GMAG NEWSLETTER

A Focused Group within The American Physical Society

Issue Nº 6, October 1999, Edited by R Bruce van Dover

March, 2000 Meeting in Minneapolis, MN

GMAG is sponsoring two Invited Symposia:

New Phenomena in Exotic Magnetic Materials

Magnetic Recording Media

We are also sponsoring a focus topic on Magnetic Recording, and contributed abstracts are solicited for this topic (see below). The total number of sessions organized for the topic will be dictated by the number of contributed abstracts received, and the sessions will then consist of a few invited talks surrounded by contributed talks. Depending on how much interest the topic generates, in subsequent years the topic can be continued with an appropriate number of invited talks (typically about one invited talk for each session filled).

GMAG Focus Session Sorting Category 6.9.1—Physics of High-Density Magnetic Recording

Recent demonstrations of very high areal density magnetic recording have started to approach regimes that probe fundamental limits of current recording technology. Typical dimensions in magnetic recording on hard magnetic media are rapidly approaching meso-/microscopic length scales, and conventional scaling arguments utilized in the design of recording systems will no longer apply. It is becoming increasingly clear that further understanding of fundamental physical phenomena associated with media grain size, noise and stability, thin-film micromagnetics, thermodynamics and dynamics, spin transport, and magnetic interfaces, is required, in order to substantially increase areal densities beyond present capabilities. This session focuses on critical aspects of the magnetic recording process and the associated underlying physical mechanisms which limit high-areal densities (including high data rates and thermal stability) as well as efforts being made to develop and understand novel alternatives to traditional recording within the framework of magnetic-transducer based technology, such as perpendicular recording and patterned media.

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Contributed abstracts should be submitted electronically, using the sorting category 6.9.1, by the deadline of December 3. The web address for submission is http://abstracts.aps.org

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Editors note:

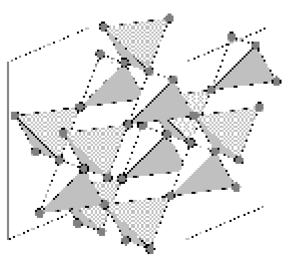
Following is a another brief technical article on a timely subject we hope you will find it interesting. Suggestions for future articles are welcome—feel free to nominate yourself, if you can write an introductory page or two on a timely subject of broad interest.

—R Bruce van Dover

Geometrically Frustrated Magnets:

New Physics in Novel Ground States

Geometrical frustration in magnets occurs when the geometry of the lattice on which spins are located prevents the simultaneous minimization of the exchange energies between the pairs of spins in the system. Such frustration is typically associated with triangle-based lattices such as the kagomi or the pyrochlore structures, and the most interesting physics arises when the competition between different exchange energies is closely balanced, leading to a large number of nearly degenerate spin states and low-lying excitations.



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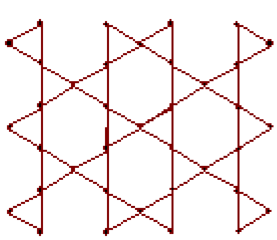

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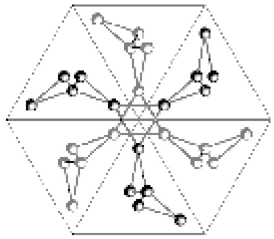

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Figure 1 Examples of geometrically frustrating magnetic sublattices: a. pyrochlore, b. kagomi, and c. garnet structures.

Geometrical frustration in magnetic materials has been theoretically predicted to lead to a variety of novel magnetic ground states, and such phenomena have recently been observed in a wide range of compounds. In each of these materials, the frustration suppresses spin ordering of any sort to temperatures well between the energy scale of the spin-spin interactions. Some of the materials, such as the pyrochlore $Y_2Mo_2O_7$, exhibit behavior which is demonstrably equivalent to spin glass transitions in disordered magnets despite the virtual absence of disorder. Others, such as the kagomi compound $SrCr_{9p}Ga_{12-9p}O_{19}$ or the pyrochlore $CsNiMnF_6$, display such transitions yet have been shown by neutron scattering and other probes to have "spin-liquid" properties, i.e. a large fraction of the spins continue to fluctuate at temperatures which are orders of magnitude below the energy scale of the exchange interactions. It is clear that geometrically frustrated magnets as a class of materials have magnetic ground states unlike those of other magnets, and these new states are only beginning to be understood. Summarized below are three examples of newly discovered low temperature behavior associated with geometrical frustration:

Cooperative Paramagnetism ($Tb_2Ti_2O_7$) -- In this pyrochlore material, the Tb spins have nearest neighbor antiferromagnetic interactions which result in a Curie-Weiss temperature of -19 K. Despite this relatively strong spin-spin interaction, Gardner et al. [1] showed through neutron scattering and muon-spin-resonance studies that there is no magnetic order of any sort down to temperatures of 0.07 K. This spin-liquid-like state of "cooperative paramagnetism" at low temperatures is attributed to the spins being antiferromagnetically correlated within weakly coupled tetrahedra which fluctuate down to the lowest temperatures.

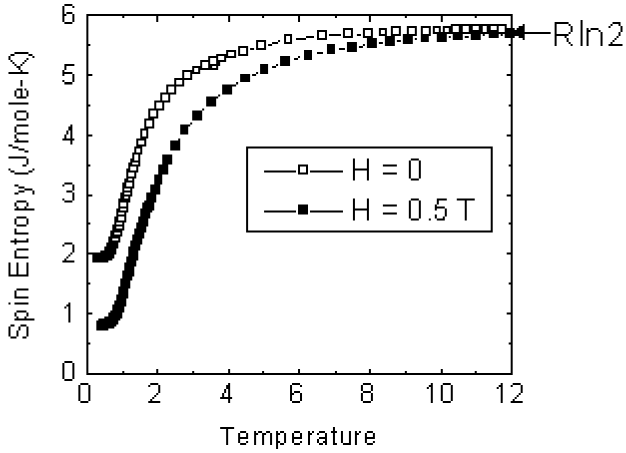

Figure 2 The reduction from Rln2 of the magnetic entropy of the spin ice compound $Dy_2Ti_2O_7$. The entropy is shown to be non-zero as T 0, and in zero applied field is almost precisely the expected value for ice. The residual entropy is reduced by an applied magnetic field [3].

Spin Ice ($Dy_2Ti_2O_7$ and $Ho_2Ti_2O_7$) -- These pyrochlore magnets have ferromagnetic nearest-neighbor interactions, but because the spins are Ising-like with a [111] anisotropy axis, these interactions are frustrated in the pyrochlore geometry. This sort of frustration has been shown to be exactly analogous to the configuration of the hydrogen atoms in frozen water, and therefore this sort of magnetic system has been dubbed "spin ice" [2]. In exact analogy to ice, Ramirez et al. showed that the ground state of $Dy_2Ti_2O_7$ has a zero point molar entropy of 0.5Rln(1.5), which is the expected value for water ice (see figure 2) [3]. Application of an external magnetic field breaks the symmetry of the systems, reduces the degeneracy of the states, and hence reduces the ground state entropy. Further application of a field induces a long range ordered state in both systems.

Analog to the ^{4}He Melting Curve ($Gd_3Ga_5O_{12}$) -- This garnet, which is commonly used as a substrate and known as gadolinium gallium garnet (GGG), has a three dimensional magnetic sublattice composed of corner-sharing triangles analogous to the kagomi structure. GGG has a spin-glass-like ground state in low magnetic fields ($H < 0.08$ T) as well as a long-range-ordered antiferromagnetic ground state in strong magnetic fields ($0.7 > H > 1.5$ T). At intermediate fields, however, the spin state is spin-liquid-like, showing no signs of long range order, and is demonstrably distinct from the spin glass phase. The boundary between this liquid-like phase and the long-range ordered phase has been shown to have a minimum which is analogous to the melting curve of ^{4}He in that the liquid-like disordered phase has less entropy near the boundary than the long-range ordered phase (see Figure 3) [4].

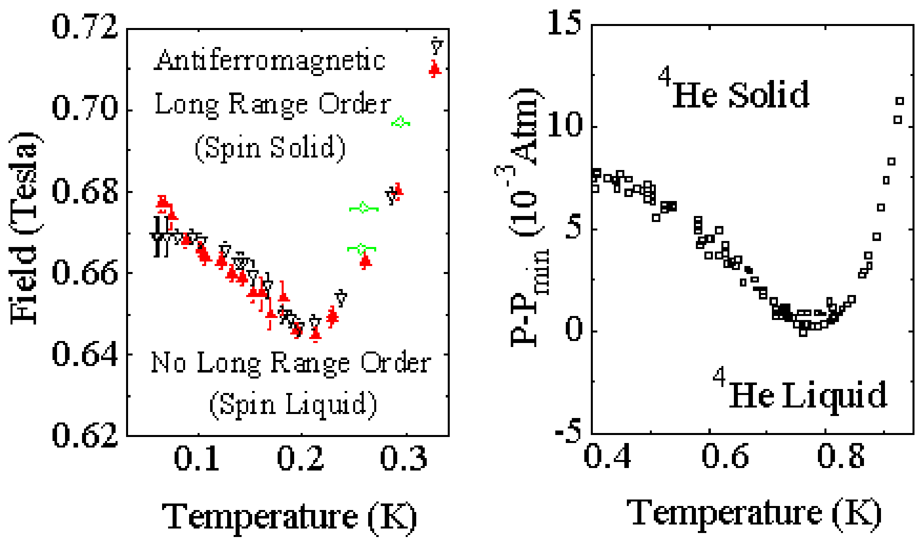

Figure 3 The phase boundary between the spin-liquid-like and the long range ordered magnetic phases of GGG and the analogous phase boundary between the superfluid and solid phases of ^{4}He. The minimum in the phase boundary in each case implies that the liquid-like state has less entropy than the ordered state. The physical origin of the entropy difference in the case of ^{4}He is in the number of excitation modes in the two phases, and the explanation for the case of GGG is likely to be similar. (The ^{4}He phase boundary data are from G. C. Straty and E. D. Adams, Physical Review Letters **17**, 290 1966).

The collective progress represented by these and other recent studies of geometrically frustrated magnetic materials represents a new phase in the experimental study of this class of materials. This progress, combined with extensive recent theoretical work on geometrically frustrated magnets, anticipates a wide array of new magnetic phenomena based on frustration awaiting to be discovered and understood.

1. J. S. Gardner et al., Physical Review Letters **82**, 1012 (1999).
2. M. J. Harris et al., Physical Review Letters **79**, 2554 (1997) and Physical Review Letters **81**, 4496 (1998).
3. A. P. Ramirez et al., Nature **399**, 333 (1999).
4. Y. K. Tsui et al., Physical Review Letters **82**, 3532 (1999).

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GMAG Exhibit Booth at the Centennial Meeting—A Great Success!

At the APS Centennial Meeting in Atlanta in March, Phil Wigen (Ohio State) organized a GMAG booth with some magnetics demonstrations, computer simulations and toys. The toys included an apparent violation of Earnshaw's Theorem (that you can't suspend a magnet in a static field) developed by Martin Simon (UCLA)—the trick is to include a diamagnet (graphite). Fred Jeffers (Kodak) suggested a demonstration of the anisotropy of the attraction between a striped refrigerator magnet and a recording tape -- the magnet will slide off the tape parallel to the stripes but not perpendicular to them. A high frequency magneto-optic device for non-destructive imaging of cracks in riveted sheet metal (aircraft skin) was demonstrated by Jerry Fitzpatrick (PRI). There was a very attractive poster on micromagnetics by Bob McMichael (NIST), which elicited many requests for copies suitable for framing. The computer simulation (by Pieter Visscher and Mourad Benakli, U. of Alabama) followed a magnetic colloid around a hysteresis loop, showing the reversing particles in one window at the same time that the hysteresis loop was traced in another. An informative poster describing ferrofluids was contributed by Stephen Arnold (NIST Boulder) and was accompanied by a demonstration (brought by Gary Mankey, U. of Alabama) of the "hedgehog" effect. This involves the spontaneous formation of a hexagonal array of conical projections from a ferrofluid surface when a field is applied normal to the surface. It is an experimental realization of a 2D coulomb lattice—the strongest pole densities in the system are at the tips of the cones, and they repel each other with a 1/r coulomb potential.

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http://www.as.ua.edu/physics/visscher.html

Editors note:

The ad hoc Display Committee did a great job of assembling reliable, interesting demos, as corroborated by the fact that the GMAG display was one of the most well-attended booths at the Centennial meeting.

Note that GMAG also co-sponsored the Neutron Poster.

Members of GMAG also contributed to other posters, notably the 20th Century Physics Timeline, which can now be viewed interactively at http://timeline.aps.org.

The wall chart version of that poster can be ordered at http://www.aps.org/timeline/order.html.

Editors note: The levitation demonstration at the Centennial Meeting GMAG Display drew a great deal of interest, so we asked the inventor to write a short article describing *the demo. Here it is.*

-R Bruce van Dover

Room tesmperature magnet levitation

With the help of weakly diamagnetic substances like graphite or bismuth, it is possible to construct a very stable permanent magnet levitator that works at room temperature without energy input.

At first glance, static magnetic levitation appears to contradict Earnshaw's theorem. Earnshaw showed that there is no stable equilibrium for charges or magnets in free space if the fields are divergenceless and irrotational. However, Earnshaw didn't consider the effects of paramagnetic or diamagnetic materials.

In this levitator, the floating magnet is naturally stable in the horizontal plane and unstable vertically. The addition of diamagnetic plates adds a small repulsive force as the magnet moves off the equilibrium position. For simplicity here, we use a dipole approximation which is valid when the floater, with dipole moment *M* and weight *mg*, is far from the plates.

Adding diamagnetic plates with susceptibility above and below the equilibrium position *z*=0 with a separation D (see figure 1) gives the energy due to the diamagnetic plates as

$$U_{dia} = \frac{6\mu_0 M^2 |\chi|}{\pi D^5} z^2 \quad (1)$$

At the equilibrium position the magnetic field gradient from the lifter magnet must balance the force of gravity or *MB'=mg*. The vertical stability condition is

$$\frac{12\mu_0 M|\chi|}{\pi D^5} > B'' > \frac{m^2 g^2}{2M^2 B_0} \quad (2)$$

In these expressions the lifter magnet field is expressed in terms of B_z and its derivatives with respect to *z* evaluated at the levitation point. The limit on the diamagnetic gap spacing in the dipole approximation is

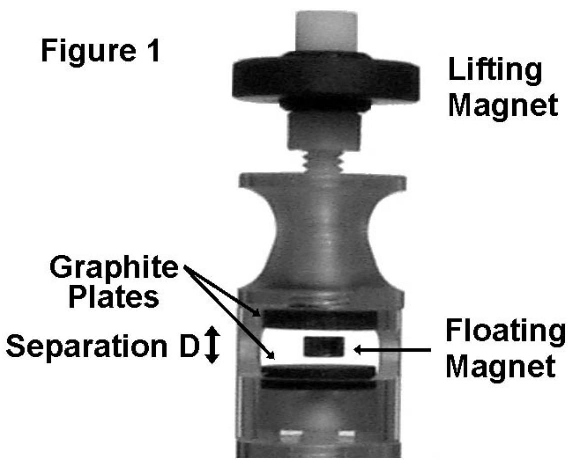
$$D < \left\{\frac{12\mu_0 M|\chi|}{\pi B''}\right\}^{1/5} \quad (3)$$

It is interesting to note that there is another equilibrium point slightly higher (on the upper side of the inflection point $B'' < 0$ where the floating magnet is stable vertically but unstable horizontally. This levitation can be stabilized by a hollow cylinder of diamagnetic material.

Bismuth and graphite have a susceptibility of about ~-170 10^{-6} in dimensionless SI units. The best diamagnetic material is pyrolytic graphite which is very anisotropic. Perpendicular to its layer direction the susceptibility is ~-450 10^{-6}. Surprisingly, even fingers with ~-10 10^{-6} can be used with a larger lifter magnet to stabilize magnet levitation (*Nature,* **400,** 323–324, 1999).

I have produced a limited number of levitators for demonstration purposes. The web page at http://www.physics.ucla.edu/marty/diamag/ has links to purchase information as well as to the Nature article.

Figure 1



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21 September 1999

Highlights of the 1999 Business Meeting

(from the unnofficial minutes, reported by R Bruce van Dover)

The 1999 GMAG business meeting was held in conjunction with the APS Centennial Meeting on Tuesday, March 23, 1999 at the Georgia World Congress Center.

The meeting was called to order by the Chair, Carl Patton, at 6:00 pm. Sixteen members were present at the start of the meeting, though the number fluctuated through the meeting. Results of the 1999 elections were announced:

Chair-Elect: Si Foner
Vice-Chair: Jeff Lynn
Exec. Comm.: Ivan Schuller, Jim Rhyne

The Program Committee Chair, Jeff Lynn, pointed out that we could have more impact if we were more active in organizing Focussed Sessions. This will require more response from the membership, suggesting topics and speakers. The timeframe for these suggestions (for the 2000 Meeting in Minneapolis) is late Spring.

Jim Rhyne suggested that all APS members should have their attention directed to our Focussed Sessions, so that they might contribute relevant papers. Jeff Lynn pointed out that Focussed Sessions are indeed announced in the Bulletin, i.e., in the call for papers. One reason for the early deadline for organizing these sessions is so that they can be announced enough in advance as to secure adequate publicity.

Larry Bennett, the Chair of the Fellowship Committee, could not be present, and Jan Herbst conveyed his regrets. Jan announced that Edward Della Torre and Eric Fullerton had been nominated by GMAG for Fellowship and accepted by the APS Council. Our two new GMAG Fellows were asked to stand up and were greeted with applause.

Jan Herbst announced that Jeff Lynn had been chosen to be head of the Fellowship Committee for 1999.

There ensued a protracted discussion regarding the deadline for submission of 1999 Fellowship applications. Many felt that the present deadline (30 March 1999) is too early and makes it confusing because people are preparing applications just as new Fellows are being announced. A motion to ask the Fellowship Chair to reschedule the deadline for the 2000 applications (and later) was passed unanimously. A vote that the 1999 deadline for Fellowship Applications be 5 May 1999 was passed unanimously.

The Chair of the ad hoc Committee on Centennial Displays, Phil Wigen, described the display and pointed out that it has been one of the most well-attended of any of the displays at the Centennial. A round of applause expressed the members appreciation for the work of Phil and the other members of his committee and contributors to the Exhibit: Martin Simon, Fred Jeffers, Jerry Fitzpatrick, Bob McMichael, Pieter Visscher, Mourad Benakli, Stephen Arnold, and Gary Mankey.

Si Foner agreed to help set up an ad hoc committee with the aim of recruiting new members. Si suggested that the APS could help us by identifying contributors to our Focussed Sessions who are not GMAG members, who we could then target for recruitment.

The Secretary-Treasurer, Bruce van Dover, reported that our income for 1998 was $4116.07, our expenses were $3752.63, and our treasury balance, as of 1 Jan 1999, was $3679.28. Thus we are financially healthy.

The meeting was adjourned by unanimous vote at 6:50 pm.

INTERNATIONAL CONFERENCE ON MAGNETISM **August 6-11, 2000** Recife, Brazil	**ICM2000 Conference Secretariat** **Departamento de Fmsica** **Universidade Federal de Pernambuco** 50 670-901, Recife, PE, Brazil Phone/Fax: +55 (81) 271.8456 e-mail: icm2000@df.ufpe.br **http://www.icm2000.org.br**

ANNOUNCEMENT AND CALL FOR PAPERS

The International Conference on Magnetism (ICM) belongs to a series of triennial conferences held under the auspices of the International Union for Pure and Applied Physics (IUPAP). The most recent conferences were held in Cairns (1997), Warsaw (1994), Edinburgh (1991), Paris (1988), San Francisco (1985) and Kyoto (1982). In the year 2000, ICM will be held in Brazil. The main conference will take place in Recife, on the Northeastern coast of Brazil, from Sunday, August 6, through Friday, August 11, incorporating the Symposium on Strongly Correlated Electron Systems.

Satellite conferences and workshops will be held in Campinas, Rio de Janeiro, Belo Horizonte and Natal. Members of the international scientific and engineering communities are invited to attend ICM2000 and the satellite meetings and contribute to their technical sessions. Detailed information about the conference, accommodation and touring in Brazil are available at:

http://www.icm2000.org.br

SCOPE: ICM is designed to bring together the international community of scientists and engineers interested in recent developments in all branches of fundamental and applied magnetism, as well as to provide a forum for the presentation and discussion of new concepts, properties and developments in materials research and magnetic applications. In addition to the contributed oral and poster presentations, there will be plenary lectures, invited talks and symposia. To celebrate the turn of the century, some sessions will be devoted to reviewing the progress made in magnetism and its applications during the twentieth century and to discuss what can be expected in the near future.

ABSTRACTS: The deadline for submission of abstracts is February 1, 2000, and will be strictly enforced. All abstracts will be submitted electronically through the web site *www.icm2000.org.br*, which has all details for submission. The password to enable the submission process is *brazil2000*. Any question regarding the submission of abstracts should be sent to the Program or Publication Chairmen. Authors are requested NOT to submit an abstract unless expecting to attend the ICM2000 without financial support from the Conference. Note also that the presenting author MUST be a registered participant of the Conference. Papers may not be presented by an author who is NOT registered.

TIME SCHEDULE

August 1, 1999 Call for papers
February 1, 2000 Deadline for submission of abstracts
March 1, 2000 Notices of acceptance of abstracts sent out
May 1, 2000 Deadline for receipt of papers and normal registration
August 1-4, 2000 Ising Centennial Colloquium, **Belo Horizonte**
August 3-4, 2000 Nuclear Methods in Magnetism, **Rio de Janeiro**
August 6-11, 2000 ICM2000 **in Recife**
August 13-18, 2000 XVI International Colloquium on Magnetic Films and Surfaces, **Natal**
August 14-16, 2000 Workshop on Applications of Synchrotron Light to Magnetic Materials, **Campinas**