KASI 한국천문연구원
Korea Astronomy & Space Science Institute

Callan-Rubakov Effect

[1982]

: monopole-catalyzed (anti ?) proton decay

- could answer the

Baryon Asymmetry Puzzle

[2017]

Hongsu Kim

Theoretical Relativistic Astrophysics

Korea Astronomy and Space Science Institute (KASI)

The Origin/ underlying nature of Matter-Antimatter (or Baryon) Asymmetry in the universe

Hongsu Kim [KASI]

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Evidence for Matter/Antimatter Asymmetry

Obviously in our local area of the Universe (solar system, Milky Way) consists of matter.

Can't tell if distant galaxies consist of matter or antimatter– spectra etc. all the same. Universe could consist of domains of matter and antimatter, with net baryon asymmetry.

If matter/antimatter domains are in contact, gamma rays produced at boundary from annihilation à Cosmic gamma ray background indicates domains must be at least ~Gpc in size.

Voids between domains would show up in the CMB.

What is Baryogenesis?

Baryogenesis is the process of creating an asymmetry between baryons and antibaryons in the Universe.

$$\frac{n_B}{n_\gamma} = (6.1^{+0.3}_{-0.2}) \times 10^{-10}$$

The net baryon number *nB* of the Universe, as calculated from Big Bang nucleosynthesis, is much less than the photon number in the CMB.

Baryon number is likely an excess after annihilation rather than an initial condition

Brief revisit and review of the original version of the Callan-Rubakov effect

[particle in “perturbative” spectrum ?]

one starts with Fock space(for free field case) or Hilbert space(for interacting field case)

and defines the vacuum that the annihilation operate destroys to nothing.

Now one builds up the perturbative particle spectrum by repeatedly operating the creation operator on the vacuum.

Then one ands up with multi-particle state with various quantum numbers (energy, momentum, charge, spin… etc)

As a result, fundamental constituents in nature such as protons, neutrons and electrons are in this perturbative spectrum.

[particle in “non-perturbative” spectrum ?]

In the quantum field theory which is the underlying principle for elementary particle physics there are other species of particles different from those in the perturbative spectrum.

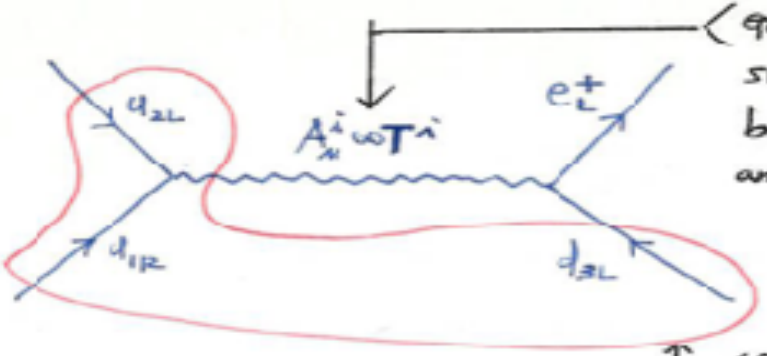
Generally speaking, this new species of particles are topological soliton solutions.

To be more specific, they are clumps of mass-energy of which the stability is secured by topologically conserved numbers(e.g, winding number).

For instance:

I) magnetic monopole(e.g., ‘thooft-Poliyakov monopole in Yang-Mils-Higgs theory with SSB).

II) Yang-Mils instantons in non-abelian gauge theory(e.g., pure Yang-Mils gauge theory).



< gauge field associated with $SU(2)_M$ — subgroup which has both the $SU(3)_c$ — color charge and $SU(2)_L$ — isospin charge >

↳ < color singlet & $Q_{em} = +1$ i.e. proton >

i.e.,

$$u_{1R} + u_{2L} + M \longrightarrow d^c_{3R} + e^+_L + M$$

or

$$(u_{1R} + u_{2L} + d_{3L}) + M \longrightarrow e^+_L + M$$

or

$$p + (\text{monopole}) \longrightarrow (\text{monopole}) + e^+ + (\text{pions})$$

i.e.,

$$\langle u_{1R}\, u_{2L}\, d_{3L}\, e^-_R \rangle^{\text{Monopole}} \neq 0$$

↳ < represents the existence of the "condensate" of the zero-angular momentum massless fermions in the presence of the magnetic monopole. >

And the scattering cross section of this type of process thus turns out to be

$$\sigma \sim \frac{1}{E^2}$$

(2) **Proton Decay**

As we have seen earlier, fermion–gauge int. involves "quark-lepton transition" and "di-quark processes" that lead to proton decay :

$$\mathcal{L}_{\text{fermion-(X,Y)}} = \frac{g}{\sqrt{2}}\Big[-\bar{d}^{\alpha}_{L} X_{\alpha} e_{L} - \bar{e}_{L} \bar{X}^{\alpha} d^{c}_{L\alpha} + \bar{d}^{c}_{L} Y_{\alpha} \nu_{L} + \bar{\nu}_{L} \bar{Y}^{\alpha} d^{c}_{L\alpha} + \bar{d}_{R\alpha} \bar{X}^{\alpha} e^{c}_{R} + \bar{d}_{L\alpha} \bar{X}^{\alpha} e^{c}_{L} + \varepsilon_{\alpha\beta\gamma} \bar{u}^{c\gamma}_{L} \bar{X}^{\alpha} u^{\beta}_{L} + \text{(h.c.)} - \bar{d}_{R\alpha} \bar{Y}^{\alpha} \nu^{c}_{R} - \bar{u}_{L\alpha} \bar{Y}^{\alpha} e^{c}_{L} + \varepsilon_{\alpha\beta\gamma} \bar{u}^{c\gamma}_{L} \bar{Y}^{\alpha} d^{\beta}_{L} + \text{(h.c.)} \Big]$$

∴ Thus a proton decay process such as

$\Rightarrow \; p\,(\sim uud) \longrightarrow e^{+} + \pi^{0}$

is possible in SU(5) – GUT.

Now SU(5)–GUT predicts the proton lifetime to be

$$\Gamma_p \; (\sim \frac{1}{M_X^4}) \quad \ldots\ldots \text{(decay rate)}$$

$$\tau_p = \frac{1}{\Gamma_p} \simeq 1.\times 10^{(31\pm2)} \text{ years.}$$

However, experiment (at IMB (U.S.A.), Japan, India) shows that

$$\tau_p^{Exp} \gtrsim 10^{33} \text{ years.}$$

..... Minimal SU(5) – GUT is almost excluded !!

We need more realistic GUT model.

Revision of the original Callan-Rubakov effect for our new perspective and new objective: “monopole-catalyzed (anti)proton decay”

Callan-Rubakov

monopole-catalyzed proton decay(1982)

$u_{1R} + u_{2L} + M \to d^c_{3R} + e^+_L + M$

$< u_{1R} u_{2L} d_{3L} e^-_R >^{\text{Monopole}} \neq 0$ (checked by Callan and Rubakov)

Hongsu Kim

monopole-catalyzed anti-proton decay(2017)(?)

$\bar{u}_{1L} + \bar{u}_{2R} + M \to \bar{d}^c_{3L} + e^-_R + M$

$< \bar{u}_{1L} \bar{u}_{2R} \bar{d}_{3R} e^+_L >^{\text{Monopole}} \neq 0$ (still remains to be seen)

Computational detail

In order to come to the conclusion regarding the (anti)proton decay catalyzed by the magnetic monopole, we essentially follow the strategy chosen by Callan-Rubakov.

That is, we should compute the 4-point Green's function but in the back ground of magnetic monopole. To this end, we should start with the construction of partition function(in the statistical mechanics) or generating functional (in the quantum field theory). We predict that the associated computational detail for the present (anti)proton decay case would essentially remain the same as the original proton-decay case.

[Concluding Remarks]

Back in 1982, Callan and Rubakov, independently, pointed out that 't Hooft-Polyakov magnetic monopole, a topological soliton solution in Yang-Mills-Higgs theory with SSB in WGS standard model for the electroweak interaction could "catalyze" the proton decay.

This is obviously an academic speculation which has NOT been motivated by any precision observational evidence at the time as the proton is known to be definitely stable &secure with its lifetime being as long as the age of the universe itself! As such, we find, after 30 years, that this effect is not just a purely academic speculation, but also a severely wrong-motivated set-up, as now we know the matter-antimatter(or baryon) asymmetry in our present universe… That is, in the present universe, we have severe matter-antimatter(or baryon) asymmetry in which, the number of proton is overwhelmingly greater than that of antiproton…

This reality teaches us the lesson that after all, it is "anti proton" rather than proton that should(spontaneously) decay and disappear ! To summarize, the age-old Callan-Rubakov Effect has to be modified to its opposite objective ; "monopole-catalyzed antiproton decay"!

In the present work, therefore, we briefly revisited and reviewed the original version of the Callan-Rubakov effect and discussed how it should be modified and reorganized for our new perspective and new objective :

"monopole-catalyzed antiproton decay"