Quantum spin liquids induced by frustration and randomness

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Experimental quest for the hypothetical “quantum spin liquid” state recently met several promising candidate materials on certain geometrically frustrated lattices such as the triangular and the kagome lattices. The former includes certain organic salts, while the latter includes inorganic herbertsmithite. These spin-$1/2$ compounds exhibit no magnetic ordering nor the spin freezing down to very low temperature, while the measured physical quantities mostly exhibit gapless behaviors. We argue that these compounds might contain significant amount of (effective) quenched randomness of varying origin, i.e., the freezing of the charge (dielectric) degrees of freedom in the case of triangular organic salts and the possible Jahn-Teller distortion accompanied by the random ionic substitution in the case of herbertsmithite, which might be essential in stabilizing the quantum spin-liquid-like behaviors observed experimentally. We propose as a minimal model the $S = 1/2$ antiferromagnetic Heisenberg model on the triangular and the kagome lattices with a quenched randomness in the exchange interaction, and study both zero- and finite-temperature properties of the model by the exact diagonalization methods. We then find that, when the randomness exceeds a critical value, the model exhibits a quantum spin-liquid-like ground state with gapless behaviors. The low-temperature state is argued to be a “random-singlet” (or “valence-bond-glass”) state. The results seem to provide a consistent explanation of the recent experimental observations.