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Baryon asymmetry generation through preonic monopoles

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Abstract. A scheme is presented for baryon asymmetry generation in early universe through monopole-induced baryon number violating processes in the context of a preonic model.

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There has been a lot of interest recently in constructing models taking quarks and leptons as composite objects (Harari 1982). The main motivation for doing this has been to understand the family structure of quarks and leptons and also to minimize the number of elementary building blocks of matter since the number of quarks and leptons has proliferated so enormously that these can no longer be considered 'elementary' to one's aesthetic satisfaction. These models are generally termed as preonic models. Though these models have not yet provided the understanding of the existence of families of quarks and leptons, one has very stringent bound on the preonic mass scale, $\Lambda_H \geqslant 10^5$ GeV coming from $g-2$ values of electron and muon, and self-energy calculations.

Sometime back Masiero *et al* (1982) analyzed the possibility of generating the baryon asymmetry in the early universe within the context of a preonic model taking the preonic mass scale to be of the order 10^5 GeV. They found that prospects of generating a sizable baryon asymmetry without proton decaying too fast are poor. This is mainly because the coupling strength of the baryon number violating reaction turns out to be extremely small ($\sim 10^{-7}$) when they impose the conditions necessary for baryon asymmetry generation in their model. This in turn is due to their choice of the preonic scale ($\Lambda_H \sim 10^5$ GeV) being much smaller compared to Planck scale m_p ($\sim 10^{19}$ GeV).

There are evidently two ways of circumventing the above difficulty; one is to take Λ_H to be of the order of the grand unification scale which will automatically enhance the coupling strength for baryon-violating process and the other is to keep Λ_H much smaller compared to Planck scale as in Masiero *et al* (1982) and provide a mechanism for the baryon number violating process to proceed at a very fast rate without affecting the stability of the proton. We wish to explore the second possibility in this note.

In this context we assume that if preons are taken as monopoles or magnetically-charged particles, because of the strong catalytic property of these monopoles (Rubakov 1981a, b; Callan 1982a, b) the cross-section for baryon number violating process can be large and the desired baryon asymmetry, perhaps, can be generated even in the context of a preonic model. This scheme fully corroborates the conjecture made earlier that the preons are bound by an abelian magnetic force (Pati 1980, 1981). It may be recalled here that the magnetic coupling strength is super strong, being roughly the inverse of electric one, and may be sufficient to bind magnetic preons of mass of the order of 10^{6-7} GeV to form massless composites as originally conjectured by Pati (1980, 1981).

We describe the scenario of baryon asymmetry generation below:

It is well known that baryon asymmetry generation requires three conditions to be simultaneously satisfied (Yoshimura 1981). These are (i) the existence of a mechanism for baryon number violation, (ii) C and CP violation and (iii) the baryon number violating process to remain out of thermal equilibrium below a certain temperature as the universe cools down. We take this temperature to be of the order of the monopole mass scale which equivalently is also the preonic scale, Λ_H, in our model. Above this temperature the universe is considered to be baryon symmetric. As the universe while cooling reaches this temperature, the monopoles start binding to form quarks and leptons. Thus at about this temperature it is reasonable to expect monopoles, quarks and leptons to coexist with monopole number gradually depleting, with lowering of temperature.

At this stage we speculate that the quarks and leptons will form fermion condensates about the monopole and generate baryon number violating processes through a Rubakov-like effect (Rubakov 1981a, b; Callan 1982a, b). It is to be emphasized that this process goes hand in hand with the condensation of monopoles to quarks and leptons. Thus it is plausible that the reverse process cannot proceed with the same rate as the system is getting out of equilibrium. If further C and P are violated by these processes, then the particle and antiparticle reactions will not proceed at the same rates. This will result in an excess of baryons over antibaryons giving rise to baryon asymmetry.

In contrast to the popular model of baryon asymmetry generation through X-boson decay where the difference of the partial decay rates of X and $\bar{X}$ to quark-quark and quark-lepton channels leads to baryon number generation, in the scenerio stated above at least two monopole-induced processes with $\Delta B = 1$ and $\Delta B = 2$ are to occur so that with CP violation the partial rates for $\Delta B = 1$ and $\Delta B = 2$ could be different for the particles and antiparticles giving the possibility of a net baryon excess. An interesting point is that such $\Delta B = 1, \Delta B = 2$ monopole catalyzed processes can occur if we have at least two families, say for example, in an SU(5) GUT model (Ellis *et al* 1982). Hence in our model the baryon asymmetry and the existence of at least two families could be intimately connected.

We now make an order of magnitude estimate for n_B/n_γ, the signature of baryon asymmetry whose observed values is 10^{-8}–10^{-10} (Yoshimura 1978; Fry *et al* 1980).

The model described above makes it plausible to take the baryon asymmetry generated to be proportional to the initial preonic monopole density η^i_m, the CP violating parameter ε, and the cross-section for baryon number violating processes σ and thus can be written as (Nussinov 1981)

$$n_B/n_\gamma = (\eta^i_m \varepsilon / N_{\mathrm{DF}})\sigma,$$

where N_{DF} is the total number of quark and lepton degrees of freedom at that temperature.

To estimate the initial monopole density, one could well assume that the monopoles, which we take to be the preons, are the solutions of the 't Hooft-Polyakov ('t Hooft 1974; Polyakov 1974) type coming into existence as soon as the subgroup H of a grand unifying group G contains a U(1) factor in its chain of spontaneous symmetry breakdown to $SU(3)_C \times U(1)$ corresponding to QCD × QED. Monopoles, in this scheme, are zeros of the fluctuating Higgs field. Assuming the spontaneous breaking of the symmetry group responsible for monopole creation to be a second order phase transition, the initial monopole density $\eta_m^i = (\zeta T)^{-3}$ where ζ is correlation length near the critical temperature. Taking $\zeta = h^2/4\pi T$ where h is the minimal magnetic charge, we get $\eta_m^i = (4\pi/h^2)^3 \simeq 10^{-6}$ (Preskill 1979). The ε factor is taken to be $O(10^{-2})$. With $N_{\rm DF} \sim 100$ and $\sigma \sim O(1)$

$$n_{\rm B}/n_\gamma \simeq 10^{-10}$$

which is of the same order as the observed value.

In the scheme presented above it is expected that, at temperatures not much lower than the one where the monopoles begin condensing to form quarks and leptons, all the monopoles would have condensed to the quark-lepton phase causing the monopole density to reduce to zero. The small temperature range considered above will also not allow the monopoles and antimonopoles to drift so far apart as to leave a residual monopole density (Preskill 1979, 1984). This could well be the cause of the absence of confirmative monopole detection in all experiments undertaken so far.

It may be emphasized at this point that the dominant process responsible for the depletion of monopole-antimonopole numbers in our scenario is their condensation to quark-lepton phase whereas monopole-antimonopole annihilation was treated as the only possible mechanism by Preskill (1979). If, however, one repeats the Preskill's calculation taking monopole-antimonopole annihilation rate and the expansion rate of the Universe, one easily finds that $\eta_m \sim 10^{-18}$. The difference from Preskill's value of $\eta_m \sim 10^{-9}$ comes solely from the reduced mass of the monopole in our model. It is thus reasonable to expect that, had one included the monopole and antimonopole condensation rate η_m would have taken an extremely low value. But we do not know of any available method of calculating monopole condensation rate to the new phase of quarks and leptons.

An alternative scheme inspired by inflationary scenario estimates the present monopole density $\eta_m \sim 10^{-220}$ which also rules out any monopole observation at the present epoch as ours. However, besides this result the two models share no common features. The inflationary universe scenario has been constructed mainly to provide possible answers to some outstanding cosmological problems within the context of big-bang hypothesis, whereas our scheme addresses the question of baryon asymmetry generation with the help of magnetically charged preons through Rubakov-like processes and provides possible qualitative explanations for existence of more than one family of quarks and leptons and the absence of magnetic monopoles at the present time.

Further, the total absence of monopoles below a certain temperature which is roughly of the same order as the temperature where monopoles are created makes the question (Ellis *et al* 1982) if the baryon asymmetry once created can be erased by monopole-induced baryon number violating process later, irrelevant. Thus the baryon asymmetry once generated through monopole-induced baryon-violating processes persists for all later times.

For the scheme described above to be realistic, it should also address questions like (i) right quantum number assignment of the magnetic preons to produce the magnetically neutral quarks and leptons, (ii) setting the preonic scale to be of the order of 10^{6-7} GeV and (iii) seeing if a Rubakov-like effect does indeed proceed with quark and leptons as composites as assumed in the text. As for (i), Pati (1980, 1981) has extensively discussed the various possibilities of quantum number assignments of preons within their topological origin. As regards (ii), a grand unification model of type proposed by Xue (1981) based on SU(7) giving rise to low mass ($\sim 10^6$ GeV) monopoles may be considered for obtaining a low preonic scale. However, since this model contains a fourth generation of quarks and leptons with charges 5/3, $-4/3$ and -2, in the quantum number assignment scheme of Pati discussed above, the Somon sector alone may be extended to include two more Somons with electric charges $+1$ and -1 where S^k_{+1} and S^k_{-1} should be combined with u and d flavours respectively. Finally, the question of proving the existence of a Rubakov-like effect considering quarks and leptons as composites, we believe, is highly complex and difficult. This needs to be investigated as a separate problem in its own right. However, not being able to see any argument against it, we take this as our assumption, though a very crucial one.

In summary, we have presented here a possible alternative explanation of baryon number generation in the early universe taking preons to be magnetic monopoles or magnetically charged particles.

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