# Isothermal Magnetic Advection: Functional Flows for Heat and Mass Transfer

*by James E. Martin and Kyle Solis*

**Motivation**—Thermal transport by convection cells was first visualized in 1900 by Henri Bénard, in an experiment wherein a thin layer of liquid with a free top surface was heated from below. This experiment produced a hexagonal pattern of flow cells that Bénard attributed to the buoyancy of the fluid near the hot surface. In 1916 Rayleigh obtained a theoretical understanding of the experimental conditions that give rise to "Rayleigh-Bénard" convection—at least for the case where the liquid surfaces are bounded by contacting plates—and predicted convective rolls, circles, and linear and square patterns. In 1970 it was discovered that applying a magnetic field gradient along the thermal gradient could enhance natural convection in magnetic fluids. The enhancement is dependent upon the thermal gradient and does not lead to new flow patterns. We have now discovered a method of stimulating heat and mass transport in fluids that requires neither a thermal or magnetic field gradient, nor gravity. This method gives rise to a unique class of vigorous, magnetic field-controllable flow patterns we call *advection lattices*, which can be used to transport heat or mass along any desired direction, using only the modest fields produced by Helmholtz coils.

**Accomplishment**—The formation of advection lattices occurs when a suspension of magnetic platelets is subjected to time-dependent, *biaxial* magnetic fields comprised of two orthogonal components whose frequency ratio can be expressed as a ratio of small integers. For such *just intervals*—octaves, perfect fourths and fifths, major thirds, etc.—a variety of flow patterns can be produced whose structure is largely determined by the phase between field components. These patterns consist of a checkerboard of anti-parallel flow columns that are normal to the plane of the biaxial field, Figure 1. With the platelets we employ, vigorous flow patterns are produced with field frequencies in the low audio range.

The simplest flow pattern we have observed occurs with an octave biaxial field having a phase angle of 45°. (This phase angle is added to the high-frequency component with both components expressed as sines.) Applying this field to the platelet suspension immediately stimulates the striking flow pattern in Figure 2 (left), which consists of 1.3 mm diameter flow columns that span the 3 cm cell. Each column has a sharp tail and a diffuse tip, with the flow running from tail to tip. Tracer particle studies show that the flow rate is about 3 $cm \cdot s^{-1}$, and that adjacent columns flow in opposite directions. Figure 2 (right) shows that these columns pack "antiferromagnetically" into a rectangular lattice. This symmetric flow pattern is unique to this effect and does not occur in Rayleigh-Bénard convection, presumably because gravity breaks up-down symmetry.

**Significance**—Isothermal magnetic advection is a useful technology that enables the transfer of heat and mass without pumps, seals or contact with the fluid—even in microgravity environments—and regardless of the magnitude of the thermal gradient. It can also be used to transfer mass without transferring heat, since the column size is frequency tunable, and thus can be small enough that the flow columns act as a counter-current heat exchanger without pipes. Understanding the unique symmetries of the flow patterns is a scientific challenge, and we have only begun to explore the experimental possibilities.

**Sponsors for various phases of this work include:** DOE Office of Basic Energy Sciences

**Contact:** James E. Martin, Nanomaterials Sciences
Phone: (505) 844-9125, Fax: (505) 844-5470, E-mail: jmartin@sandia.gov

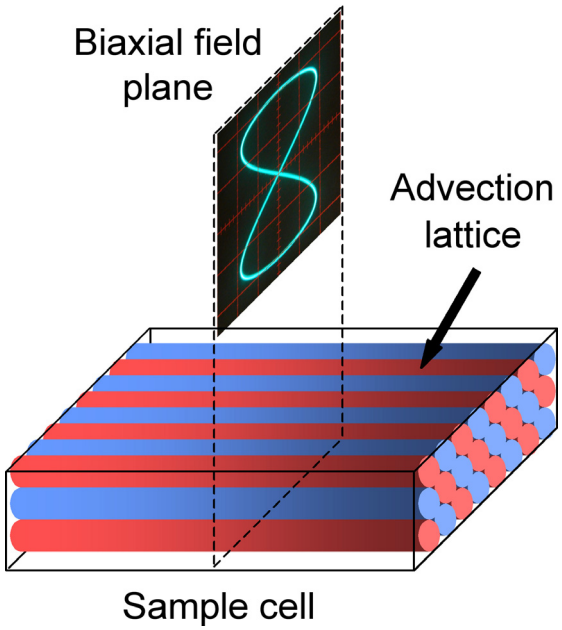


**Figure 1.** Advection lattice and biaxial magnetic field geometry. The flow columns form normal to the magnetic field plane. In this case the field components are a 2:1 frequency ratio.

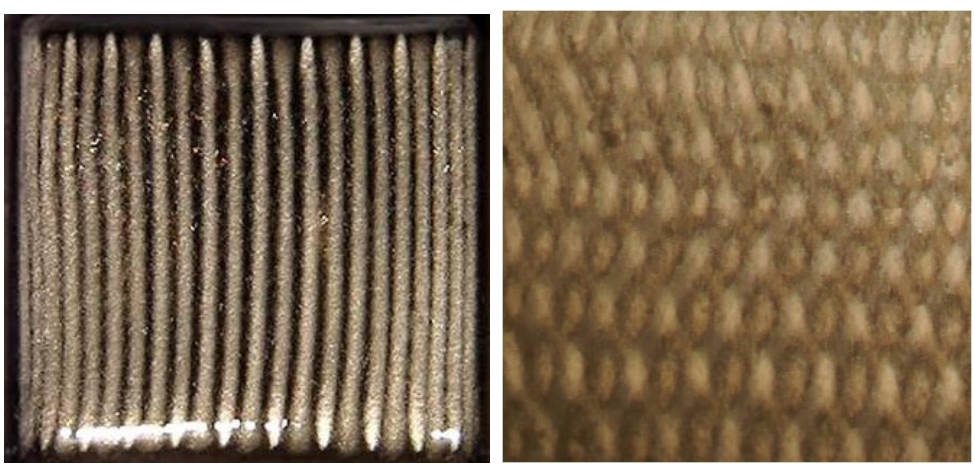

**Figure 2.** Morphology of an advection lattice. **(left),** View in the plane of the magnetic field of the advection lattice for an octave field (75 and 150 Hz components with rms amplitudes of 150 G) at a 45° phase angle. The pattern is insensitive to the boundaries, and the flow runs from the sharp column tails to the diffuse tips. **(right)** View of the advection lattice normal to the field plane shows the columns form a rectangular lattice.