INTRODUCTORY LECTURE

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1. INTRODUCTION

Neutrino physics and weak interactions, (e^+e^-) phenomena, deep inelastic processes, hadron spectroscopy, quark theories and quark confinement: all these are hot topics in the field of subnuclear physics.

It is time to revive a long-discontinued practice; namely, the introductory lecture, which is intended to present a general review of the main themes and to correlate them in a unique picture. Let me try to do this.

2. THE DESERT AND THE PROTON DECAY

The main result to date in subnuclear physics is the existence of the three gauge symmetry groups: $SU(3)_{colour}$, $SU(2)_L$, and $U(1)_{L,R}$, which are believed to be at the origin of the superstrong and of the electroweak forces.

However, the main outcome of this great theoretical goal is the danger of a DESERT. We all expect the electroweak unification, $SU(2)_L \times U(1)_{L,R}$, to be at $\sim 10^2$ GeV. According to some theoretical speculations, the next unification -- between superstrong and electroweak forces -- should be not very far from the Planck mass (see Fig. 1), i.e. at $\sim 10^{15}$ GeV, the energy level appropriate to the celebrated SU(5) grand unification group; with nothing between 10^2 GeV and 10^{15} GeV (see Fig. 1).

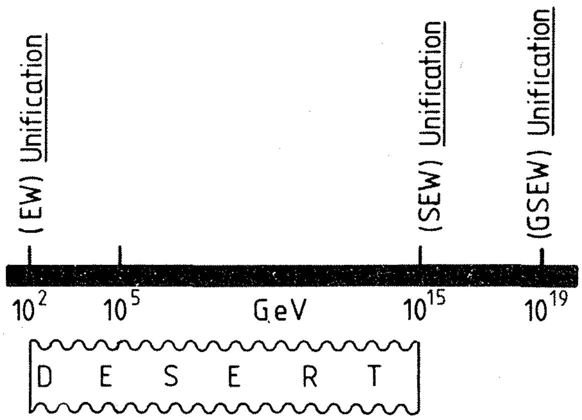


Fig. 1

Everybody agrees that there must exist a grand unifying gauge group "G", which contains

$$SU(3)_c \times SU(2)_L \times U(1)_{L,R} .$$

The great problem is to find how nature goes from the group "G" down to $SU(3)_c \times SU(2)_L \times$ $\times\ U(1)_{L,R}$. If the descent is "direct", the desert is catastrophic: from 10^{15} GeV down to 10^2 GeV.

This theoretical energy range for the Desert should be compared with 10^4 GeV, the maximum energy we can hope to reach in the next two decades via a proton-antiproton collider or proton-proton intersecting storage rings (ISR): 5 TeV + 5 TeV.

If we believe in the theoretical desert, the only experiment left would be the study of proton decay. It is in fact a general feature of the grand unification, to predict that the "brick of the Universe" has to lose its stability. The reason is simple. Grand unified theories must put leptons and quarks in the same multiplet of the unifying group "G". The gauging of this group produces quark-lepton transformation: i.e. proton decay. The proton instability follows from the concept of grand unification. It is not the result peculiar to a particular grand unifying group chosen. The particular choice can produce different lifetimes. For example, if the grand unifying group is SU(5), τ_p is $\sim 10^{31}$ years. However, the various models investigated so far, produce lifetimes in the range 10^{28}-10^{34} years.

And now a few words about the decay channels. If quarks and leptons are put in the same multiplet (q,ℓ) (fermion number conserved), the predicted decays would be, with three leptons in the final state:

$$p \rightarrow \begin{cases} 3\nu + \pi^+ & (\sim 80\%) \\ 3\nu + \pi^+\pi^-\pi^+ & (\sim 8\%) \end{cases} .$$

If fermions and antifermions are put in the same multiplet $(q,\ell,\bar{q},\bar{\ell})$, the decay modes would be, with only one lepton:

$$p \rightarrow \begin{cases} e^+\pi^0, \omega^0, \rho^0, \eta^0 & (\sim 75\%) \\ \mu^+ K^0 & (\sim 10\%) \end{cases} .$$

The present best limit on the proton lifetime is $\tau_p \gtrsim 10^{30}$ years. The new experimental jump should be about 3 orders of magnitude: $\tau_p \gtrsim 10^{33}$ years. This implies the study of the stability of 10^4 tons of matter, with an expected counting rate of 5 events/year (for $\tau_p = 10^{33}$ years). The experiment should be planned with a minimum energy bias, in order to avoid the limitations of previous results, where the proton decay was investigated, assuming that its disappearance had to produce a large energy release.

3. THE LESSON FROM PAST DESERTS

As you know, Europe is planning to build a new machine, the greatest ever built. This is why it is important to recall our previous experience with predicted theoretical deserts and experimental findings.

• Let us start with the 30 GeV proton synchrotrons of CERN and BNL. The original theoretical motivations were: πp and pp scattering and phase-shift analyses, as well as tests of isospin and T invariances. What did we get with these machines?

- New particle states, which produced the celebrated SU(3) symmetry of Gell-Mann [not to be confused with $SU(3)_{colour}$].
- The first measurement of the $(\omega - \phi)$ mixing angle resolved the puzzle of the vector meson masses and provided the proof of the existence of such a symmetry.
- The measurement of e^+e^- and $\mu^+\mu^-$ production in hadronic interactions, started in 1964 at CERN, resulted in the discovery of the J particle at BNL in 1974.
- The first proof of the electromagnetic structure of the proton in the time-like region.
- The discoveries of: the existence of antinuclei $(\bar{d})$; two kinds of neutrinos $(\nu_e \neq \nu_\mu)$; the fact that ν_μ is not equal to $\bar{\nu}_\mu$; CP and T violation; neutral currents.

All these findings had nothing to do with the original motivations.

• Some more examples: SLAC. The original physics aims were the study of the electromagnetic form factors of the nucleon, the electromagnetic transition form factors $(N\text{-}N^*)$, and QED checks. Found: the very important phenomenon called deep inelastic effect, i.e. the proof that point-like structures exist inside the proton.

• Let us look at ADONE, the Italian 1-3 GeV e^+e^- machine; what were the motivations there? The list was extensive: QED and radiative correction checks; μe electromagnetic equivalence; electromagnetic form factors of pions, kaons, and protons; the study of the tails of vector mesons. It is probably interesting to recall that these vector mesons (ρ, ω, ϕ) were theoretically needed to understand the conserved hadronic currents associated with isospin, hypercharge, and baryon number. Notwithstanding all these motivations, a particularly relevant and totally unexpected fact was discovered: the ratio of hadronic to muonic cross-sections was shown to be much higher than the theoretically predicted value, based on the tails of the three known vector mesons. Finally there was the search for heavy leptons via the analysis of the μe final states but this search had no theoretical motivation.

• Now let us look at SPEAR and DORIS. SPEAR started with great enthusiasm because of ADONE's discovery of the high cross-section ratio mentioned above. However, they found three great new things: the J/ψ spectroscopy; the open charm states; and last but not least, the heavy lepton from the μe final-state analysis -- just what the Frascati people were looking for, but were prevented from finding because of insufficient energy.

• The ISR is a special case. It is a machine where the physics results could have been tremendous. Unfortunately, the general trend was to study small angle and small p_T physics. Then large p_T phenomena came. The observations of the J and, recently, of the Υ at the ISR show that the physics was there.

• Finally, the 400 GeV machines at Fermilab and CERN. These are too new to be of use in our historical survey. However, not very many people would have bet on the existence of the 9.5 GeV object discovered by Lederman at Fermilab.

What lessons can we learn from this experience?

Firstly, There should be no energy gap. The maximum energy of ADONE was 3 GeV. SPEAR started at 3 GeV but then jumped to higher energies and was for some time bound to miss the J/ψ. SPEAR's maximum lay at 8.5-9 GeV, whereas PETRA started above 10 GeV. Lederman's Υ was found at 9.5 GeV. *Secondly,* compared with the actual discoveries. the anticipated findings have the appearance of a desert of imagination. The conclusion we should draw from this is that however great and significant the physics motivations for the new (e^+e^-) machine appear to us now -- the Z^0, $W^\pm$; new hadronic thresholds and, hence, flavours; new heavy leptons; free quark states, leptonic or hadronic; QED checks -- the actual discoveries should make these motivations look as fruits of a desert of imagination.

4. QCD AND COLOUR EFFECTS

The world in which we live has no deserts. The extreme left-hand corner of the desert in Fig. 1 is very rich, as the following review will show.

When we started, the six fundamental interactions were as shown in Fig. 2: the strong interactions, namely the SU(3) invariant and the semistrong SU(3) breaking ones; the electromagnetic, weak, superweak and gravitational interactions. How they appear to us now is shown in Fig. 3. It is evident that we were on the wrong track, with regard to the celebrated SU(3) of Gell-Mann. Now we see that the superstrong coloured forces represent the basic fundamental interactions. The strong and the semistrong are a byproduct of the superstrong ones, these being originated by gauging $SU(3)_{colour}$. We were also wrong in thinking that electromagnetic, weak, and superweak interactions were just unrelated. At present it seems that, with six quarks and six leptons, the electroweak and the superweak interactions can all be merged together.

WHAT WE STARTED WITH ...

1) Strong : $SU(3)_f$ invariant
2) Semistrong: $SU(3)_f$ breaking
3) Electromagnetic
4) Weak
5) Superweak
6) Gravitational

Fig. 2

THE INTERACTIONS NOW

I. The Superstrong (coloured) $SU(3)_c$ — { Strong, Semistrong }

II. The Electroweak (6 quarks and 6 leptons) $SU(2)_L \times U(1)_{LR}$ — { Electromagnetic, Weak, Superweak }

III. The Gravitational

Unification of I and II with III needs Supersymmetry: (bosons $\rightleftarrows$ fermions)

Fig. 3

Back to $SU(3)_{colour}$. What evidence is there for the existence of colour? The diagrams of Fig. 4 illustrate three types of measurement of colour effects. *Firstly,* if it were not for colour the π^0 lifetime should be nine times less (Fig. 4a). No new data on this topic are being presented at this Conference. *Secondly,* the ratio $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ should be three times larger than in the no-colour case (Fig. 4b). The *third* check for colour is provided by the so-called Drell-Yan mechanism (Fig. 4c), where an ocean (or valence) quark is annihilated with an ocean antiquark to produce a lepton pair. Here the probability for a quark to annihilate with an antiquark of the correct colour is $1/3$ compared to the case of no colour. The existence of colour implies a factor of 27 when we go from π^0 decay to Drell-Yan pairs. At this Conference there will be new results from PETRA on R and from CERN on the Drell-Yan process.

Let us now see where we stand with QCD. This is shown in Fig. 5. At the very bottom, for $t = \infty$, $\alpha_s \to$ zero, there is asymptotic freedom, with quarks and coloured gluons obeying QCD. The first step, where quarks and gluons interact without becoming real particles, is relatively easy; this jump will be discussed in the theoretical sessions devoted to QCD. However, the most difficult jump is the second one, where quarks and gluons should produce the well-known particles and their associated phenomena, such as "quark jets" and "gluon jets". For $t \simeq (1\ \text{fermi})^{-1}$, i.e. for real hadrons, nobody knows what α_s becomes, and nobody

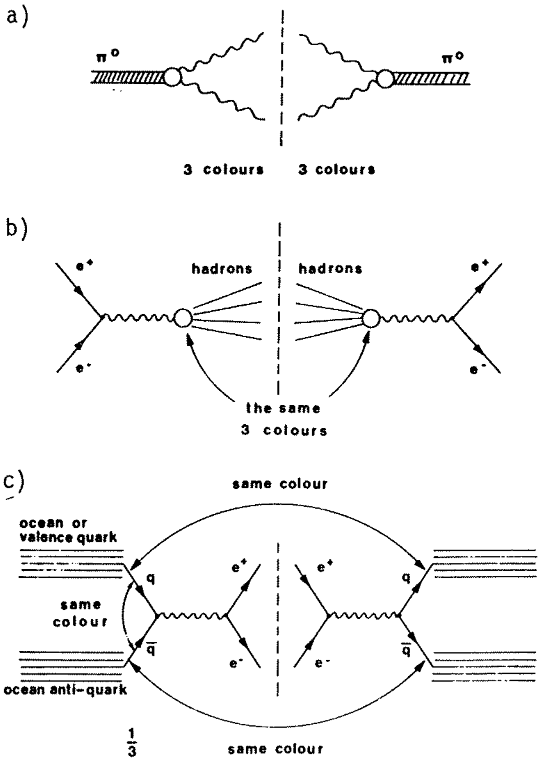


Fig. 4

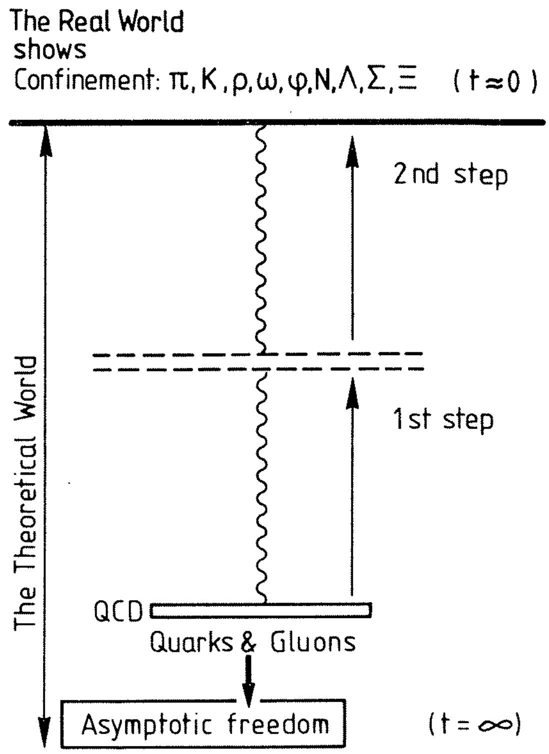


Fig. 5

has so far been able to prove confinement. If confinement were an exact result of a theory, there would be no point in looking for quarks. Sorry: it would be more exciting. But the present theoretical status on confinement is as follows: QCD at small distances produces asymptotic freedom, unlike QED; but QCD at large distances, like QED, does not produce confinement. Both results are perturbative, but they are the only ones available.

5. PRE-CHARM

Now let us consider the status of pre-charm physics. The baryons in the SU(6) multiplets given in Table 1 appear to be organized in such a way as to confirm our belief in the existence of $(56, 0^+)$. There is also overwhelming evidence for the existence of $(70, 1^-)$. Only a few states are missing. The question is whether the $(70, 0^+)$ is really absent. The expected states are shown in Fig. 6, but only one candidate exists for this multiplet. Moreover, there is no evidence of the 20-plet for any L^P value. The absence of these states is a basic problem for the baryon multiplets. And it is related to the question of whether the baryon structure is of the "quark-diquark" type. All this will be discussed at the hadron sessions of the Conference.

The pre-Conference status of the mesonic multiplets is shown in Table 2. There are some problems with the (L = 1) multiplet of 108 states. These will be discussed in the hadron sessions, where new states with higher L-value will also be presented.

Table 1

Baryons in SU(6) multiplets

$[SU(6), L^P]$	$SU(3)_f$	J^P	Standard names of particle states
$(56, 0^+)$	8	$1/2^+$	N, Λ, Σ, Ξ
	10	$3/2^+$	N^*, Σ^*, Ξ^*, Ω^-
$(70, 1^-)$	1	$1/2^-$	Repeat singlet
	8	$1/2^-$	Repeat octet
	10	$1/2^-$	Repeat decuplet
	1	$3/2^-$	Repeat singlet
	8	$3/2^-$	Repeat octet
	10	$3/2^-$	Repeat decuplet
	8	$1/2^-$	Repeat octet
	8	$3/2^-$	Repeat octet
	8	$5/2^-$	Repeat octet

[Repeat means that the quantum numbers (isospin and strangeness) of the states are identical to the "octet" and "decuplet" already known for the 56-case.]

BARYON SUPERMULTIPLET

J	SU(3)	
½	1	(70, 0^+) only one state seems to be there
½	8	
½	10	
3/2	8	

Fig. 6

Table 2

SU(6) mesonic multiplets

SU(6)	$SU(3)_f$	J^{PC}	Particle states	No. of states
$[(35 \oplus 1) \otimes 1]$; (L = 0)	$8 \oplus 1$	0^{-+}	π, K, η, η'	36
	$8 \oplus 1$	1^{--}	ρ, K^*, ω, ϕ	
$[(35 \oplus 1) \otimes 3]$; (L = 1)	$8 \oplus 1$	1^{+-}	B, $Q_{1,2}$...?	108
	$8 \oplus 1$	0^{++}	S, χ, S^*, ε	
	$8 \oplus 1$	1^{++}	A_1, $Q_{1,2}$, D, E	
	$8 \oplus 1$	2^{++}	A_2, K^{**}, f, f'	

At previous Conferences a lot of attention has been devoted to new multiquark hadronic states, baryonium and mesonium, made up of "peculiar" combinations of quarks and antiquarks. Earlier results supporting the existence of these types of quark-antiquark combinations will be confronted with new data -- some of which do not confirm these findings.

So much for pre-charm physics.

6. POST-CHARM

In post-charm physics the impressive fact is that so many states have been discovered in such a short period. Figure 7 shows the pre-Conference status of the "charmonium" and "bottomium" families. The $\chi(2830)$ and $\chi(3455)$ states will be questioned by new results, but everything else will remain as it is. A detailed analysis of the Υ decay from DORIS will be presented in the (e^+e^-) Session. These results deal with the problem of the Υ decay into three gluons.

If we now go into the "open-charm" states, Fig. 8 shows the status of the SU(4) flavour multiplet for the pseudoscalar mesons. The same SU(4) multiplet holds for the vector mesons; they have the same quark-antiquark content, the only difference being the spin state which here is a triplet. These two SU(4) multiplets are well established.

The status of open-charm baryons is quite different. Figure 9 shows the old baryon octet in the c = 0 plane, plus the new open-charm states. There are very many new states still to be discovered in the c = 1 and c = 2 planes. The only case reported so far is the Λ_1^+, and many new results will be presented at this Conference. In Fig. 10, the old, well-established baryonic decuplet in the c = 0 plane is reported with the new open-charm baryonic states, with c = +1, c = +2, c = +3, all to be discovered. An interesting result to be presented in the "charm" sessions is the measurement of the lifetime for open-charm states.

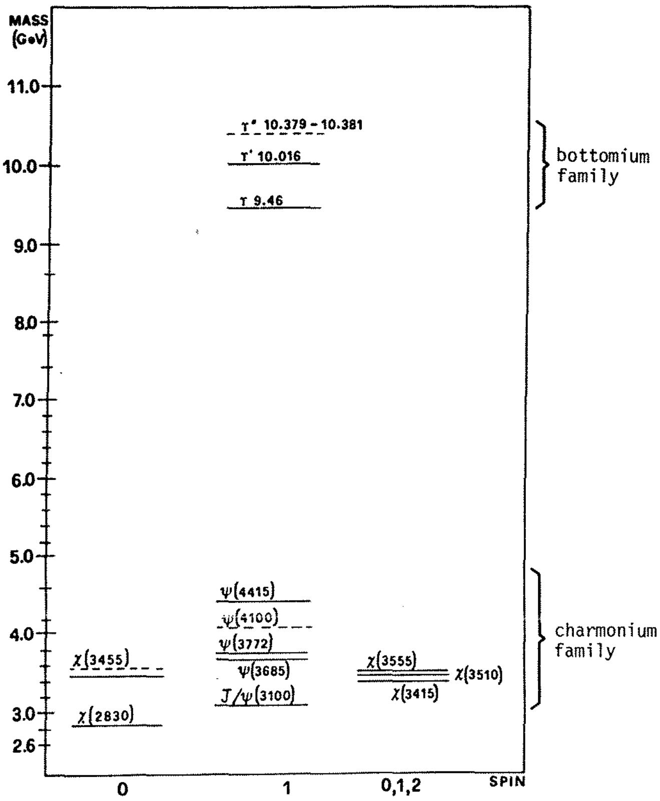


Fig. 7

All the states mentioned so far can be obtained from five quarks, the sixth, the "top" quark, being predicted on the basis of the lepton-quark family structure (e, ν_e; u, d), (μ, ν_μ; c, s), (τ, ν_τ; t, b). Unfortunately up to the highest PETRA energies, there is no sign of t.

The status of the six quarks is shown in Table 3.

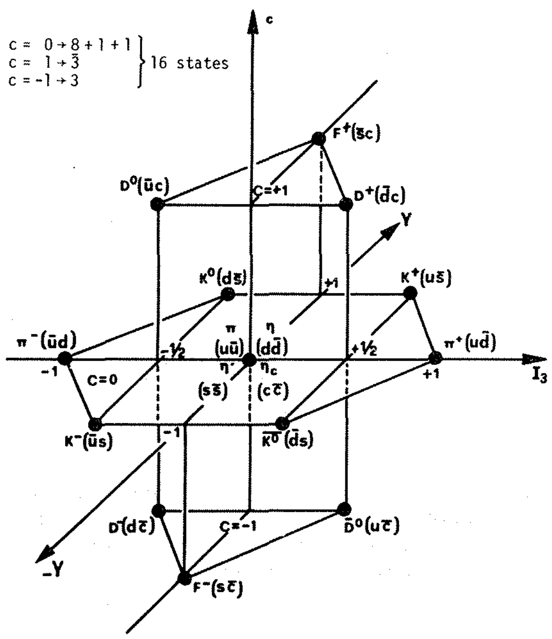


Fig. 8

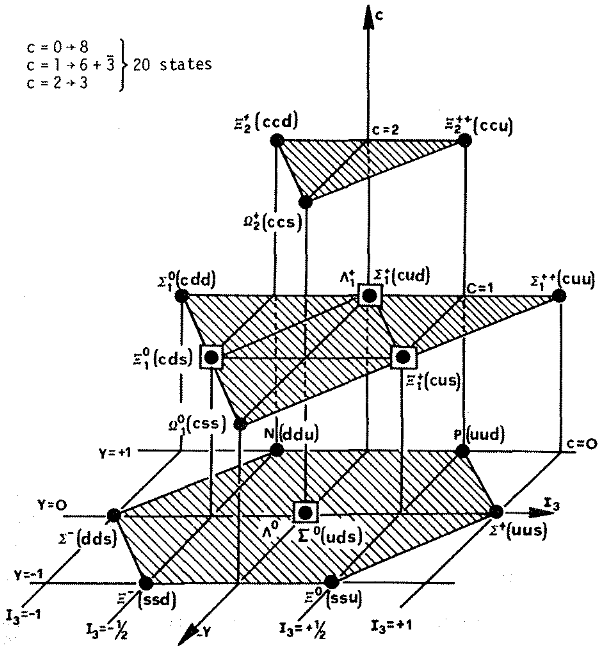


Fig. 9

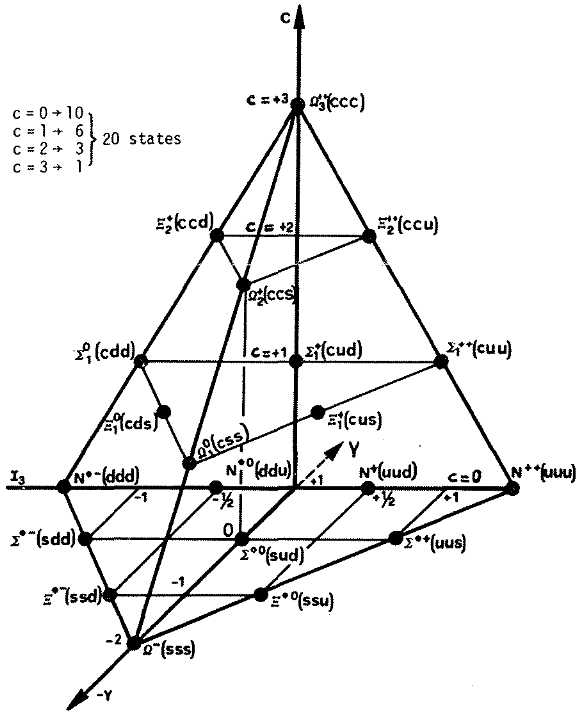


Fig. 10

Table 3

Six quarks

Quark	u	c	t	d	s	b
Mass	0.39	1.55	?	0.39	0.51	4.75
Q	+2/3			-1/3		

$m_u = m_d = \frac{1}{2}$ (ρ) mass; $m_s = \frac{1}{2}$ (ϕ) mass;

$m_c = \frac{1}{2}$ (J/ψ) mass; $m_b = \frac{1}{2}$ (Υ) mass.

7. THE ELECTROWEAK FORCES

Now we go to the celebrated electroweak interaction. Let me show you the basic ingredients of it. The reason why I do this, is because there is overwhelming evidence that Glashow, Salam and Weinberg (GSW) are indeed going to be right.

The basic coupling constant in $SU(2)_L \times U(1)_{L+R}$ is not "e", and the basic Lagrangian is made of two pieces, one which depends on the electroweak isospin $\vec{\tau}$ operator and the other which depends on the electroweak hypercharge Y:

$$\mathcal{L}_{weak+em} = g_\tau\left[\sum_i \bar{\psi}^i_L \frac{\vec{\tau}}{2} \psi^i_L\right] \vec{W} + g_Y\left[\sum_i \bar{\psi}_i Y\psi_i\right] W^Y , \qquad (1a)$$

where W^+, W^-, and W^3 are the intermediate vector Bose fields -- quanta of the electroweak isospin group SU(2) -- coupled to the electroweak isospin $\vec{\tau}$; and W^Y is the field coupled to the electroweak hypercharge Y and is a quantum of the electroweak group U(1). The complete symmetry is $SU(2)_L \times U(1)_{L+R}$. The index i runs over all leptons and quarks listed in Table 4.

The basic coupling constant is "g". The way in which this "electroweak" charge g is projected into the two electroweak axes $\vec{\tau}$ and Y is shown in Fig. 11. The thick lines indicate the observable coupling constants. Thus

$$\left.\begin{matrix} g_\tau = g \cos\theta \\ g_Y = g \sin\theta \end{matrix}\right\} \frac{g_Y}{g_\tau} = \tan\theta ,$$

where θ is the famous electroweak angle of the GSW theory. Notice the following equalities:

$$g^\pm = g_\tau , \quad g^Z = g ,$$

i.e. the "weak charged coupling" $g^\pm$ coincides with the "electroweak" isospin projection of g. Moreover, the "weak neutral coupling" g^Z coincides with the original electroweak charge g. This is why

$$g^\pm/g^Z = \cos\theta .$$

Table 4

The electroweak quantum numbers of the point-like particles

		T^3	Y	Q^{em}
LEPTONS	$\begin{pmatrix}\nu_e \\ e^-\end{pmatrix}_L \begin{pmatrix}\nu_\mu \\ \mu^-\end{pmatrix}_L \begin{pmatrix}\nu_\tau \\ \tau^-\end{pmatrix}_L$	$+\frac{1}{2}$ $-\frac{1}{2}$	-1 -1	0 -1
	$(e^-)_R$ $(\mu^-)_R$ $(\tau^-)_R$	0	-2	-1
	No neutrinos (R) because m_ν = all zero			
QUARKS × 3 COLOURS	$\begin{pmatrix}u \\ d_C\end{pmatrix}_L \begin{pmatrix}c \\ s_C\end{pmatrix}_L \begin{pmatrix}t \\ b_C\end{pmatrix}_L$	$+\frac{1}{2}$ $-\frac{1}{2}$	$+\frac{1}{3}$ $+\frac{1}{3}$	$+\frac{2}{3}$ $-\frac{1}{3}$
	$(d_C)_R$ $(s_C)_R$ $(b_C)_R$	0	$-\frac{2}{3}$	$-\frac{1}{3}$
	$(u)_R$ $(c)_R$ $(t)_R$	0	$\frac{4}{3}$	$+\frac{2}{3}$

$$Q^{em} = T^3 + \frac{Y}{2}$$

C = stands for Cabibbo mixed states

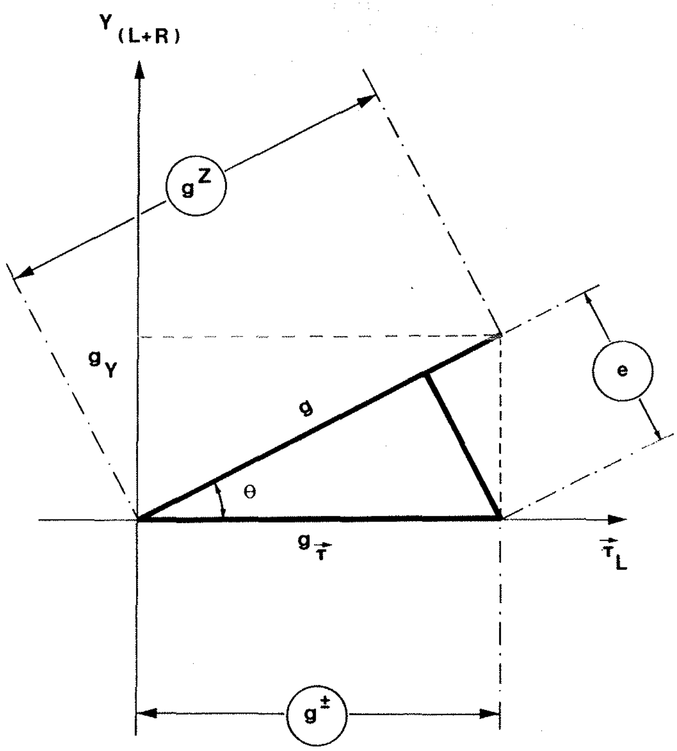


Fig. 11

As we will see later, if the simplest Higgs mechanism is at work, the damping factor between the "charged" and "neutral" intermediate boson masses is: $m_{W^\pm}/m_{Z^0} = \cos\theta$. This exactly compensates the above ratio of coupling constants, the key reason for the important result $\rho = 1$ (see page 18). Another interesting remark: the electric charge "e" is the result of the original "electroweak" charge g projected twice:

$$g \cdot \cos\theta \cdot \sin\theta = e .$$

It follows that

$$g_\tau = \frac{e}{\sin\theta}, \quad g_Y = \frac{e}{\cos\theta} .$$

The way in which the original field W_μ splits into the two axes, $\vec{\tau}$ and Y, is shown in Fig. 12a. Notice that in the $\vec{\tau}$ projections there are three fields: W^+_μ, W^-_μ, W^3_μ. These fields are coupled to left-handed currents only, while W^Y_μ is coupled to both left and right currents. The projections of W^3_μ and W^Y_μ to make up the electromagnetic field A_μ are shown in Fig. 12b. Finally, the projections making up the "neutral weak field" Z^0_μ are shown in Fig. 12c.

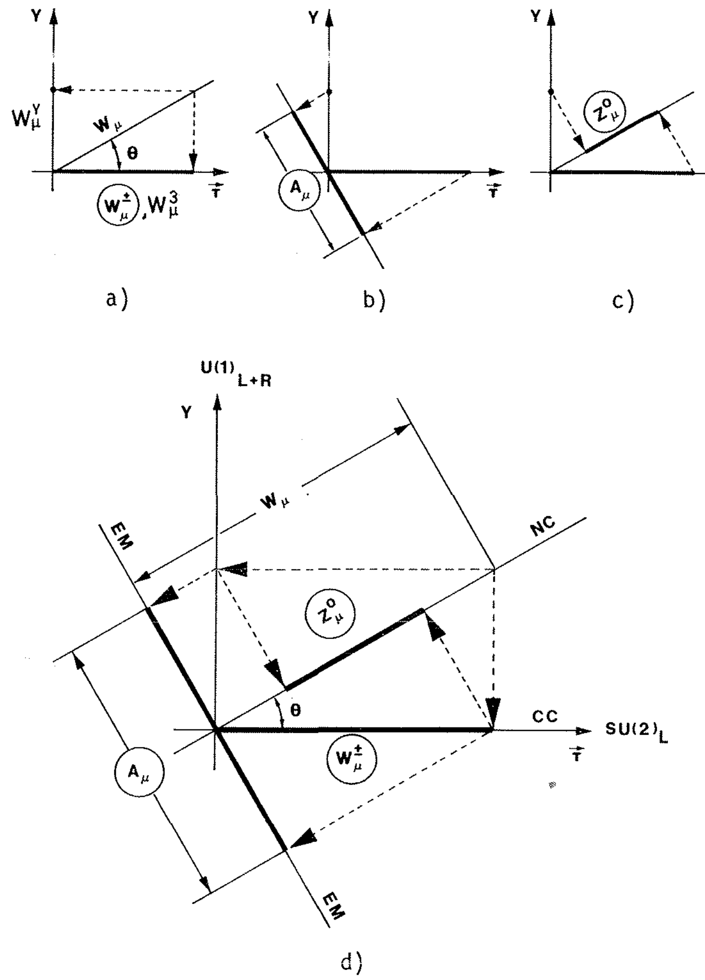


Fig. 12

The $SU(2)_L \times U(1)_{L+R}$ [or equivalently $SU(2)_{ew\ isospin} \times U(1)_{ew\ hypercharge}$] symmetric Lagrangian (1a) reproduces all results of the "charged" currents and electromagnetism. Obviously, the great new point of it is in the domain of the "neutral" currents; these currents should, more correctly, be called "electric charge not changing" currents. For brevity we will go on calling them "neutral currents" (NC). As we have seen above, there are two neutral intermediate vector bosonic fields, W^3 and W^Y, and two neutral currents, J^3_L and J^Y_{L+R}. So far, there are no masses in the theory. The physical particles corresponding to these are mixtures of W^3 and W^Y. This mixing has its origin (in the GSW theory) in spontaneous symmetry breaking, as a consequence of which W^3 and W^Y combine in such a way as to produce the other two neutral fields: one, A_μ, associated with massless quanta, the photon; the other, Z^0_μ, corresponding to massive quanta. In terms of the original electroweak isospin and hypercharge vector fields, the physical fields are:

$$A_\mu = W^Y_\mu \cos\theta + W^3_\mu \sin\theta$$

$$Z^0_\mu = -W^Y_\mu \sin\theta + W^3_\mu \cos\theta .$$

The summary of all this is shown in Fig. 12d. Notice that circled quantities indicate the fields whose quanta are observable. Thus $W^\pm_\mu$ correspond to the charged weak bosons; W^3_μ and W^Y_μ do not have observable quanta. Their mixing produces A_μ and Z_μ, whose quanta are the photon and the neutral weak boson, as we will see later. In Figs. 12a-d the thick lines indicate where the observable quantities come from.

Before the $SU(2)_L \times U(1)_{L+R}$ electroweak theory, our knowledge was all along the $\vec{\tau}$ axis, where we had the so-called charged currents (more correctly these currents should be called "electric charge changing currents"). We knew that A_μ exist but we did not know of the existence of the neutral current NC axis, nor of the intimate connection between A_μ and Z^0_μ.

Note that $\vec{\tau}$ indicates the existence of the three components (τ^+, τ^-, τ^3). These are the generators of the group SU(2) while Y is the generator of the group U(1). The electroweak angle θ_{ew} (to be called θ for simplicity) determines the relative weight of these two basic gauge groups, whose merging generates the electromagnetic and the weak interactions.

We have learned that the e.m. field is not a fundamental field; it is made up of two other fields, W^3_μ and W^Y_μ. Their mixing generates A_μ and Z^0_μ; the quanta of these fields are the observable quantities. The A_μ is well known and is associated with a massless particle, the photon. The Z^0_μ is associated with a particle whose mass, as mentioned above, is expected to be near 85 GeV or so.

While only one of the two neutral fields is known, if we go from the fields to the currents we find out that both neutral currents are known. The electromagnetic neutral current is known since a long time, but not its structure in terms of J^3_L and J^Y_{L+R}, as shown in the formula

$$J^{em}_{L+R} = J^3_L + \tfrac{1}{2} J^Y_{L+R} \ .$$

The other neutral current is the so-called "weak neutral current", discovered in 1973 [1] and predicted much earlier by the $SU(2)_L \times U(1)_{L+R}$ theory, in spite of the experimental evidence against it[2].

It is in the field of the neutral weak currents that in these last years there has been a very intense experimental activity going on.

In order to understand how this "neutral weak current" is derived from the $SU(2)_L \times U(1)_{L+R}$ symmetric Lagrangian (1a), let us mention the basic steps. The first one is to write (1a) explicitly, omitting the spinors and other details for simplicity:

$$\mathcal{L}_{weak+em} = g_\tau (W^+_\mu J^-_\mu + W^-_\mu J^+_\mu + W^3_\mu J^3_\mu) + g_Y W^Y_\mu J^Y_\mu \ .$$

Once again we emphasize that the "neutral" part of this Lagrangian has two pieces:

$$\mathcal{L}^{\text{before mixing}}_{\text{neutral}} = g_\tau W^3_\mu J^3_\mu + g_Y W^Y_\mu J^Y_\mu \ . \qquad (1b)$$

After the mixing between W^3_μ and W^Y_μ, we have the other two fields A_μ and Z^0_μ coupled to the appropriate currents.

We know that electromagnetism exists, and that A_μ is coupled to the e.m. current J^{em}_μ with coupling "e": $e A_\mu J^{em}_\mu$.

By definition, the remaining "neutral" part is

$$g^Z Z_\mu J^{NC}_\mu \ ,$$

where g^Z is the "weak" neutral coupling constant and J^{NC}_μ is the weak neutral current. After the mixing has taken place the "neutral" Lagrangian is

$$\mathcal{L}^{\text{after mixing}}_{\text{neutral}} = e A_\mu J^{em}_\mu + g^Z Z_\mu J^{NC}_\mu \ . \qquad (1c)$$

Equating the two Lagrangians (1b) and (1c) we have:

$$g_\tau W^3_\mu J^3_\mu + g_Y W^Y_\mu J^Y_\mu = e A_\mu J^{em}_\mu + g^Z Z_\mu J^{NC}_\mu \ , \qquad (1d)$$

which gives "e" and g^Z in terms of the original coupling g and of the mixing angle θ:

$$e = g \cdot \sin\theta \cdot \cos\theta \ ; \quad g^Z = g \ ,$$

already illustrated in Fig. 11. The above equality (1d) gives J^{NC}_μ in terms of J^3_μ and J^{em}_μ. More precisely:

$$J^{NC}_{L,R} = J^3_L - \sin^2\theta \cdot J^{em}_{L+R} \ .$$

This formula tells us that in order to know the "neutral" weak coupling, all we need to know are the values of the electroweak isospin T^3_L, and of the electric charge of a given particle (leptons or quarks) as given by Table 4.

Notice that the electroweak isospin is only left; it contributes only to the "left" coupling constant. The electric charge is left and right; it therefore contributes to the "left" as well as to the "right" coupling constant. All this is shown below:

$$
\begin{aligned}
J^{NC}_{L,R} &= J^3_L - \sin^2\theta \cdot J^{em}_{L+R} \\
\rightarrow g_L &= T^3_L - \sin^2\theta \cdot Q^{em}_L \leftarrow \\
\rightarrow g_R &= \text{zero} - \sin^2\theta \cdot Q^{em}_R \leftarrow
\end{aligned}
\qquad (2)
$$

For example, take the "up" quark. The electroweak isospin third component is $T^3_L(\text{up}) = +1/2$, while the electric charge is $+2/3$; the result is

$$g(u)_L = +\frac{1}{2} - \sin^2\theta \cdot \frac{2}{3} .$$

If $\sin^2\theta = 1/4$, we have $g(u)_L = +1/3$.

The values of the weak neutral coupling constants for all known leptons and quarks are given in Table 5.

Table 5

Neutral weak coupling constants of leptons and quarks, as predicted by the $SU(2)_L \times U(1)_{L+R}$ standard theory.

Spinors	T^3_L	Q^{em}_L	Q^{em}_R	g_L	g_R	g_V	g_A
ν_e, ν_μ, ν_τ	$+\frac{1}{2}$	0	0	$\frac{1}{2}$	0	$\frac{1}{4}$	$-\frac{1}{4}$
e^-, μ^-, τ^-	$-\frac{1}{2}$	-1	-1	$\left(-\frac{1}{2} + \sin^2\theta\right)$	$\sin^2\theta$	$-\frac{1}{4} + \sin^2\theta$	$+\frac{1}{4}$
u, c, t	$+\frac{1}{2}$	$+\frac{2}{3}$	$+\frac{2}{3}$	$\left(\frac{1}{2} - \frac{2}{3}\sin^2\theta\right)$	$-\frac{2}{3}\sin^2\theta$	$\frac{1}{4} - \frac{2}{3}\sin^2\theta$	$-\frac{1}{4}$
d_C, s_C, b_C	$-\frac{1}{2}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$\left(-\frac{1}{2} + \frac{1}{3}\sin^2\theta\right)$	$+\frac{1}{3}\sin^2\theta$	$-\frac{1}{4} + \frac{1}{3}\sin^2\theta$	$+\frac{1}{4}$
If $\sin^2\theta = 1/4$:							
Neutrinos (ν_e, ν_μ, ν_τ)				$+\frac{1}{2}$	0	$+\frac{1}{4}$	$-\frac{1}{4}$
Charged leptons (e^-, μ^-, τ^-)				$-\frac{1}{4}$	$+\frac{1}{4}$	0	$+\frac{1}{4}$
Up-like quarks (u, c, t)				$+\frac{1}{3}$	$-\frac{2}{12}$	$+\frac{1}{12}$	$-\frac{1}{4}$
Down-like quarks (d_C, s_C, b_C)				$-\frac{5}{12}$	$+\frac{1}{12}$	$-\frac{2}{12}$	$+\frac{1}{4}$

Notice that in $SU(2)_L \times U(1)_{L+R}$, $T^3_R = 0$ for all quarks and leptons. Therefore g_R, the "right" neutral weak coupling, can be $\neq 0$ only for particles with $Q^{em} \neq 0$. In other words, in the "standard" $SU(2)_L \times U(1)_{L+R}$ theory the "right" coupling is coming from the existence of "electrically" charged spinors. Otherwise the weak neutral coupling would be "left-handed" only.

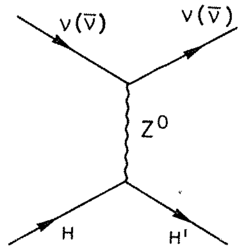
Notice also that the "vector" (g_V) and "axial" (g_A) neutral weak couplings can be worked out in terms of the "chiral" neutral weak couplings (g_L, g_R) by

$$g_V = \frac{1}{2}(g_L + g_R) = \frac{1}{2} T^3_L - \sin^2\theta \cdot Q^{em} , \qquad g_A = \frac{1}{2}(g_R - g_L) = -\frac{1}{2} T^3_L .$$

All this explains how the weak neutral coupling constants of quarks and leptons, in terms of the "chiral" (g_L, g_R) or of the "vector" (g_V) and "axial" (g_A), are related. The results, shown in Table 5, are an example of the predictive power of the theory.

Let us review the experimental pre-Conference results. The neutral current experiments can be divided into four classes: I) lepton-hadron scattering; II) lepton-lepton scattering; III) lepton-hadron interference (free particle states); IV) lepton-hadron interference (bound particle states).

Class I: Lepton-hadron scattering



The typical diagram is shown here. In this class of experiments the leptons are electrically neutral, i.e. neutrinos (or antineutrinos). The target hadrons are "up" and "down" quarks. The "strange" quark is in the "ocean". More massive quark states are more damped by the ν-energy so far available. The final state can either be the same quark (elastic scattering) or any other hadronic state (inelastic processes), provided the known conservation laws are fulfilled. H stands for a hadronic state.

A series of 15 processes, using primary high-energy neutrino and antineutrino beams against either protons or neutrons, is the source of all experimental information to check how measurements compare with theoretical predictions. These processes are: inclusive neutrino and antineutrino on neutrons and protons; elastic neutrino and antineutrino scattering on protons; inclusive π production on neutrons and protons; exclusive π production on neutrons and protons.

The pre-Conference results[3,4] in terms of the basic weak neutral coupling constants $g(u)_L$, $g(u)_R$, $g(d)_L$, and $g(d)_R$, are given in Table 6, where the theoretical predictions of Table 5 are repeated for the sake of comparison.

Without the standard $SU(2)_L \times U(1)_{L+R}$ theory, many parameters would be needed to describe these 15 neutrino processes, and we would miss the link between electromagnetism and weak interactions.

Table 6

Comparison of the $SU(2)_L \times U(1)_{L+R}$ weak neutral coupling constant with experiments

GSW predictions	Taking $\sin^2\theta = 1/4$	Experimental
$g(u)_L = \frac{1}{2} - \frac{2}{3}\sin^2\theta$	+0.33	+0.35 ± 0.07
$g(d)_L$ a) $= -\frac{1}{2} + \frac{1}{3}\sin^2\theta$	-0.42	-0.40 ± 0.07
$g(u)_R = -\frac{2}{3}\sin^2\theta$	-0.17	-0.19 ± 0.06
$g(d)_R$ a) $= +\frac{1}{3}\sin^2\theta$	+0.08	0.00 ± 0.11

a) The Cabibbo angles are neglected here. The exact formula should read $g(d)_L$ = (same)·cos θ_C; $g(d)_R$ = (same)·cos θ_C. These effects are too small, compared with the experimental uncertainties.

Class II: Lepton-lepton scattering

The experiments performed so far have used as primary leptons ν_e and ν_μ. The target has always been "electrons". In these experiments the "target mass" is m_e, to be compared with the "target mass" of the previous class, m_N. In fact, for the same primary neutrino energy E_ν, the q^2 values for processes of classes I and II are in the ratio

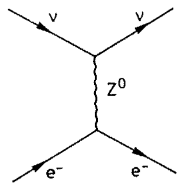
$$\frac{q_I^2}{q_{II}^2} = \frac{E_\nu \cdot m_N}{E_\nu \cdot m_e} \simeq 2{,}000 \ .$$

The cross-sections in this second class of experiments are damped by about 3 orders of magnitude, with respect to the class I experiments. The order of magnitude of the cross-sections is

$$\sigma(\nu e \to \nu e) \sim 10^{-42} \text{ cm}^2 \ ,$$

where ν stands for ν_e and ν_μ. These are the smallest cross-sections measured on earth.

The diagram describing the elastic lepton-lepton processes $\nu_e e^- \to \nu_e e^-$, $\nu_\mu e^- \to \nu_\mu e^-$

is 

where ν can be either ν_μ or ν_e.

The experimental pre-Conference results are shown in Table 7.

Table 7

Comparison of the $SU(2)_L \times U(1)_{L+R}$ predictions for purely leptonic processes with experimental information

$\sigma(10^{-42}\ cm^2/GeV)$	Theoretical predictions (with $\sin^2\theta = 0.27$)	Experimental value	Refs.
$\nu_e e^- \to \nu_e e^-$	5.2	(5.7 ± 1.2)	5
$\bar{\nu}_\mu e^- \to \bar{\nu}_\mu e^-$	1.6	(2.2 ± 1.0)	6
		$\left(1.0 \begin{matrix} +2.1 \\ -0.9 \end{matrix}\right)$	7
$\nu_\mu e^- \to \nu_\mu e^-$	1.4	(1.1 ± 0.6)	6
		$\left(3.9 \begin{matrix} +2.6 \\ -2.1 \end{matrix}\right)$	8
		(1.8 ± 0.8)	9

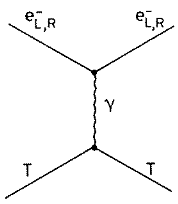
Class III: Lepton-hadron interference (free particle states)

Two experimental results are known since about a year. They come from the Taylor group at SLAC.

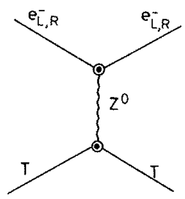
Using polarized electrons e_L and e_R, Taylor and co-workers[10] have established a non-zero value for the following ratio:

$$A = \frac{\sigma(e_L + D \to e_L + \text{any}) - \sigma(e_R + D \to e_R + \text{any})}{\sigma(e_L + D \to e_L + \text{any}) + \sigma(e_R + D \to e_R + \text{any})} ,$$

which is a "parity non-symmetric" quantity. This, according to $SU(2)_L \times U(1)_{L+R}$, arises from the interference between these two diagrams, where $\bullet \equiv \sqrt{\alpha}$ and $\odot \equiv \sqrt{g_F} \equiv g^Z/m_{Z^0}$, and where T stands for target (i.e. protons or deuterons and their quark content). The parity properties of the "interference term" are as follows:



(1)



(2)

$$\begin{cases} J_e^V & \equiv \text{the vector current at the "electron" vertex} \equiv \bar{\psi}_e \gamma_\mu \psi_e \\ J_e^A & \equiv \text{the axial current at the "electron" vertex} \equiv \bar{\psi}_e \gamma_\mu \gamma_5 \psi_e \\ J_{quark}^V & \equiv \text{the vector current at the "quark" vertex} \equiv \bar{\psi}_q \gamma_\mu \psi_q \\ J_{quark}^A & \equiv \text{the axial current at the "quark" vertex} \equiv \psi_q \gamma_\mu \gamma_5 \psi_q \ . \end{cases}$$

Parity violation is due to two terms:

$$J_e^V \cdot J_{quark}^A \quad \text{and} \quad J_e^A \cdot J_{quark}^V \; .$$

Notice that the other terms

$$J_e^V \cdot J_{quark}^V \quad \text{and} \quad J_e^A \cdot J_{quark}^A$$

are also proportional to the product $(\alpha \cdot G_F)$ but conserve parity.

Notice also that the first diagram contributes purely vectorially, while the second diagram, with the Z^0, has both vector and axial currents at the "lepton" and "quark" vertices. The exact calculation predicts[11])

$$A = \frac{gG_F q^2}{20\sqrt{2}\,\pi\alpha}\left\{\underbrace{1 - \frac{20}{9}\sin^2\theta}_{\substack{\text{this term is}\\ \text{generated by}\\ J_e^A \cdot J_{quark}^V}} + (1 - 4\sin^2\theta)\underbrace{\left[\frac{1-(1-y^2)}{1+(1-y^2)}\right]}_{\substack{\text{this term is}\\ \text{generated by}\\ J_e^V \cdot J_{quark}^A}}\right\}, \tag{3}$$

the experimental results being

$$A_D = (9.5 \pm 1.6) \times 10^{-5} \text{ in deuterium ,}$$

and

$$A_H = (9.7 \pm 2.7) \times 10^{-5} \text{ in hydrogen ,}$$

in excellent agreement with Eq. (3), for $\sin^2\theta = 0.20 \pm 0.03$.

We will see the newest data on the q^2- and the y-dependences, at the weak interactions sessions of the Conference.

This y-dependence is generated by the product $J_e^V \cdot J_{quark}^A$, and its detection is going to be as hard as $\sin^2\theta \to 1/4$. For example, if $\sin^2\theta = 1/4$, the asymmetry has no y-dependence, as can be deduced from the inspection of Table 5 without the need of any detailed calculation.

Class IV: Lepton-hadron interference (bound particle states)

Here we are in the field of atomic physics experiments. The "lepton" is charged (electrons in the atom), while the hadron is the nucleus. The basic diagrams are as shown here.

It is the interference between these two diagrams which produces the parity-violating effects. Notice that, in contrast to the class III experiments, the "electrons" as well as the target hadrons, or an assembly of quarks, are in bound states. Therefore atomic and nuclear physics structures come into play. Moreover, the q^2 values are very small, typical of atomic physics. And this is why the interference effects are much smaller than in the SLAC-type of experiments[10]).

The pre-Conference results[12-21]) are summarized in Table 8; two atoms have been investigated: bismuth and thallium.

The bismuth experiments. Bismuth is an atom with 83 electrons, of which 80 are in the core. Here a reliable theoretical calculation of the three-electron wave function at the site of the nucleus is needed.

In this class of experiments the trend has been towards a series of contradictory results. In 1977 the difficult laser experiment gave the first results reported in Table 8, in contradiction with the standard "electroweak" theoretical predictions. However, the three electron wave function calculations were later questioned by the same authors. The first evidence for the existence of a parity violation effect of the size expected in the standard theory was then reported by the Novosibirsk group[12,13]), using the same spectral line investigated at Oxford (6476 Å) [14,15]). Later the Seattle group[16,18]) reported new evidence which shows the existence of an asymmetry, even if the measured value is still far from the expected one. The most recent Novosibirsk data will be presented by L.M. Barkov at the Conference.

Table 8

The atomic physics experiments

Theoretical references	Theoretical predictions $\sin^2\theta = 0.27$	Experimental results	Refs. for experiments
	Atom used (bismuth) Z = 83		Oxford
20	1^{st} -25×10^{-8} } Line 6476 Å	$(2.7 \pm 4.7) \times 10^{-8}$	14
21	2^{nd} -12×10^{-8} } Line 6476 Å	$(-5 \pm 1) \times 10^{-8}$	15
			Seattle
20	1^{st} -18×10^{-8} } Line 8757 Å	$(0.7 \pm 3.2) \times 10^{-8}$	16
21	2^{nd} -9×10^{-8} } Line 8757 Å	$(-0.5 \pm 0.7) \times 10^{-8}$	17
		$(-2.4 \pm 0.9) \times 10^{-8}$	18
	Line 6476 Å	$\frac{\text{Experiment}}{\text{Theory}} = (1.10 \pm 0.30)$	Novosibirsk 12
		$(-19 \pm 5) \times 10^{-8}$	13
	Atom used (thallium) Z = 81		Berkeley
	2.6×10^{-3} Line 2927 Å	$(4.2 \pm 1.6) \times 10^{-3}$	19

Finally, a few words on the *thallium experiment.*

This is an element with only one external electron. Commins et al.[19] have selected a highly forbidden M1 transition, and the effect observed is due to the relative largeness of the quantity which is the imaginary part of the electric dipole moment divided by the (relatively) small M1 transition amplitude in the 2927 Å level of thallium.

The effect is called dichroism; it is, in fact, a measurement of the absorption cross-section for "left" and "right" helicity photons

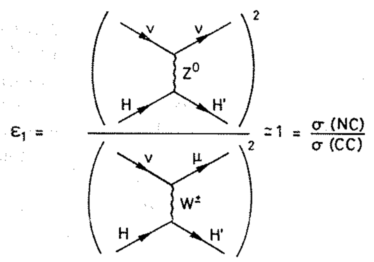
$$(\sigma_R - \sigma_L)/(\sigma_R + \sigma_L) \ ,$$

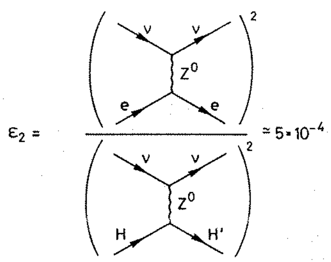
just like the SLAC experiment[10] except that we are dealing with polarized photons rather than polarized electrons. In principle this experiment should be on better grounds when compared with the bismuth one. Here, in fact, we have a higher frequency of the spectroscopic line (2927 Å) and we are dealing with a one-electron system. Thus the core corrections should be much smaller than in the bismuth case.

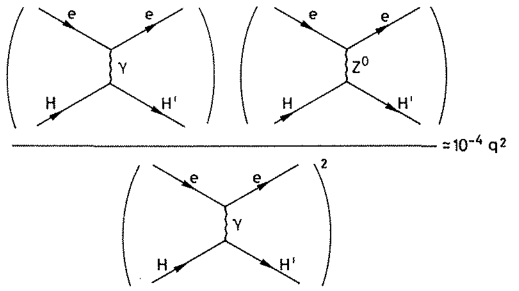
The four classes discussed above can be characterized by the following parameters:

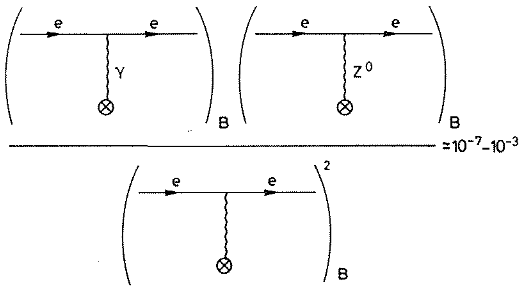
$$\varepsilon_i = \frac{\sigma(\text{wanted effect})}{\sigma(\text{other processes})} \qquad (i = 1, 2, 3, 4) \ ,$$

whose order of magnitude is given by the typical diagrams shown below (B = bound state).





$\varepsilon_3 =$ 

$\varepsilon_4 =$ 

When comparing experimental results with theoretical predictions the value of ε_i should be taken into account, especially in order to understand the well-known history of the neutral current experiments. Thus we see that no problems have ever existed in the class I experiments, for which $\varepsilon_1 \simeq 1$. The class II experiments have produced some problems; here $\varepsilon_2 \simeq 5 \times 10^{-4}$. In class III we have a unique high-precision experiment. So, in spite of the small value of $\varepsilon_3 \simeq 10^{-4}$, no problem has existed. In the last class, we started with experiments characterized by $\varepsilon_4 \simeq 10^{-7}$ and many contradictory data have appeared in the literature. However, the Novosibirsk experiment and the recent thallium data (for which $\varepsilon_4 \simeq \simeq 10^{-3}$), have produced the first evidence for the existence of parity violation effects in accordance with the standard $SU(2)_L \times U(1)_{L+R}$ theoretical predictions. Table 9 summarizes the pre-Conference status of all neutral weak current experiments. At present there is not a single experiment that has proved to have results in contradiction to the standard theory of the electroweak interactions. We will see that the data to be presented at the Conference will confirm this trend.

Table 9

Neutral weak current experiments. Summary status.

Type of experiment	ε	Problems of inconsistency	At present a)
Class I	1	No	OK
Class II	5×10^{-4}	Yes	OK
Class III	$10^{-4}\ q^2$	No	OK
Class IV	10^{-3}-10^{-7}	Yes	OK

a) Agreement with $SU(2)_L \times U(1)_{L+R}$

What have we learnt?

The knowledge of the following five quantities:

i) α, the fine structure constant,

ii) θ, the mixing angle between the two gauge groups $SU(2)_L$ and $U(1)_{L+R}$,

iii) the Clebsch-Gordan coefficients of the $SU(2)_L \times U(1)_{L+R}$ symmetry groups,

iv) the Fermi coupling constant, G_F, or one mass, $m_{W^\pm}$ or m_{Z^0},

v) the generalized Cabibbo angles,

is all that is needed to describe weak and electromagnetic processes, in the framework of a theory which is renormalizable. The old times when weak processes needed a cut-off are over.

Let me say a few words on the simple Spontaneous Symmetry Breaking (SSB).

Here comes an impressive experimental check, known since one year and to be reported with more precision at the Conference. In a weak interaction theory, with the Higgs mechanism unknown, there are two unknown parameters: the famous mixing angle θ; and the ratio ρ of neutral to charged currents, introduced in order to keep free the masses of the intermediate bosons:

$$\rho^2 = \frac{\text{rate of neutral currents}}{\text{rate of charged currents}} = \frac{g^4_{NC}}{g^4_{CC}} \cdot \frac{(1/m^2_{Z^0})^2}{(1/m^2_{W^\pm})^2} \quad . \tag{4}$$

If SSB really takes place, as suggested by Salam-Weinberg[22], i.e. via the simplest Higgs mechanism, the masses of the charged and neutral intermediate bosons are related:

$$m_{W^\pm}/m_{Z^0} = \cos\theta \quad . \tag{5}$$

In this case, as mentioned before, the damping of the neutral currents, with respect to the charged ones, is compensated exactly by the ratio of the coupling constants: $g^2_{CC}/g^2_{NC} = \cos^2\theta$; in fact, $g_{CC} = g^\pm = g_{ew} \cdot \cos\theta$, and $g_{NC} = g_{ew}$, as we have already seen. Therefore

$$\rho^2 = \frac{m^4_{W^\pm}}{m^4_{Z^0}} \cdot \frac{1}{\cos^4\theta} = 1 \quad . \tag{6}$$

The pre-Conference result[23] is

$$\rho = 0.98 \pm 0.05 \quad .$$

Let me close by calling your attention to the following three features of the GSW theory:

i) the existence of the two quantum numbers, the electroweak isospin and the electroweak hypercharge, shared by quarks and leptons;

ii) the discovery of a new law which relates the weak neutral current to the electromagnetic current:

$$J^{NC}_{L,R} = J^3_L - \sin^2\theta \cdot J^{em}_{L+R} \quad .$$

iii) the strength of neutral to charged current effects, i.e. $\rho = 1$, which implies that the simplest SSB is at work.

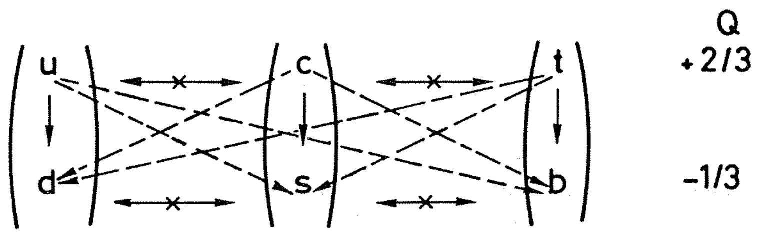
8. THE GENERALIZED CABIBBO MIXING

Here the great point of concern is to bring the PC- and T-violating interactions into the standard weak interaction scheme. This can be done if nature has, at least, six quarks to play with. These six quarks form three weak isospin doublets

$$\begin{pmatrix} u \\ d_C \end{pmatrix}, \quad \begin{pmatrix} c \\ s_C \end{pmatrix}, \quad \begin{pmatrix} t \\ b_C \end{pmatrix} . \tag{7}$$

Notice that "C" indicates a "Cabibbo" mixed state, as shown below. The transitions among the various states would be as given in Fig. 13.

Notice that there are no "charm-changing" neutral currents -- there will be new results presented at the Conference on this important topic -- in perfect analogy with the absence of the "strangeness-changing" neutral currents. In fact, the "horizontal" transitions in Fig. 13 are all "naturally forbidden", i.e. forbidden for any value of the mixing angles. This is indicated by ←×→ in Fig. 13.



Allowed neutral currents:

$\bar{u}u, \bar{c}c, \bar{t}t, \bar{d}d, \bar{s}s, \bar{b}b$.

Generalized Cabibbo mixing opens the dashed channels. Without it, the dashed transitions would not exist. The only allowed transitions would be those inside a quark doublet, indicated by the full arrows.

Fig. 13

In this six-quark theory there are three Cabibbo angles: the original one and two more; plus a phase angle.

The generalized Cabibbo angles and the phase angle entering with the various weak transitions are shown in Fig. 14. Notice that there is no mixing in the lepton case if all neutrinos, ν_e, ν_μ, ν_τ, are massless.

Pre-Conference results already indicated that the process $\nu + d \rightarrow c + \mu^-$ is Cabibbo suppressed. Notice that "d" is a "valence" quark. New results will also be presented on the allowed one: $\nu + s \rightarrow c + \mu^-$, where "s" is of course an "ocean" quark. As shown in Fig. 14, $s \rightarrow c$ has only cos's ($C_1C_2C_3$) whilst $d \rightarrow c$ has a sine: (S_1C_2).

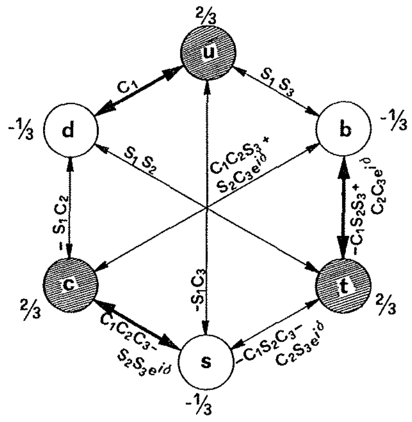


Fig. 14

Six quarks mixing with CP violation
$S_i = \sin\theta_i$
$C_i = \cos\theta_i$

9. SUPERSYMMETRY AND R ≠ 0 PARTICLES

All particles obey either Fermi or Bose statistics. Fermions and bosons exhaust all possible particle states. In his famous lecture at Erice in 1967, Coleman[24] discussed "All possible symmetries of the S-matrix". All but one. This one is the symmetry which tells you that if you have a boson you must have a fermion and vice versa. This supersymmetry can be traced back to the structure of space-time. Superspace tells us that we had forgotten the "fermionic" dimensions and have limited our concept of space to only the "bosonic" space-time dimensions.

The well-known "no go" theorems of SU(6) [i.e. $SU(3)_{flavour}$ combined with $SU(2)_{spin}$] are overcome; not because their proof was wrong, but simply because the nature of the space-time was too restrictive. It was only based on Lie algebra, i.e. no anticommutation relations were allowed in the basic algebra. The algebra related to superspace is a "graded" Lie algebra, i.e. anticommutation relations are allowed. One of the striking results of this new concept of superspace is the fact that a standard "space-time" translation is not the most elementary motion in superspace. In fact, the space-time displacement operator P_μ can be obtained as a result of the anticommutator of the spinoral operators[25] Q_α, Q_β:

$$\{Q_\alpha, Q_\beta\} = -2\gamma^\mu_{\alpha\beta}P_\mu \ .$$

The notion of superspace[26] provides us with the concept of a superelementary displacement, which can be thought of as the "square root" of the standard space-time displacement operator. This is reminiscent of the Dirac equation, which can be thought of as the "square root" of the Klein-Gordon equation. The concepts of mass and spin are on an equal footing in superspace. Its curvature is related to the "mass density"; its torsion to the "spin density".

Supersymmetric theories provide a theoretical motivation for the mutual occurrence of both FERMIONS and BOSONS through a symmetry principle which is related to the underlying geometrical structure of space and time.

A possible consequence of the supersymmetric approach to particle physics is shown in Table 10.

As we can easily deduce from this table, the existence of a photon would imply a massless spin ½ particle, the photino. The gluon would be accompanied by a gluino. Quarks have as supersymmetric partners new "heavy leptons" -- not to be confused with the standard ones (R = 0). The existence of "gluinos" means that in hadron physics we should one day discover "mesons" behaving as "fermions" and "baryons" behaving as "bosons".

Table 10 [following Farrar and Fayet[27)]]

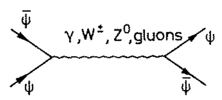
The particle states are specified according to the quantum number R, which is zero for all known standard states. The values of R are indicated in parenthesis.

Multiplets	Vectors	Spinors	Scalars
$m = 0$ Gauge part.	Photon (0) Gluons (0)	Photino (1) Gluino (1)	
$m \neq 0$ Gauge part.	Intermediate bosons $W^{\pm}$, Z^0 (0)	Heavy leptons (1)	Higgs scalars (0)
Matter multiplets		Quarks (0) e, ν_e (0) μ, ν_μ (0) τ, ν_τ (0)	Quarks (±1) Leptons (±1) Leptons (±1) Leptons (±1) ....

10. PRESENT OUTLOOK

Excluding gravitational forces, all fundamental interactions of nature seem to share an impressive series of common features:

1) They are all described by the same basic diagram, where a pair of spinors (leptons and quarks) ($\bar{\psi}\psi$) interact with another pair ($\bar{\psi}\psi$), via the exchange of a spin-one particle (γ, $W^{\pm}$, Z^0, gluons).



2) Each interaction is originated by a gauge symmetry group. These are:

$$\begin{array}{ccc} U(1) & SU(2) & SU(3)_c \\ \downarrow & \downarrow & \downarrow \\ g_Y & g_T & g_c \end{array}$$

where g_Y and g_T are the electroweak "hypercharge" and "isospin" coupling constants whose mixing produces the electromagnetic and the weak couplings; and g_C is the "colour" coupling between coloured quarks and gluons. All (g_Y, g_T, g_C) are dimensionless.

It is perfectly legitimate to think that a supergroup is at the origin of all the gauge symmetry groups; This needs to be a very large group. For example, SO(8) is too small, in fact: $SO(8) \not\supset SU(3)_c \times SU(2) \times U(1)$. However, as will be discussed at the Conference, the supersymmetric Lagrangian with SO(8) internal symmetry shows SU(8) properties.

It is interesting to remark that any group which contains $SU(3)_c$ and U(1) has the very interesting feature[28)] that coloured states are associated with fractional charges, while colour singlet states have integral charges. If we identify the leptons with the colour-singlet basic fermions, and the quarks with the coloured basic fermions, this is exactly what seems to happen in nature.

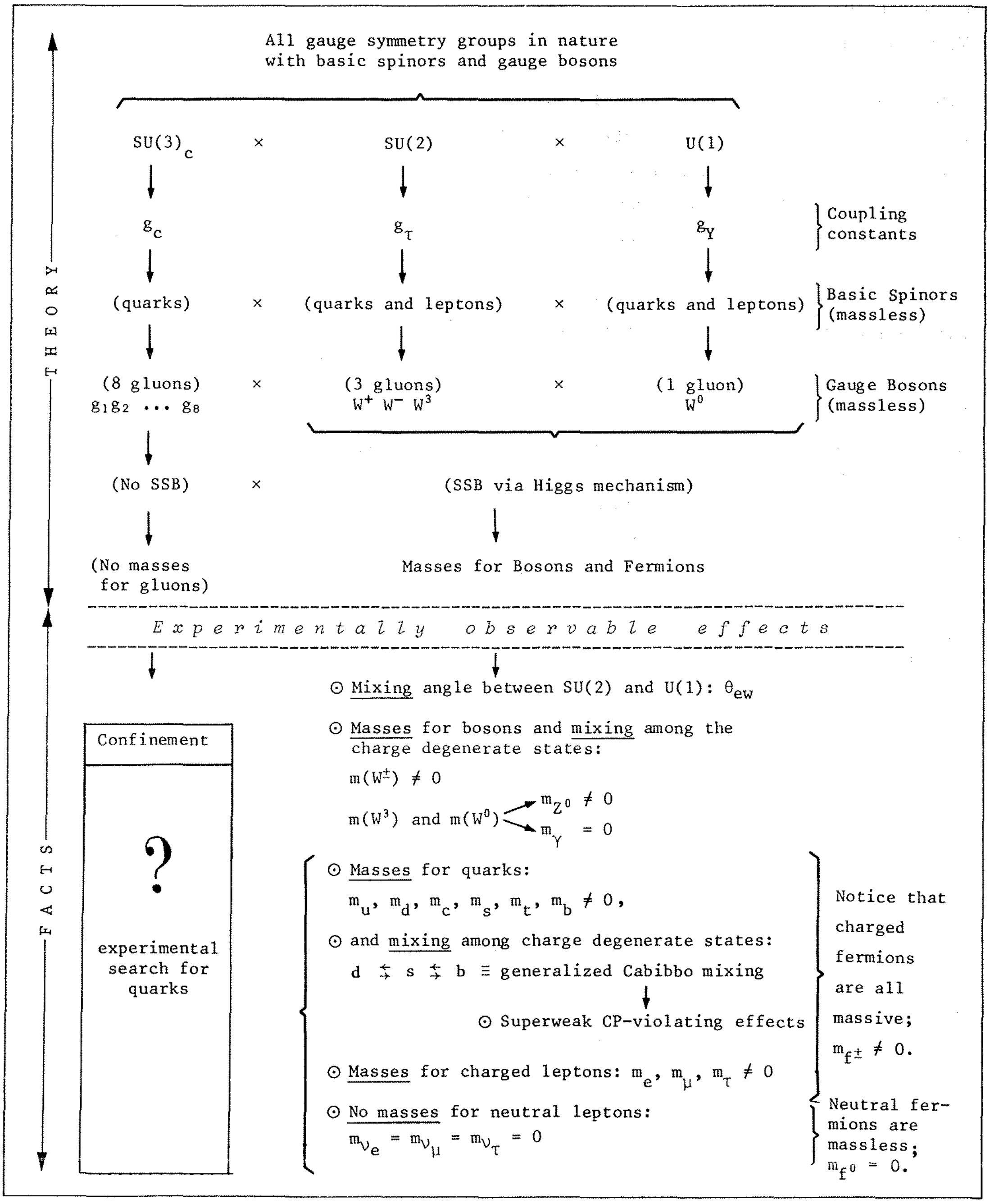
Notice also that renormalizability requires strong interactions to be invariant under electroweak isospin $\vec{T}$ and hypercharge Y. As $SU(3)_c$ commutes with the gauge group of weak interactions and since the strong couplings occur through a gauge-invariant coupling of quarks and vector particles (the gluons), there are no parity-violation and no strangeness-violation effects to order α, as is found experimentally.

The Lagrangian of these basic unbroken interactions involves only massless gauge fields coupled minimally to conserved currents. These are basic features which guarantee the renormalizability of the theory. The masses of the real particles (intermediate bosons, leptons, and quarks) and the non-conservation of the currents are the result of spontaneous symmetry breaking. The basic point is that SSB does not spoil the renormalizability of the theory.

Conclusions: It seems that nature has constructed the world in such a way that we can always choose locally (i.e. at every space-time point) the angles of rotation: in one real dimension, U(1); in two complex dimensions, SU(2); in three complex dimensions, SU(3); and, if we add gravity, the reference system → {SO(3,1) + translations} {≡ Poincaré group}. This is shown synthetically in Table 11. The freedom to make these choices, without producing observable effects, generates the fundamental forces of nature and is at the origin of the vector nature of the gauge particles (photons, W's, Z^0, and gluons). Gravity is a special case. A point in space-time is already a vector quantity. To be free at every space-time point is another vector operation. This is why the graviton is a tensor.

To sum up the situation at the opening of this Conference: we are faced with what appears to be a grand synthesis. We must, however, remain open-minded, just in case ... .

Table 11: The Present Grand Synthesis



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