PROCEEDINGS OF SCIENCE

The Meissner Effect and the Physics of Light

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A new approach for electromagnetism comes from the so-called Physics of Light . Based on a new universalism for light invariance, it generates an electromagnetism beyond the electric charge. As a consequence, it brings new electromagnetic fields different from the usual pair.

Thus this works studies the possibilities of electromagnetic fields originated from the approach set out by the Physics of Light. A massive photon comes out without violating gauge invariance. Considering a model with just two fields $\{A_\mu, B_\nu\}$ where A_μ is the usual photon and B_ν is the massive photon, one derives granular and collective electromagnetic fields. There is a new possibility for explaining the Meissner effect different from Procca in the framework of Physics of Light.

4th International International Conference on Fundamental Interactions
August 1 - 7, 2010
Viçosa, Brazil

*Poster Section

PoS(ICFI 2010)020

1. Introduction

A new gauge approach means to consider a set of fields $\{A_{\mu I}\}$ transforming under a same group. Quark confinement and complexity are supporting this antireductionist aproach to physics. They are saying that one should look beyond the parts for the phenomena interpretation [1].

Thus there are strong motivations for describing physics through an antireductionist gauge model. Nature is more than its parts. This fact suggest us to introduce a common group of fields $\{A_{\mu I}\}$ transforming under a same gauge parameter as

$$A_{\mu I} \to A_{\mu I} = A'_{\mu I} + \partial_\mu P_I(\alpha) \tag{1.1}$$

where I means a diversity index which varies from $I = 1, \ldots, N$ and $P_I(\alpha)$ a gauge parameter polynomial expansion, $P_I(\alpha) = a_{Im}\alpha^m(x)$ [2].

Eq. (1.1) leads to the Lagrangian

$$L = Z_{\mu\nu}Z^{\mu\nu} - \frac{1}{2}m^2_{IJ}A^I_\mu A^{\mu J} \tag{1.2}$$

which is gauge invariant under the condition $a_I P'^I(\alpha) = 0$. Its correspondent fields strength are

$$Z_{[\mu\nu]} = a_I F^I_{[\mu\nu]} + z_{[\mu\nu]} \tag{1.3}$$

and

$$Z_{(\mu\nu)} = b_I S^I_{(\mu\nu)} + z_{(\mu\nu)} + g_{\mu\nu}(c_I S^{\alpha I}_\alpha + z^\alpha_\alpha) \tag{1.4}$$

where

$$F_{\mu\nu I} = \partial_\mu A_{\nu I} - \partial_\nu A_{\mu I}, \quad S_{\mu\nu I} = \partial_\mu A_{\nu I} + \partial_\nu A_{\mu I} \tag{1.5}$$

$$z_{[\mu\nu]} = \gamma_{[IJ]}A^I_\mu A^J_\nu, \quad z_{(\mu\nu)} = \gamma_{(IJ)}A^I_\mu A^J_\nu \tag{1.6}$$

Notice that while eq. (1.5) contains a granular composition of fields, eq. (1.6) propiates a collective term.

Calculating the corresponding field equations, one gets

$$\partial_\nu T^{\nu\mu}_I + m^2_{(IJ)}A^{\mu J} = J^\mu_I$$

where

$$T^{\nu\mu}_I = (a_I a_J + b_I b_J)F^{\nu\mu J} + a_I z^{[\nu\mu]} + b_I z^{(\nu\mu)} + (b_I + 5c_I)z^\alpha_\alpha$$

and

$$J^\mu_I = \gamma_{[IJ]}Z^{[\mu}{}_{\nu]}A^{\nu J} + \gamma_{(IJ)}Z^{(\mu}{}_{\nu)}A^{\nu J} + \gamma_{(IJ)}Z^\alpha_\alpha A^{\mu J} \tag{1.7}$$

In order to simplify eq. (1.7), a gauge fixing term $\xi_{IJ}\partial_\alpha A^{\alpha I}\partial_\beta A^{\beta J}$ and the kinetic identity $\partial_\nu S^{\nu\mu}_I = \partial_\nu F^{\nu\mu}_I + \eta^{\nu\mu}\partial_\nu S^{\alpha I}_\alpha$ were introduced.

A second type of equations for analysing this abelian model are the Bianchi identities. They are

$$\partial_\mu F_{\nu\rho I} + \partial_\rho F_{\mu\nu I} + \partial_\nu F_{\rho\mu I} = 0, \tag{1.8}$$

$$\begin{aligned} &\partial_\mu z_{[\nu\rho]} + \partial_\nu z_{[\rho\mu]} + \partial_\rho z_{[\mu\nu]} \\ &= \gamma_{[IJ]} A^I_\nu F^J_{\mu\rho} + \gamma_{[IJ]} A^I_\rho F^J_{\nu\mu} + \gamma_{[IJ]} A^I_\mu F^J_{\rho\nu} \end{aligned} \tag{1.9}$$

and

$$\begin{aligned} &\partial_\mu z_{(\nu\rho)} + \partial_\nu z_{(\rho\mu)} + \partial_\rho z_{(\mu\nu)} \\ &= \gamma_{(IJ)} A^I_\mu S^J_{\nu\rho} + \gamma_{(IJ)} A^I_\nu S^J_{\rho\mu} + \gamma_{(IJ)} A^I_\rho S^J_{\mu\nu} \end{aligned} \tag{1.10}$$

Here, we should mention that our formulation though it sets out a non-linear extension of the electromagnetic theory, it does not correspond to any particular regime of the Born-Infeld action. We extend Electromagnetism by introducing extra gauge potentials and non-linearity comes out as a consequence of gauge symmetry.

2. Global Maxwell Equation

Expressing the previous equations in vector form, $A^\mu_I \equiv (\phi_I, \vec{A}_I)$, ones derives the so-called Global Maxwell equation

$$\begin{aligned} \vec{\nabla} \cdot (\vec{E}_I + b_I \vec{e}) + m_I^2 \phi_I &= \rho_I(A) \\ \vec{\nabla} \times (\vec{B}_I + b_I \vec{b}) + \frac{\partial}{\partial t}(\vec{E}_I + b_I \vec{e}) + m_I^2 \vec{A}_I &= \vec{J}_I(A) \\ \vec{\nabla} \times \vec{E}_I + \frac{\partial \vec{B}_I}{\partial t} &= 0 \\ \vec{\nabla} \cdot \vec{B}_I &= 0 \\ \vec{\nabla} \times \vec{e} + \frac{\partial \vec{b}}{\partial t} &= \gamma_{[IJ]}(\vec{A}^I \times \vec{E}^J - \phi^I \vec{B}^J) \\ \vec{\nabla} \cdot \vec{b} &= \gamma_{[IJ]} \vec{A}^I \cdot \vec{B}^J \end{aligned}$$

where

$$\begin{aligned} \vec{E}_I = -\vec{\nabla}\phi_I - \frac{\partial \vec{A}_I}{\partial t}, \quad \vec{B}_I = \vec{\nabla} \times \vec{A}_I \quad &\textit{are the usual electromagnetic fields} \\ \vec{e} = -\gamma_{[JK]} \phi^J \vec{A}^K, \quad \vec{b} = \gamma_{[JK]} \vec{A}^J \times \vec{A}^K \quad &\textit{are the collective fields} \end{aligned} \tag{2.1}$$

Similarly, one gets longitudinal electromagnetic fields derived from tensor $S_{\mu\nu I}(\varepsilon, \vec{\varepsilon}, \beta_{ij})$ and the collective fields derived from $z_{\mu\nu}(s, \vec{s}, s_{ij})$. For simplification, the sources were written just symbolically. The symmetric fields are there.

3. Two Fields Solution

In order to solve the above Global Maxwell equation one has to rewrite it in terms of potential fields $(\phi_I, \vec{A}_I)$. It gives,

$$\begin{aligned} a_{IJ}\nabla^2\phi^K + b_{IJK}\vec{A}^K\cdot\vec{\nabla}\phi^J + c_{IJK}\phi^J\vec{\nabla}\cdot\vec{A}^K \\ +d_{IJK}\vec{A}^J\cdot\frac{\partial\vec{A}^K}{\partial t} + c_{IJK}\phi^J\frac{\partial\phi^K}{\partial t} + f_{IK}\frac{\partial^2\phi^K}{\partial t^2} - m^2_{(IK)}\phi^K \\ = g_{IJKL}\phi^J\phi^K\phi^L + h_{IJKL}\phi^K\vec{A}^J\cdot\vec{A}^L \end{aligned} \tag{3.1}$$

and

$$\begin{aligned} a_{IK}\nabla^2\vec{A}^K - a_{IK}\vec{\nabla}(\vec{\nabla}\cdot\vec{A}^K) + i_{IJK}(\vec{A}^J\cdot\vec{\nabla})\vec{A}^K \\ +j_{IJK}\vec{A}^J(\vec{\nabla}\cdot\vec{A}^K) + l_{IJK}(\vec{\nabla}\cdot\vec{A}^K)\vec{A}^J + m_{IJK}\phi^J\vec{\nabla}\phi^K \\ +a_{IK}\frac{\partial^2\vec{A}^K}{\partial t^2} + a_{IK}\vec{\nabla}\frac{\partial\phi^K}{\partial t} + p_{IJK}\phi^J\frac{\partial\vec{A}^K}{\partial t} + m^2_{(IK)}\vec{A}^K \\ = n_{IJKL}\phi^J\phi^K\vec{A}^L + o_{IJKL}(\vec{A}^K\cdot\vec{A}^L)\vec{A}^J \end{aligned} \tag{3.2}$$

where $a_{IJ}, \ldots o_{IJKL}$ are free coefficients which can take any value without breaking gauge invariance. They are functions on the initial parameters stipulated through eqs. (1.3-1.6).

Considering the two fields case $\{A_\mu, B_\nu\}$ where $A_\mu \equiv (\phi, \vec{A})$, $B_\mu = (\varphi, \vec{B})$ and taking the static approximation, Coulomb gauge $\phi = 0$, $\vec{\nabla}\cdot\vec{A} = 0$ and spherical symmetry, one derives from eqs. (3.1-3.2) the following four equations

$$\begin{aligned} a_{12}\nabla^2\varphi + b_{121}\vec{A}\cdot\vec{\nabla}\varphi + b_{122}\vec{B}\cdot\vec{\nabla}\varphi + c_{122}\varphi\vec{\nabla}\cdot\vec{B} - m^2_{(12)}\varphi \\ = g_{1222}(\varphi)^3 + h_{1121}\varphi(\vec{A}\cdot\vec{A}) + (h_{1122}+h_{1221})\varphi\vec{A}\cdot\vec{B} + h_{1222}\varphi\vec{B}\cdot\vec{B} \end{aligned} \tag{3.3}$$

$$\begin{aligned} a_{22}\nabla^2\varphi + b_{221}\vec{A}\cdot\vec{\nabla}\varphi + b_{222}\vec{B}\cdot\vec{\nabla}\varphi + c_{222}\varphi\vec{\nabla}\cdot\vec{B} - m^2_{(22)}\varphi \\ = g_{2222}(\varphi)^3 + g_{2121}\varphi\vec{A}\cdot\vec{A} + (g_{2122}+g_{2221})\varphi\vec{A}\cdot\vec{B} + g_{2222}\varphi(\vec{B}\cdot\vec{B}) \end{aligned} \tag{3.4}$$

$$\begin{aligned} a_{12}\nabla^2\vec{B} - a_{12}\vec{\nabla}(\vec{\nabla}\cdot\vec{B}) + i_{111}(\vec{A}\cdot\vec{\nabla})\vec{A} + i_{112}(\vec{A}\cdot\vec{\nabla})\vec{B} \\ +i_{121}(\vec{B}\cdot\vec{\nabla})\vec{A} + i_{122}(\vec{B}\cdot\vec{\nabla})\vec{B} + j_{112}\vec{A}(\vec{\nabla}\cdot\vec{B}) + j_{122}\vec{B}(\vec{\nabla}\cdot\vec{B}) \\ +l_{111}(\vec{\nabla}\cdot\vec{A})\vec{A} + l_{112}(\vec{\nabla}\cdot\vec{B})\vec{A} + l_{121}(\vec{\nabla}\cdot\vec{A})\vec{B} + l_{122}(\vec{\nabla}\cdot\vec{B})\vec{B} \\ +m_{122}\varphi\vec{\nabla}\varphi + m^2_{(11)}\vec{A} + m^2_{(12)}\vec{B} \\ = n_{1221}(\varphi)^2\vec{A} + n_{1222}(\varphi)^2\vec{B} + o_{1111}(\vec{A}\cdot\vec{A})\vec{A} \\ +(o_{1112}+o_{1121})(\vec{A}\cdot\vec{B})\vec{A} + o_{1122}(\vec{B}\cdot\vec{B})\vec{A} + o_{1211}(\vec{A}\cdot\vec{A})\vec{B} \\ +(o_{1212}+o_{1221})(\vec{A}\cdot\vec{B})\vec{B} + o_{1222}(\vec{B}\cdot\vec{B})\vec{B} \end{aligned} \tag{3.5}$$

$$\begin{aligned} a_{22}\nabla^2\vec{B} - a_{22}\vec{\nabla}(\vec{\nabla}\cdot\vec{B}) + i_{211}(\vec{A}\cdot\vec{\nabla})\vec{A} + i_{212}(\vec{A}\cdot\vec{\nabla})\vec{B} \\ +i_{221}(\vec{B}\cdot\vec{\nabla})\vec{A} + i_{222}(\vec{B}\cdot\vec{\nabla})\vec{B} + j_{212}\vec{A}(\vec{\nabla}\cdot\vec{B}) + j_{222}\vec{B}(\vec{\nabla}\cdot\vec{B}) \end{aligned}$$

$$
\begin{aligned}
&+l_{211}(\vec{\nabla}\cdot\vec{A})\vec{A}+l_{212}(\vec{\nabla}\cdot\vec{B})\vec{A}+l_{221}(\vec{\nabla}\cdot\vec{A})\vec{B}+l_{222}(\vec{\nabla}\cdot\vec{B})\vec{B}\\
&+m_{222}\varphi\vec{\nabla}\varphi+m^2_{(21)}\vec{A}+m^2_{(22)}\vec{B}\\
&=n_{2221}(\varphi)^2\vec{A}+n_{2222}(\varphi)^2\vec{B}+o_{2111}(\vec{A}\cdot\vec{A})\vec{A}\\
&+(o_{2112}+o_{2121})(\vec{A}\cdot\vec{B})\vec{A}+o_{2122}(\vec{B}\cdot\vec{B})\vec{A}+o_{2211}(\vec{A}\cdot\vec{A})\vec{B}\\
&+(o_{2212}+o_{2221})(\vec{A}\cdot\vec{B})\vec{B}+o_{2222}(\vec{B}\cdot\vec{B})\vec{B}
\end{aligned}
\tag{3.6}
$$

with a solution without considering sources

$$
\varphi(r)=\frac{\varphi_0 e^{-\beta r}}{r},\quad \beta=\sqrt{\frac{m^2_{(12)}b_{221}-m^2_{(22)}b_{121}}{a_{12}b_{221}-a_{22}b_{121}}}
\tag{3.7}
$$

$$
\begin{aligned}
B(r)&=\frac{B_0 e^{-\alpha r}}{r^2},\\
\alpha&=\sqrt{\left(\frac{b_{122}b_{221}}{b_{221}c_{122}-b_{121}c_{222}}\right)\left(\frac{m^2_{(12)}b_{221}-m^2_{(22)}b_{121}}{a_{12}b_{221}-a_{22}b_{121}}\right)}
\end{aligned}
\tag{3.8}
$$

$$
A(r)=\frac{a}{r+\gamma}+\frac{b}{r(r+\gamma)}+\frac{c\cdot r}{r+\gamma}+\left(\frac{e}{r}+f\right)\frac{1}{r(r+\gamma)}e^{-\alpha r}
\tag{3.9}
$$

which yields the following spectrum of electromagnetic fields

$$
\begin{aligned}
&\vec{E}_1=0,\quad \vec{E}_2=\frac{\phi_0\beta}{r}e^{-\beta r}\left(1+\frac{1}{r}\right)\hat{r}\\
&\vec{B}_1=0,\quad \vec{B}_2=0\\
&\varepsilon_1=0,\quad \varepsilon_2=0,\quad \vec{\varepsilon}_1=0,\quad \vec{\varepsilon}_2=-\frac{\phi_0\beta e^{-\beta r}}{r}\left(1+\frac{1}{r}\right)\hat{r}
\end{aligned}
\tag{3.10}
$$

$$
\begin{aligned}
&\vec{e}=\frac{\gamma_{[21]}\phi_0 e^{-\beta r}}{r}A(r)\hat{r},\quad \vec{b}=0\\
&s=\frac{\gamma_{[22]}{\phi_0}^2 e^{-2\beta r}}{r^2},\quad \vec{s}=\left[\frac{\gamma_{(21)}\phi_0 e^{-\beta r}}{r}A(r)+\frac{\gamma_{(22)}\phi_0 e^{-\beta r}}{r}B(r)\right]\hat{r}\\
&\beta_i^{i1}=0,\quad \beta_i^{i2}=\frac{2B_0}{r^2}\left(\frac{1}{r}+\alpha\right)e^{-\alpha r}\\
&s_i^i=\gamma_{(11)}(A(r))^2+\gamma_{(22)}(B(r))^2+2\gamma_{(12)}A(r)B(r)
\end{aligned}
\tag{3.11}
$$

4. Conclusion

Thus, due to the simplification on the spherical symmetry, the magnetic field presence nearly disappear, unless for β^i_{i2}, but through to show a Meissner performance. On the other hand, the Meissner damping effect [3] can be more clearly noticed through the electric fields. It is interesting to observe that cut-off parameters as α and β do not depend only of the mass. In a further work we intend to investigate the influence coming from the interactive sector.

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