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Massive Gauge Boson and its generation: Some comments and discussion

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ABSTRACT

Starting with proper application of Feynman gauge in quantum field theory the proposal has been made to remove the unphysical degree of freedom from the gauge boson propagator. It has also been shown that the unphysical degree of freedom corresponding to the goldstone boson and breaking of global U (1) symmetry alone is sufficient for generation of massive gauge boson.

Key words: Higgs mechanism, Gauge symmetry, Gauge Boson.

INTRODUCTION

Concept of spontaneous symmetry breaking and introduction of gauge covariant derivative are the key points in mass gaining process of intermediate vector bosons through Higgs mechanism[1]. There is always a massless scalar Goldstone boson for a generator of a symmetry that is broken in the ground state. When broken symmetry is local U(1)[2], this redundant degree of freedom supposed to be absorbed into the longitudinal polarization part of the gauge boson. This way the intermediate vector bosons or electroweak gauge bosons gain mass but, at the cost of introduction of a new field known as Higgs field. Though this Higgs field has not been observed so far, its presence is supposed to be responsible for the mass of the massive particles occurring in quantum field theory. We, however in our own purview of perception think that the gaining of mass by a gauge boson is not a consequence of mere a presence of the Higgs field but due to redistribution of mass between an already existing massive field and a new mass gaining gauge field. It thus seems unnecessary to give importance to Higgs field and look for Higgs boson in mass gaining mechanism.

Higgs mechanism

Local quantities that transform covariantly are of particular interest in quantum field theory. For a lagrangian $\mathcal{L}$, which is invariant under the local symmetry U(1), introduction of covariant derivative D_μ is a common practice. Correspondingly requirement of local gauge invariance introduces the concept of gauge field Aμ(x). The gauge covariant derivative $D\mu$ is defined by the expression

$$D\mu = \partial_\mu + i_q A_\mu \quad \text{...(1)}$$

where *q* is simply a parameter.

Lagrangian L satisfying above requirement of invariance under U(1) can be written as [1]

$$L = \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + (D^\mu \phi) + (D_\mu \phi) - \mu^2 |\phi|^2 - \lambda |\phi|^4 \quad \text{...(2)}$$

where $F^{\mu\nu}$ is coupled gauge field and θ is a complex scalar field.

Theory around this lagrangian is invariant under following transformations:

$$\phi(x) \rightarrow e^{-iq(x)}\phi(x),$$
$$A_\mu(x) \rightarrow A_\mu(x)\partial_\mu a(x) \qquad \text{... (3)}$$

Now one can observe that for the case of $\mu^2 < 0$ and $\lambda >, 0$, where μ^2 represents the mass term of the lagrangian, the potential part of L possess energy minima $\phi = \mu n$ at $v = \sqrt{\frac{-\mu^2}{\lambda}}$ where.

As usual we observe that in the ground state global U(1) symmetry is broken and we write

$$\phi(x) = \frac{1}{\sqrt{2}}\left(v + \eta(x) + i\xi(x)\right) \qquad \text{...(4)}$$

where η(x) and ξ (x) are the quantum fields and can be expanded in terms of creation and annihilation operators.

With eq. (4) in the expression for $\mathcal{L}$ one can get a massless ξ field, a massive scalar field η and a massive A_μ field. The massless ξ field can be removed from the lagrangian with the effective use of unitary gauge and then we are left with only physical fields appearing in the lagrangian along with massive gauge field and local U(1) symmetry broken.

Spontaneous breaking of global u(1) symmetry and massive gauge boson

We here propose that the introduction of A_μ is a demand of gauge invariance and assume that there is no interaction between fields ξ and A_μ as such. Instead we take up a situation where both the fields appear on the same ground of observation.

Now the introduction of gauge fixing term, namely:

$$L_{GF} = \frac{1}{2\theta}\left(\partial_\mu A^\mu - \theta q v \xi\right)^2 \qquad \text{...(5)}$$

leads to the following expression of propagator for Aμ field [3]:

$$iD_{\mu\nu}(k) = \frac{1}{(k^2 - q^2v^2 + i\varepsilon)}\left[-ig_{\mu\nu} + \frac{i(1-\theta)k_\mu k_\nu}{k^2 - \theta q^2 v^2}\right] \text{...(6)}$$

here θ is the gauge parameter.

For ξ field the expression of propagator is:

$$iD(k) = \frac{1}{k^2 - \theta q^2 v^2} \qquad \text{...(7)}$$

We note that with the choice of unitary gauge and using transformation rules in eq. (3), one can actually remove ξ field from the lagrangian but in our case we choose a different line of action and do not give importance to the independent appearance of the propagator for ξ . Being a part of propagator for *A*, it is already there. Then the only thing remains to be done is to set the value of θ equal to unity and make the second term in eq. (6) vanish. Obviously absence of the second term in eq. (6) would lead to a proper propagator expression for massive gauge field. Simultaneously the gauge propagator for gauge field becomes free from the ambiguity of having poles at two different mass values. Now for modified kinetic term $(D^\mu\phi)+(D_\mu\phi)$ in eq.(2) we get with substitution from eq. (4)

$$(D^\mu\phi)+(D_\mu\phi) = \frac{1}{2}\left[(\partial^\mu\eta)(\partial_\mu v) + (\partial^\mu\xi)(\partial_\mu\xi) + q^2v^2A^\mu A_\mu\right] + qvA^\mu\partial_\mu\xi + \ldots. \qquad \text{..(8)}$$

here dots include unwanted interaction field terms.

Since we work with unit value of gauge parameter (Feynman Gauge), ξ field should be there in the lagrangian, though its appearance in our case is mere a naïve interpretation of the term. What we propose that this term simply shows a sort of phase transition and not an interaction between fields and ξ during conversion of ξ into massive. Naturally with massive gauge boson into existence there will be no unphysical field left.

CONCLUSION

We have tried to present the technique of Higgs mechanism in Feynman Gauge with an assumption of having Goldstone boson propagator as a part of covariant gauge field propagator. Thus denying its independent existence. We observe that this departure from main line of action of Higgs mechanism does not affect the renormalization aspect of the theory. It also appears that spontaneous breaking of global U(1) symmetry alone is sufficient for mass gaining process of Higgs mechanism.

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