Quantum/Spin liquids, geometrical phases and edge states

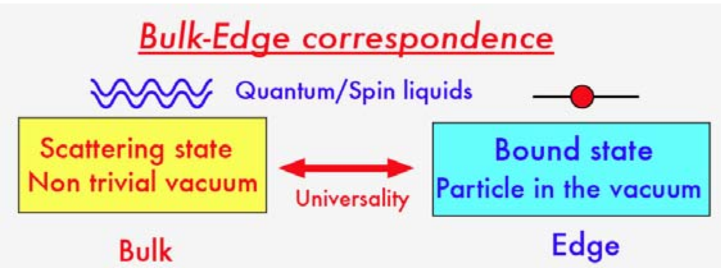
Y. Hatsugai

Institute of Physics, University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi, Ibaraki 305-8571, Japan

Strong quantum effects in low dimensional electron systems prevent formation of conventional order and result in realization of exotic phases without characteristic symmetry breaking. Such a class of states is a quantum/spin liquid where any local order parameters do not play fundamental roles. Various kinds of quantum Hall states are typical examples. Today we have a long list of states which belong to this class. It includes Haldane spin chains, spin ladders with/without ring exchanges, orthogonal dimers as Shastry-Sutherland antiferromagnets, half-filled Kondo insulators, quantum spin Hall systems and so on.

A quantum state with spontaneous breaking of continuous symmetry is supplemented by gapless excitations as the Nambu-Goldston modes. However for these quantum liquids, we do not have sufficient reasons to guarantee existence of gapless excitations. It is then natural to have a gapped quantum ground state where absence of the low energy excitation implies that they do not respond against for usual small external perturbation. As a result, a featureless quantum ground state is realized.

Even in such a situation, they are apparently interesting states and we realized wide variety among them. Therefore something to distinguish and characterize the states is required and can be quite useful. A concept of the topological orders were used here based on topological field theories about decades ago which should be compared with a standard local field theory which describes criticality by diverging local fluctuations. Recently we have noticed that geometrical phases which are intrinsic for quantum systems are useful for a description of such featureless quantum liquids [1]. Although the geometrical phase does not affect expectation values of classical (hermite) observables, it can be measured by interferences between the quantum states. The geometrical phase is a quantum observable. The Berry phase is a typical one that is defined by using a fictitious vector potential (Berry connection), which is essentially an overlap $\langle \Phi | \Phi' \rangle$ between infinitesimally different two states. We are proposing to use this Berry phases to characterize the quantum liquids and gave classifications for several class of the systems [2]. Recently we also apply the strategy to characterize the BEC-BCS crossover of the cold atoms [3] and two dimensional dimers. Also this geometrical phase is generalized for a time reversal invariant system with Kramers degeneracy where the quaternion is fundamental like the complex number is crucial for the standard Berry phase [4].



Although the bulk looks like featureless, the gapped quantum/spin liquids with boundaries show characteristic local physics by appearance of edge states. The edge states reflect non trivial topological properties of the bulk. This *bulk-edge correspondence* is also a fundamental property of the quantum/spin liquids as topological insulators. We demonstrate this for various quantum liquid systems, which include graphene and anisotropic superconductors [5] (see also above figure).

We summarize our contribution for the project, "Physics of New Quantum Phases in Superclean Materials (PSM)", as described above and present some of recent results.

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[3] M. Arikawa, I. Maruyama and Y. Hatsugai, in preparation.
[4] Y. Hatsugai, arXiv:0909.4831, to appear in New J. Phys., special issue of topological insulators.
[5] Y. Hatsugai, Phys. Rev. Lett. 71, 3697 (1993), Solid.State Comm. 149, 1061 (2009).