Unification and mass spectrum in a $B-L$ extended MSSM

R. J. Hernández-Pinto and A. Pérez-Lorenzana

Departamento de Física, Centro de Investigación y de Estudios Avanzados del I.P.N., Apdo. Post. 14-740, 07000 México D.F., México.

Abstract. The simplest B-L extension of the minimum supersymmetric standard model (MSSM) may change some of the conceptions about the path for gauge unification as well as to affect the predicted spectrum of the supersymmetric particles at low energy. We present our results for the running of gauge coupling constants and mass parameter in this context.

Keywords: Renormalization group evolution of parameters, Supersymmetric models
PACS: 11.10.Hi, 12.60.Jv

RGE. Including the gauge group $U(1)_{B-L}$ to the SM group, the general superpotential that can be written wich conserves the symmetry is,

$$W = \bar{U}\mathbf{Y}_u Q H_u + \bar{D}\mathbf{Y}_d Q H_d + \bar{E}\mathbf{Y}_e L H_d + \bar{N}\mathbf{Y}_N^D L H_u + N\mathbf{Y}_N^M N\sigma_1 + \mu H_d H_u + \mu'\sigma_1\sigma_2,$$

where besides standard superfields we have additional fields, which under the symmetry group $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$, have the following representation, $\bar{N} = (\mathbf{1},\mathbf{1},0,1)\,,\sigma_1 = (\mathbf{1},\mathbf{1},0,-2)\,,\sigma_2 = (\mathbf{1},\mathbf{1},0,2)$.

The soft breaking terms that involve the new fields are

$$\mathscr{L}_{SB} = 1/2 M_{B-L}\tilde{Z}_{B-L}\tilde{Z}_{B-L} + \tilde{\bar{N}}\mathbf{h}_N^D \tilde{L}\tilde{H}_u + \tilde{N}^\dagger m_N^2 \tilde{N}.$$

And finally, the scalar potential has as the only new terms,

$$V(\sigma_1,\sigma_2) = m'^2_{\sigma_1}|\sigma_1|^2 + m'^2_{\sigma_2}|\sigma_2|^2 - (B'\sigma_1\sigma_2 + c.c.) + g''(|\sigma_1|^2 - |\sigma_2|^2)^2/8,$$

where $m_j^2 = m_j'^2 + \mu'^2$ for $j = \sigma_1, \sigma_2$. For a general superpotential and soft breaking terms, the beta functions could be calculated, using the representations of the superfields[1]. The notation is $\Delta\beta_f = \beta_f - \beta_f^{MSSM}$, where $\beta_f = 16\pi^2(df/dt)$, with $t = \ln(Q/Q_0)$. We present the RGE for the gauge couplings, Yukawa couplings, gaugino mass, μ and μ' term,

$$\beta_{g_i} = c_i g_i^3, \quad \beta_{M_i} = 2c_i g_i^2 M_i, \quad \Delta\beta_{y_t} = y_t\left\{y_D^2 - g_{B-L}^2/6\right\}, \qquad \Delta\beta_{y_b} = -y_b g_{B-L}^2/6,$$
$$\Delta\beta_{y_\tau} = y_\tau\left\{y_D^2 - 3g_{B-L}^2/2\right\}, \quad \beta_{y_D} = y_D\left\{4y_D^2 + 3y_t^2 + y_M^2 - 3g_1^2/5 - 3g_2^2 - 3g_{B-L}^2/2\right\},$$
$$\beta_{y_M} = y_M^2\left\{3y_M^2 + 4y_D^2 - 9g_{B-L}^2/2\right\}, \quad \Delta\beta_\mu = \mu y_D^2, \qquad 2\beta_{\mu'} = \mu'\left\{y_M^2 - 3g_{B-L}^2\right\},$$

where $i = 1,2,3,B-L$, and we had made the following approximations, $\mathrm{Y}_u = \mathrm{diag}(0,0,y_t)$, $\mathrm{Y}_d = \mathrm{diag}(0,0,y_b)$, $\mathrm{Y}_e = \mathrm{diag}(0,0,y_\tau)$, $\mathrm{Y}_N^D = \mathrm{diag}(0,0,y_D)$, $\mathrm{Y}_N^M = \mathrm{diag}(0,0,y_M)$. For the corresponding anomalous dimensions to $\mathbf{h}_i$, it had been used the approximations, $\mathrm{h}_u = \mathrm{diag}(0,0,a_t)$, $\mathrm{h}_d = \mathrm{diag}(0,0,a_b)$, $\mathrm{h}_e = \mathrm{diag}(0,0,a_\tau)$, $\mathrm{h}_N^D = \mathrm{diag}(0,0,a_D)$, $\mathrm{h}_N^M = \mathrm{diag}(0,0,a_M)$. Then,

$$
\begin{aligned}
\Delta\beta_{a_t} &= a_t\left\{y_D^2 - g_{B-L}^2/6\right\} + y_t\left\{2a_D y_D + g_{B-L}^2 M_{B-L}/3\right\},\\
\Delta\beta_{a_b} &= -a_b g_{B-L}^2/6 + y_b g_{B-L}^2 M_{B-L}/3,\\
\Delta\beta_{a_\tau} &= a_\tau\left\{y_D^2 - 3g_{B-L}^2/2\right\} + y_\tau\left\{2a_D y_D + 3g_{B-L}^2 M_{B-L}\right\},\\
\beta_{a_D} &= a_D\left\{12y_D^2 + 3y_t^2 + 2y_M^2 + y_\tau^2 - 3g_1^2/5 - 3g_2^2 - 3g_{B-L}^2/2\right\}\\
&\quad + y_D\left\{6a_t y_t + 2a_M y_M + a_\tau y_\tau + 6g_1^2 M_1/5 + 6g_2^2 M_2 + 3g_{B-L}^2 M_{B-L}\right\},\\
\beta_{a_M} &= a_M\left\{15y_M^2 + 8y_D^2 - 9g_{B-L}^2/2\right\} + \left\{8a_D y_D + 9g_{B-L}^2 M_{B-L}\right\}.
\end{aligned}
$$

For the mass anomalous dimensions the following approximations had been made, $m_Q^2 = \mathrm{diag}(m_{Q_1}^2, m_{Q_1}^2, m_{Q_3}^2)$, $m_L^2 = \mathrm{diag}(m_{L_1}^2, m_{L_1}^2, m_{L_3}^2)$, $m_u^2 = \mathrm{diag}(m_{u_1}^2, m_{u_1}^2, m_{u_3}^2)$, $m_d^2 = \mathrm{diag}(m_{d_1}^2, m_{d_1}^2, m_{d_3}^2)$, $m_e^2 = \mathrm{diag}(m_{e_1}^2, m_{e_1}^2, m_{e_3}^2)$, $m_N^2 = \mathrm{diag}(m_{N_1}^2, m_{N_1}^2, m_{N_3}^2)$. Then,

$$
\begin{aligned}
\Delta\beta_{m_{H_u}^2} &= 2y_D^2\left\{m_{H_u}^2 + m_{L_3}^2 + m_{N_3}^2\right\} + 2a_D^2, & \Delta\beta_{m_{H_d}^2} &= 0,\\
\Delta\beta_{m_{Q_3}^2} &= -g_{B-L}^2 M_{B-L}^2/3 + g_{B-L}^2 S'/4, & \Delta\beta_{m_{u_3}^2} &= -g_{B-L}^2 M_{B-L}^2/3 + g_{B-L}^2 S'/4,\\
\Delta\beta_{m_{d_3}^2} &= -g_{B-L}^2 M_{B-L}^2/3 + g_{B-L}^2 S'/4, & \Delta\beta_{m_{e_3}^2} &= -3g_{B-L}^2 M_{B-L}^2 - 3g_{B-L}^2 S'/4,
\end{aligned}
$$

$$
\begin{aligned}
\Delta\beta_{m_{L_3}^2} &= 2y_D^2\left\{m_{H_u}^2 + m_{L_3}^2 + m_{N_3}^2\right\} + 2a_D^2 - 3g_{B-L}^2 M_{B-L}^2 - 3g_{B-L}^2 S'/4,\\
\beta_{m_{\sigma_1}^2} &= 2y_M^2\left\{m_{\sigma_1}^2 + m_{N_3}^2\right\} + 2a_M^2 - 12g_{B-L}^2 M_{B-L}^2 - 3g_{B-L}^2 S'/2,\\
\beta_{m_{\sigma_2}^2} &= -12g_{B-L}^2 M_{B-L}^2 + 3g_{B-L}^2 S'/2,\\
\beta_{m_{N_3}^2} &= 4y_D^2\left\{m_{H_u}^2 + m_{L_3}^2 + m_{N_3}^2\right\} + 4y_M^2\{m_{\sigma_1}^2 + m_{N_3}^2\} + 4(a_M^2 + a_D^2) - 3g_{B-L}^2 M_{B-L}^2\\
&\quad - 3g_{B-L}^2 S'/4,
\end{aligned}
$$

where $S' = 2m_{\sigma_2}^2 - 2m_{\sigma_1}^2 + Tr[2m_Q^2 - 2m_L^2 + m_u^2 + m_d^2 - m_e^2 - m_N^2]$.

Unification. The RGE for g_i can be rewritten in terms of α_i^{-1} and, at one loop order, the general solution is[2], $\alpha_i^{-1}(m) = c_i\left[\alpha_i^{-1}(m_Z) + (2\pi)^{-1} b_i \ln(m/m_Z)\right]$. The Kac-Moody (c_1, c_2, c_3, c_{B-L}) are $(3/5, 1, 1, 3/8)$; and the b_i are, $(b_1, b_2, b_3, b_{B-L}) = (-11, -1, 3, -24)$. It's know that $\alpha_1^{-1}(m_Z) \approx 98.33$, $\alpha_2^{-1}(m_Z) \approx 29.57$ and $\alpha_3^{-1}(m_Z) \approx 8.4$[3]. Supposing unification for $\alpha_{B-L}^{-1}(m)$, the RGE have the solution shown in the figure below. Then $\alpha_{B-L}^{-1}(m_Z) \approx 191.1$, so, $g_{B-L}(m_Z) \approx 0.2565$.

Mass Spectrum. The RGE for the masses could be solved imposing initial conditions. As it is customized, those are fixed at the unification scale, $Q_0 \approx 2.5 \times 10^{16}$ GeV. The already known solution for the MSSM[4] is recovered (for the β_f^{MSSM} functions) as depicted in the plot below. When $B-L$ contributions are included, the initial conditions are forced to be different due to the phenomenology at low-energies, if one desires to have the SUSY breaking at the same scale, as it can be seen in the following figures. For the squarks and sleptons, the solid lines correspond to the third family, while the dashed lines do to the first and second families.

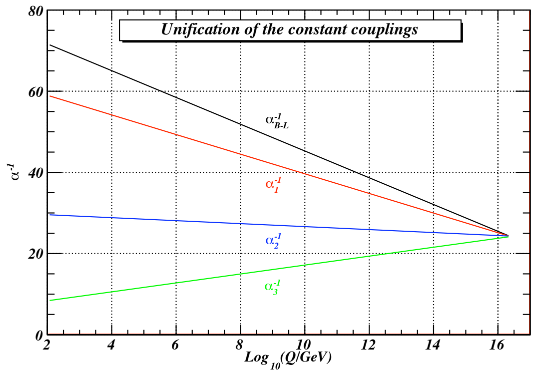

FIGURE 1. Running of gauge couplings.

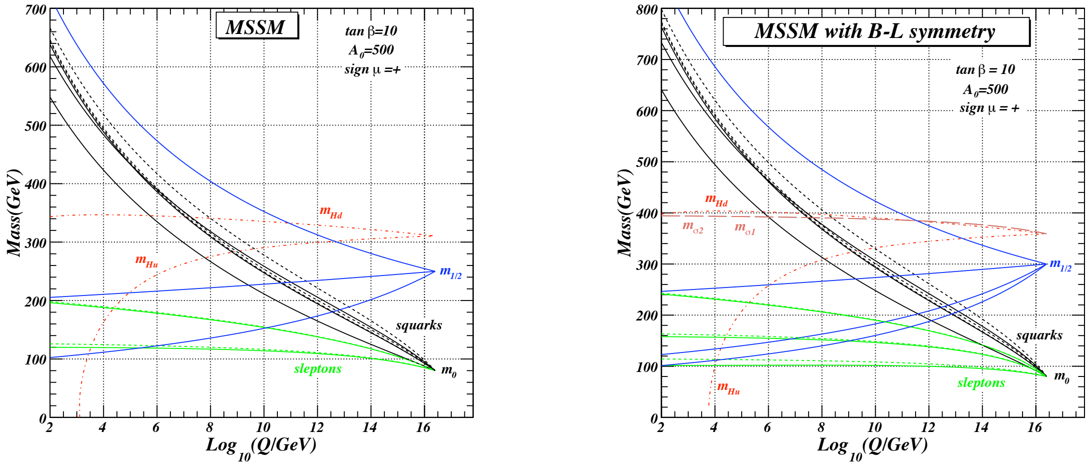

FIGURE 2. Mass spectrum in MSSM and its $B-L$ extension.

Conclusions. It had been calculated the RGE for the $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$ SUSY model. It had been shown that it is possible the unification of α^{-1}_{B-L} at $Q_0 \approx 2.5 \times 10^{16}$ GeV. Slight modifications should be done to the initial conditions if the $B-L$ symmetry is included in the standard model, in order to preserve the phenomenology at low energies.

Acknowledgments. Work supported in part by Conacyt, México, grant 54576.

REFERENCES

1. S. Martin and M. Vaughn, *Phys. Rev. D 50, 2282 (1994)*
2. A. Pérez-Lorenzana, A. Zepeda, and W. Ponce, *Mod. Phys. Lett. A 13, 2153 (1998)*
3. C. Amsler *et al., Physics Letters B667, 1 (2008)*
4. S. Martin, arXiv:hep-ph/9709356