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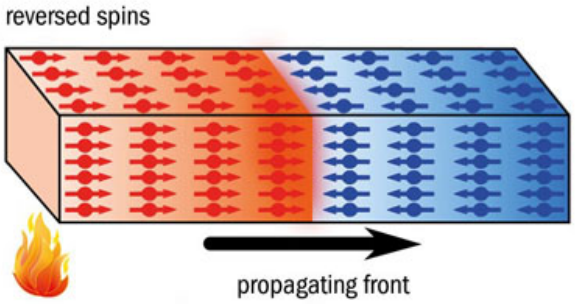
# Flipping spins spread like wildfire

May 20, 2013 1 comment




Lighting the touch paper: heat sets off magnetic deflagration

New research into how local heating sets off a chain reaction of magnetic domain reversal could provide important insights into how wildfires spread. That is the conclusion of scientists in the US and Spain, who have pinpointed with greater precision than ever before the conditions under which such a magnetic deflagration will occur. The results could provide insights into runaway chemical reactions and even forest fires.

When a magnetic domain flips from a higher-energy metastable state to a lower-energy stable state, energy is released as heat. If enough energy is released, the temperature of the surrounding domains will rise to the point that they also flip, releasing more heat. This can spark a chain reaction that rapidly causes the magnetization of the entire material to reverse direction.

Magnetic deflagration can, in principle, be observed in any material with a metastable magnetic state. Molecular nanomagnets such as $Mn_{12}$ acetate are particularly suitable. Each molecule of this crystal has a large-net-spin magnetic moment that is energetically constrained to point in one of two opposite directions. Ordinarily, these two states have the same energy; but if an external magnetic field is applied along the magnetic axis, the antiparallel spins are raised in energy relative to those parallel to the field. However, both the antiparallel and the parallel orientations have a lower energy than an intermediate orientation. This means that spins in the antiparallel direction will not flip unless they are given an activation energy, which can be delivered in the form of heat.

## Experiment and theory

In the new work, Andy Kent and scientists at New York University and colleagues at the University of Barcelona, City College of New York and the University of Florida have used experimental results to create a model describing what happens next. They mounted a single crystal of $Mn_{12}$-acetate cooled to a temperature of 0.4 K, with all its spins aligned in one direction, on an array of uniformly spaced magnetic-field sensors. They then applied a magnetic field in the opposite direction to the polarization of the spins in the crystal, leaving the spins in the metastable antiparallel state. Finally, they applied heat to one end of the crystal.

The energy released when a spin changes from an antiparallel to a parallel orientation

depends on the external magnetic field. If the field is weak, the energy is small and the heat simply dissipates. In this case, the spins reverse gradually over a period of about 80 ms as the heat from the applied heat pulse thermally diffuses along the crystal. Above a critical field, however, the energy released by one spin flipping provides enough activation energy to flip adjacent spins. In this case, the magnetic-field sensors detected a wave of spin flips propagating through the material at a constant speed, reversing all the spins in about 100 μs – nearly 1000 times faster than thermal diffusion.

## Under control

Based on their observations, the researchers derived a criterion for whether or not such a reversal will ignite. The criterion depends on several properties of the magnetic material: the activation energy of the spin-reversal process; the amount of energy released when a spin reverses; and the rate at which heat diffuses through the material. If heat diffuses away relatively slowly, the energy of adjacent magnetic domains will be raised higher by a neighbouring spin flip. The criterion, the team finds, agrees broadly with previous results from other researchers. Kent explains that, in the new work, the onset of deflagration is more precisely controlled than in previous experiments. "People were able to trigger these processes," he says, "but not to see this crossover behaviour and how the actual instability is generated. In this work we can control it and that allows us to study it."

Carley Paulsen of the Neel Institute in Grenoble was involved in the first observation of sudden spin reversal in 1994. He says that although these latest results are "not surprising", the novel experimental set-up allows new insight into the abrupt crossover from diffusion to deflagration.

In 2005 two of Kent's co-workers – Myriam Sarachik of City College and George Christou of the University of Florida – were part of a team that argued magnetic deflagration could be understood by analogy to the advancing flame front in a burning chemical. Kent now hopes that the magnetic model may help generate and test models of macroscopic fires and other exothermic chemical reactions that can take off in a similar way. "One thing that makes it really nice from the experimental point of view is that we can study these reactions and then reset the system," he says. We're not really burning anything so we don't have to throw away the ash and start again."

The research is described in *Physical Review Letters*.

**About the author**
Tim Wogan is a science writer based in the UK

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1 **shpend**
May 21, 2013 11:08 PM
Basel, Switzerland

**Burning and magnetic order are similar**

The flame temperatures of butan, propan, methan, ethin etc. are between 2000 and 3000 deg. Celsius. Chemical burning is an exothermic reaction, where $CO_2$ is produced. The C=O average bond length is 1.18 Angström. There are two possible resonance structures for $CO_2$, +O=C=O- and -O=C=O+, i.e. one electron jumps periodically from -O to +O and vice versa. The distance between -O and +O is 2.36 Angström.

Iron becomes ferromagnetic below 1043K, it is cubic and its lattice constant is 2.866 Angström.
Now we assume that electrons collide elastically with O in CO2 and with Fe atoms in ferromagnetic iron and calculate the Curie temperature and flame temperature with the same formula:
T=(pi*h^2)/[2*k_{B}*sqrt(m_{e}*M_{Fe})*2.866^2]=1043K for Electron-Fe collisions
and
T=(pi*h^2)/[2*k_{B}*sqrt(m_{e}*M_{O})*2.36^2]=2590 deg. Celsius for Electron-O collisions.

h is the Planck const.
k_{B} represent the Boltzmann const.
M_{O} and M_{Fe} are O and Fe atomic masses
m_{e} is the electron mass
pi=3.141

Yes, magnetic order and burning are similar and they are caused by elastic electron-atom collisions!