Gauge Symmetry Breakdown
due to Dynamical versus Elementary Higgs 1)

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We study in details on how gauge bosons can acquire mass when the chiral symmetry dynamically breaks down for massless gauge theory without scalars. Introducing dynamical scalar fields into the original gauge theory, we show that when the chiral symmetry breaks down, the theory gives gauge boson masses different from what would be obtained if an elementary Higgs is included. We clarify the reason and propose one method how to calculate gauge boson masses in this case. We explain the method by using an example in which SU(5) massless gauge theory breaks down to SU(4) with massless fermions in appropriate representations.

Most of the elementary particles have their own mass, fermions as well as gauge fields. A general method to give mass to a fermion is to introduce a scalar field, let it couple with a fermion, and then give a vacuum expectation value (VEV) to that scalar. In the case of a gauge field, again introduce a scalar field, let it couple with a gauge field so that the interaction is gauge invariant, and give a VEV to a scalar. In these cases, however, there is no principle to determine the value of mass which can be arbitrarily made large or small by changing a Yukawa coupling constant and/or the value of VEV. Hence it seems natural and physical to consider that mass is generated as a result of some dynamics starting from a massless theory.

The method that people normally use to calculate gauge boson masses from massless gauge theory without an elementary scalar is to apply the Jackiw-Johnson sum rule1), which gives an expression, $g \times f$ for a gauge boson mass, i.e., a gauge coupling constant times a decay constant. The latter quantity, $f$, is more explicitly given by the Pagels-Stokar formula.2) This decay constant is directly related to a fermion mass when the chiral symmetry breaks down and it is well-known how to give mass to a fermion dynamically. When breakdown of the chiral symmetry causes that of gauge symmetry at the same time due to condensation of a gauge non-singlet fermion-anti-fermion scalar bound state, then gauge boson mass is dynamically generated. That is, dynamical gauge boson mass cannot be generated without a dynamically generated fermion mass. Although the mechanism to generate gauge boson mass is given by the above Jackiw-Johnson sum rule, since the vertex among fermion, anti-fermion, and dynamical scalar or the Nambu-Goldstone particle is nonlocal (it is essentially given by fermion mass), care must be taken to calculate gauge boson mass through a fermion one-loop diagram. This is why we would like to reconsider the mechanism of dynamical gauge boson mass generation

1) A talk given by T.M.
in this paper.

When the method of Jackiw and Johonson is combined with the idea of the tumbling proposed by Raby, Dimopoulos, and Susskind\(^3,4\), people had thought they have everything in their hands, namely how to obtain the breaking orientation of the gauge group, how to obtain fermion masses, and how to obtain gauge boson masses. Actually the developments of dynamical theories since then, like theories of technicolor, extended-technicolor, etc., solely assume this expression, \(M_G = g f\). Also it is taken for granted that the results of technicolor theory\(^5\) can be in principle derived by a theory replacing the condensation with an elementary Higgs scalar even though technicolor theory gives some restriction on model building. Our question we would like to ask in this paper is whether gauge boson masses should be calculated after the breaking direction is determined by fermion condensation. Or is it possible to determine both fermion and gauge boson masses at the same time once the condensation pattern is determined? Is there really no difference between theories with and without scalars?

Let us recall what the idea of tumbling brings us when constructing a dynamical model. Assumption of the tumbling is supposed to give us the scenario how gauge symmetry dynamically breaks down in series, once an original massless gauge theory with massless fermions but Higgs scalars is given. The direction of breakdown is selected by the so-called most attractive channel (MAC), which can be determined from the second Casimir invariants. Due to the chiral symmetry breakdown, fermions in a certain representation acquire mass and tacitly assumed is that at the same time some gauge bosons also acquire mass since the gauge symmetry breaks down via a gauge-non-singlet dynamical scalar which is a composite of fermion-anti-fermion pair. What we would like to study in this paper is on this point. That is, when the chiral symmetry spontaneously breaks down, we shall calculate the decay constants of the Nambu-Goldstone (NG) bosons which are absorbed by would-be massive gauge bosons. These decay constants are nothing but gauge boson masses up to coupling constants. However, these massive gauge bosons are assumed to be massless when one determines the MAC. This seems to be contradiction. Hence we should also reconsider the criterion how the breaking direction should be determined. After this consideration and calculation we will compare the results with those expected from a theory with an elementary Higgs scalar and see whether they are equivalent or not.\(^6\)

In this study, by adopting the massless \(SU(5)\) gauge theory as an example which breaks down to \(SU(4)\), we will show what is the problem and where is the problem when one wants to calculate gauge boson masses. We will also point out that at least in our model calculation, theories with and without elementary Higgs scalars are not equivalent to each other. In this study, we will propose one solution how to calculate gauge boson masses and apply it to our case. Mass formulae both for fermions and gauge bosons are given for the massless \(SU(5)\) gauge theory without scalar and we find that one arbitrary parameter comes in for gauge boson masses. That is, one of gauge boson masses cannot be determined uniquely \textit{a la} Pagels and Stokar. This may be resolved by adopting the interpretation of a bound state as a classical object and assuming the flow of an external momenta inside of a composite
is proportional to their masses. Finally the results are compared with those of a theory with an elementary Higgs and explicitly show the difference between theories with and without Higgs.

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