How do we measure bipartite entanglement for Heisenberg antiferromagnets?

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In this lecture we elucidate methods of calculating entanglement entropy in spin-1/2 Heisenberg systems. We begin by reviewing all important definitions of measures of entanglement that have been used so far: valence bond entanglement entropy, loop entanglement entropy, Renyi entropy and the most basic one — von Neumenn entropy. One can calculate easily the first two within the quantum Monte Carlo approach in over-complete and non-orthogonal valence bond basis. The clear geometrical meaning of this basis enables to define other efficiently computable quantities like *mean singlet length* (MSL) and *mean loop length* (MLL). Subsequently, we show that these *geometrical quantities* i) scale logarithmically with the subsystem size for 1D gapless quantum critical systems and linearly in gaped phase. ii) in 2D they fulfill area law (without a a multiplicative logarithmic correction) in gapless phase and valence bond (gaped) phase, i.e., they they share properties of von Neumen entropy. Finally, we examine the finite size scaling properties of MSL, MLL and their fluctuations and show that using them one can effectively calculate the quantum critical points and critical exponent related to the divergence of the correlation length.