PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 62, No. 3
March 2004
pp. 771–773

Leptogenesis with left–right domain walls

U A YAJNIK[1], J CLINE[2] and M RABIKUMAR[1]
[1]Indian Institute of Technology, Mumbai 400 076, India
[2]Department of Physics, McGill University, Montréal, Québec H3A 2T8, Canada

Abstract. The presence of domain walls separating regions of unbroken $SU(2)_{\rm L}$ and $SU(2)_{\rm R}$ is shown to provide necessary conditions for leptogenesis which converts later to the observed baryon asymmetry. The strength of lepton number violation is related to the Majorana neutrino mass and hence related to current bounds on light neutrino masses. Thus the observed neutrino masses and the baryon asymmetry can be used to constrain the scale of left–right symmetry breaking.

Keywords. Leptogenesis; baryogenesis; domain walls; left–right symmetry.

PACS Nos 12.10.Dm; 98.80.Cq; 98.80.Ft

Explaining the observed baryon asymmetry of the Universe within the framework of gauge theories and the standard Big Bang cosmology remains an open problem. The combination $B + L$ of the baryon and lepton numbers is known to be anomalous in the standard model (SM). For $T > T_{\rm EW}$, the temperature of the electroweak phase transition, the $B + L$ violation becomes unsuppressed [1–3]. Thus any $B + L$ generated at the scales of grand unified theories (GUTs) would be erased. Further, all the known GUTs preserve $B - L$ whose natural value should be zero. Thus the GUT solution [4,5] of baryogenesis is unlikely to be true.

Possible mechanisms for generating observed baryon asymmetry at electroweak scale are reviewed in [6–8]. The strategy is to assume a first-order phase transition to ensure an epoch of non-equilibrium evolution, during which the B, C and CP violating effects must take place, satisfying the Sakharov criteria [9]. However with Higgs mass as large as 115 GeV, the phase transition in SM would be second order, making baryogenesis unfeasible in SM.

Mechanisms in which the non-equilibrium evolution is due to the presence of topological defects, viz., domain walls [10], and cosmic strings [11,12] have also been considered. Ensuring first-order phase transition requires fine-tuning the couplings and particle content of the model, while existence of defects relies only on topological features of the vacuum manifolds. An appealing possibility is provided by the intermediate scale unification in the left–light symmetric model. Large Majorana masses for the neutrinos permit lepton number violation and the resulting baryogenesis can be used to constrain the scale of the large mass from astrophysical data on the neutrino mass scale.

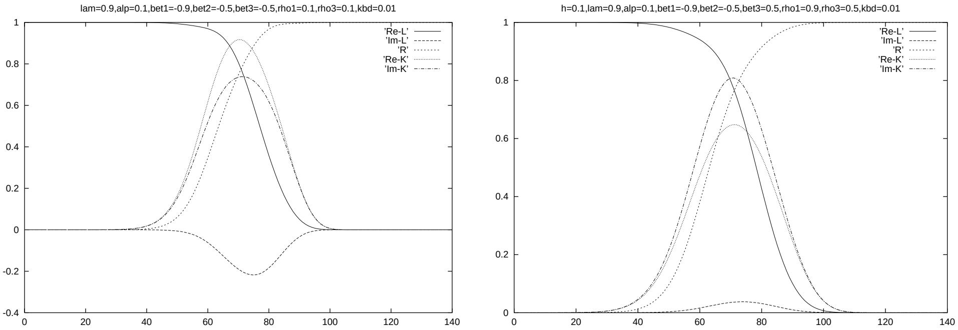

Figure 1. Scalar field condensates for two sets of parameter values.

The left–right symmetric model consists of an additional group $SU(2)_{\rm R}$, under which the $e^-_{\rm R}$ possesses a partner $\nu_{\rm R}$. A new hypercharge needed turns out to be $B-L$ and the formula for the electric charge reads [13,14] $Q = T^3_{\rm L}+T^3_{\rm R}+\frac{1}{2}(B-L)$. The neutrinos naturally possess Majorana masses permitting unrestricted 'L' violation if the symmetry breaking is achieved using two Higgses $\Delta_{\rm R}$, $\Delta_{\rm L}$, triplets under the groups suggested by the respective subscripts. A bidoublet ϕ is also needed and contains two copies of the SM-type Higgs. The breakdown $SU(2)_{\rm R} \otimes U(1)_{B-L} \rightarrow U(1)_Y$ also signals breaking of the discrete symmetry $SU(2)_{\rm L} \leftrightarrow SU(2)_{\rm R}$ which gives rise to domain walls [15] separating two kinds of degenerate vacuua. It also signals C violation. CP violation arises out of complex expectation values for the Higgs and finally the motion of the walls must be directional in order to produce a final state with $SU(2)_{\rm L}$ unbroken. Thus the Sakharov criteria are satisfied when the L $\leftrightarrow$ R violating phase transition occurs.

At least two of the Higgs expectation values in L–R model are generically complex, thus providing natural CP violation [16] permitting all parameters in the Higgs potential to be real. Within the thickness of the domain wall the CP violating phase becomes position-dependent. Under these circumstances a formalism exists [17–19], wherein the chemical potential $\mu_{\rm L}$ created for the lepton number can be computed as a solution of the diffusion equation

$$-D_\nu \mu''_{\rm L} - v_{\rm w}\mu'_{\rm L} + \theta(x)\,\Gamma_{\rm hf}\,\mu_{\rm L} = S(x). \tag{1}$$

Here D_ν is the neutrino diffusion coefficient, $v_{\rm w}$ is the velocity of the wall, taken to be moving in the $+x$ direction, $\Gamma_{\rm hf}$ is the rate of helicity flipping interactions taking place in front of the wall (hence the step function $\theta(x)$), and S is the source term which contains derivatives of the position-dependent complex Dirac mass. In [20] the existence of such a position-dependent phase was established on general grounds and in a few numerical examples, two of which are included in figure 1. Here the expectation values of the $\Delta_{\rm L}$, denoted by L and that of the bidoublet denoted by K are taken to be complex while that of $\Delta_{\rm R}$, denoted by R is real. After integration of the above equation and using inputs from the numerical solutions we find raw lepton asymmetry expressed as a ratio to the entropy density,

$$\eta^{\rm raw}_{\rm L} \cong 0.01\, v_{\rm w} \frac{1}{g_*} \frac{M^4_N}{T^5 \Delta_{\rm w}} \tag{2}$$

with M_N, the Majorana neutrino mass, Δ_{w}, the wall width and g_*, the effective thermodynamic degrees of freedom at the epoch with temperature T. This undergoes depletion due to 'L' violating processes which are in equilibrium at that epoch. However, the high-temperature sphalerons are efficiently converting the 'L' asymmetry into the B asymmetry according to the chemical potential balance in SM [21], given by $\Delta n_B = \frac{28}{79}\Delta n_{B-L} = -\frac{28}{51}\Delta n_L$. After all these processes are taken into account, we require B asymmetry η_B to be 10^{-d_B}, observed d_B being ~ 11, leading to the following predictions. If the heaviest neutrino mass is 1 eV, for example, the temperature of the LR phase transition is predicted to be

$$T_{\mathrm{LR}} \lesssim 10^{13}\ \mathrm{GeV} \times \left(\frac{\mathrm{eV}}{m_\nu}\right)^2 \times \left(\frac{d_B}{10}\right). \tag{3}$$

If we are in the opposite regime, $M_{\mathrm{N}} < T_{\mathrm{LR}}$, the bound on the heaviest neutrino mass is $m_\nu < 0.3\ \mathrm{eV} \times (d_B/10)$. It is interesting that this value is compatible with, and not very far from the value implied by atmospheric neutrino observations.

Thus a hitherto unexplored mechanism exists in the left–right symmetric model for generation of the observed baryon asymmetry of the Universe. Further implications and detailed discussion are contained in [20].

References

[1] V A Kuzmin, V A Rubakov and M E Shaposhnikov, *Phys. Lett.* **B155**, 36 (1985)
[2] P A Arnold and L Mc Lerran, *Phys. Rev.* **D36**, 581 (1987); **D37**, 1020 (1988)
[3] J Ambjorn, T Askgaard, H Porter and M E Shaposhnikov, *Phys. Lett.* **B244**, 479 (1990); *Nucl. Phys.* **B353**, 346 (1991)
[4] M Yoshimura, *Phys. Rev. Lett.* **41**, 281 (1978); Erratum, **42**, 740 (1979)
[5] S Weinberg, *Phys. Rev. Lett.* **42**, 850 (1979)
[6] A G Cohen, D B Kaplan and A E Nelson *Ann. Rev. Nucl. Part. Sci.* **42**, 27 (1993)
[7] M Trodden, *Rev. Mod. Phys.* **71**, 1463 (1996)
[8] U A Yajnik, *Pramana – J. Phys.* **54**, 471 (2000)
[9] A D Sakharov, *JETP Lett.* **5**, 24 (1967)
[10] S Ben-Menahem and A S Cooper, *Nucl. Phys.* **B388**, 409 (1992)
[11] S Bhowmik Duari and U A Yajnik, *Phys. Lett.* **B326**, 21 (1994)
[12] R Brandenberger, A-C Davis and M Trodden, *Phys. Lett.* **B335**, 123 (1994)
[13] R N Mohapatra, *Unification and supersymmetry* (Springer-Verlag, New York, 1992)
[14] R N Mohapatra and G Senjanovic, *Phys. Rev. Lett.* **44**, 912 (1980), *Phys. Rev.* **D23**, 165 (1981)
[15] U A Yajnik, H Widyan, S Mahajan, A Mukherjee and D Choudhuri, *Phys. Rev.* **D59**, 103508 (1999)
[16] N D Deshpande, J F Gunion, B Kayser and F Olness, *Phys. Rev.* **D44**, 3320 (1991)
[17] M Joyce, T Prokopec and N Turok, *Phys. Rev. Lett.* **75**, 1695 (1995); Erratum **75**, 3375 (1995)
[18] J Cline, M Joyce and K Kainulainen, *Phys. Lett.* **B417**, 79 (1998); Erratum arXiv:hep-ph/0110031
[19] J Cline and K Kainulainen, *Phys. Rev. Lett.* **85**, 5519 (2000)
[20] J M Cline, U A Yajnik, S N Nayak and M Rabikumar, *Phys. Rev.* **D66**, 65001 (2002)
[21] S Yu Khlebnikov and M E Shaposhnikov, *Nucl. Phys.* **B308**, 885 (1988)