrons) in the bottom observation plane. White color in the bottom observation plane means that no electrons hit the plane. For simplicity, only deflected electrons are shown in the observation plane on the right side.

Lorentz microscopy has been much improved through the use of a bright and collimated field-emission electron beam (allowing detection of a slight deflection of the "probe" electrons) combined with a low-temperature specimen stage. This has allowed observations of microscopic magnetic structures emerging even in low-temperature regions [see p. 147 in (*4*)], including vortices in superconductors [see, for example, (*5*)]. Magnetic domains that are likely produced by helical spin order were observed by Uchida *et al.* (*2*) using this improved technique. However, this technique only reveals the projected in-plane magnetic structures, because electrons interact with magnetic field components perpendicular to the electron trajectory. As a result, it cannot be conclusively determined with this technique whether the observed structure is really helical, or simply two-dimensional domains. Other methods will be needed to confirm the helical structure.

In order to capture all the information about magnetic structures, the specimen must be observed from various directions. In fact, one of us (A.T.) and collaborators have devised a method (*6*) based on electron holography (*4*), in which vector fields such as magnetic fields can be determined from the phase distributions of the transmitted electrons observed from various directions, when the sample is tilted around two perpendicular axes. The study of the rich spatiotemporal dynamics of magnetic domains by Uchida *et al.* (*2*) is remarkable, even though they observed the projected, and not three-dimensional, magnetic structures. It should be possible to obtain the latter with the use of electron holography, which could provide a fuller picture of the behavior of spins, including the formation of tiny magnetic helices. Indeed, monitoring the spatiotemporal dynamics of spin structures is like making movies of the billions of spins inhabiting the sample. This provides an unprecedented direct view inside magnets, revealing essential information about the properties of magnetic materials and the many devices using them.

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ASTRONOMY

Nucleosynthesis in Binary Stars

C. Simon Jeffery, Christopher A. Tout, John C. Lattanzio

Nearly all elements in the universe heavier than helium are synthesized in stars. Binary stars, because they exert strong influences on one another, have contributed more elements than previously recognized.

The past decade has seen a revolution in the study of stellar evolution and nucleosynthesis, both in observations and theory. Despite this progress, however, the role of binary stars has been much neglected. Although their importance in iron production in some supernovae and in the production of rare isotopes of carbon, nitrogen, and oxygen in novae has been known for some time, binary stars have been treated only in isolation. Some effort to redress this situation was made in 1998 when Tout *et al.* (*1*) considered a full population of binary stars and showed how they could systematically alter the chemical evolution of carbon from one generation of stars to the next. This is because the largest stars, the asymptotic giant branch (AGB) stars, are a major source of carbon and are also the stars most likely to interact in a binary system. Recently, a more complete accounting was given at the Lorentz Workshop on Nucleosynthesis in Binary Stars, held in April 2005 (*2*). This international gathering of experts in the field and others interested in stellar evolution and nucleosynthesis featured presentations of data, models, and lengthy discussions on what problems should be tackled and how.

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Stars are the cosmic factories that manufacture nearly all atoms heavier than helium. The mechanisms that dredge these nuclei from the stellar interior and distribute them through space are crucial to seeding the next generations of stars and planets. The main events are the explosions at the end of stars' active lives, whether in supernovae (massive stars) or ejection of planetary nebulae (less massive red giants). In a cosmic recycling exercise, this material forms new stars with an enriched chemical composition. A preliminary to quantifying the effects of binary stars on these processes is, of course, a detailed understanding of the processes operating in single stars. The Lorentz Workshop began with presentations by some of the main contributors to this area from recent years, including Norbert Langer, Roberto Gallino, Lionel Siess, and John Lattanzio. Specific talks on type Ia supernovae were given by Chris Tout and Sung-Chul Yoon.

The first generation of stars must have formed essentially from hydrogen and helium, the only species produced by the Big Bang. No observations have ever found these stars. Possibly this is because they were all relatively massive and all died out long ago. But when they died they ejected newly formed elements into space. A second generation of stars formed from these ejecta, and it is likely that these stars have been identified in recent surveys of the galactic halo. Astronomers measure the compositional age of a star by using the concept of "metallicity." Traditionally, but incorrectly, astronomers refer to all species heavier than

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