Exploring Remnant Gauge Symmetry Breaking

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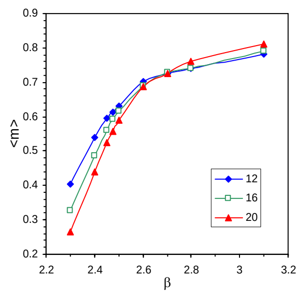
Using minimal Coulomb Gauge – this maximizes traces of all links lying in the first three directions. Set gauge after each Monte Carlo Sweep using an iterative overrelaxation algorithm. Average link is pushed fairly close to the identity at typical couplings, e.g. the average link magnetization in the gauge-fixed directions at β=2.8 in pure SU(2) is 0.9188. This is close to the fourth root of the plaquette (0.9145).

Magnetization in the unfixed fourth direction becomes an order parameter. Writing fourth direction links $U(x)=a_0+i\sum_{j=1}^{3}a_j\tau_j$ and considering them as a unit O(4) vector $\vec{a}=(a_0,a_1,a_2,a_3)$, each 3-d hyperlayer with x_4 fixed appears similar to the 3-d O(4) spin model. If the sideways links (first three directions) were exactly the identity, then the 4-link plaquette interaction degenerates into a two-link spin interaction – one would have exactly N copies of a 3-d O(4) spin model. The hypothesis I am considering is that at weak coupling, the gauge condition can push the sideways links close enough to the identity that the fourth-direction links will magnetize like the low-temperature phase of the O(4) spin model.

Such a magnetization breaks a residual or remnant SU(2) gauge symmetry, global across each hyperlayer but still local in the x_4 direction, in other words N separate SU(2) symmetries on an N^4 lattice. A nonzero magnetization also breaks the Polyakov loop symmetry, therefore a magnetizing phase transition in this order parameter is deconfining. This can also be seen from the relationship between this symmetry and the instantaneous Coulomb potential, which shows that realization of this remnant symmetry is a necessary condition for an absolutely confining potential[1].

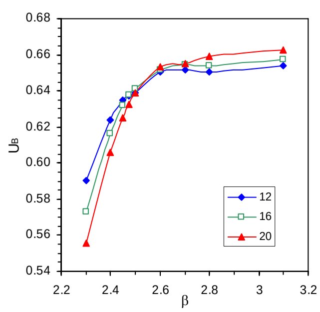
The basic idea is that in the Coulomb gauge, the gauge theory can be analyzed like a layered spin model, with a magnetization on each layer which is the average of a local magnetization vector. All of the usual techniques applied to a magnetic phase transition with local order parameter can be used.

Results for **magnetization** $\langle|\vec{m}|\rangle=\langle\left|\frac{1}{N^3}\sum_{layer}\vec{a}\right|\rangle$ on the **Wilson axis:**



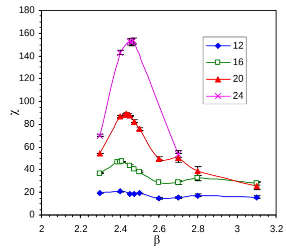
Note that above β=2.7 the magnetization actually *increases* with lattice size. This trend seems to leave little doubt that the magnetization survives the infinite lattice limit at these couplings. Error bars are about 1/3 size of plotted points. At beta=3.1, the 20^4 result is 10 standard deviations above the 12^4 value.

Binder Cumulant, $U_B=1-\langle|\vec{m}|^4\rangle/(3\langle|\vec{m}|^2\rangle^2)$:



Note that, for an O(4) order parameter, this should vary from 1/2 in an unbroken phase to 2/3 in a fully-broken phase. Crossings for different lattice sizes are expected at a phase transition. The crossing point is generally taken to be the *infinite-lattice* critical point. A clear crossing exists between β=2.5 and 2.7. Differences between 12^4 and 20^4 values at β=2.8 and 3.1 are about 10 standard deviations, with error bars about half the size of points.

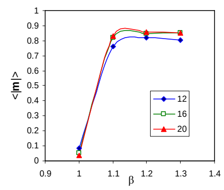
Susceptibility:



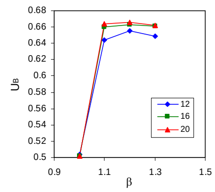
Peak heights scale in a manner consistent with a first-order phase transition, where an N^3, dependence is predicted. Comparing 24^4 with 20^4 peaks gives $N^{2.99\pm0.15}$, and 20^4 vs. 16^4 gives $N^{2.85\pm0.12}$. It must be a *weak* first-order transition, in that there is no signal in the specific heat. Latent heat must be smaller than ordinary plaquette fluctuations.

Results in **fundamental-adjoint plane at β_A=1.5**, where a strong 1st order transition is known to exist:

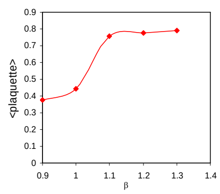
Magnetization:



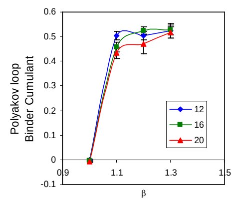
Binder Cumulant:



Average plaquette:



Polyakov loop Binder Cumulant:



Here there is a strong first-order transition with latent heat of about 0.26 (plaquette jump). It appears clear that the Binder cumulant crossing occurs at the previously-known phase transition (about beta =1.04). This indicates that this is a *symmetry-breaking phase transition,* which is consistent with an earlier energy analysis[2]. This means that the confining phase must be separated from the weak coupling phase *everywhere* in the fundamental-adjoint plane. This is consistent with the observation of a zero-temperature phase transition on the Wilson axis as seen above.

Conclusions:

1) A zero-temperature symmetry-breaking and deconfining phase transition exists in SU(2) lattice gauge theory on the infinite symmetric lattice. Therefore the continuum limit is not absolutely confining.

2) The continuum limit has a broken residual gauge symmetry (as does QED). This allows both the photon, gluon and probably W and Z bosons to be interpreted as Goldstone Bosons associated with broken symmetries.

3) The interquark potential may still exhibit "temporary confinement", due to a rising running coupling. This is a linearly rising potential over a certain distance range, but which flattens out at infinity. This could be enough to explain Charmonium potentials etc.

4) The finite-temperature deconfining phase transition is *not* a physical transition, since the zero temperature theory is already in the deconfined phase. Rather it is a version of the same artifact-driven phase transition seen here.

5) When light quarks are added an additional temporary confinement force may arise from chiral symmetry breaking. A physical finite-temperature chiral symmetry unbreaking transition should also exist, which would be relevant to quark-gluon plasma etc.

6) One should consider actions which remove artifacts responsible for this phase transition, such as the SO(2)-Z2 monopoleless action[3].

For further details see Ref. [4].

References:

[1] J. Greensite, S. Olejnik, and D. Zwanziger, Phys. Rev. D **69** (2004) 074506.

[2] M. Grady, Nucl. Phys. B **713** (2005) 204.

[3] M. Grady, hep-lat/9806024.

[4] M. Grady, hep-lat/0607013