SUSY Introduction

Notation: Θ_α $\alpha = 1, 2$ SU(2) Spinor

anticommuting object

$\Theta_\alpha = \epsilon_{\alpha\beta}\Theta^\beta$ $\epsilon_{\alpha\beta} = \epsilon^{\alpha\beta}$ $\epsilon_{12} = +1$

$\bar{\Theta}^{\dot\alpha} = (\Theta^\alpha)^+$ (SU(2) "Antispinor")

$\bar{\Theta}_{\dot\alpha} = \epsilon_{\dot\alpha\dot\beta}\bar{\Theta}^{\dot\beta}$

$\Theta^2 := \Theta^\alpha\Theta_\alpha = \epsilon_{\alpha\beta}\Theta^\alpha\Theta^\beta =$

$= -\epsilon_{\alpha\beta}\Theta^\beta\Theta^\alpha = -\Theta_\alpha\Theta^\alpha$

$\bar{\Theta}^2 = \bar{\Theta}_{\dot\alpha}\bar{\Theta}^{\dot\alpha} = -\epsilon_{\dot\alpha\dot\beta}\bar{\Theta}^{\dot\alpha}\bar{\Theta}^{\dot\beta}$

(since $(\Theta^2)^+ = \bar{\Theta}_{\dot\alpha}\bar{\Theta}^{\dot\alpha}$)

$\epsilon^{\gamma\beta}\epsilon_{\alpha\beta} = \delta_\alpha^\gamma$

Pauli-matrices $\sigma_\mu^{\alpha\dot\beta}$

Lorentz group $SU(2) \times SU(2)$

$$\theta^{\alpha} \hat{=} \left(\tfrac{1}{2}, 0\right)$$

$$\bar{\theta}^{\dot{\alpha}} \hat{=} \left(0, \tfrac{1}{2}\right)$$

$$V^{\mu} \hat{=} \bar{\psi}^{\dot{\alpha}} \sigma^{\mu}_{\dot{\alpha}\beta} \psi \hat{=} \left(\tfrac{1}{2}, \tfrac{1}{2}\right)$$

Dirac spinor $\left(\tfrac{1}{2}, 0\right) \oplus \left(0, \tfrac{1}{2}\right)$

$$\psi_a = \begin{pmatrix} \chi_{\alpha} \\ \bar{\xi}^{\dot{\beta}} \end{pmatrix}$$

where χ_{α}, $\bar{\xi}^{\dot{\beta}}$ are left, right-handed Weyl spinors.

Differentiation

$$\partial_{\alpha} \theta^{\beta} = \frac{\partial \theta^{\beta}}{\partial \theta^{\alpha}} = \delta_{\alpha\beta}$$

exercise: $\bar{\partial}_{\dot{\beta}} \bar{\partial}^{\dot{\beta}} (\bar{\theta}_{\dot{\alpha}} \bar{\theta}^{\dot{\alpha}}) = -4$

Integration

$$\int d\theta = 0 \quad ; \quad \int \theta \, d\theta = 1$$

SUSY relates fermions to bosons

$\rightarrow$ Generator (Charge) Q_α is fermionic

Algebra:

$$\{ Q_\alpha , \bar{Q}_{\dot\beta} \} = 2 \sigma^\mu_{\alpha\dot\beta} P_\mu$$

P_μ generates translations

$$[Q_\alpha , P_\mu] = 0$$

SUSY enhances Poincaré - group nontrivially !

- $Q\,|B\rangle = |F\rangle \qquad Q\,|F\rangle = |B\rangle$

  $\Rightarrow \quad m_B = m_F$

  mass degeneracy of multiplets

- Hamiltonian

  $$H = P^0 \sim Q Q^+$$

Suppose groundstate $|0\rangle$ is symmetric

$$Q|0\rangle = 0$$

(ground state is not necessarily paired)

$\rightarrow$ $E_{vacuum} = \langle 0|H|0\rangle = 0$

If $Q_\alpha |0\rangle = |\psi_\alpha\rangle \neq 0$

$\rightarrow$ $\langle \psi_\beta | J_{\mu\alpha} |0\rangle = f\,\sigma_{\mu\beta\alpha}$

$$\left(Q_\alpha = \int d^3x \, J_{0\alpha} \right)$$

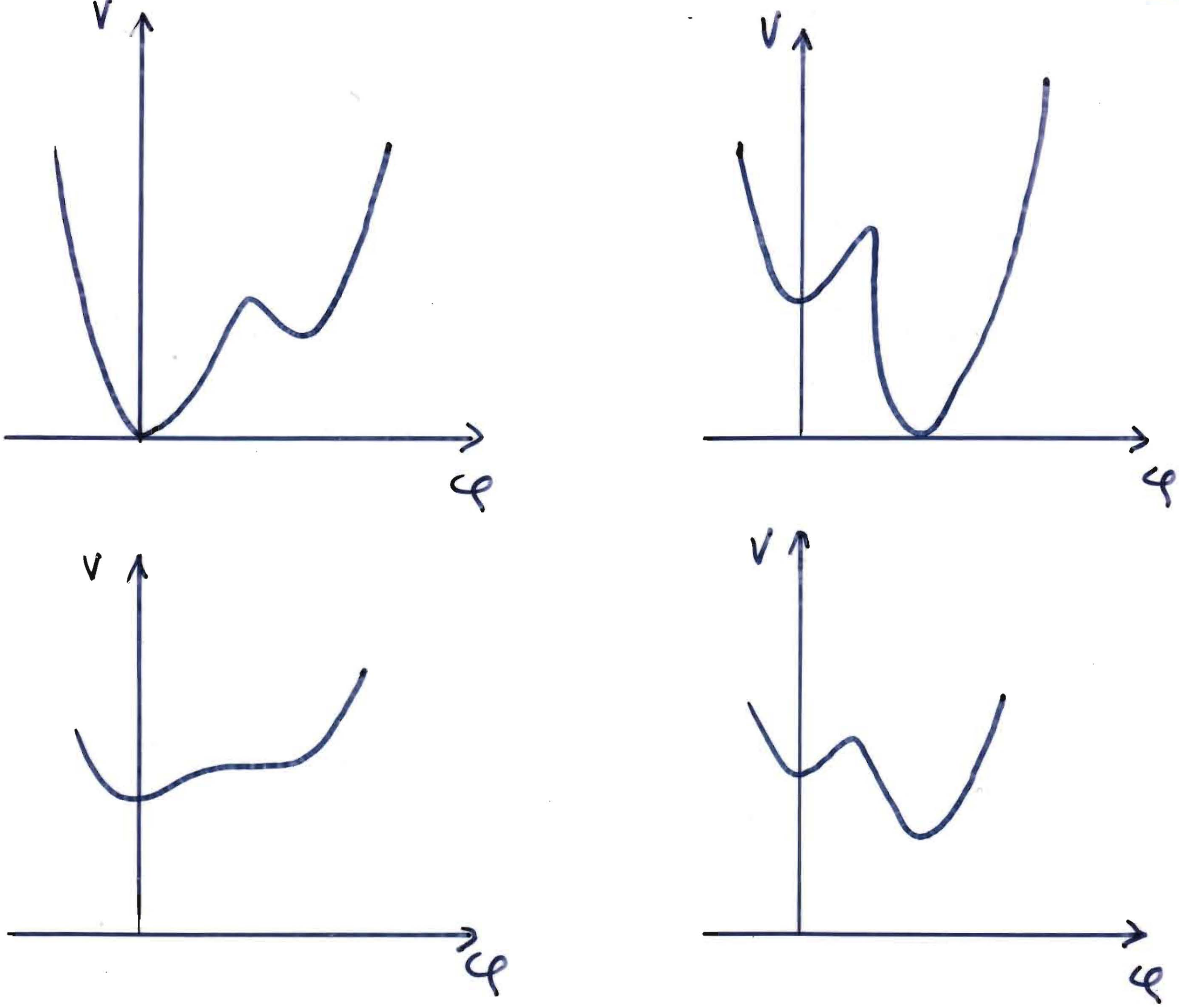
$\rightarrow$ $E_{vacuum} = f^2 > 0$

and presence of goldstone fermion

(in analogy to goldstone bosons in case of spontaneously broken "normal" symmetry)

In supersymmetric theories

$$E_{vacuum} \geq 0$$



Problem of the cosmological constant even more pronounced!

(since we know that susy is spontaneously broken)

multiplets and super-fields

parameters $\theta^\alpha, \bar{\theta}^{\dot{\alpha}}$ anticommute

$$[\theta Q, \bar{Q}\bar{\theta}] = 2\,\theta\sigma_\mu\bar{\theta}P^\mu$$

$$[\theta Q, \theta Q] = [\bar{Q}\bar{\theta}, \bar{Q}\bar{\theta}] = 0$$

finite SUSY transformation

$$S(x^\mu, \theta, \bar{\theta}) = \exp[\theta Q + \bar{Q}\bar{\theta} - i x_\mu P^\mu]$$

$$S(x, \theta, \bar{\theta})\, S(y, \alpha, \bar{\alpha}) =$$

$$= \exp\Big[\bar{Q}(\bar{\theta} + \bar{\alpha}) + (\theta + \alpha)Q - iP(x+y) + P(\theta\sigma_\mu\bar{\alpha} - \alpha\sigma_\mu\bar{\theta})\Big]$$

$$= S(x + y + i\theta\sigma_\mu\bar{\alpha} - i\alpha\sigma_\mu\bar{\theta},\ \theta + \alpha,\ \bar{\theta} + \bar{\alpha})$$

SUSY transformation as geometrical operation in superspace

$$(x_\mu, \theta, \bar{\theta})$$

Scalar Superfield $\phi(x,\theta,\bar\theta)$
should transform covariantly

$$S(y,\alpha,\bar\alpha)[\phi(x,\theta,\bar\theta)] :=$$

$$= \phi(x+y-i\alpha\sigma\bar\theta+i\theta\sigma\bar\alpha,\ \theta+\alpha,\ \bar\theta+\bar\alpha) \qquad (*)$$

$\to$ compute representation of operators Q, $\bar Q$ und P_μ in superspace

infinitesimal transf.

$$S = \mathbb{1} + \delta\theta Q + \bar Q\delta\bar\theta - i\delta x P$$

acting on $\phi(x,\theta,\bar\theta)$

and compare Taylor-expansion of $(*)$

$$\Rightarrow \boxed{\begin{aligned} P_\mu &= i\partial_\mu \\ Q_\alpha &= \partial_\alpha - i\sigma^\mu_{\alpha\dot\beta}\bar\theta^{\dot\beta}\partial_\mu \\ \bar Q_{\dot\alpha} &= -\partial_{\dot\alpha} + i\theta^\beta\sigma^\mu_{\beta\dot\alpha}\partial_\mu \end{aligned}}$$

exercise: verify commutation rules

covariant derivatives

$$\mathcal{D}_\alpha (\delta_S \phi) = -\delta_S (\mathcal{D}_\alpha \phi)$$

$$\mathcal{D}_\alpha = \partial_\alpha + i\sigma^\mu_{\alpha\dot\beta}\bar\theta^{\dot\beta}\partial_\mu$$

$$\bar{\mathcal{D}}_{\dot\alpha} = -\partial_{\dot\alpha} - i\sigma^\mu_{\beta\dot\alpha}\theta^\beta\partial_\mu$$

will be used later for projections

equivalent representation

$$S_L = \exp[\theta Q - ixP]\exp(\bar Q\bar\theta)$$

$$S_R = \exp[\bar Q\bar\theta - ixP]\exp[\theta Q]$$

$$Q_L = \partial_\theta \qquad Q_R = \partial_\theta - 2i\sigma^\mu\bar\theta\partial_\mu$$

$$\bar Q_L = -\partial_{\bar\theta} + 2i\theta\sigma_\mu\partial^\mu \qquad \bar Q_R = -\partial_{\bar\theta}$$

$$\mathcal{D}_L = \partial_\theta + 2i\sigma_\mu\bar\theta\partial^\mu \qquad \mathcal{D}_R = \partial_\theta$$

$$\bar{\mathcal{D}}_L = -\partial_{\bar\theta} \qquad \bar{\mathcal{D}}_R = -\partial_{\bar\theta} - 2i\theta\sigma_\mu\partial^\mu$$

relation:

$$\phi(x_\mu, \theta, \bar\theta) = \phi_L(x_\mu + i\theta\sigma_\mu\bar\theta, \theta, \bar\theta)$$

$$= \phi_R(x_\mu - i\theta\sigma_\mu\bar\theta, \theta, \bar\theta)$$

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consider $\phi(x_\mu, \theta, \bar\theta)$ and expand in θ and $\bar\theta$

$$(\theta)^3 = (\bar\theta)^3 = 0$$

$$\Rightarrow \phi(x, \theta, \bar\theta) = \varphi(x) + \theta^\alpha \psi_\alpha(x) + \theta^\alpha\theta_\alpha F(x) + \bar\theta_{\dot\alpha} \bar\chi^{\dot\alpha}(x) + \bar\theta_{\dot\alpha}\bar\theta^{\dot\alpha} G(x) + \theta^\alpha \sigma^\mu_{\alpha\dot\beta} \bar\theta^{\dot\beta} V_\mu(x) + \ldots\ldots + \bar\theta^2\theta^2 D(x)$$

still quite complicated

spin 0, ½, 1

Is there a smaller irreducible representation can e.g. take $\phi = \phi^*$

or project with covariant derivatives

chiral superfield $D\phi = 0$

(or $\bar{D}\phi = 0$)

consider $\bar{D}\phi = 0$ (left handed chiral)

$\bar{D}_L = -\partial_{\bar{\theta}}$ is simple in L-repr.

$\Rightarrow \phi$ independent of $\bar{\theta}$

$$\boxed{\begin{aligned}\phi_L(x,\theta) = \varphi(x) &+ \theta^\alpha \psi_\alpha(x) \\ &+ \theta^\alpha \theta_\alpha F(x)\end{aligned}}$$

$\varphi(x)$ is scalar field

$\psi_\alpha(x)$ is Weyl spinor

$F(x)$ auxiliary (see later)

SUSY transformations

$$\delta\varphi = \alpha^\beta \psi_\beta$$

$$\delta\psi_\beta = 2\alpha_\beta F(x) + 2i\sigma^\mu_{\beta\dot{\alpha}}\bar{\alpha}^{\dot{\alpha}}(\partial_\mu\varphi)$$

$$\delta F = -i(\partial_\mu\psi^\beta)\sigma^\mu_{\beta\dot{\alpha}}\bar{\alpha}^{\dot{\alpha}}$$

$$\varphi \longrightarrow \psi \longrightarrow F$$

but also derivatives

Dimension of $F = 2$

$\dim Q = 1/2$

Important:
highest component F
transforms (necessarily) into
a total derivative

Products of superfields

$$\bar{D}\Phi = 0 \Rightarrow \bar{D}\Phi^n = 0$$

$\Rightarrow \Phi^n$ is chiral superfield

example:

$$\Phi^2 = (\varphi(x) + \theta^\beta \psi_\beta + \theta^2 F)^2 =$$

$$= \varphi^2 + 2\theta^\beta(\varphi\psi_\beta) + \theta^2[2\varphi F - \tfrac{1}{2}\psi^\alpha\psi_\alpha]$$

$$(\tilde{\varphi}, \quad \tilde{\psi}, \quad \tilde{F})$$

again $\delta\tilde{F} = -i(\partial_\mu\tilde{\psi})\sigma^\mu\bar{\alpha}$
under susy transformation

- chiral superfield for spin 0 and 1/2

- Φ with $\bar{D}\Phi = 0$ closes under susy
  "smallest" irreducible repr.
  (Φ in general is not irreducible)

Spin 1 ?

have seen that $\Phi(x,\theta,\bar\theta)$ contains

$$\theta^\alpha \sigma^\mu_{\alpha\dot\beta} \bar\theta^{\dot\beta} V_\mu$$

real superfield $V(x,\theta,\bar\theta) = V^\dagger(x,\theta,\bar\theta)$

$$V(x,\theta,\bar\theta) = \left(1 + \tfrac{1}{4}\theta^2\bar\theta^2 \Box\right) C +$$

$$+ \left(i\theta + \tfrac{1}{2}\theta^2 \sigma^\mu \bar\theta \partial_\mu\right)\chi + \tfrac{i}{2}\theta^2 (M + iN) +$$

$$+ \left(-i\bar\theta + \tfrac{1}{2}\bar\theta^2 \theta \sigma_\mu \partial^\mu\right)\bar\chi - \tfrac{i}{2}\bar\theta^2 (M - iN) -$$

$$- \theta\sigma_\mu\bar\theta V^\mu + i\,\theta^2\bar\theta\bar\lambda - i\,\bar\theta^2\theta\lambda + \tfrac{1}{2}\theta^2\bar\theta^2 D$$

Susy transformation

$$\delta D \sim (\partial_\mu \lambda)$$

$\exists$ gauge theory V_μ, λ

(D auxiliary, $C, \chi, \bar\chi, M, N$ are gauge artifacts)

Action

highest component of superfield
transforms in total derivative

$\to$ F- and D- terms

$$S = \int d^4x \left[\int d^2\theta\, d^2\bar\theta\, \mathcal{L}_D + \left(\int d^2\theta\, \mathcal{L}_F + h.c \right) \right]$$

$\mathcal{L}_F$ is usually called superpotential

example:

$$\mathcal{L}_F = m\phi^2 + \lambda\phi^3$$

$$\Rightarrow \int d^2\theta\, \mathcal{L}_F = \text{highest component}$$

$$= m\left(2\varphi F - \tfrac{1}{2}(\psi\psi)\right) +$$

$$+ \lambda\left(3\varphi^2 F - \tfrac{3}{2}\varphi(\psi\psi)\right)$$

contain only left-handed chiral
superfields

kinetic terms $(\Phi\Phi^{+})_D$

$$\Phi_L(x,\theta) = \varphi + \theta\psi + \theta^2 F$$

$$(\Phi_L)^{+} = \varphi^* + \bar\theta\bar\psi + \bar\theta^2 F^*$$

is independent of θ and therefore in R-representation

$$(\Phi_L)^{+} = (\Phi^{+})_R$$

has to be brought back to L-repr. for multiplication

$$(\Phi^{+})_L(x,\theta,\bar\theta) = (\Phi^{+})_R(x-2i\theta\sigma_\mu\bar\theta,\ \bar\theta)$$

or formally

$$(\Phi\Phi^{+})(x,\theta,\bar\theta) =$$

$$= \Phi(x,\theta)\exp\left[-2i\theta\sigma^\mu\bar\theta\partial_\mu\right]\Phi^{+}(x,\bar\theta)$$

This is a general vector superfield and can be expanded lengthy calculation

$$(\Phi\Phi^\dagger)_D = \int d^2\theta\, d^2\bar\theta\, (\Phi\Phi^\dagger) =$$

$$= FF^* - \varphi\,\Box\,\varphi^* - \frac{i}{2}\psi^\beta \sigma^\mu_{\beta\dot\gamma}\,\partial_\mu \bar\psi^{\dot\gamma}$$

providing kinetic terms for φ and ψ

no derivatives of F

$\Rightarrow$ auxiliary field

recall $\quad 2m\varphi F + 3\lambda\varphi^2 F + FF^*$

equation of motion gives

$$F^* + 2m\varphi + 3\lambda\varphi^2 = 0$$

and can be used to eliminate F

Observe that $\quad F^* = -\dfrac{\partial \mathcal{L}_F(\varphi)}{\partial\varphi}$

and scalar potential becomes

FF^* once we plug back in action

scalar potential:

$$V = FF^* = \left|\frac{\partial \mathcal{L}_F}{\partial \phi}\right|^2 =$$

$$= |2m\varphi + 3\lambda\varphi^2|^2 \geq 0$$

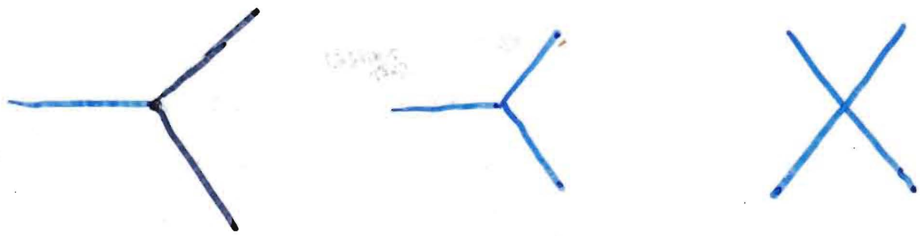
ϕ^3 in superpotential leads to
φ^4 in components
($\phi^4 \to$ nonrenormalizable)

complete action in components

$$(\partial_\mu\varphi)^2 - \frac{i}{2}\psi\sigma_\mu\partial^\mu\bar{\psi} -$$

$$-\frac{1}{2}m(\psi\psi + \bar{\psi}\bar{\psi}) - \frac{3}{2}\lambda(\varphi^*\bar{\psi}\bar{\psi} + \varphi\psi\psi)$$

$$-|2m\varphi + 3\lambda\varphi^2|^2$$



λ $\quad$ $m\lambda$ $\quad$ λ^2

gauge interactions

take $V(x,\theta,\bar\theta)$ as given earlier

gauge-field in $\theta\sigma_\mu\bar\theta V^\mu$ term

usual gauge transformation

$$V_\mu \longrightarrow V_\mu + \partial_\mu \eta$$

where $\eta(x)$ is a real field

generalization in superfield language

$$V \longrightarrow V + i(\Lambda - \Lambda^+)$$

where Λ is chiral superfield

Wess-Zumino gauge

$$V_{WZ}(x,\theta,\bar\theta) = -\theta\sigma_\mu\bar\theta V^\mu +$$

$$+ i\theta^2\bar\theta\bar\lambda - i\bar\theta^2\theta\lambda + \tfrac{1}{2}\theta^2\bar\theta^2 D$$

($C, M, N, \chi, \bar\chi$ gauged away)

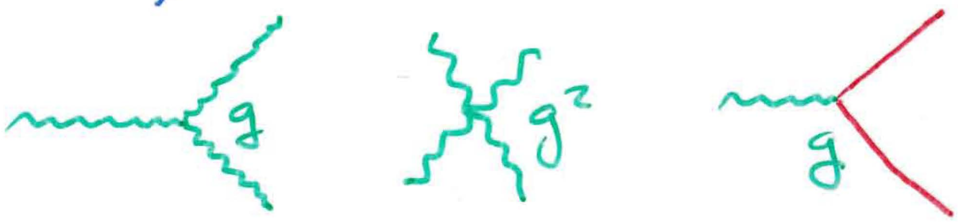
superfield $V \sim (V_\mu, \lambda, D)$
auxiliary

$$W_\alpha = \bar{D}\bar{D}\left[\exp(-gV)\, D_\alpha \exp(gV)\right]$$

$$\bar{D} W_\alpha = 0$$

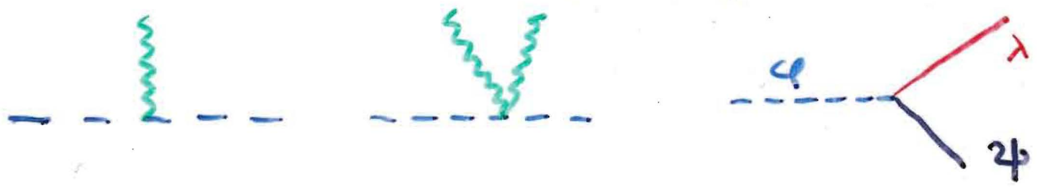
$$(W^\alpha W_\alpha)_F \to -\frac{1}{4} G^{\mu\nu} G_{\mu\nu} + \frac{1}{2} D^2 -$$
$$- \frac{i}{2}\left[\lambda \sigma_\mu (\partial^\mu \bar{\lambda} + ig\,[V^\mu, \bar{\lambda}]) - \right.$$
$$\left. - (\partial^\mu \bar{\lambda} + ig\,[V^\mu, \bar{\lambda}]) \sigma_\mu \lambda \right]$$

with $G_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu + ig\,[V_\mu, V_\nu]$



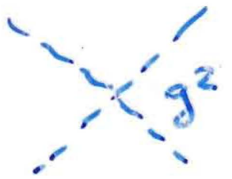
minimal coupling

$$(\Phi^\dagger \exp(2gV)\Phi)_D = |D_\mu \varphi|^2 - \frac{i}{2} \bar{\psi} \sigma_\mu D^\mu \psi$$
$$+ g \varphi^* D \varphi + ig\left[\varphi^* (\lambda \psi) - (\bar{\lambda}\bar{\psi})\varphi\right]$$
$$+ F F^* \qquad (D_\mu = \partial_\mu + ig V_\mu)$$



$\frac{1}{2} D^2 + g \varphi^* D \varphi$

$\Rightarrow$ D is auxiliary $\quad D = -g \varphi^* \varphi$

$\Rightarrow$  φ^4 term

potential $\quad V = \frac{1}{2} D^2$

(D is real)

SUSY breakdown

remember: order parameter is the vacuum energy

scalar potential

$$V = FF^* + \frac{1}{2} D^2 \qquad \geq 0$$

SUSY broken if and only if auxiliary fields aquire v.e.v

and fermionic partner is goldstino

$$\delta \psi = \{ Q, \psi \} = F + \ldots\ldots$$

example: O'Raifeartaigh-model

$$(XX^+)_D + (YY^+)_D + (ZZ^+)_D +$$

$$+\left([\lambda X(Z^2-M^2) + gYZ]_F + h.c\right)$$

$$F_x^* = -\lambda(z^2 - M^2) \quad = 0 \quad \Rightarrow z^2 = M^2$$

$$F_y^* = -gz \quad = 0 \quad \Rightarrow z = 0$$

$$F_z^* = -gy - 2\lambda x z$$

$\Rightarrow$ SUSY broken $\quad V_{min} > 0$

have to minimize

assume $\quad M^2 < g^2/2\lambda^2$

$\Rightarrow$ minimum at $\quad z = y = 0$

$$\langle F_x \rangle = \lambda M^2$$

$$V_{min} = \lambda^2 M^4 = E_{vac}^4$$

observe that vev of x is undetermined (flat direction) spectrum after susy breakdown

superpotential $W = \lambda X (Z^2 - M^2) + g Y Z$

fermion masses

$\lambda x \psi_z \psi_z + z \psi_x \psi_z + g \psi_y \psi_z$

$\langle z \rangle = 0 \Rightarrow \psi_x = 0$

is goldstino since $\langle F_X \rangle \neq 0$

ψ_y, ψ_z Dirac fermion with mass g

Note: Fermion do not feel susy breakdown at tree level

scalar masses

$V = \lambda^2 |z^2 - M^2|^2 + g^2 |z|^2 + |gy + 2\lambda x z|^2$

- x massless (flat direction)
- $g^2 y y^*$ as in susy case

- $z = a + ib$

$$g^2 z z^* - \lambda^2 M^2 (z^2 + z^{*2})$$

$$= g^2 (a^2 + b^2) - 2\lambda^2 M^2 (a^2 - b^2)$$

$$m_a^2 = g^2 - 2\lambda^2 M^2$$

$$m_b^2 = g^2 + 2\lambda^2 M^2$$

simple rule: mass splitting determined by coupling to F_X

- fermions do not couple

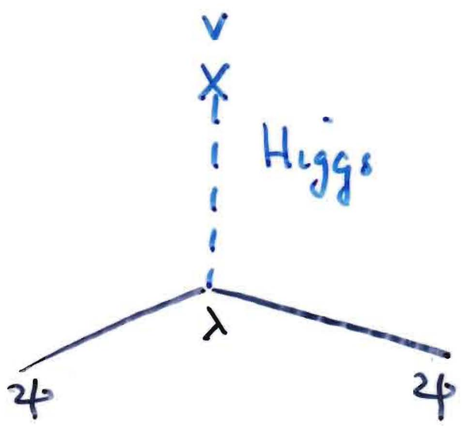
- $(\lambda X z^2)_F \to \lambda F_X z^2$

  z couples to F_X and goldstino

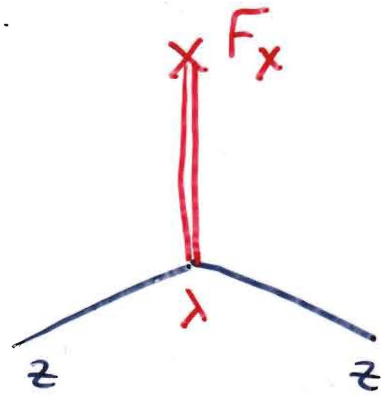
$$\Delta m^2 = \frac{1}{2}(m_b^2 - m_a^2) \sim \lambda^2 M^2$$

$$\Delta m^2 \sim \lambda F_X = \lambda^2 M^2$$

(no splitting if $\lambda = 0$)



$m = \lambda v$

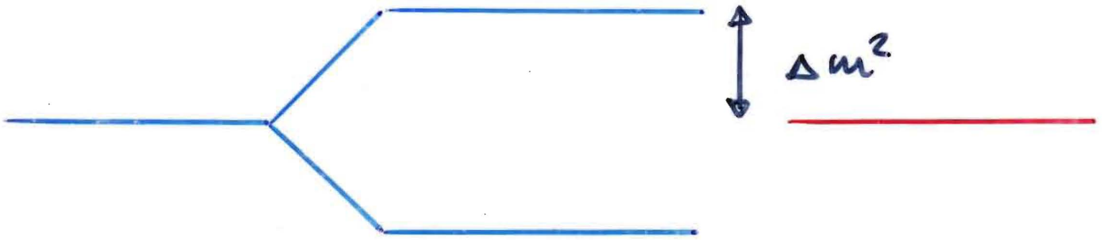


$\Delta m = \lambda F_X$

Sum rule

$$m_a^2 + m_b^2 = 2 m_F^2$$

and this is quite general.



$$\mathrm{STr}\, M^2 = \sum_J (-1)^{2J} (2J+1)\, M_J^2 = 0$$

even in presence of a spontaneous susy breakdown.

D-term breakdown

example: Fayet Iliopoulos term (need $U(1)$)

$$\mathcal{L} = \frac{1}{32}\left[W^\alpha W_\alpha\right]_F + \left[\Phi^* \exp(2gV)\Phi\right]_D + \underbrace{\left[2\xi V\right]_D}_{\to\ \xi D}$$

elimination of auxiliary fields

$F = 0$

$D + \xi + g\varphi^*\varphi = 0$

$$V = \frac{1}{2}D^2 = \frac{1}{2}\left|\xi + g\varphi^*\varphi\right|^2$$

two cases

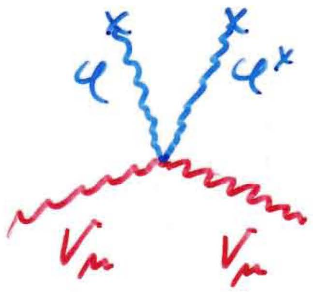
- $g\xi < 0 \Rightarrow \langle D\rangle = 0$ SUSY unbroken
  $\langle \varphi\varphi^*\rangle = -\xi/g$ $U(1)$ broken

- $g\xi > 0 \Rightarrow \langle D\rangle \neq 0$ SUSY broken

$\langle \varphi^* \varphi \rangle = - \xi / g > 0$

Higgs effect

$|D_\mu \varphi|^2$



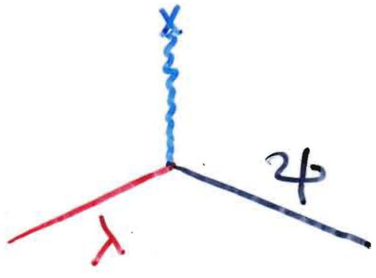
$$V_\mu^{m=0} + \varphi + \varphi^*$$

$$\to V_\mu^{m \neq 0} + \eta$$

in addition we have

gaugino λ and ψ (partner of φ)

$$g\left(\varphi^* (\lambda \psi) - \varphi (\bar{\lambda} \bar{\psi})\right)$$



combine to Dirac fermion of mass gv

SUSY Higgs effect

$$(V_\mu , \lambda)_{m=0} + (\psi, \varphi) \to$$

all same mass

$$\to V_\mu^{m \neq 0} + \begin{pmatrix} \lambda \\ \psi \end{pmatrix} + \eta_{\text{real}}$$

S27

$$V = \frac{1}{2} | \xi + g \varphi^* \varphi |^2$$

and $g\xi > 0$

$V_{min} = \frac{1}{2}\xi^2$ $\qquad \langle \varphi \rangle = 0$

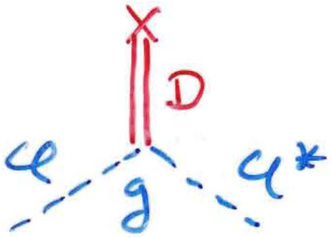
(need not be always the case)

$\langle D \rangle = \xi$

λ is goldstino

V_μ massless since $U(1)$ unbroken

only φ couples to λ and D



$m_\varphi^2 = g\xi$

$m_\psi = 0$

$\Delta m^2 = \text{coupling} \times \langle D \rangle$

$$\mathrm{STr}\, \mathcal{M}^2 = 2\, \mathrm{Tr}\, Q \,\langle D \rangle \neq 0$$

nonrenormalization theorems

remember  $= 0$

not just absence of quadratic divergence

$$\delta m = 0$$

true for all terms in superpotential

all contributions from loops have integrals over full superspace

always $\int d^2\theta \, d^2\bar{\theta} \ldots\ldots$

nonrenormalization of superpotential

higher N $\rightarrow$ less and less divergences

N=4 SUSY is finite

nonrenormalization theorems are crucial for the survival of SUSY

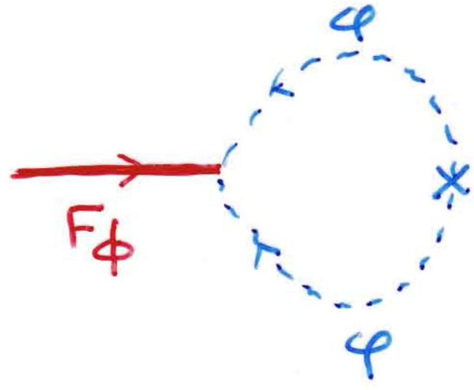
consider $\lambda X Z^2 + gYZ - \lambda M^2 X$

$M^2 = 0 \Rightarrow$ SUSY unbroken

$F_X^* = -\lambda z^2 \qquad F_Y^* = -gz$

$F_Z^* = -gy - 2\lambda xz$

radiative correction $M^2 \int d^2\theta\, \phi = F_\phi M^2$



in WZ model

$m\phi^2 + \lambda\phi^3$

coupling $3\lambda(F\varphi^2 + F^*\varphi^{*2})$

$F = f + ig \qquad \varphi = a + ib \Rightarrow 6\lambda\left[f(a^2 - b^2) - 2gab\right]$

$4m^2\varphi\varphi^* = 4m^2(a^2 + b^2) \Rightarrow \langle g \rangle = 0$

no ab term.

and we have $fa^2 - fb^2 = 0$

"soft" breaking terms

terms that do not lead to quadr. div.

$\int d^4\theta\, V$ potentially quadr. divergent

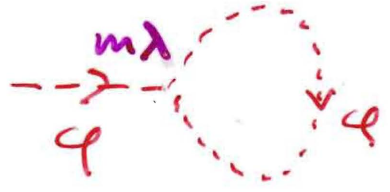
$\to \sum Q_i = 0$

soft terms $m^2 \varphi\varphi^*$, $m^2(\varphi^2+\varphi^{*2})$

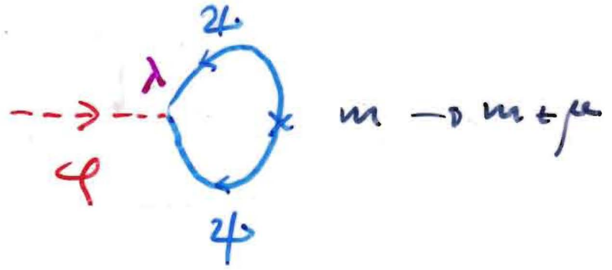
$\mu(\varphi^3+\varphi^{*3})$, $\mu\lambda\lambda$

observe: gaugino mass term is soft

other mass terms $m\,\psi\psi$ not!



$\varphi^2\varphi^*$



$\varphi\psi\psi$