Geometric Frustration Induces Liquid-like Ground State of Electric Dipoles

Quantum mechanical fluctuations and geometric frustration may prohibit the formation of long-range ordering even at the lowest temperature, and therefore a liquid-like ground state could be expected. A well-known example is the quantum spin liquid in frustrated antiferromagnets, which represents an exotic phase of matter and has drawn enormous attention from both theoretical and experimental aspects. Compared with the impressive progress and diversity in theory, nevertheless, clear identification of quantum spin liquids in real materials has proved challenging, with a very limited number of possible candidates found so far.

Geometric frustration and quantum fluctuations can happen beyond magnetic systems. Recently Prof. SUN Yang and Prof. YANG Yifeng from the Institute of Physics (IOP), Chinese Academy of Sciences have conceived a new type of quantum liquids in frustrated dielectrics. They propose that quantum electric-dipole liquid, an analog of quantum spin liquid, could emerge on a triangular lattice where antiferroelectrically coupled electric dipoles experience strong quantum fluctuations. To verify this concept, Prof. SUN Yang in collaboration with Prof. SUN Xuefeng from University

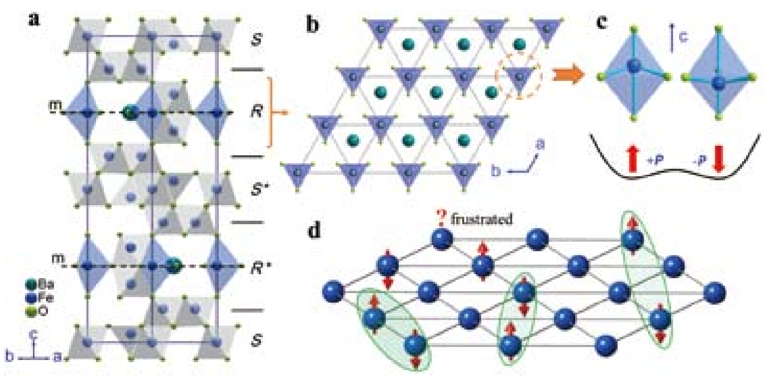

Fig.1 Uniaxial electric dipoles on a triangular lattice in $BaFe_{12}O_{19}$. (Image by courtesy of IOP)

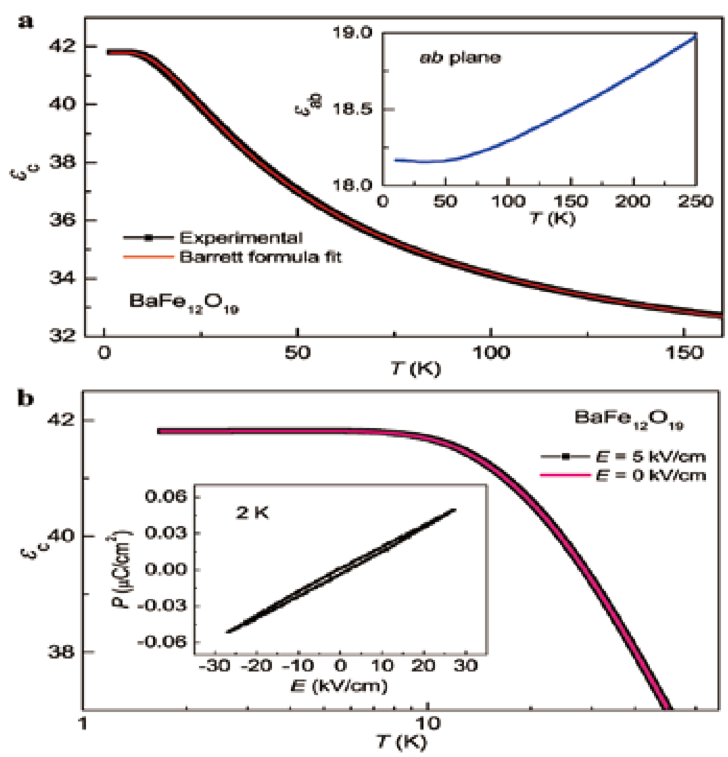

Fig.2 Quantum paraelectric behavior of $BaFe_{12}O_{19}$. (Image by courtesy of IOP)

of Science and Technology of China performed a careful study on a unique quantum paraelectric hexaferrite $BaFe_{12}O_{19}$. This material holds small electric dipoles originated from the off-center displacement of Fe^{3+} in the FeO_5 bipyramids as well as strong quantum fluctuations. Fortunately, these dipoles constitute a two-dimensional triangular lattice and interact antiferroelectrically. The researchers measured its dielectric permittivity, heat capacity, and thermal conductivity down to 66 mK, and found evidence pointing to an unusual liquid-like ground state. This ground state is characterized by itinerant low-energy excitations with a tiny gap much smaller than the effective dipole-dipole interaction constant. Since $BaFe_{12}O_{19}$ is a good insulator with long-range ferrimagnetic ordering, these itinerant low-lying excitations should not be due to electron or spin excitations but from electric dipoles. Thus, this liquid-like ground state in $BaFe_{12}O_{19}$ could be a possible candidate of an exotic quantum electric-dipole liquid.

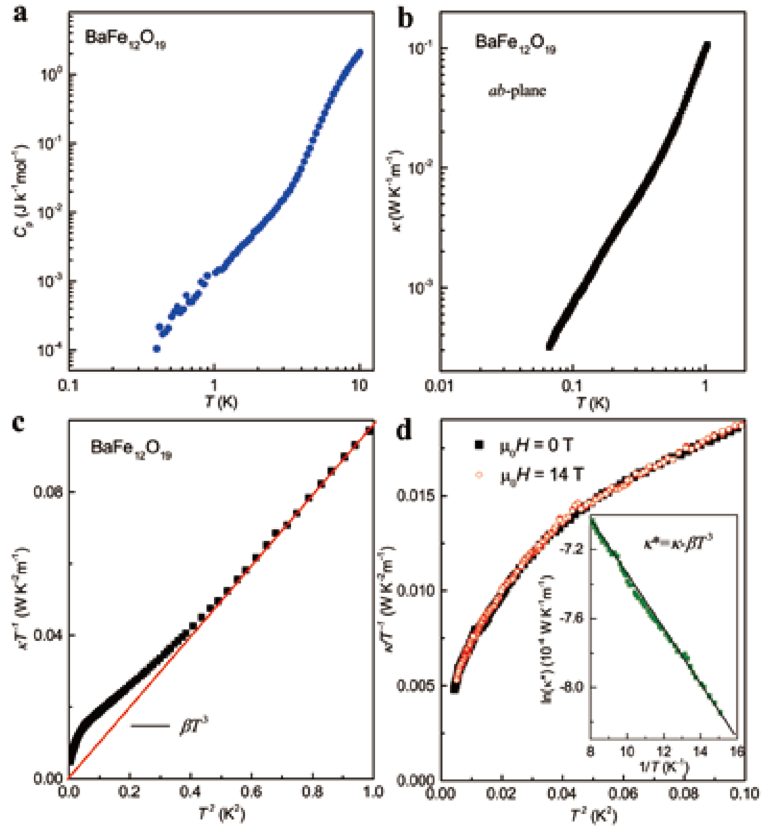

Fig.3 Heat capacity and thermal conductivity of $BaFe_{12}O_{19}$. (Image by courtesy of IOP)

Current theoretical models proposed for frustrated spin systems are inadequate for the frustrated electric dipoles, because the nature of dipole-dipole interactions is quite different from the short-range spin-spin exchange interactions. The quantum liquid states of electric dipoles in frustrated dielectrics provide a new playground for fundamental physics and may find applications in quantum information and computation as well.

This study entitled "Quantum electric-dipole liquid on a triangular lattice" was published on *Nature Communications*.

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