CYBERSUSY

A new mechanism for supersymmetry breaking
in models like the Supersymmetric Standard Model (SSM):

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Abstract

The SUSY breaking in Cybersusy is proportional to the VEV that breaks the gauge symmetry $SU(2) \times U(1)$ down to $U(1)$, and it is rather specific to models like the SSM. Assuming full breaking, as explained below, for the leptons, Cybersusy predicts a spectrum of SUSY breaking that is in accord with experimental results so far. In particular, for the choice of parameters below, Cybersusy predicts that the lowest mass superpartner for the charged leptons is a charged vector boson lepton (the Velectron), which has a mass of 316 Gev. The Selectron has a mass of 771 Gev for that choice of parameters. The theory also leads to a zero cosmological constant after SUSY breaking. The mechanism generates equations that restrict models like the SSM. This version of this paper incorporates recent results and changes discovered subsequent to the talk.

1 Composite Superfields when Auxiliaries are Integrated

Cybersusy arises from a study of the BRS cohomology of D=3+1, N=1 quantum field theories with chiral and gauged supersymmetry, like the SSM. Integration of the auxilliary fields gives rise to a non-linear realization of supersymmetry, embodied in the nilpotent anticommuting BRS operator $\delta_{BRS}$. Certain composite expressions, made from the component fields and the Zinn sources, behave almost as though they were superfields. The non-linearity implies ‘Cybersusy Constraints’ that must be satisfied to form composite ‘pseudosuperfields’. When the vacuum expectation value that breaks gauge symmetry becomes non-zero, one finds that these composite pseudosuperfields give rise to a new ‘anomalous’ realization of supersymmetry. Mapping the composite superfields onto new elementary effective superfields yields a new action with broken supersymmetry.

It turns out that the SSM is an excellent model in which to find solutions to the Cybersusy Constraints. The new realization that arises, when the VEV appears, gives rise to a natural mechanism for SUSY breaking. And those solutions, and that SUSY breaking, look very much like the particles we observe. Here we only consider the leptons, but it does appear that the mechanism extends to most or all other particles. Cybersusy is an acronym standing for ‘Cohomologically Broken Effective Retro SUperSYmmetry’. The word Retro refers to the fact that Cybersusy leads us back to composite particles like baryons which were the ultimate origin of supersymmetry, through duality, the string and the superstring.

2 BRS operator for chiral matter in a general theory

Our considerations are restricted to the the chiral matter here. However, it appears that nothing essential changes when the gauge theory is introduced. The action is
\( \mathcal{A}_{SSM} = \int d^4x \ d^4\theta \hat{A} \hat{\partial} \hat{A}_p + \int d^4x \ d^2\theta \left\{ \frac{1}{3} g_{ppq} \hat{A}^p \hat{A}^q - m^2 g_r \hat{A}^r \right\} + *\). The SSM develops a VEV of \( A^p > m v^p \) and \( g_{ppq} v^q - g_r = 0 \) which breaks \( SU(2) \times U(1) \) down to \( U(1) \). We add Zinn Justin terms \( Y_i^\alpha \delta_{WZ} \psi^i_\alpha = Y_i^\alpha \left( \partial_{\alpha \beta} A^\beta C^\beta + F^4 C_a \right) \) and \( \Gamma_i \delta_{WZ} A^i = \Gamma_i C^\alpha \psi^i_\alpha \) to the Lagrangian, place this in a Feynman path integral, observe the supersymmetry, integrate \( F^r \), and perform the usual steps to get a nilpotent \( \delta_{\text{BRS}} \) which satisfies \( \delta_{\text{BRS}}^2 = C^\alpha C^\beta \partial_{\alpha \beta} \approx 0 \). Here is the operator:

\[
\delta_{\text{BRS}} = \int d^4x \ \psi^i_\beta C^\beta \frac{\delta}{\delta A^i} + \int d^4x \ \left\{ \partial_{\alpha \beta} A^\beta C^\beta + C_a G^i \right\} \frac{\delta}{\delta \psi^i_\alpha} + \int d^4x \left\{ -\frac{1}{2} \partial_{\alpha \beta} \partial_{\alpha \gamma} \bar{\psi}_i + \partial_{\alpha \beta} Y_i C^\beta + g_{ijk} \left[ 2 \hat{A}^{i} C^k - \psi^{j \alpha} \psi^{k \alpha} \right] + 2 m g_{ijk} \psi^{j \alpha} \psi^{k \alpha} - \Gamma_i C^\alpha \right\} \frac{\delta}{\delta Y^\alpha} + * \quad (1)
\]

The composite field \( G^i \) is \( G^i = -\left( \bar{g}^{ijk} A_j \bar{A}_k + 2 m g^{ijk} \bar{A}_j v_k + \bar{\psi}^{(i \beta} A_j \bar{A}_k + \bar{\psi} \Gamma_{ij} \bar{C}^\beta \right) \).

3 Fundamental Superfields with integrated auxiliaries

Certain combinations of fields, sources and \( \theta, \bar{\theta} \) act like superfields. We will call them Fundamental Superfields. The first is the Fundamental chiral superfield \( \hat{A}^{\text{Fund}}(x) = A^i(y) + \theta^\alpha \psi^i_\alpha (y) + \frac{1}{2} \theta^\alpha \theta^\beta G^i (x) \) where the translated spacetime variable is \( x_{\alpha \beta} = x_{\alpha \beta} + \frac{1}{2} \theta_{\alpha \beta} \bar{\theta} \). The transformation induced by \( \delta_{\text{BRS}} \) is summarized by the following equation: \( \delta_{\text{BRS}} \hat{A}^{\text{Fund}}(x) = \delta_{SS} \hat{A}^{\text{Fund}}(x) \) where the superspace operator is \( \delta_{SS} = C^\alpha Q_\alpha + \bar{C}^\beta \bar{Q}_\beta \). This relation means that the effect of \( \delta_{\text{BRS}} \) on this particular combination is the same as the effect of the superspace operator \( \delta_{SS} \). The supertranslations are: \( Q_\alpha = \frac{\theta}{g_{\alpha \beta}} - \frac{1}{2} \theta_{\alpha \beta} \bar{\theta} \) and \( \bar{Q}_\alpha = \frac{\bar{\theta}}{g^{\alpha \beta}} - \frac{1}{2} \bar{\theta}_{\alpha \beta} \theta \). Next is the surprise. There is a new kind of superfield which is not present in the usual treatment! It is the Fundamental chiral dotted spinor superfield: \( \bar{\psi}^{\text{Fund} \ i \alpha}(x) = \bar{\psi}_i^{\alpha}(y) + \theta^\beta \left[ \partial_{\beta \alpha} \bar{A}_i(y) + \bar{C}_\alpha Y_{i \alpha}(y) \right] - \frac{1}{2} \theta^\alpha \theta_\gamma \Gamma_{i \alpha}(x) \bar{C}_\alpha \). Its transformation under the action of \( \delta_{\text{BRS}} \) is:

\[
\delta_{\text{BRS}} \hat{\bar{\psi}}^{\text{Fund} \ i \alpha}(x) = \delta_{SS} \hat{\bar{\psi}}^{\text{Fund} \ i \alpha}(x) - g_{ijk} \hat{A}_j^{\text{Fund}} \bar{A}_k^{\text{Fund}} \bar{C}_\alpha - 2 m g_{ijk} \psi^{j \alpha} \hat{A}_k^{\text{Fund}} \bar{C}_\alpha. \]

It behaves as a chiral superfield if and only if the theory is free and massless, which happens if and only if \( g_{ijk} = m^2 g_i = 0 \). Its nonlinear transformation suggests that we form composite superfields as follows.

4 Composite Superfields in general theory

Consider the composite expression \( \hat{\omega}^{\text{Comp} \ \alpha} = f_j^{\beta \gamma} \hat{\bar{\psi}}^{\text{Fund} \ i \alpha} \left( m v^j + \hat{A}_j^{\text{Fund}} \right) \). The constraint equations are \( f_{ij} g_{kij} = 0 \) and if they are satisfied, then we get \( \delta_{\text{BRS}} \hat{\omega}^{\text{Comp} \ \alpha} = \left( \delta_{SS} + \delta_{\text{GSB}} \right) \hat{\omega}^{\text{Comp} \ \alpha} \), where the new variation is \( \delta_{\text{GSB}} \hat{\omega}^{\text{Comp} \ \alpha} = m^2 f_j^{\beta \gamma} \hat{A}_j^{\text{Fund}} \bar{C}_\alpha \). GSB stands for gauge symmetry breaking. If \( m^2 g_i = 0 \), then \( \hat{\omega}^{\text{Comp} \ \alpha} \) behaves as a superfield \( \left( \delta_{\text{BRS}} = \delta_{SS} \right) \) and if \( m^2 g_i \neq 0 \), then \( \hat{\omega}^{\text{Comp} \ \alpha} \) has a new term in the algebra, namely \( \delta_{\text{BRS}} = \delta_{SS} + \delta_{\text{GSB}} \).
5 Solutions of Cybersusy Constraints for SSM

The SSM superpotential has the following form in terms of the usual Quark, Lepton, and Higgs doublet and singlet multiplets:

\[ P_{SSM} = g_{ij} H^i K^j J + p_{pq} \epsilon_{ij} L^p H^j P^q + r_{pq} \epsilon_{ij} L^p K^j R^q \]

\[ + t_{pq} \epsilon_{ij} Q^{pq} K^j T^e + b_{pq} \epsilon_{ij} Q^{pq} H^j B^q = -m^2 g_{ij} J \]

The term \(-m^2 g_{ij} J\) yields VEVs: \(< H^i >= m_h^i; < K^j >= m_k^j\). These break \(SU(2) \times U(1) \rightarrow U(1)\), but there is no spontaneous breaking of SUSY, because the auxiliary fields have zero VEV: \(< F^p >= < D^a >= 0 \leftrightarrow Zero\ Vacuum\ Energy \leftrightarrow Zero \ Cosmological\ Constant\). Now we look at the SSM in detail to find solutions of the constraint equations \(f^i_{(jk)l}; = 0\). The SSM (and related models) provide surprising examples of these. Observe that \((\delta_{CS})\) has a corresponding algebra for the effective fields, namely \(\delta_{Mix} \equiv \delta_{Mix}\). The next step is to map these composite fields \(\tilde{\omega}_{Comp, \alpha}\) onto elementary effective fields, \(\tilde{\omega}_{Rp\alpha}\), and to deduce the algebra of the effective fields from the algebra of the composite fields:

6 Generators for Charged Leptons in the SSM:

The operators \(\mathcal{L}^+_p = p_{pq} P^q \frac{\partial}{\partial J} + g K^j \frac{\partial}{\partial L^p} + g \epsilon_{ij} H^i K^j \frac{\partial}{\partial p} \) both satisfy \(\mathcal{L}_{Cubic} = 0\) for the SSM. Each invariant Lie algebra operator yields a chiral dotspinor superfield. For example \(\mathcal{L}^+_p = p_{pq} P^q \frac{\partial}{\partial J} + g K^j \frac{\partial}{\partial L^p} \Rightarrow \tilde{\omega}^+_{Mix, p, \alpha} = p_{pq} \tilde{\psi}_{p, j} + g \tilde{K}^j \tilde{\psi}_{Lp, j}\alpha\). The next step is to map these composite fields \(\tilde{\omega}^+_{Mix, p, \alpha}\) onto elementary effective fields, \(\tilde{\omega}_{Rp\alpha}\), and to deduce the algebra of the effective fields from the algebra of the composite fields:

| Cybersusy Effective Superfields from the SSM for the Charged Leptons | Composite | \(Y\) | \(L\) |
|--------------------------|-----------|-----|-----|
| \(A^p_L\) | \(L^p (m_h^i + H^i)\) | -2 | 1 |
| \(A^p_R\) | \(P^p\) | +2 | -1 |
| \(\tilde{\omega}_{Lp\alpha}\) | \(p_{pq} (m_h^j + \tilde{H}^j) \tilde{L}^j \tilde{\psi}_{j, \alpha} + g (m_h^j + \tilde{H}^j)\) | -2 | 1 |
| \(\tilde{\omega}_{Rp\alpha}\) | \(p_{pq} \tilde{P}^q \tilde{\psi}_{j, \alpha} + g (m_k^j + \tilde{K}^j) \tilde{L}^j \tilde{\psi}_{Lp, j}\alpha\) | +2 | -1 |

In the above, \(p=1,2,3\) is a flavour index. \(Y\) is electric hypercharge and \(L\) is lepton number. These superfields are singlets under SU(2) and SU(3):

The operator \(\delta_{BRS} = \delta_{SS} + \delta_{GSB}\) acting on the composite fields implies a corresponding algebra for the effective fields, namely \(\delta_{Cybersusy} \equiv \delta_{CS} = \delta_{SS} + \delta_{Mix}\). The new variations are \(\delta_{Mix} \tilde{\omega}_{Lp\alpha} = p_{pq} \tilde{A}^q L \psi_{j, \alpha}; \delta_{Mix} \tilde{\omega}_{Rp\alpha} = p_{pq} \tilde{A}^q R \psi_{p, \alpha}; \delta_{Mix} \tilde{A}^q_L = 0; \delta_{Mix} \tilde{A}^q_R = 0\).

7 Effective Fields and Action for Charged Leptons

Now we look for a new action expressed in terms of the above effective fields. We want this to be invariant under the new transformation \(\delta_{CS} = \delta_{SS} + \delta_{Mix}\). So we start with: \(\delta_{SS} A_{WZ} = 0\) and then look for \(A_{Compensator}\) to satisfy: \(\delta_{Mix} A_{WZ} + \delta_{SS} A_{Compensator} = 0\).
First we need a Kinetic Compensator $A_{KCL} = A_{KCL1} + A_{KCL2}$ The action so far takes the form:

| Name            | Action                                                                 |
|-----------------|-------------------------------------------------------------------------|
| $A_{ScalarL}$   | $\frac{1}{4} \int d^4x \, d^4\theta \hat{A}_L^\alpha \hat{A}_L^\beta$ |
| $A_{ScalarR}$   | $L \Rightarrow R$                                                      |
| $A_{Scalar Mass}$| $\frac{1}{2} \int d^4x \, d^2q_{pq} m_{\Delta}^2 \hat{A}_L^\alpha \hat{A}_R^\beta + \ast$ |
| $A_{DotspinorL}$| $\frac{1}{4} \int d^4x \, d^2q_{pq} m_{\Delta}^2 \hat{A}_L^\alpha \hat{A}_R^\beta$ |
| $A_{DotspinorR}$| $L \Rightarrow R$                                                      |
| $A_{Dotspinor Mass}$ | $\frac{1}{2} \int d^4x \, d^2q_{pq} m_{\Delta}^2 \hat{A}_L^\alpha \hat{A}_R^\beta + \ast$ |

Adding the $A_{KCR}$ action yields a new action $A_{Cybersusy} = A_{WZ} + A_{KCL} + A_{KCR}$. Next we look for a Mass Compensator $A_{MC1}$. It needs to satisfy $\delta_{MIX} A_{Dotspinor Mass} + \delta_{SS} A_{MC1} = 0$. It is easy to show that no such local Mass Compensator $A_{MC1}$ can exist, because $\delta_{MIX} A_{Dotspinor Mass} = m^2 A_{Anomaly} \in \text{Cohomology of } \delta_{SS}$. But $\delta_{MIX} = 0$ implies that there is no gauge symmetry breaking, and $A_{Dotspinor Mass} = 0$ implies that there is a massless charged lepton supermultiplet. The only sensible choice is that $m^2 A_{Anomaly} \neq 0$. The anomaly comes from the algebra, the action, and physical reasoning, not from a loop diagram. This uniquely defined action yields SUSY breaking proportional to gauge symmetry breaking.

After this talk was given, the author realized that the $\delta_{Mix}$ part of the algebra disappears for the left sector if one chooses the left composite operator to be $\hat{\omega}_{Lpq} \approx p_{q0}(m\lambda + \hat{H})L^\alpha_q \hat{\psi}_{L\alpha} + \{g(m\lambda + \hat{H})(mk_j + \hat{K}_j) - m^2 g_j\} \hat{\psi}_{Lpq}$ in place of (4). No such possibility arises for the right sector. So Cybersusy still breaks SUSY after this change, but a reasonable spectrum may require a modification of the model.

8 Broken SUSY Spectrum for one flavour of Charged Leptons

We now describe the mass spectrum for the simplest case of one flavour, assuming both left and right breaking, as it arises from table (4). G, P and D are positive parameters. Define $X = \frac{g^2 m^4}{m^2}$. The fermionic lepton masses are the negative solutions of $P_{Quintic \, Fermi}(X) = X \{X^2(1 - P - D)^2 + G \{X^2 - D\}^2\} = 0$. The bosonic lepton masses are the negative solutions of $P_{Quadratic \, Bose}(X) = X^2 - D = 0$ and $P_{Quartic \, Bose}(X) = X^2 (X(1 - P)^2 + G)^2 - (X(1 - P)^2 + G)^2 D = 0$. The following choice of parameters is interesting: $P = 1 - 10^{-5.8}, G = 2.5 \times 10^{-7}, D = 10^{10}$. It yields two very heavy fermionic leptons with masses 8992 and 8834 Gev, plus the light Electron with mass $0.5 \times 10^{-3}$ Gev. Then there is one very heavy scalar boson lepton with mass $355,000$ Gev, and a much lighter scalar boson lepton, the Selectron with mass 771 Gev. The lightest superpartner for this choice of parameters is the vector boson lepton, the Velectron, with mass 316 Gev.

Reference

More complete references can be found in J. A. Dixon, Cybersusy I, arXiv: 0808-0811 hep-th, Aug 6, 2008 and Cybersusy II-V, also on arXiv. These papers require some revision to incorporate the modification to equation (4) discussed above.