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Effective mass of photon in liquid water environment of life and soft maters

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Abstract. It is well known that from four fundamental forces, only electro-magnetic force plays clear and important role in our life reality. The spin one exchange boson caring the electro-magnetic interaction is photon. The condition of zero-mass of photon leads to the Coulomb law with long-range interaction behavior. We consider analogy Anderson-Higgs mechanism, in some liquid water environments at a certain temperature, photon can have a finite effective mass, consequence to a Yukawa type potential. This screening potential could leads to sort-range behavior of electro-magnetic effective interaction. We use this mechanism to develop physics models to explain some phenomena in life and soft systems.

1. Introduction

From four fundamental forces, only electro-magnetic force plays clear and important role in our life reality (see figure 1).

According to gauge invariance the exchange boson spin 1 must be massless. In reality, only photon has zero mass, the other exchange particles have a mass, $M_W \approx 80.4 GeV$, $M_Z \approx 91.2 GeV$; $M_\pi \approx 13510^{-3} GeV$. The problem origin of mass of exchange vector bosons is interesting and important in history of physics.

In the beginning of sixties years of last century, it is known that there are two sources of zero mass bosons: from gauge field theory (because of gauge invariance) which dont correspond to anything to see, and from spontaneous symmetry breaking (SSB) of a continuous symmetry (Nambu-Goldston particles) also are not observed, so both theories had a huge problem. Because of the Goldstone theorem, no observed massless spin 0 boson (Nambu-Goldston particle) means that no spontaneous breaking of a continuous symmetry [7, 8, 9]. The problem also hard in relativistic field theory: spontaneous symmetry breaking implied the existence of massless spineless boson, since no such bosons had been seen, so spontaneous symmetry breaking was rule out, while other models with explicit symmetry breaking were clearly divergent giving infinite results.

Anderson non-relativistically [1], and a lit a bit later Higgs [4, 5] and the others [2, 3] relativistically way gave outstanding answer to that trouble problem: when both gauge symmetry and spontaneous symmetry breaking exist, the Nambu-Goldstone massless mode can combine with the massless gauge field modes to produce a physical massive vector field (exchange boson).

Now a day a type of quasi-particles in condensed mater: plasmon becomes more and more important in modern technology. In practical, we are going from electronics (with the main

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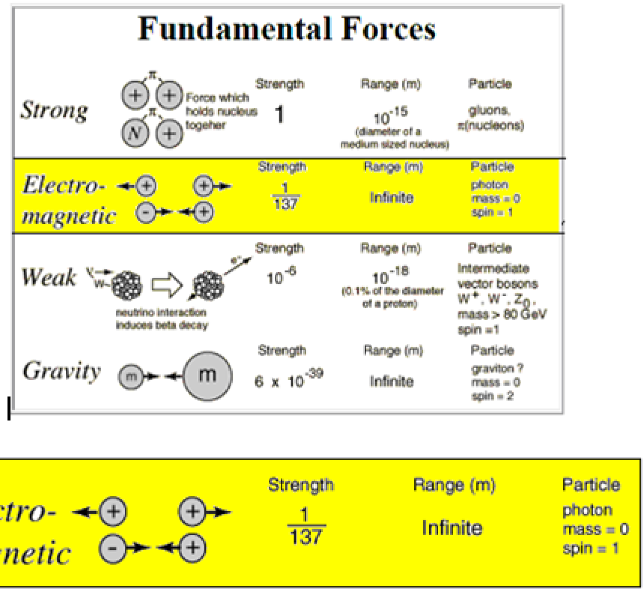

Figure 1. From four fundamental forces, only electro-magnetic force plays clear and important role in our life reality.

particle: electron) to photonics (with the main particle: photon). With photonics, because photon has no rest mass as electron so in one side is good: operating time of photonic devices is speed up and loss energy is less, but in another side is bad because photon interacting time to short so difficult to control and operate them. Plasmonics a new technology with the main particle: plasmon, this trouble is overcame and solved.

We take special attention to the spontaneous breaking of gauge symmetry, giving to plasmon mass, was known in superconductivity [1]. Nambu [7] suggested a similar mechanism could give mass to elementary particles. The condensate of charged pairs (Cooper pair) breaks the gauge invariant of medium. There were found intrinsically massles collective excitations of pairs (NG modes) that restored broken symmetries, and they turned into the plasmon by mixing with the Coulomb field.

In this work we assume that bio liquid water (pH=7.3, salt concentration n=0.9%) is a bio-vacuum with some kind of bio-plasmon. Following the non-relativistic Anderson-Higgs mechanism and Nambu idea [1, 7, 8, 9] on mass problem of plasmon in superconductivity, but instead of photon in a real plasma, we take to investigation mass problem of quasi-photon in bio-plasma (bio water).

We use the unit system with $\hbar = c_0 = 1$ where c_0 is speed of photon in vacuum.

2. Model for Polymer chains

Define end-to-end vector R (see the figure 2) [6]

$$R = r_N - r_0 = \sum_{i=1}^{N} a_i \tag{1}$$

We assume a simple model for zip-unzip transformation of polymer like Cooper pair formation mechanism in superconductivity with two effective charges Q in a bio-water vacuum. This mechanism is well presented in language of spontaneously symmetry broken with a Mexican hat

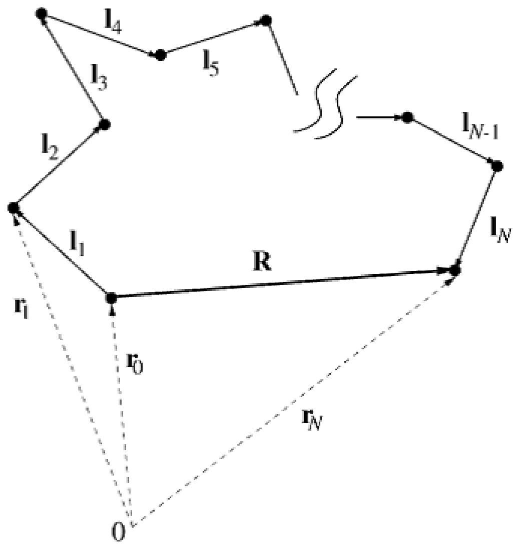

Figure 2. A simple discription of a polymer chain. The filled circles denote atoms in those positions, the bond length is a, R is the end-to-end vector.

like potential.
According to gauge invariance the exchange boson spin 1 must be massless. In the case of massless bio-photon (exchange boson), electro-magnetic effective potential between two charge Q is

$$W_0(r) = \frac{Q^2}{\varepsilon * r} \tag{2}$$

where $\varepsilon*$ is the dielectric constant of bio-water, r is distance between two charges. This process can be expressed by a Feynman diagram in figure 3.

Figure 3. Feynman diagram for the electromagnetic interaction between two charges.

By mean of Anderson-Higgs mechanism with bio-plasmon, bio-photon can be massive by spontaneously broken some symmetry (denoted as long-sort symmetry) mechanism (see figure 4).
Using the Yukawa idea of massive exchange pi-meson in strong interaction, we assume the Yukawa like potential for electro-magnetic effective potential in bio-water

$$W(r) = \frac{Q^2}{\varepsilon * r} \cdot \exp(-mr) \tag{3}$$

where $\varepsilon*$ is the dielectric constant of bio-water, m is effective of bio-photon (exchange boson).

Figure 4. Spontaneously symmetry broken problem with a Mexican hat like potential.

We take $m = 1/R$ as a parameter of our model.
For the case of ideal (or Gaussian) unzipping chains

$$R_0 = \sqrt{\langle R^2 \rangle} = aN^{1/2} \tag{4}$$

where a is the bond length, N is total number of sites in the chain. In the case of a long chain $N \to \infty$, $R_0 \to \infty$, so $m = 1/R_0 \to 0$, bio-photon is nearly massless.
If the chain go to its zipping state with $R = b << R_0$ then $m = 1/b$, bio-photon now became massive.
A typical zip-unzip phase transition of polymers is presented in Figure 5.

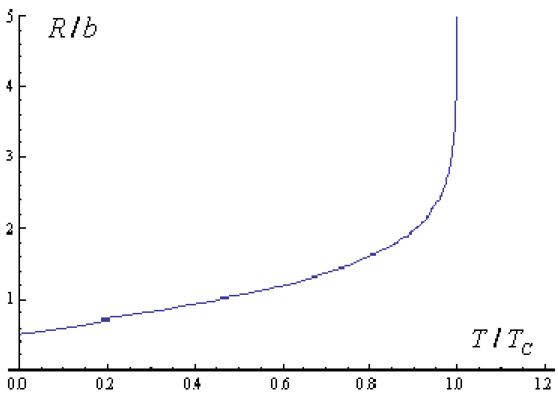

Figure 5. A typical zip-unzip phase transition of.

3. Ginzburg-Landau formalism

We express the phase transition between zipping and unzipping states of a polymer by Ginzburg-Landau formalism.
Introducing the free energy density $f(\psi, T)$ which is a function of the real local order parameter ψ and temperature T in the form

$$f(\psi, T) = f_0(T) + \alpha (T - T_C) \psi^2 + \frac{1}{2}\beta\psi^4 \tag{5}$$

where α and β are some constants, T_c is the critical temperature.

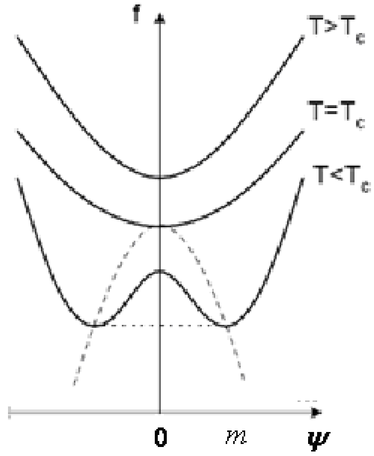

Figure 6. Free energy density f as a function of ψ. Below T_c new minima at nonzero $\pm\psi_0 = \pm m$ develop (the dashed curve denotes $m(T)$).

The value ψ_0 corresponding a minimum are

$$\psi_0 = 0 \qquad \text{for } T > T_C \tag{6}$$

$$\psi_0 = \left(\frac{\alpha}{\beta}\right)^{1/2} (T_C - T)^{1/2} \qquad \text{for } T > T_C \tag{7}$$

Define here $\psi_0 = m = \frac{1}{b}$ is bio-photon mass. The values of bio-photon mass ratio m/m_0 where $m_0 = (\alpha/\beta)^{1/2} {T_C}^{1/2}$ versus temperature are presented in the figure 7.

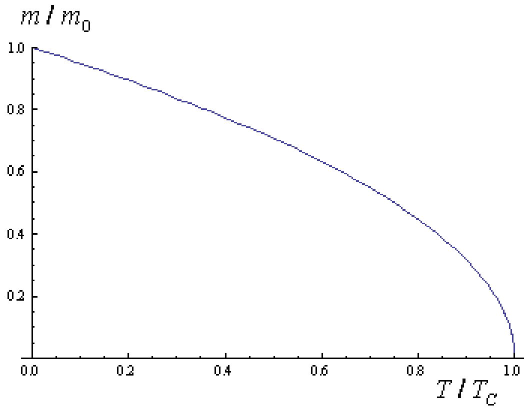

Figure 7. The values of bio-photon mass ratio m/m_0 versus temperature.

Evaluating f at ψ_0 gives

$$\psi_0 = 0 \qquad \text{for } T > T_C \tag{8}$$

$$f = f_0(T) - \frac{\alpha^2}{2\beta}(T_C - T)^2 \qquad \text{for } T > T_C \tag{9}$$

showing the lowering free energy under transition temperature.

Note that f deviates from f_0 quadractically, this will yield a jump discontinuity in the specific heat $\Delta C = (\alpha/\beta)\, T_C = {m_0}^2$ at $T = T_C$. So that measure the jump discontinuity in the specific heat at critical temperature by experiments could give us the maximum mass value of bio-photon.

4. Discussion

In this work we consider a new type of quasi-particle for bio systems in bio-water vacuum and called it bio-photon. In analogy Anderson-Higgs mechanism, in liquid water environments under critical temperature, bio-photon can have a finite effective mass, consequence to a Yukawa type potential. This screening potential could leads to sort-range behavior of electro-magnetic effective interaction like Cooper pairs formulation in superconductivity. Based on Ginzburg-Landau formalism, we proposed a simple physics model to describe zip-unzip phase transition of polymers. This new model might be useful in investigation other similar bio systems.

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