Supersymmetric Gauge Theories with Confining Phases

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Outline

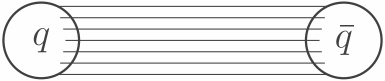
1. Background
2. Our Work

Background

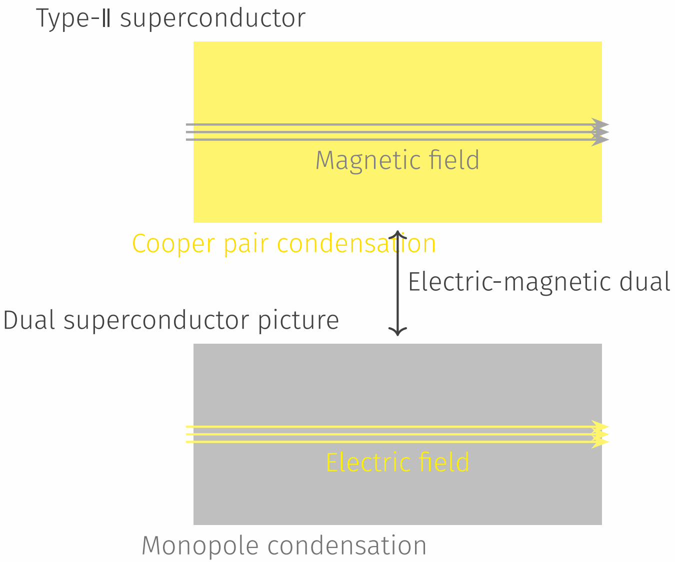
Confinement

Motivation:To understand the mechanism of confinement
Confinement:Color charged particles cannot exist as isolated particles at low energies

$$V(r) = \sigma r$$

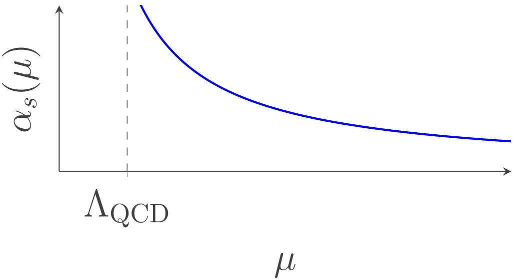


Dual Superconductor Picture



Supersymmetric Gauge Theories

Asymptotic freedom



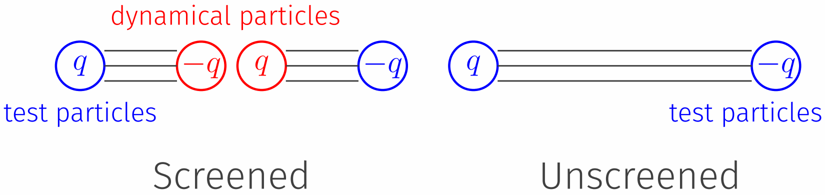
Non-perturbative effects matter at low energy
$\Rightarrow$ For the time being, we consider supersymmetric gauge theories

Our Work

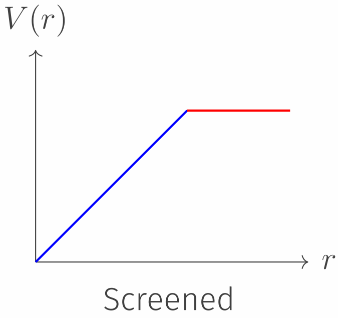
T(Truly)-confining Theories

We studied a theory whose center symmetry is non-trivial, even though it differs from real QCD

$\Rightarrow$ Test particles remain unscreened



The Behaviors of The Potentials



Confining phase	$V(r) \sim \sigma r$(linear)
Higgs phase	$V(r) \sim$ const.

The List of T-confining Theories

1. Pure Yang-Mills
2. $SO(k)$ with $k-4$ vectors
3. $SO(k)$ with $k-3$ vectors
4. $SU(6)$ with $\yng(1,1,1)$
5. $Sp(2k)$ with $\yng(1,1)$
6. $SU(2k)$ with $\yng(1,1)$ and $\overline{\yng(1,1)}$
7. $SO(12)$ with 2 spinors

“Magnetic” Condensate

	Theories	“Magnetic” condensate	Discrete symmetry breaking
(A)	G	$\mathrm{tr}(\mathcal{W}^\alpha \mathcal{W}_\alpha)$	$\mathbb{Z}_{2h} \to \mathbb{Z}_2$
(B)	$SO(k) + (k-4)\,\square$	$\mathrm{tr}\big(V^{k-4}\mathcal{W}^\alpha \mathcal{W}_\alpha\big)$	$\mathbb{Z}_{2k-8} \to \mathbb{Z}_{k-4}$
(C)	$SO(k) + (k-3)\,\square$	magnetic monopole	
(D)	$SU(6) + \begin{smallmatrix}\square\\\square\\\square\end{smallmatrix}$	$\mathrm{tr}\big(A^2\mathcal{W}^\alpha \mathcal{W}_\alpha\big)$	$\mathbb{Z}_6 \to \mathbb{Z}_2$
(E)	$Sp(k) + \begin{smallmatrix}\square\\\square\end{smallmatrix}$	$\mathrm{tr}\big(A^{k-1}\mathcal{W}^\alpha \mathcal{W}_\alpha\big)$	$\mathbb{Z}_{2k-2} \to \mathbb{Z}_{k-1}$
(F)	$SU(2k) + \begin{smallmatrix}\square\\\square\end{smallmatrix} + \overline{\begin{smallmatrix}\square\\\square\end{smallmatrix}}$	$\mathrm{tr}\{(A\tilde{A})^{k-1}\mathcal{W}^\alpha \mathcal{W}_\alpha\}$	$\mathbb{Z}_{4k-4} \to \mathbb{Z}_{2k-2}$
(G)	$SO(12) + 2\,S$	$\mathrm{tr}\big(S^8\mathcal{W}^\alpha \mathcal{W}_\alpha\big)$	$\mathbb{Z}_{16} \to \mathbb{Z}_8$

AMSB(Anomaly Mediated Supersymmetry Breaking)

We investigated SUSY-broken vacua of t-confining theories

AMSB: a mechanism for SUSY breaking with UV insensitivity

UV insensitivity: SUSY breaking effects are controlled at all energy scales

T-confining theories with AMSB

We obtained stable AMSB vacua for each t-confining theories

$\rightarrow$ This result supports "dual superconductor picture" in t-confining theories even after SUSY breaking

Summary

Confinement

Motivation:To understand the mechanism of confinement

Non-perturvative effects are essential $\rightarrow$ SUSY

Previous Work

T-confining theories
“Magnetic” condensates

AMSB

Future Work

Monopole condensation

Backup Slides

Area Law of the Wilson Loop

Unscreened $\rightarrow$Area law of the Wilson loop

Wilson line $\mathcal{W}_R = \mathrm{Tr}_R \mathcal{P} e^{2\pi i \int A}$

Area law : $\lim_{r,T\to\infty} \langle \mathcal{W}_R[C] \rangle \sim e^{-V(r)T} = e^{-\sigma r T} = e^{-\sigma A[C]}$

$A[C]$:Area enclosed by the loop C

loop C

The Conditions for T-confining Theories

Non-trivial center symmetry

$$Z(\bar{G})/\gcd(q_1, \cdots, q_m) \neq \mathbf{1}$$

Dynkin index condition

$$\sum_{\text{matter fields}} I < I_{\text{Gauge}} + 2$$

Anomaly matching condition

$$\mathcal{A}_{UV} = \mathcal{A}_{IR}$$

“Magnetic” Condensate

s-confining theory
$SU(2k) + A^{ij} + \tilde{A}_{ij} + 3(Q^i + \tilde{Q}^i)$
$M_i = \tilde{Q}(A\tilde{A})^i Q$

$$W_{\text{eff}} \supset \frac{1}{\Lambda^{4k-1}} M_0 M_{k-1}^2$$

When the mass term for M_0 is included,VEV of M_{k-1} becomes nonzero.

The List of T-confining Theories

1. Pure Yang-Mills
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3. $SO(k)$ with $k-3$ vectors
4. $SU(6)$ with $\ydiagram{1,1,1}$
5. $Sp(2k)$ with $\ydiagram{1,1}$ (Only the cases with$k \leq 3$ have been studied so far(Csaki,Skiba,Schmaltz(1997),Cho,Kraus(1996)))
6. $SU(2k)$ with $\ydiagram{1,1}$ and $\overline{\ydiagram{1,1}}$ (Dotti and Manohar (1997) mention this case, but no comprehensive analysis)
7. $SO(12)$ with 2 spinors (Dotti and Manohar (1997) mention this case, but no comprehensive analysis)

“Magnetic” Condensate

Konishi anomaly

$$\bar{D}^2(Q^\dagger E^i Q) = m\tilde{Q}E^i Q + \frac{1}{16\pi^2}\,\mathrm{tr}\big(E^i \mathcal{W}^\alpha \mathcal{W}_\alpha\big)$$

$$\begin{aligned} M_{k-1} &= \tilde{Q}(A\tilde{A})^{k-1}Q \\ &= \tilde{Q}E^i Q\,\mathrm{tr}\Big\{E^i (A\tilde{A})^{k-1}\Big\} \\ &\propto \mathrm{tr}\big(E^i \mathcal{W}^\alpha \mathcal{W}_\alpha\big)\,\mathrm{tr}\Big\{E^i (A\tilde{A})^{k-1}\Big\} \\ &= \mathrm{tr}\Big\{(A\tilde{A})^{k-1}\mathcal{W}^\alpha \mathcal{W}_\alpha\Big\} \end{aligned}$$

Applying AMSB to our theories

Scaler Potential in Supersymmetric theories with AMSB

$$V = \underbrace{\sum_i \left| \frac{\partial W}{\partial \phi_i} \right|^2}_{\text{SUSY}} + \underbrace{m\left(\phi_i \frac{\partial W}{\partial \phi_i} - 3W\right) + c.c.}_{\text{AMSB}}$$

Minima of this scalar potential correspond to AMSB vacua