

MAGNETIC HELICITY ATTRACTS INTERDISCIPLINARY PARTICIPATION AT CHAPMAN CONFERENCE

During the last 5 years interest in magnetic helicity has grown dramatically in solar physics as a result of improved capabilities to measure and image magnetic fields. Magnetic helicity was introduced by K. Moffatt in the late 1950s as a topological invariant that describes the complexity of a magnetic field. The topological aspect of helicity is readily visualized in a Moebius strip, in which the system of interest is closed and helicity takes two forms, the writhing of the central axis of the strip and the twisting of the edges of the strip about that axis.

In many plasmas (but not atmospheres like that of Earth, for example), helicity is conserved, just as the sum of twist and writhe is conserved in a Moebius strip. Mathematically, it is related to linking integrals, which K. F. Gauss employed to study asteroid paths on the sky. In the late 1970s the concept of magnetic helicity was introduced in laboratory plasma physics, turbulence theory, space physics, and statistical theory.

Participants at a Chapman Conference on "Magnetic Helicity in Space and Laboratory Plasmas" discussed the use of the concept of magnetic helicity to better understand magnetic fields in space and laboratory plasmas. The conference brought together solar and space physicists, laboratory plasma physicists, astrophysicists, and pure mathematicians well versed in the concept to share their understanding and apply it to a new discipline.

An exciting aspect of the meeting was the demonstration that the helicity of magnetic fields observed at the solar surface, in the solar corona, and in the solar wind that streams out past Earth, contains unique and useful signatures of the physical conditions and processes deep below the Sun's visible surface, or photosphere. In the last decade the techniques of helioseismology have revealed strong velocity shear at the interface between the Sun's radiative core and its convection zone. Theorists and modelers at the conference demonstrated that indeed one should expect magnetic fields generated there to gain twist as part of the dynamo process. However, other mechanisms for twisting magnetic fields were proposed and shown to work, as well.

Solar physicists believe that the magnetic flux responsible for sunspots and active regions at the photosphere has survived a long journey through the convection zone. Recent work on the effects of convection zone turbulence on such flux was presented at the meeting. Putting this work with that of the dynamo theorists, one would plausibly infer that buffeting by such turbulence is the dominant source of twist, not the dynamo. However, it has been shown that unless the dynamo imparts significant twist to flux generated before the buoyant rise to the surface begins, the flux will be highly fragmented, contrary to observation.

Atmospheric physicists would expect the Coriolis force to cause convective flows to have a preferred net sign of helicity, or handedness, in each hemisphere, and would expect that sign to change across the solar equator. The observations confirm that such asymmetry exists throughout the solar atmosphere – in the photosphere, the corona, and the solar wind. The observed handedness of the helicity of the magnetic fields in all these regions supports the notion that the solar dynamo operates in the interface between the solar convective and radiative zones, in agreement with modern solar dynamo theory. It does not seem to support dynamos operating in the bulk of the convection zone. Not all participants,

however, agreed with this interpretation. It was shown that a dynamo may operate even under purely random motions. In that case, the observed hemispheric asymmetry might be explained by the interaction between rising magnetic flux tubes and turbulent flows in the convective zone.

It was also noted that a dynamo operating in the bulk of the convection zone may produce helicity of both signs. Helicity of one sign may evolve toward small spatial scales and dissipate, but helicity of the opposite sign may relax toward larger spatial scales and appear in the observational data. Experiments in laboratory plasmas support such inverse cascading. Also, several numerical experiments were shown which demonstrated that large-scale surface motions, including solar differential rotation, may twist magnetic field and thus produce magnetic helicity not related to dynamo action. Most participants, however, agreed that the preponderance of evidence indicates a sub-photospheric origin of the helicity of magnetic fields on the Sun.

In 1975 J. B. Taylor predicted that as a magnetized plasma relaxes, its magnetic field will evolve toward a force-free state, conserving total magnetic helicity. The results of laboratory plasma experiments presented at the conference support Taylor's conjecture; the magnetic energy evolves toward small spatial scales and dissipates much faster than magnetic helicity, which cascades toward larger spatial scales. However, conservation of magnetic helicity is applicable only for closed magnetic systems; locally, helicity may show significant changes. This imposes a major problem in applying the helicity concept to the Sun, whose magnetic fields can be observed at only certain atmospheric levels, not throughout the system.

Magnetic reconnection is another phenomenon in which magnetic helicity may play an important role. In laboratory plasmas magnetic helicity plays a role in the orientation of the magnetic field, and hence may either accelerate or hinder reconnection. The Sun, however, behaves differently from a laboratory plasma. It seems that in case of reconnection on the Sun, electric current closure is a more important factor to reconnection than is magnetic field orientation. An opposite opinion was expressed, however, that perhaps the role of helicity is overestimated, at least for reconnection in solar plasmas. This view is based on the expectation that although helicity is a global parameter, reconnection is a local process, and magnetic helicity simply follows the changes in topology after reconnection. Although magnetic helicity is conserved in a global sense, it may be redistributed locally between magnetic systems as a result of reconnection. Such helicity exchange may lead to instability in a system with higher helicity. Some solar flares and jets may be understood in the framework of helicity exchange processes. Numerical simulations and solar observations presented during the conference showed several examples of eruptive events related to transfer of helicity and instability. Geometry similar to solar prominences is being created in laboratory experiments to study the effects of magnetic helicity on stability.

Measurements of the magnetic helicity in the solar wind reveal hemispheric sign asymmetry, similar to the photospheric and coronal data. But does this asymmetry indicate a helicity continuity from the interior of the Sun to the outer heliosphere? One point of view is that the magnetic field is constantly removed from the Sun, carrying out helicity generated by the dynamo. Another is that the magnetic field gets disconnected from the solar surface as a result of several reconnection events. Thus the magnetic field leaving the

Sun carries magnetic helicity of one sign, leaving behind magnetic helicity of the opposite sign. It is unclear how this process may influence the solar dynamo itself. The theory predicts a cycle-related variation of magnetic helicity on the Sun, although it is totally unrelated to helicity accumulation.

Solar eruptions – in particular coronal mass ejections, which are among the most dramatic and spectacular of solar events – carry magnetic flux and helicity from the Sun. When the erupted magnetic field reaches the orbit of the Earth, it interacts with the magnetosphere, causing magnetic substorms. The severity of the substorm depends on the orientation of the magnetic field that impinges on the magnetosphere, which in turn depends on the hemisphere on the Sun from which the field erupted and on its helicity.

The concept of magnetic helicity also has been successfully applied to various galactic and extragalactic objects from the early universe to star formation to stellar and galactic dynamos. The dramatic behavior of jets from active galactic nuclei clearly implies the presence of twist-related instabilities and suggests that awareness of helicity has a role to play in understanding its nature. In general, however, the helicity approach has not yet been widely applied in the study of astrophysical objects. Plans are for the invited talks at the conference, which was sponsored by NASA and the National Science Foundation, to form the basis of a book in the American Geophysical Union Monograph Series. Abstracts of both invited talks and contributed papers are available on the Web:

http://solar.physics.montana.edu/chapman/program_draft/index.html

Further information on helicity can be found at the "Helicity on the Web" site:

<http://solar.physics.montana.edu/chapman/webhelicity.html>.

The Chapman Conference on "Magnetic Helicity in Space and Laboratory Plasmas" was held in Boulder, Colorado, July 28-31, 1998.