Antiferromagnetic fractons in percolating magnets

Shinichi Itoh and Tsuneyoshi Nakayama[1]
High Energy Accelerator Research Organization and [1]Hokkaido University

The fractal concept is based on self-similarity characterized by invariance under an isotropic scale-transformation on certain length scales. Diluted magnets with a magnetic concentration close to the percolation concentration (c_p) exhibit an ideal fractal network with a definite fractal dimension, D_f [1]. Fractons are introduced to describe vibrational modes of the fractal lattice [2]. Scaling theory suggests that the dynamics of fractons are based on the single-length-scaling postulate (SLSP), claiming that the localization length, wavelength, and scattering length (mean free path) collapse onto a single length scale, $\Lambda(\omega)$ [3]. The density of states for fractons is characterized by a spectral dimension $\tilde{d}$ as $D(\omega) \propto \omega^{\tilde{d}-1}$, where ω is the frequency. Since $D(\omega) \propto 1/\omega\Lambda^{D_f}$, the dispersion relation follows the relation $\omega \propto \Lambda^{-z}$ or $\omega \propto q^z$ with the dynamical exponent being given by $z = D_f/\tilde{d}$ [4], where the localization length is scaled as $\Lambda(\omega) \propto \omega^{-1/z}$. It has been suggested on the basis of theories and numerical simulations that the spectral dimension for antiferromagnetic fractons takes a universal value of $\tilde{d}_{AF} = 1$ that is independent of the embedding Euclidean dimensions [5]. Also, the scaling form of the dynamical structure factor for the SLSP takes the form $S(q,\omega) = q^{-y}F[q\Lambda(\omega)]$, where q is the wavenumber [2].

We observed $S(q,\omega)$ for antifferomagnetic fractons in diluted three-dimensional (3d) and two-dimensional (2d) Heisenberg systems, $RbMn_{0.4}Mg_{0.6}F_3$ and $Rb_2Mn_{0.598}Mg_{0.402}F_4$, with a magnetic concentration close to the percolation concentration ($c_p = 0.312$ and 0.598, respectively), which were obtained by means of high-resolution ($\Delta E = 17.5$ μeV) inelastic neutron scattering experiments [6]. The peak intensity $A(q)$ and the dispersion relation $E(q)$ showed the clear scaling laws following to $A(q) \propto q^{-y}$ with $y = 2.9 \pm 0.1$ and $E(q) \propto q^z$ with $z = 2.5 \pm 0.1$ for the 3d system, and $y = 2.9 \pm 0.2$ and $z = 1.8 \pm 0.2$ for the 2d system. These values agreed with theory [5], and we showed that the spectral dimension of antiferromagnetic fractons is unity independent of the embedding Euclidean dimension of the systems, because the obtained values of z were identical to D_f. Also, the validity of the SLSP for $S(q,\omega)$ were demonstrated, for the first time.

[1] T. Nakayama, K. Yakubo and R. Orbach, Rev. Mod. Phys. 66 (1994) 381.
[2] S. Alexander and R. Orbach, J. Phys. (Paris) 43, L625 (1982).
[3] S. Alexander, E. Courtens, and R. Vacher, Physica A 195 (1993) 286.
[4] R. Rammal and G. Toulouse, J. Phys. (Paris) 44, L13 (1983).
[5] K. Yakubo, T. Terao and T. Nakayama, J. Phys. Soc. Jpn. 63 (1994) 3431.
[6] S. Itoh, T. Nakayama and M. A. Adams, J. Phys. Soc. Jpn. 80 (2011) 104704.