ASTROPHYSICAL LIMITS ON GAUGE INVARIANCE BREAKING IN ELECTRODYNAMICS WITH TORSION

Letter to the Editor

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Abstract. General relativistic electrodynamics in a torsion background can give rise to a situation where the photons can have a non-zero rest mass and magnetic moment. Astrophysical limits are used to constrain these parameters.

While considering torsion effects in massive electrodynamics, one can consider an additional term in the Lagrangian for the torsion-massive-photon interaction like

\[ L_I \sim \alpha G_\gamma R(\Gamma) A_\mu A^\mu \]

(1)

where \( R(\Gamma) \) is the curvature scalar constructed from the affine collection which includes torsion; \( \alpha \) is the fine structure constant and \( G_\gamma \) is the photon-torsion coupling constant. This implies a mass term for the photon \( m_\gamma \), which is related to the torsion vector \( Q \), through a relation of the form

\[ \left( \frac{m_\gamma c}{\hbar} \right)^2 \approx \lambda Q^2 \]

(2)

where \( \lambda \) is the dimensionless torsion-photon coupling constant; \( Q \) is related to the average spin density \( \sigma \) of the background (the net spin density being the source for the torsion) as:

\[ Q = 4\pi G\sigma / c^3 \]

(3)

In De Sabbata et al. (1992), Eqs. (2) and (3) were applied to the magnetosphere of a neutron star giving a constraint on \( \lambda \) which is an arbitrary parameter of the theory as:

\[ \lambda \leq 10^{-24} \]

(4)
This puts the limit on any direct photon-torsion coupling which violates gauge invariance. Again the violation of gauge invariance also implies non-conservation of electric charge in the sense of Lyttleton-Bondi. In the present context this means that the torsion modified Maxwell equations, i.e.,

$$\partial_k F^{ik} = 4\pi J^i + (2\alpha/3\pi)\eta^{iklj} F_{kl} Q_j$$

(5)

are not compatible with the current conservation law $\partial_i J^i = 0$. This could imply a net charge carried away by the mediating field. One can use arguments similar to those given in the case of massive neutrinos to put astrophysical limits on the violation of electric charge conservation, i.e., on $q/\epsilon$ ($\epsilon$ being the electron charge). Following Sivaram (1989) we can write:

$$q/\epsilon < (Gm^2/\epsilon^2)^{1/2}.$$  

(6)

Substituting $m_\gamma$ we have:

$$\frac{q}{\epsilon_\gamma} < \frac{G\lambda}{\epsilon^2} \sim \left(\frac{G\lambda R_H^{-1}/\alpha}{\epsilon^2}\right)^2 \sim 10^{-18}.$$  

(7)

Using Eq. (5) and using for $\lambda$ Eq. (4) and $Q \sim R_H^{-1}/\alpha$ from De Sabbata et al. (1992), $R_H$ being the Hubble radius. This is one order of magnitude less than the astrophysical limit $(g/\epsilon)_\nu$ for neutrinos and shows that $\lambda \leq 10^{-24}$, is consistent from considerations other than neutron stars. Also, in De Sabbata et al. (1992), the photon magnetic moment induced by torsion background was estimated as $\mu_{\gamma \text{amma}} \sim 10^{-20} \mu_B$, where $\mu_B = (e\hbar/2m_\epsilon c)$ is the Bohr magneton. In the galactic magnetic field, $B_{\text{gal}} \sim 10^{-6}$ Gauss, this value of $\mu_\gamma$ implies an energy of $\mu_\gamma B_{\text{gal}} \approx 10^{-45}$ ergs. It is interesting that this is consistent with the minimum operationally definable energy, $E_{\text{min}}$ in cosmology as given by the uncertainty principle. As shown in Sivaram (1982),

$$E_{\text{min}} \approx \hbar H_0$$

(8)

$H_0$ is the Hubble constant, $H_0 \approx 10^{-18}$ s$^{-1}$). So if we insist that $\mu_\gamma$ must be operationally definable, then this gives

$$\mu_\gamma \approx \frac{\hbar H_0}{B_{\text{gal}}} \approx 10^{-20} \mu_B.$$  

(9)

For a pair of annihilation $\gamma$-ray photons ($E \approx 0.5$ MeV), in a neutron star magnetic field ($10^{12}$ Gauss), this implies a fractional energy change of $\Delta E/E \approx 10^{-21}$ (Mossbauer techniques could detect $\Delta E/E \approx 10^{-18}$ at present). A $\mu_\gamma$ of this order could also imply an additional energy loss of $\approx 10^{37}$ ergs in a SN explosion (as about $N_\gamma \approx 10^{63}$ photons are emitted in a typical SN explosion, so $E_\gamma \approx N_\gamma \mu B \approx 10^{37}$ ergs). However this is only $10^{-14}$ of the blast energy which is typically $\approx 10^{51}$ ergs in a supernova explosion.