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STRONG COUPLING QED WITH TWO FERMIONIC FLAVORS

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We report the recent results of our simulation of strong coupling QED, with non-compact action, on lattices 10^4 and 16^4. Since we are dealing with two staggered fermionic flavors, we use hybrid algorithm to do the simulation. In addition to the measurement of the chiral order parameter $\langle\bar{\psi}\psi\rangle$, we also measure magnetic monopole susceptibility, χ, throughout the region of chiral transition.

1. INTRODUCTION

In the past, QED was thought of as an effective low energy theory. However, in the recent year, various ladder calculations have given QED a whole new interpretation.[1] An ultraviolet fixed point exists in the strong coupling region and it is marked by a chiral phase transition. In addition, the four fermi interaction becomes renormalizable at this particular fixed point.[2] In the most recent results from the lattice calculation of quenched non-compact QED the chiral phase transition exhibits non-mean field behavior.[3] All these results imply that quenched QED is a non-trivial and non-asymptotically free field theory.

These new developments in the quenched theory prompt us to investigate the full theory, that is QED with dynamic fermions. Based on our past simulations on small lattices,[4] we are particularly interested in doing the simulation with two staggered fermions. In these new systematic studies, we seek to answer the following questions. Does this theory have a chiral phase transition? If it has such transition, can we determine the order of the transition? What kind of physical mechanisms drive the transition. (e.g., Strong/Vector Force, Monopoles, or Induced Four Fermi)? Does the transition have anything to do with the continuum physics?

In the second section, I will present some technical details of our simulation. Also, I will discuss the two physical quantities that we are measuring. In the third section, I will present the data and discuss its interpretation. In forth section, I will illustrate some problems with the non-compact action. Finally, I will draw some conclusions.

2. SIMULATION

The Lagrangian of non-compact QED is well known:

$$
\begin{aligned}
S &= -\frac{\beta}{2}\sum_{p}\Theta_p^2 \\
&+ \frac{1}{2}\sum_{x,\mu}\eta_\mu(x)[\bar{\psi}_x e^{i\theta_\mu(x)}\psi_{x+\mu} - h.c.] \\
&+ m\sum_{x}\bar{\psi}_x\psi_x
\end{aligned}
$$

where Θ_p is the sum of gauge fields around a plaquette. Since we are interested in a system with two fermionic flavors, we use Hybrid Molecular Dynamics as our simulation method. We do the simulations on two different size lattice, specifically 10^4 and 16^4.

We measure two different quantities in our simulations. The first one is the usual chiral order parameter $\langle\bar{\psi}\psi\rangle$. For the 10^4 lattice, we measure $\langle\bar{\psi}\psi\rangle$ for the following different fermion masses $m = 0.03, 0.02, 0.015, 0.01, 0.005$ and for the 16^4 lattice, we have data for $m = 0.03, 0.02, 0.01$. The second quantity that we measure in our simulations is the

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DISCLAIMER

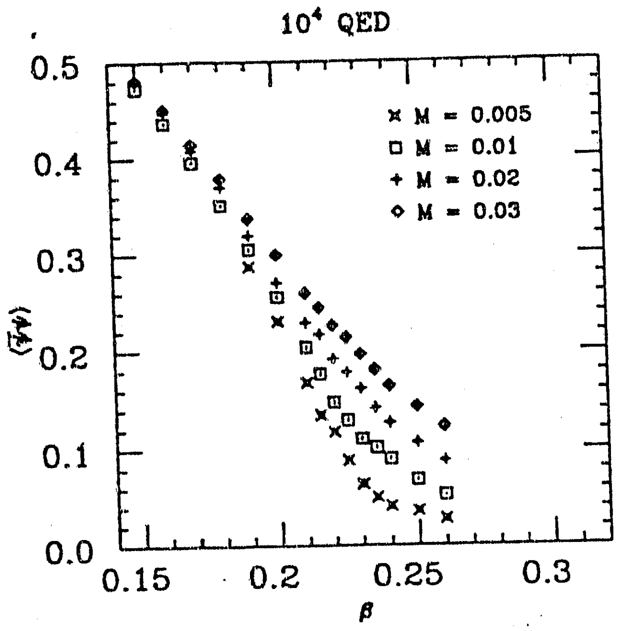

Figure 1: $\langle\bar{\psi}\psi\rangle$ for the 10^4 lattice.

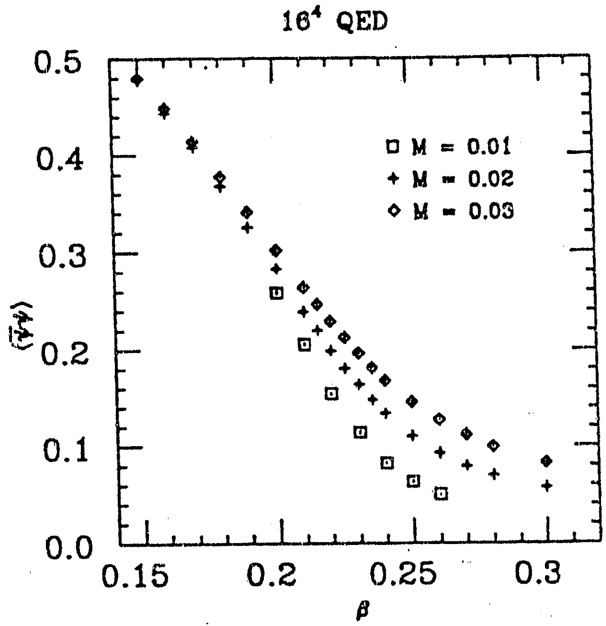

Figure 2: $\langle\bar{\psi}\psi\rangle$ for the 16^4 lattice.

magnetic monopole susceptibility χ.[5] It is a good parameter for monitoring the activity of monopoles on lattice. When the monopole density reaches the critical value, at which the large monopole loops start to form, χ reaches its maximum value. For the 10^4 lattice, we measure χ for fermion mass $m = 0.005$. For the 16^4 lattice, we measure χ for all three different fermion masses.

The choices of the other parameters of our simulations are as follow. The time step dt for the 10^4 lattice ranges from 0.02 to 0.0025 and the time step for the 16^4 lattice ranges from 0.02 to 0.01. The residue for the conjugate gradient is 0.001 per site. However, it is adjusted for the lowest fermion mass. For both lattice sizes, our simulations cover β values ranging from 0.26 to 0.19. For each β and m, we obtain at least 200 trajectories and each trajectory consists of $1/dt$ sweeps. Moreover, for the 16^4 lattice, we use a random refreshment interval to improve the decorrelation time.

3. DATA AND INTERPRETATION

In Fig. 1, we present part of the 10^4 $\langle\bar{\psi}\psi\rangle$ data. There are some slight fluctuations in the data for the lowest fermion mass. This is caused by the exceedingly long correlations around the transition. In Fig. 2, we present the 16^4 $\langle\bar{\psi}\psi\rangle$ data. By comparing with Fig. 1, we conclude that the finite size effect is very small. In Fig. 3, $\langle\bar{\psi}\psi\rangle$ in limit of

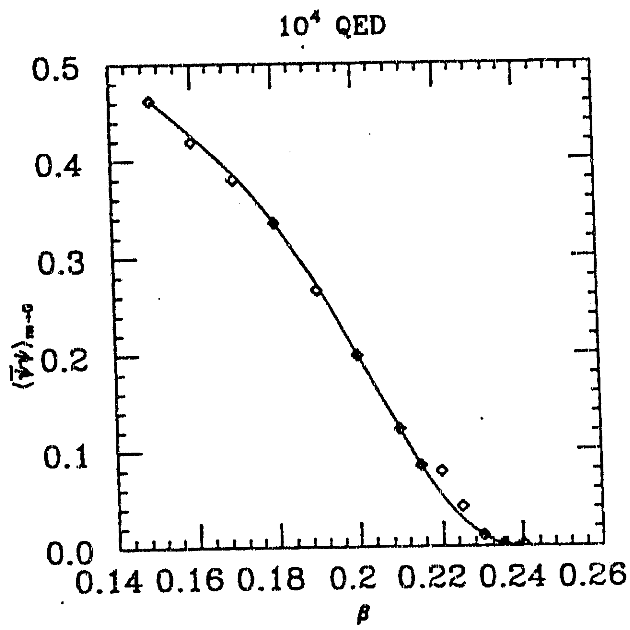

Figure 3: $\langle\bar{\psi}\psi\rangle$ in the limit of $m = 0$

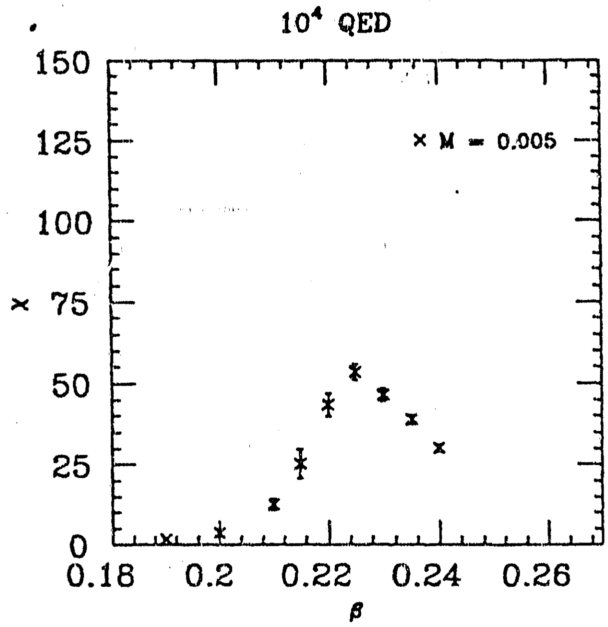

Figure 4: χ for the 10^4 lattice.

$m = 0$ is plotted. It is obtained from measurements, on the 10^4 lattice, at $m = 0.005, 0.01, 0.015$, by a $\langle\bar{\psi}\psi\rangle(m = 0) = a + bm + cm^3$ extrapolation at each β. We do not make any extrapolation on the 16^4 data because the fermion masses are still too large. It is very clear from our data that there exists a chiral phase transition. The transition occurs most probably around $\beta = 0.225$. Due to the long correction time around the transition, it is very hard to determine the order of the transition. It may be second order.

In Fig. 4, we plot the monopole susceptibility, χ, verse β for the 10^4 lattice. We see that χ peaks at $\beta = 0.225$. In Fig. 5, we plot χ verse β for the 16^4 lattice. We find that the peak of χ is independent of the fermion mass; again it is located at $\beta = 0.225$. The locations of the various peaks are the same for two different lattice sizes. Only the magnitudes of the peaks depend on the lattice sizes. In Fig. 6, we rescale χ so that it can be ploted in the same scale as $\langle\bar{\psi}\psi\rangle(m = 0)$ for the 10^4 lattice. One clearly sees that the monopole susceptibility peaks at the chiral critical point. Therefore lattice monopoles are important at the critical point. Lattice monopoles drive the chiral transition at least in part.

Based on the data that we present, we believe that non-compact lattice QED's chiral phase transition has no continuum analogue. The reasons for this are very simple. First, the chiral transition is

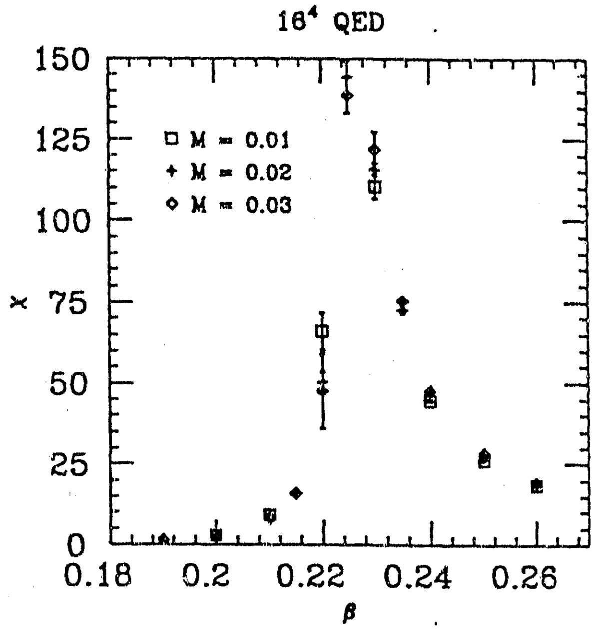

Figure 5: χ for the 16^4 lattice.

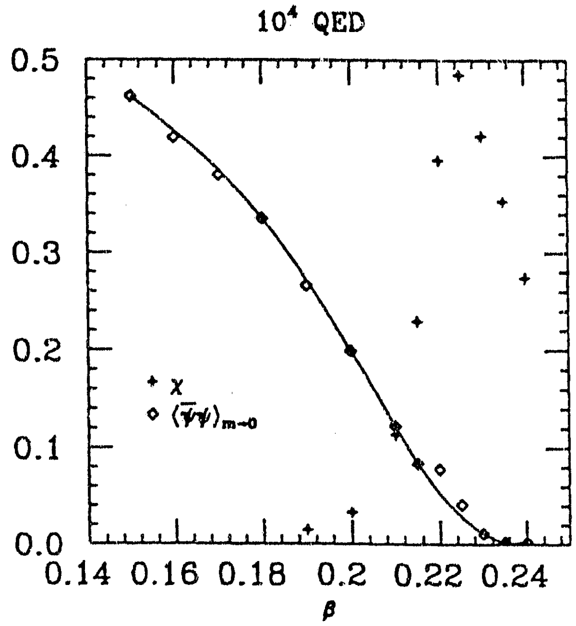

Figure 6: $\langle\bar{\psi}\psi\rangle$ and χ for the 10^4 lattice

driven in part by monopoles, which are lattice artifacts, not by the strong vector force. In other words, since the U(1) monopole condensation occurs at the critical point, the U(1) gauge group is relevant at the critical point instead of the R gauge group of the continuum theory. In addition, at $\beta_c = 1/e_c^2 = 0.225$, the coupling constant is $\alpha \sim 0.3537$. The Callan-Symanzik beta function up to forth order[6] is

$$\beta(\alpha_c) = \frac{2}{3}\left(N_f\frac{\alpha_c}{\pi}\right) + \frac{1}{2}\left(N_f\frac{\alpha_c}{\pi}\right)^2$$

At this α_c, the second order contribution is 0.15 and the forth order contribution is 0.02536. Therefore we expect that the perturbative QED will work reasonably well. We conclude that we cannot use the non-compact lattice action to discuss the possible triviality of QED.

4. PROBLEMS WITH NON-COMPACT QED

The first problem is associated with the fermionic part of the action which contains a U(1) phase. This U(1) phase will eventually induce compact terms back into the action. Let us look at a simple illustration. At strong coupling and large fermion mass, one can integrate out the fermion fields and obtain an effective action for gauge fields. The lowest order contribution is proportion to.

$$\sim \frac{\beta}{m^4}\sum_p e^{i\Theta_p}$$

Therefore a compact term is induced. In sum, the present of dynamic fermions enhance the importance of monopoles.

The second problem is associated with the simple gauge field action which will induce an effective four fermi interaction. As an illustration, we look at the simple single photon exchange interaction. In continuum, the photon propagator is just $\frac{g_{\mu\nu}}{k^2}$. However, on the lattice, the inverse photon propagator is $D^{-1}(k) \sim \sum_\mu\{1-\cos(k_\mu)\}$. In the low k limit, the lattice photon propagator is a good representation of the continuum propagator. However, in the high k limit, the lattice photon propagator is just a constant. Thus the single photon exchange interaction behaves like a four fermi interaction. Since QED is not an asymptotically free field theory, this effect is large and it does not go away as the lattice spacing goes to zero. This effect is a very plausible mechanism for driving the chiral transition.

5. CONCLUSION

Non-compact lattice QED is an interesting lattice theory with many structures. However we believe that this theory has no continuum analogue. Thus we can not use it to draw any conclusion about the triviality of the continuum QED. It would be interested to repeat the same study for four fermionic flavors. The most important problem is associated with the U(1) phase in the fermionic part of the action. Therefore, in order to continue the study of continuum strong coupling QED, one needs a new lattice QED action which will better match the continuum action.

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