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COMPOSITE MODELS OF THE WEAK INTERACTIONS

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I have been asked to talk about composite models where the scale of the binding force is less than 1 TeV. These models have interactions whose scale is less than 1 TeV which is very near the weak interaction scale of \( G_{\text{F}}^{-1/2} \approx 300 \text{ GeV} \). Therefore I will assume that the weak interactions are in fact a residue of the underlying strong interaction binding force.

Models of this type have three general features:

i) Quarks and leptons are composite on the scale \( G_{\text{F}}^{-1/2} \approx 300 \text{ GeV} \).

ii) The weak interaction bosons \( W^+, W^-, \) and \( Z \) are also composite on this scale.

iii) The observed weak interactions are a remnant of the confining interaction.

These ideas have appeared in the literature in various schemes\(^1\). However most of the models introduced are not based on sensible dynamical reasoning. For a model to have a glimmer of hope of being correct, it must confront three issues.

i) Spectrum - The quantum numbers of the bound states are determined by the quantum numbers of the constituents. The bound states must have the observed quantum numbers of the quarks and leptons. If bound states with the wrong quantum numbers can be formed, their absence from the spectrum must be explained.

ii) Lightness of fermions - The observed fermions are much lighter than the binding scale. This is only possible if the bound state fermions satisfy the 't Hooft anomaly conditions.

iii) Correct weak interaction phenomenology - The residual interactions induced by the confining force must look like the known four fermi charged currents, universality and the famous neutral currents.

One model which seems to work, although it does have some problems with point (iii), is the one introduced by L. F. Abbott and myself\(^2\). The key feature of this model is that the dynamics are determined by the same Lagrangian as the standard Glashow-Weinberg-Salam theory. However the parameters are adjusted so that there is no spontaneous symmetry breaking and the SU(2)_L gauge interaction becomes strong at \( G_{\text{F}}^{-1/2} \approx 300 \text{ GeV} \). The theory looks very much like QCD and our analysis uses many of the lessons learned from hadronic physics.

The ingredients in the Lagrangian are the SU(2)_L doublet fields \( \chi^a (a = 1,N) \), 2N right handed SU(2)_L singlets and a fundamental scalar doublet \( \phi \). The U(1) quantum numbers are the usual ones with \( \phi \) assigned - 1/2 etc. At the confining scale, gauge singlet bound states form. For each doublet fermion \( \chi^a \) we can form two fermionic bound states with \( \phi \). These are \( \phi \chi^a \) and \( \phi \psi \chi^a \) and correspond to the two ways to make a singlet out of two SU(2) doublets. These bound states have 0(1) quantum numbers which equal the electric charges of the observed quarks and leptons. These states, which are left handed, also satisfy the 't Hooft anomaly conditions and we expect them to be light on the binding scale. The right handed partners of these bound states are the right handed fields introduced into the Lagrangian. These right handed fields are singlets under the confining...
group and have the correct charge assignments as long as we use the values given by the Weinberg-Salam theory.

Thus, the spectrum and lightness of the fermionic bound states works out perfectly in this model. I will now discuss the form of the effective low energy interaction induced by the strong interaction SU(2)\(_{\text{L}}\). At or near the scale \( G^{1/2}_s = 300 \text{ GeV} \) there exists a variety of bound states held together by the strong force. Three of these bound states have the quantum numbers of the \( W^+ \), \( W^- \) and \( Z \). They are formed by taking spin one, gauge singlet, combinations of \( \phi \), \( \phi^* \) and \( \phi^* \phi^* \). The exchange of these particles and all the other possible bound states will give rise to an effective interaction between the left handed bound state fermions. The right handed fermions are pointlike and do not participate in these interactions.

At or near the scale \( Q^* \sim G_{pl}^{1/2} \) there exists a variety of bound states held together by the strong force. Three of these bound states have the quantum numbers of \( \phi^+ \), \( \phi^- \) and \( \phi^0 \). They are formed by taking spin one, gauge singlet, combinations of \( \phi \), \( \phi^* \) and \( \phi^* \phi^* \). The exchange of these particles and all the other possible bound states will give rise to an effective interaction between the left handed bound state fermions. The right handed fermions are pointlike and do not participate in these interactions.

At \( Q^* \sim G_{pl}^{1/2} \) the dominant operator in this effective interaction is a four-fermi interaction between the left handed fields. The form of this operator can be greatly restricted by insisting that it respects the symmetries of the underlying Lagrangian. If we neglect U(1) and color at the scale \( G_{pl}^{1/2} \) then the Lagrangian has a global SU(N)\( \times SU(2) \) symmetry.

The SU(N) comes from the N left handed doublets (For three generations \( N=12 \)). The SU(2) is an extra symmetry which acts only on the scalar field \( \phi \). Now there are only two possible four-fermi interactions between the left handed bound states which respect these symmetries:

\[
J^{\mu L} J^{\nu L} , \quad J^{\mu L} J^{\nu L} \]

where

\[
\begin{align*}
J^{\mu L} &= \sum_{\alpha=1}^{N} \bar{\psi}^{\alpha} (1-\gamma_5)^T \psi^{\alpha} \\
J^{\nu L} &= \sum_{\alpha=1}^{N} \bar{\psi}^{\alpha} (1-\gamma_5)^T \psi^{\alpha}
\end{align*}
\]

Here \( \phi^0 \) is a doublet under the global SU(2). Its two components are the two different gauge singlets made from \( \phi \) and \( \phi^0 \).

The first interaction is most of the observed four-fermi interaction:

\[
(4G_f^2/\Lambda^2) \left( J^{\mu L} \gamma^\mu J^{\nu L} - \sin^2 \theta \right) ,
\]

except for the part involving \( \sin^2 \theta \). We can also get this if we assume vector meson dominance. This idea was first discussed by Hung and Sakurai and by Bjorken. Imagine that the three bound states \( W^+ \), \( W^- \) and \( Z \) are constructed. The unwanted term could arise from the exchange of the SU(2) singlet partner of the triplet. However this spin one state can not be made out of two scalars, as the \( W^+ \), \( W^- \) and \( Z \) are constructed. Since the singlet exchange term is necessarily different in origin perhaps its suppression is not surprising.

Another source of possible deviations from the desired four-fermi interactions are order \( \alpha \) corrections to universality which are induced when we no longer neglect color. This has been emphasized by Susskind and Veltman. In fact, Sirlin has calculated these corrections in the standard model and they agree with experiment to a fraction of a percent. We need a better understanding of these corrections in confining models.

The greatest difficulty faced by all confining models of the weak interaction is the large value of the observed \( \sin^2 \theta = .22 \). If this is a measure of the photon - \( Z \) mixing then it is difficult to understand why
it is not more typically electromagnetic in magnitude. For example, the rho meson photon coupling, measured in $\rho \rightarrow e^+e^-$, would produce a "$\sin^2\theta$" of .02. Some enhancement mechanism must be discovered.

Still, I believe that the weak interactions may be due to a strong interaction. Can this be experimentally tested? First at low $Q^2$ there could still be a very small SU(2) singlet exchange term waiting to be discovered. Also if there are excited $Z$'s contributing to the neutral current, these could add an additional $j^\mu_m j_{\mu em}$ term to the neutral current at low $Q^2$.

More spectacularly, the $W^+$, $W^-$ and $Z$ produced at high energy machines, would have properties very different from those predicted by spontaneously broken gauge theories. The $W$ and $Z$ would be heavier and wider with masses between 100 and 170 GeV. The relationship $m_W/m_Z = \cos \theta$ would not hold. In fact the $W$ to $Z$ mass ratio would be closer to unity. The widths would follow a simple scaling law:

$$\Gamma_{\text{composite}} = \left(\frac{m_{\text{composite}}}{m_{\text{standard}}}\right)^3 \Gamma_{\text{standard}}$$

however the branching ratio's would be very close to those in the standard model.

Another exciting effect would be the production of a host of unusual resonances. These would come in three varieties:

1) Excited $W$'s and $Z$'s.
2) Excited bound state fermions
3) Exotics - those bound states which do not have the quantum numbers of (1) and (2). For example, a colored fermionic preon and a leptonic fermionic preon could bind to form a spin one, charge $-2/3$, color 3, resonance. This state would decay into a lepton and antiquark and could most easily be made in an ep machine. The observation of these resonances would help determine the exact form of the underlying strong interaction.

As a final remark, I would like to say that although these composite models of the weak interactions are attractive and amusing, they are very difficult to understand in the context of standard grand unified models. The minimal GUT predicts $\sin^2\theta$ exactly and we would have to interpret this as serendipity. Our whole understanding of GUT's is based on spontaneous symmetry breaking and if the weak interactions have a different origin, then the larger picture is thrown into doubt. The discovery of a $Z$ having the properties I outlined above would radically change the wonderful unified ideas developed in the last fifteen years.

References

