QUARKS AND LEPTONS; WHAT NEXT?

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1. Introduction.

The present situation in elementary particle physics may be conveniently presented in the form of a picture resembling three flagpoles (fig. 1):

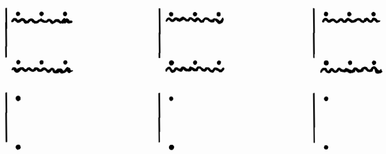

fig .1

Each dot represents a particle (fig. 2):

u_r	u_y	u_b	c_r	c_y	c_b	t_r	t_y	t_b
d_r	d_y	d_b	s_r	s_y	s_b	b_r	b_y	b_b
ν_e			ν_μ			ν_τ		
e			μ			τ		

fig .2

The wavy lines represent strong interactions mediated by 8 gluons (fig. 3):

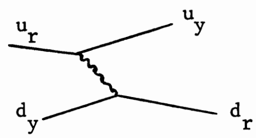

fig. 3

The straight lines represent weak and e.m. interactions mediated by charged and neutral vector bosons and a photon (fig. 4):

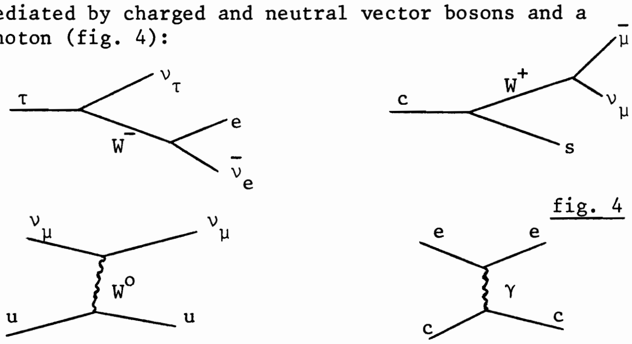

fig. 4

The theory of strong interactions is supposedly quantum chromodynamics, an unbroken gauge theory based on the group SU(3). The theory of weak and e.m. interactions is believed to be described by the Weinberg-GIM model, based on the spontaneously broken symmetry SU(2) x U(1).

There are many uncertainties around these theories. Quantum chromodynamics has met with many successes, but the most important feature, quark confinement, has not been proven. Also other things, such as PCAC, have not yet been understood. And we have no reasonable calculation of particle masses (pion, proton, etc.). Nevertheless we consider quantum chromodynamics a reasonably respectable theory, and in this talk we will take that theory for granted.

The situation with respect to the SU(2) x U(1) theory is much more difficult. No vector bosons have yet been observed, and the Higgs system is more obscure than ever. Glashow's model [1] has been turned into a renormalizable [2] model by Weinberg [3] through the use of the Higgs system, but up to now no radiative corrections of the appropriate type have been measured. The only thing we know is that at low energies this Glashow model reduces to a four-fermion theory involving certain currents, and this has been checked reasonably well. Also, the discovery of charm (and hopefully the discovery of a top quark) fits beautifully into the picture along the lines of the GIM [4] mechanism. CP violation could be due to complex quark masses according to the Kobayashi-Maskawa scheme [5]. We will take the point of view that the existence of vector bosons is not evident, and the Higgs mechanism is a possibility at best. It is the purpose of this talk to outline and clarify this view.

One more fact must be mentioned. The vector boson masses in the Glashow model are free parameters, and they appear as such in the four-fermion theory observed at low energies. It is an experimental fact that the ratio of these masses is nearly equal to the cosine of the weak mixing angle:

$$\frac{M^2}{M_o^2 \cos^2\theta_w} = \rho = 1.01 \pm 0.03 \ . \qquad (1)$$

Further, experimentally

$$\sin^2\theta_w \equiv s_\theta^2 = 0.230 \pm 0.009 \ .$$

2. The mass relation.

In considering the whole system sketched above one cannot escape the feeling that all this is only the top of an iceberg, where the rest of the iceberg is whatever exists above 30 GeV. The first question then is this: do we have any information on the region above 30GeV?

Evidently, the only way that present data would contain information about higher energy systems is through radiative corrections. Thus the question may be rephrased as follows: do there exist radiative corrections sensitive to high mass states?

Now there exists the Appelquist-Carazzone [6] decoupling theorem, which states that high mass states decouple from low energy amplitudes, that is, their contribution is of order $1/m^2$, with m the mass in question. In fact, the $O(1/m^2)$ terms have been worked out in more detail by Kazama and Yao [7]. For example, we do not expect that high mass systems influence the anomalous magnetic moment of the electron or muon.

However, this decoupling theorem is not airtight, and we will try to outline where interesting information on high mass states may be available.

In general, a one loop radiative correction gives rise to an integral of the form:

$$\int d_4q \frac{1}{(q^2+m^2)^\lambda} \ .$$

The quantity m^2 is some linear combination of the internal and external masses squared. Because of dimensional reasons we have that this integral behaves as $(m)^{4-2\lambda}$, and for large m we will find a small result unless λ equals one or two. Now if λ one or two then we have a quadratic or logarithmic divergent integral, and in any renormalizable theory such integrals occur only as corrections to masses or coupling constants.

The question is thus: can we observe corrections to masses or coupling constants? In general, masses and and coupling constants are free parameters, which then makes these corrections unobservable. The only escape is if some of the masses or coupling constants are not free.

This latter case occurs if there are relations between masses or coupling constants. For instance, the near equalness of the muon decay coupling constant and the vector coupling constant of β-decay may be used to give an upper limit [8] to the W-mass (W is the vector boson of weak interactions). The limit is about 160 GeV. Thus vector bosons, or something else, should turn up below this energy.

Let us now assume that vector bosons exist. Then the mass-relation eq. (1) is the evident target for further investigation. It turns out that radiative corrections to eq. (1) due to virtual particles from a new flagpole become large if the mass differences between the quarks, or between the leptons become large [9,10]. From this one derives a limit of about 400 GeV for the mass of a new lepton accompanied by a mass-less neutrino, and a limit of 100/300 GeV for a quark doublet with a mass ratio of 3.

Also the Higgs system may influence the mass relation, but it turns out that there is only logarithmic dependence on the Higgs mass, and the coefficient is very small. In fact, the above mentioned corrections give rise to deviations from the relation eq. (1) as given by the equation

$$\rho = 1 + \frac{G}{8\pi^2}\left\{m_1^2 + m_2^2 - \frac{2m_1^2m_2^2}{m_2^2-m_1^2}\,\ln\frac{m_2^2}{m_1^2} - \frac{3M^2 s_\theta^2}{c_\theta^2}\,\ln\frac{m^2}{M^2}\right\} \qquad (2)$$

with

$s_\theta = \sin\theta_w$, $c_\theta = \cos\theta_w$

m_1, m_2 = masses of new doublet

M = vector boson mass, ~ 80 GeV for $s_\theta^2 = 0.22$

m = Higgs mass

$G = \dfrac{1.02\times10^{-5}}{\sqrt{2}\, m_p^2}$, m_p = proton mass.

Finite corrections not growing with either heavy lepton or quark or Higgs mass have not been included. A Higgs of 3000 GeV gives an effect of only 0.4%, far beyond experimental limits.

The above numbers, 400 and 100/300 GeV, applying to possible new flagpoles, are at this moment the only reasonably hard figures known about the region above 100 GeV. In view of the way that flagpole masses seem to behave it appears that really not more than one new flagpole should exist.

This is perhaps the moment to quote the limits coming from cosmological arguments [11]. These arguments indicate that there should be no more than 3 mass-less neutrinos. However, such arguments are open to doubts, and also the basic assumptions are not necessarily true [12].

3. Large Higgs mass.

In present day gauge theories the symmetry breaking needed to obtain non-zero vector boson masses as well as fermion masses is generated by the Higgs system. At least one physical scalar particle is needed, with well defined properties [13]. The mechanism involves a non-zero vacuum expectation value for this Higgs particle. This gives rise to a non-zero energy content for the vacuum (assuming zero energy before symmetry breaking), which may be observed through the use of gravitation. More precisely, spontaneous symmetry breakdown generates a cosmological constant many orders of magnitude larger than allowed by experiment [14].

Now one could argue that the cosmological constant is a free parameter in the theory, and one could invoke a term of the necessary magnitude before symmetry breaking, such that after symmetry breaking zero results. If this sounds already unnatural, it becomes even worse if one realizes that higher order radiative corrections again upset this balance, which requires further fine of the initial constant.

The question is now how serious this should be taken. Since no one has suggested a reasonable answer to this question there is no objective way out of this difficulty. My personal view is this: perhaps the Higgs system is not as suggested by present day theories, involving at least one physical scalar particle. Maybe this scalar Higgs particle is just some effective way to describe a far more complex system.

Now this is very vague, and in order to get nevertheless to something more definite, we will pose the problem into another form. Clearly, something has to be there at some energy, else the theory runs into problems. This is clear from the work of Llewellyn-Smith [15], and Cornwall et al [16], who have established that without a Higgs particle certain amplitudes grow indefinitly, which is not allowed. This has been reformulated as a unitarity limit by Dicus and Mathur [17], and Lee, Quigg and Thacker [18], and it follows from this work that before 1000 GeV the lowest order theory without Higgs cannot describe a physical situation. We now ask the following question: suppose the Higgs particle is heavier than 1000 GeV. What happens with the theory?

The answer is that a certain part of the theory becomes a strongly interacting system. Thus either the Higgs is well below 1000 GeV, or we have new strong interactions. We may speak of a new threshold: either the Higgs or new strong interactions must become visible before 1000 GeV [19].

Let us now suppose that the second case (new strong interactions) is realized in nature. How can we study these strong interactions experimentally? Unfortunately, things are quite well hidden. All particles that are known today (leptons, quarks) are only indirectly coupled to these new strong interactions, just as for instance the electron is only indirectly (through the photon, implying a factor α) coupled to the usual strong interactions. This fact has been named the screening theorem [19].

There are two cases where the screening is somewhat less effective, and that is in corrections to the W-masses, and in corrections to certain coupling constants. Now, in the mass corrections the term given before is representative; the occurrence of $\ln m_H^2$ instead of m_H^2 is a typical screening effect. The new strong interactions would typically manifest themselves with effects of order 1 compared to $\ln m_H^2$; we have seen however that there is really very little sensitivity to this.

The only other case is the three W-coupling constant. This constant, predicted to be equal to the μνW coupling constant also suffers corrections of the form $\ln m_H^2$. And fortunately things are less bad now; in $e^+e^- \to W^+W^-$ the effects are of the order of 5% [20] . This is still small, and perhaps very difficult to see; but if there are new strong interactions then we must see this number of 5% as a conservative guess of the order of magnitude.

4. Other limits.

Meanwhile many authors have investigated the behaviour of the theory in case the Higgs, or the fermions are very heavy. Also alternatives to the usual Higgs system have been considered [21]. Here I want to discuss briefly some of these results.

First of all, in the Weinberg-GIM model, the inclusion of heavy fermions leads to strong fermion-Higgs coupling. This is because this coupling is proportional to the fermion mass. Thus for heavy fermions another strongly interacting system shows up. The crucial number is again of the order of 1000 GeV [10].

Next there is the question of the influence of heavy particles on the Higgs system. In 1973 Coleman and E. Weinberg [22] discussed the influence of radiative corrections onto the Higgs potential. This potential must have a minimum somewhere in order to give the usual spontaneous symmetry breakdown. Radiative corrections modify this potential, and in particular heavy fermions have a strong effect [23, 24]. In fact, if the fermion mass is higher than 100 GeV the usual Higgs system cannot be maintained. A similar discussion within the framework of grand unified theories by Cabibbo et al [25] also gives strong constraints, including constraints on the Higgs mass. What emerges from these arguments is this: if there exist heavy fermions ($\gtrsim$ 100 GeV), and also if the Higgs mass is large ($\gtrsim$ 200 GeV) then the Higgs mechanism as employed in the Weinberg model cannot be maintained. And for still higher fermion masses further new strong interactions come into existence.

5. Extensions of the theory.

The foregoing discussion has been one on relatively solid basis. We now want to enter a discussion of a much more speculative nature, namely the question of the compositeness of the known, or usually accepted to exist, particles.

The main problem now seems to be this: why are there so many flagpoles, and what is the origin of the masses of the flagpole particles? It is quite contrary to the past experience of particle physics to be happy with so many "elementary" particles and so many free parameters (the masses). Moreover there are arguments against the Higgs system as used in the Weinberg-GIM model beyond those that we have mentioned already.

Thus let us now suppose that the flagpole particles are composite*1. And even further, we will suppose that they are characterized by a definite particle content (such as a proton, made up from three quarks). Here we may try to follow the procedure that has led to the quark postulate: first try to find a symmetry and then assume that all multiplets are build up from a multiplet of the lowest dimensional nontrivial representation.

The obvious candidate for this approach is the grand unified theory (GUT) of Georgi and Glashow [27]. This theory is based on the symmetry group SU(5), and the aim of the authors was to unify the weak, e.m. and strong interactions. This is not what we are aiming at, and maybe theirs is the correct attitude, but we are not going to discuss that aspect of the theory. The multiplet structure is for a given flagpole, so there is no clue as to the question of number of flagpoles.

Let us now consider one flagpole. The SU(5) multiplet assignment is that a flagpole is made up from one 5-plet and one 10-plet. The 5 transforms as an SU(5) vector, and the 10 is an antisymmetric two-tensor.

Suppose we want to repeat the procedure that led from SU(3) to quarks. Thus we assume the existence of a 5-plet of quincks*2 and take these to be the basic building blocks. These quincks are then evidently spin 1/2 fermions. The 10, being an antisymmetric two-tensor, could then be seen as a bound state of two quincks. But this cannot be true, because two quincks necessarily form a bosonic state.

One must however not hastily conclude that SU(5) is worthless. It just so happens that it seems not to contain a useful clue to the structure of quarks and leptons. But the fact that the flagpoles fit so naturally into these multiplets is nevertheless striking, in particular the fact that the neutrino must be massless. After all, symmetry arguments would have been of little value to discover for instance the structure of the hydrogen atom. The spectral lines obey an O(4) symmetry, and that is not simply related to the idea of the Bohr model.

There is another feature of GUT that is very unpleasant. The theory contains two Higgs systems, one with masses of the order of 100 GeV, the other with masses of order 10^{17} GeV. The trouble is now that radiative corrections involving the heavy objects give contributions of order 10^{15} GeV to the low objects. Why then such contributions would conspire to maintain the 100 GeV scale is quite incomprehensible. The theory is called unnatural. Of course, the usual Higgs system is already unnatural with respect to the cosmological constant, but many physicists experience the SU(5) unnaturalness as even more flagrant.

All together, SU(5) seems to be good for the classification of the flagpole particles, but extending it to a gauge theory unifying weak, e.m. and strong interactions seems not very attractive.

6. Naturalness.

Apart from the cosmological constant the Higgs sector of the Weinberg model is still unnatural in another sense, which has been the basis of further speculations [28]. Roughly speaking it is this: the Higgs particle mass receives further corrections due to self energy diagrams. These diagrams are quadratically divergent, and must be cut-off at about 3000 GeV to avoid a contribution that exceeds the order of magnitude as needed in the Weinberg-GIM model. In fact, it seems that scalar particles are never natural [28] (unless they form part of a supersymmetry scheme). In other words, one expects that the Higgs particle is composite, and this structure should show up above 3000 GeV.

The big problem is now to make a model that remedies this defect. This now turns out to be very difficult, and leads in general to complications that exceed by far the complexity of the flagpole-W-Higgs structure of the Weinberg-GIM model.

The line of attack suggested by Dimopoulos and Susskind [28] is as follows. Evidently, if the Higgs is a composite system then there must be strong interactions that hold the system together. The idea is now to suppose that these interactions are analogous to the only other strong interactions that we know, namely quantum chromodynamics. The new interactions are termed technicolor, and their effects are deduced by analogy. The scaling factor, with respect to masses, is about 3000.

In the technicolor scheme there are hadrons of the order of 1000 GeV. The technicolor pions are exploited to give masses to the vector bosons, while the technicolor σ gets a vacuum expectation value of 250 GeV, as required.

Thus in order to construct the Higgs system a whole new scheme of strong interactions is introduced. No attempt has been made in ref. 28 to construct the flagpoles out of the techniquarks. The price that must be paid in order to preserve naturalness is very high. But this seems very difficult to avoid, it seems to be in the nature of things. In fact, thinking about the technicolor system one is led to the introduction of a super technicolor system, etc., etc., presumably up to the Planck length!

If one tries to construct the flagpole particles as bound states of techniquarks then another approach may be possible. The basic idea can best be explained by analogy with the well-known σ-model (see ref. 29 for an excellent review).

The Lagrangian for the σ-model is:

*1 Speculations of this type have been made before, at various occasions and within various contexts. See for instance [26].

*2 A quinck is the generic name for anything that can be taken as a building block of a quark, lepton, W, Higgs or gluon. I am indebted to G. 't Hooft for suggesting this name.

$$\mathcal{L} = \bar{\psi}\left\{\not\partial - g\left(\sigma + i\vec{\pi}\vec{\tau}\gamma^5\right)\right\}\psi + \tfrac{1}{2}\left[\left(\partial_\mu\sigma\right)^2 + \left(\partial_\mu\vec{\pi}\right)^2\right] - \frac{\mu^2}{2}\left[\sigma^2 + \vec{\pi}^2\right] - \frac{\lambda^2}{4}\left[\sigma^2 + \vec{\pi}^2\right]^2 + c\sigma \, .$$

This model may well be understood as an effective description of the hadron world if only u and d quarks existed. Now there are two cases, depending on the value of the parameter μ^2:

i If $\mu^2 > 0$ there is no spontaneous symmetry breakdown. The pion has a mass and the nucleons become mass-less.

ii $\mu^2 < 0$. In this case there is spontaneous symmetry breakdown of the symmetry. The π-mass becomes zero and the nucleons become massive.

It is this latter case that supposedly describes the usual strong interactions. But perhaps the first case applies to the technicolor interactions. The flagpole particles that seem to have zero or almost zero mass would then be analogous to the nucleons of the σ-model, case i.

't Hooft [30] has tried to find candidates for such a theory on the basis of a study of anomalies. Thus assume an SU(n) theory with technicolor interactions, anomaly free. Next suppose bound states according to some representation of the theory; subsequently the anomalies of such a subsystem are analyzed as a function of the indices. (An index is defined as the number of left handed bound states minus the number of right handed bound states for a given representation). Also these anomalies must vanish, and this gives a constraint on the indices. The point is then to see if there exist reasonable solutions to these indices.

Unfortunately the results are rather discouraging. The anomaly equations seem to have only non-integer indices as solutions, which is of course unacceptable The only reasonable case turns out to be SU(2), that is precisely the case of the σ-model. But that is not evidently applicable to the case of the flagpoles.

7. Economy.

In the preceding section naturalness was the guiding principle in dismissing the Higgs particle as an elementary particle. The Higss particle is seen as a bound state, with a mass presumably in the 3000 GeV region. At higher energy its structure would become visible. Basically it is a discussion about the world above 3000 GeV.

Now naturalness is, from a physical point of view, a quite objective and reasonable criterium. It seems to lead to systems that are even more complicated than the three flagpole system. That may or may not be the truth, but at first sight this is not very appealing from an economic point of view. And things are really complicated. If indeed this Higgs particle is so heavy then, as noted before, we must have new strong interactions, and these could lead to quite some complications.

Let us therefore entertain the idea of economy. Thus we suppose that the flagpoles are composite systems, made up from less particles than contained in the flagpoles themselves. If this is true then the following observation can be made: sooner or later some conservation law that we believe in now must be violated. By sooner or later we mean either at sufficiently high energy, or in sufficiently small amount at low energy.

In order to illustrate the issues we will now introduce a very crude model. Its region of validity is up to 3000 GeV.

Imagine a basic flagpole, with quarks and leptons. The basic quarks are called high and low, and the leptons L and ν_L. Suppose further the existence of a very heavy scalar particle ϕ, having strong interactions with this basic flagpole such that bound states arise. We now assume that the first flagpole (u, d, ν_e, e) is made up from the basic flagpole bound with one ϕ, the second (c, s, ν_μ, μ) contains two ϕ, and the third (t, b, ν_τ, τ) contains three ϕ's. In short, the number of ϕ's serves as a quantum number to differentiate the various flagpoles. One may visualize this as a sort of atom model: a nucleus of ϕ's is encircled by a basic flagpole particle (or vice versa).

If we assume that ϕ-number is a reasonably well conserved number then obviously at low energies we have the situation as we know today. Deviations would occur if we have collisions at such high energy that the "nuclei" would actually collide. We would see that e, μ etc. are not pointlike, but have a structure. And also we could have ϕ-exchange. For example, the following reaction would conserve ϕ-number:

$$\mu + u \rightarrow e + c \, .$$

What happens is that the lepton and the high quark exchange "orbits". Of course, this would only happen if μ and u-quark come so near to one another that the "orbits" start to overlap, which would be at very high energy. What would be observed is a breakdown of muon and electron number conservation.

The model has one big advantage with respect to models whereby the constituents of the electron etc. would be, for example, three fermions. In such models one would expect also spin 3/2 flagpoles, which are not only not observed, but would also be very difficult to fit into an SU(2) x U(1) gauge theory. On the other hand there is another big difficulty, namely the zero mass of the various neutrinos.

Now it seems not excluded that bound states have zero mass. Bound states are usually investigated with the help of the Bethe-Salpeter equation, but that is inadequate for a situation where one of the constituents as well as the resulting bound state is mass-less. Here the following observation can be made.

The fact that the neutrinos are mass-less seems to imply that there is a symmetry responsible for this, and of course one would think this to be chiral symmetry. Thus we would expect that the basic Lagrangian contains a chiral symmetry, and then it seems natural to assume that there are mass-less fermions in this basic Lagrangian. Would it not be natural to identify these mass-less fermions with the mass-less, or nearly mass-less particles that we know today?

In any case, if we assume that the various neutrinos are composite then we really need insight in how mass-less bound states can arise. Up to now we know only very little about this. It seems very far from trivial.

It is perhaps necessary to emphasize that this is not only a neutrino question. On the scale of weak interactions - 100 GeV - also the electron mass, and the masses of the u and d quark are very nearly zero. One would like to think that those masses arise as small perturbations (maybe of e.m. or weak origin) onto a zero mass situation. And perhaps also μ, τ, c, s, b, t must be seen as such. The very fact that one thinks in this way already is suggestive of a composite nature of these particles, but of a kind that would derive from a composite mass-less situation.

Let us now come back to the model mentioned. In terms of economy one could try to identify the ϕ with the one scalar that we need anyway (even if in the end, above 3000 GeV, it turns out to be composite), namely the Higgs particle. This is not completely excluded, even has some advantages, but meets also with a number of difficulties. The main problem is that there is no evident conservation of ϕ-particle number. To begin with, the Higgs can decay into a photon pair. This would imply the decay $\mu \rightarrow e\gamma\gamma$. An estimate of the rate gives an answer quite below experimental values. More serious is the decay $\mu \rightarrow eee$, due to the creation of a W^o in a reaction also involving the annihilation of a ϕ. Lack of understanding of the model prevents an estimate of this kind of process.

Finally there is another difficulty with economic systems, and that is CP violation. Making the basic system simpler increases the difficulty concerning CP violation. We may perhaps remind the reader of the fact that six quarks were needed in this context. In our case complications would have to be introduced in the Higgs sector.

Apart from all these difficulties there is also a more positive suggestion emanating from this model. We have argued that mass differences of new flagpoles are constrainted, and plausibly there is no new flagpole beyond, say, 200 GeV. In the above model this would imply that at some point the addition of one more ϕ gives no new flagpole, or rather no new stable situation arises. This would imply that at these energies these systems show their structure, become unstable, and the value of 200 GeV can then be interpreted as a threshold above which the composite structure becomes manifest. This, at least, holds some promise for near future experiments!

8. Conclusions.

The previous discussion may now be summarized as follows:

i The first reasonably strong fact is that mass differences must not exceed a certain value. Very plausibly this indicates no flagpoles above 200 GeV.

ii Next we may note that there is a threshold at 1000 GeV: either the Higgs particle shows up, or new strong interactions must be there. This is perhaps observable in the process $e^+e^- \rightarrow W^+W^-$.

iii The theory itself in its simplest form shows difficulties if there exist fermions heavier than 100 GeV.

iv Naturalness (the idea that radiative corrections should be of the same order of magnitude or less than the observed parameters) is a desirable property. This casts a shadow on

- a Spontaneous symmetry breakdown in view of the cosmological constant;
- b The grand unified theory SU(5) of Georgi and Glashow;
- c The very existence of the Higgs particle as an elementary particle.

v Because of iv the need for a composite structure of the Higgs arises. This, rather naturally, leads to the concept of composite vector bosons as well.

vi It is very difficult to construct reasonable and economic models that lead to a spectrum of composite states as presently observed.

vii Perhaps the value of 200 GeV mentioned above may be seen as a threshold above which the composite structure of quarks and leptons becomes visible.

viii Very precise measurements of processes violating a conservation law such as muon number make sense. Also μ-e universality should always be the subject of close attention.

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SPEAKER: M. Veltman

QUESTION: N. Christ, Columbia

I would like to comment on the role of supersymmetry in the masslessness of your bound states. If the usual gauge couplings do not participate in the supersymmetry, then their couplings will not contain the Adler zeros to which you referred.

Veltman:

No comment.

QUESTION: H. Lipkin, Weizmann-Fermilab-Argonne

The SU(5) composite model - if you start out with these 5 fermions or "quincks" whatever you call them, then the natural thing to do is to take 1, 3 and 5 quincks and then you get exactly the states that come into the spinorial representation of SO(10) that Wilczek was talking about. This sounds crazy to me but in 1962 when Chaim Goldberg came around and told us he could make the baryon octet out of three fundamental triplets with fractional charge we thought he was crazy too and maybe we should think twice about these things.

Veltman:

I did think only once about it.

QUESTION: H. Harari, Weizmann Institute

A general comment on composite models of quarks and leptons. There are many difficulties in such models but it seems to me that one of them is more profound than all the others. All composite models occur at very high energy scales (I do not care whether 10^3 or 10^{15} GeV). It is extremely difficult to reconcile this scale with the e-μ or d-s mass difference. This discrepancy is the only one which begins to appear as if it is inconsistent with some very fundamental principles (such as those of quantum field theory).

Veltman:

I couln't agree more; it is very difficult. The trick that you find for instance in the Dimopoulos-Susskind scheme is to some extend the replacement of mass-scales by scales of coupling constants. Maybe this is too severe a judgement, but anyway, if you have various coupling constants you can manipulate a lot of mass scales, and it becomes rather arbitrary. Maybe that is too negative, but it seems to me a bit like shifting the problem.

QUESTION: L.M. Jones, University of Illinois at Urbana

I just wanted to ask both Harari and Veltman how they would like getting excited electrons of higher spin and so on, or how do you imagine we should apply that constraint to this sort of model.

Veltman:

Well, as far as I am concerned, I do not have too much trouble with that quation in my simple model, because I would expect that the higher spin states would be above the threshold for these systems, i.e. they would be at the 200 GeV scale or higher. You could imagine that the states with ℓ equal one are quickly getting out of the region of stability of the system. Now, as Harari, I do not know, and certainly these things should be listed under the general difficulties. Here one could enter a long discussion, but let me just say a few words. If you have a high mass system which for some reason or other produces low mass bound states then the very fact that you are not able to see this high mass scale (the structure) until you get at very high energies implies that the whole collection of low lying states must behave as a renormalizable theory. Of course, the big question is how that would work. But anyway, you have to assume that this is what is happening in this world. Now it happens that it is very difficult, if not impossible to make a gauge theory around spin 3/2 particles. So, spin 3/2 should not be there. The difficulty is not really solved by this remark, but it shows how one difficulty - how to produce low lying bound states - is the same as the one you raise.

QUESTION: Y. Yamaguchi, University of Tokyo

May I ask - you often quote 200 GeV - does that have something to do with antiproton collider?

Veltman:

I base it entirely on this number which I consider to be coming from experiment. Now, whether or not Rubbia will find something out there, that I do not know. I would like it of course - it would be nice - it is a sad thing if we would have structure only above 1000 GeV because then you and I will probably not see it anymore. So, I would like there to be something low and here is something you can take courage from.

QUESTION: V.L. Telegdi, ETHZ

You talked about g_ν^β and g_ν^μ. Perhaps you could repeat your standard argument (radiative corrections) which - as far as I know - is the only experimental evidence for gauge theory.

Veltman:

The near equality of g_ν^β and$_\nu^\mu$ implies that the four-fermi theory cannot be valid above 130 GeV, but what is there instead is not known. The simplest solution would be vector bosons as in the standard model, but also other solutions are conceivable. I would hesitate to call this near-equality evidence for a gauge theory; it is more like evidence for the non-validity of the four-fermion theory above 130 GeV.

QUESTION: N-P. Chang, City College of New York

Comment. Higgs systems tend to destroy another property of the gauge theory, viz. that of asymptotic freedom. You can turn that around to your advantage by looking for eigenvalue conditions on all Higgs and other couplings. You have thus gained a true one coupling unified theory. For SU(5) such an asymptotically free model exists with one coupling constant, and one large mass scale.