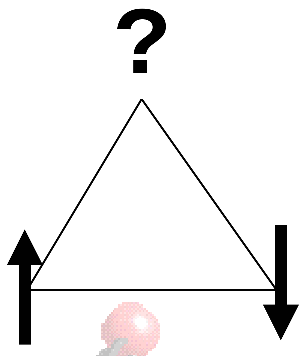
Geometrically Frustrated Magnets

We have been studying the magnetic properties of "frustrated magnets"[*see* Magnetic Systems with Competing Interaction, edited by H.T. Diep (World Scientific, Singapore, 1994)] using many magnetic probes including muon spin relaxation and neutron scattering.. These materials generally contain antiferromagnetically coupled magnetic moments on units whose geometry inhibits the formation of the usual collinear ordered state. This is easily pictured for a triangle of magnetic moments ("spins") connected by antiferromagnetic interactions that cause nearest neighbour moments to prefer an antiparallel "up-down" spin arrangement (see picture). In this situation any two moments can align antiparallel, but the third spin cannot be positioned such that it is antiparallel to both its neighbors. Geometrically frustrated magnets usually consist of a macroscopic array of such frustrated triangular units. They have interested physicists for many years for the intriguing diversity of electronic and magnetic phenomena they reveal, including spin-glass-like transitions and low temperature disordered phases. In contrast to conventional magnets, the ground state of such systems is often macroscopically degenerate; i.e. consists of a macroscopic number of different spin arrangements. It is this degeneracy that promotes exotic behavior by preventing the formation of a conventional ordered state down to extremely low temperatures.



Currently the most active area of frustrated magnet research is into magnets with a 3-D network of corner-sharing tetrahedra. Here the magnetic spins sit at the corners of a tetrahedron and two antiferromagnetic bonds are broken when collinear spins try to arrange themselves on the corners. This type of 3-D network, which can be shown to be the most frustrated of all common lattice types, can be found in the spinel, laves and pyrochlore type compounds.

These studies will be centred on the oxide pyrochlores with general composition $A_2B_2O_7$, which crystallise into a FCC structure with eight formula units per conventional unit cell [*Prog. Sol. State Chem.* **15** 55 (1983).]. The metal atoms A and B form two infinite chains of corner sharing tetrahedra. If either the A or B atoms is magnetic with an antiferromagnetic nearest neighbour interaction, then there is a high degree of frustration within the lattice and are thus good candidates for a super degenerate system. Many insulating $(RE)_2Ti_2O_7$ compounds have been studied recently because only the tri-valent rare earth ion, in its eight fold oxygen co-ordination environment, is magnetic making it a relatively simple system to deal with. These studies have revealed a variety of exotic ground states including a co-operative paramagnet at 50mK in $Tb_2Ti_2O_7$ [*Phys. Rev. Lett.*, **82**, 1012 (1999)], although the Curie constant is 20K and the moment on the rare earth site is $9.4\mu_B$/Tb ion and $Ho_2Ti_2O_7$ [*Phys. Rev. Lett.* **87**, 047205 (2001).] which is known as a "Spin Ice" compound. This new type of magnetic ground state, which includes $Dy_2Ti_2O_7$ [Nature **399**, 333 (1999)], has recently been reviewed in Science [Science **294**, 1495 (2001)].