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Concluding Talk

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It is now my task to look back with you, at the six days of eventful sessions that we have had, take stock of our accomplishments, summarize them, and put them in perspective. However, you will understand that it is not possible for me to cover all the subjects uniformly. Nor would it be desirable. I will focus on what I think are the main themes, and devote the rest of my time to a bit of palm reading into the future.

§I.

Almost four years have passed since that november of 1974, and it thrills us to think about the long strides high energy physics has made within that short span of time. I will start by showing a chronological list of representative classes of new particles (Table I).*

Table I. A chronological list of representative classes of particles. The numbers in the paretheses are the years of discovery.

J/ψ	(1974)
χ	(1975)
τ	(1975)
D	(1976)
Υ	(1977)

These particles belong to new classes because, first of all, they have high masses and yet are relatively stable. In other words, a new scale of mass or level spacing larger than the known hadronic mass scale seems to exist. Remarkably, the leptons are also beginning to show a parallel trend. These discoveries are a direct result of the development of a new generation of high energy accelerators. It is gratifying that going to the next level of energy range one should immediately be rewarded with such a wealth of exciting new phenomena. One can always question the value and wisdom of pursuing ever increasing energy with ever increasing cost and effort. But I doubt that anyone is hesitant or doubtful about it now.

The real significance of the experimental discoveries, however, can be appreciated only when they are combined with theoretical developments. It is in fact remarkable that the theorists had more or less anticipated the general scenario according to which the events seem to be unfolding. But this scenario is naturally not unique. In order to make progress, one has to narrow down one by one the various alternative possibilities by means of crucial tests. If I have to summarize the Conference in one sentence, I will say that this is the year when a significant advance was made in the narrowing down process thanks to the completion of a large number of precision experiments, which are impressively consistent with each other and with a particular theoretical framework. The agreement is a quantitative one, and hence it is a real and definite step forward.

I am here talking, primarily, about the Weinberg–Salam theory[1] of unified weak and electromagnetic interactions, and the comparison is between the original model and the generalized and more complicated versions of it. As usual, the latter were motivated either by the earlier confusion in experimental data, or by a desire to improve on the theory. Very often, however, one ends up spoiling everything in the process. So it is reassuring to find out that nature likes simplicity after all; according to the developments in very recent months, the original Weinberg–Salam version seems to be the sole survivor of the various "low energy" tests. I use the word "low energy" only in a relative sense. Crucial in this sudden narrowing down of options are the beautiful SLAC results on parity violation in electron–deuteron and electron–proton scattering.[2] Also important is the impressive consistency shown by numerous neutrino reaction experiments.[3] Indeed, the neutrino physics has come of age. So we now seem to be in a situation in which all the low energy weak

* More detailed data will be found in the talks of the corresponding speakers of the plenary sessions of this Conference, Flüge, Hara, Lederman and Feldman.

processes, that is to say, the processes that do not involve production of W's, Z's or H's (Higgs), are consistently described with just one parameter.

In a more phenomenological approach, the neutral weak current has the form

$$J^0_{\mathrm{L,R}}=\rho(I_3-Q\sin^2\theta_{\mathrm{W}})_{\mathrm{L,R}}$$

where ρ measures the ratio of neutral to charged current. We now know that

a) $\rho\approx 1$ (0.98±0.05) (ref. 3)
b) $\sin^2\theta_{\mathrm{W}}\approx .2\sim .3$ (.24±.02) (ref. 3)
c) left-handed q and l are (weak) doublets, and right-handed q and l are singlets. In other words, the gauge group is $SU(2)_{\mathrm{L}}\times U(1)$.

Remarkably, a) and c) were already built into the specific model of Weinberg and Salam. Combining a) and b), one makes the prediction

$$m_{\mathrm{W}}\approx 75\ \mathrm{GeV},$$
$$m_{\mathrm{Z}}\approx 85\ \mathrm{GeV}.$$

So, we should be satisfied that the rather simple and even naive synthesis of electromagnetic and weak currents, with which are associated such names as Schwinger, Glashow, Salam and Weinberg, has been indicated. Following Salam's suggestion in his talk today, I will from now on refer to the two unified interactions as electroweak interaction. It sounds a bit awkward, but certainly does simplify the terminology.

One may also view the above development as a further success of the quark and quark–parton model. The charmed quark, which was an essential ingredient in the development of the theory of weak interactions, is now firmly established as more and more data accumulate regarding the charmed particles. But here nature is playing a little trick with us. The four quarks and four leptons do not seem to be enough, as the minimum theory of weak interactions would have demanded. We have now the τ and the Υ.

The Υ has been observed in p–p as well as e^+–e^- interactions, as in the earlier case of the J/ψ. The new lepton τ is so far known only in electron reactions. These "undesirable" particles tell us in unmistakable terms that the world of leptons and quarks is bigger than we thought, quite possibly a lot bigger, and both theorists and experimentalists will face a busy future in search of more particles and more theories. I will come back to these problems of the future, but let me next turn to the status of strong interaction physics.

The strong interactions affect not only the hadronic reactions, but also semi-leptonic processes that involve electroweak interactions I have just discussed. One of the tests of the quantum chromodynamics (QCD) has to do with the characteristic deviations from the scaling law, *i.e.*, from the naive quark–parton model. Such deviations have been seen for some time, and at least qualitatively they have been showing agreement with QCD predictions. I am impressed by the fact that these deviations seem to be even in quantitative agreement with the predictions of QCD as expressed, for example, by the q^2 dependence of the parton x distribution, although one may still have to regard it as tentative.[4] Other aspects of QCD, like the presence of jets with computable characteristics, also are beginning to be tested. So one may say that, as far as the high energy or short distance behavior is concerned, QCD with its asymptotic freedom is gaining more and more credentials as the basis for strong interaction dynamics. But, for really critical tests, one would have to go to still higher energies. There is, however, the problem that it is not possible to completely separate strong interaction phenomena into high and low energy, or short and long distance, regimes, and unfortunately the low energy properties of QCD are a greatly more difficult problem over which we do not yet have a firm control. Nonetheless, we are witnessing a great deal of activity in this long distance and strong coupling regime of QCD.

The central question is the dynamics of quark confinement, assuming as one does that confinement is true. It might not be true, as is held by a minority of people, but there is no question about at least a partial confinement. In the meantime, what we have now for low energy hadron dynamics are the string and bag models. Actually one may safely regard these two as representing different aspects of one and the same basic model, namely a thick string = a deformable bag. But when it comes to the details, several different variants emerge.

At the phenomenological and qualitative level, these models seem to be working rather well in general. We have heard more and more evidence for exotic mesons and baryons having chemical compositions $q^2\bar{q}^2$, $q^4\bar{q}$, q^6, etc.[5] So those quark compounds that are expected to exist do actually seem to exist. The string-bag models can explain their relative stability by assigning them specific molecular or bond structures. This represents an amusing and welcome return of the intuitive chemistry. At the moment, however, there are various different versions or hypotheses competing with each other, and none of them are yet capable of making quantitatively reliable predictions. If that is asking too much, at least one would like a well defined model to emerge as the most successfull one. The different versions can be illustrated by the following examples (Fig. 1).

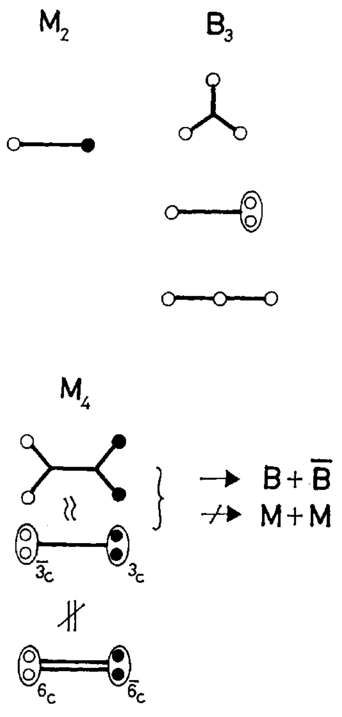

Fig. 1. Different versions for the phenomenological models of hadrons. White circle and black circle represent quark and antiquark, respectively. M, B and G stand for meson, baryon and meson without quarks, respectively. The subscript is the number of quarks and antiquarks in the hadron.

So, roughly speaking, this is what we know about the quarks, leptons and their weak, electromagnetic and strong interactions. In addition to the table of new particles I have shown, there are a few numbers that symbolize our knowledge

$\sin\theta_c \approx 0.22$ (ref. 6)

$\sin^2\theta_W \approx 0.24$ (ref. 3)

$1/\alpha = 137.035987(29)$ (ref. 7)

$1/\alpha_s \approx 1.5 \ln (Q/\Lambda)^2$,* $(Q/\Lambda \gg 1$, $\Lambda \approx .4 \sim .8$ GeV) (ref. 4)

$1/\alpha' \approx 1.1/\mathrm{GeV}^2$

The last one is the common Regge slope of ordinary hadrons. You will notice that there is a remarkable simplicity in the numbers as well as symbols. But I am also a bit disappointed by the physicists' lack of imagination in the use of symbols.

§II.

I would next like to come to mainly theoretical problems confronting us, and discuss some of the recent developments in this regard that have been reported at this Conference.

I think it is safe to start from the set of propositions:

a) The leptons and quarks are the elementary constituents of today; that is, particles which are pointlike, and make up the material particles — leptons and hadrons — that are known at the present energy range.

b) There are four kinds of interactions; gravitational, weak, electromagnetic, and strong.

There may well be new kinds of constituents and new kinds of interactions, but we do not know for sure. The leptons and quarks might not be elementary at much higher energies, although the definition of elementarity is never a clear and precise one. There are four flavors coming in two doublets of well established leptons and quarks, plus a fifth lepton τ, and a fifth quark indicated by the Υ. It would be safe to supplement the latter two with ν_τ and t so that there are six flavors or three doublets. The parallelism between the number of leptons and the number of quarks seems interesting, and points to some regularity or symmetry which was emphasized by Gamba, Marshak, Okubo[8] at a time when only three flavors were known. But how many of them will there be eventually? One can only speculate at the moment.

* The factor 1.5 is an approximate representation of a theoretical and flavor dependent ($n_f \approx 3$) number, not an experimental determination.

In any case, the existence of at least three flavor doublets makes life interesting. For one thing, the CP violation can be generated through a complex mass matrix as was first noted by Kobayashi and Maskawa.[9] It also poses an intriguing question: What are the masses of ν_τ and t?

If ν_τ is massless, it raises the specter (or maybe a welcome thing) of all neutrinos being massless, including those associated with the possible 4th 5th, ... generations of lepton doublets. On the other hand, there are cosmological arguments[10] that the number of low mass neutrinos should not be too large ($\lesssim 4$ helicity doublets), lest they disturb the scenario for nucleosynthesis. Also there is a nice observation that the number of neutrinos may be determined from the process,[11] $e^+ + e^- \rightarrow \gamma + \nu + \bar{\nu}$, and this could give us an answer about low mass neutrinos. If, on the other hand, the ν_τ has a nozero mass, there is no reason for ν_e and ν_μ to be strictly massless and two-component. This would also have significant experimental and theoretical implications. As for the t quark, it is probably heavier than the b because lower resonances are not found. Then in both (c, s) and (t, b) doublets the first member is the heavier one, in contrast to the (u, d) doublet, and the leptons. Why? I do not know.

Now if the number of leptons and quarks keeps increasing with energy, we will have to question our premises regarding their elementarity. On the other hand, the number may be finite, and reasonably small, like 6, 8, etc., as some people would like to believe. If it is finite, one would like to know if there is a sensible reason why it is a particular number. Operationally, the number I am talking about is the number of repetitions of the events I have listed in Table I, as we sweep higher and higher energies with bigger and bigger accelerators.*

But probably the situation will not be that simple. The weak interaction is getting stronger with energy, and will become comparable to the electromagnetic interaction in the 100 GeV center of mass energy range. So some new phenomena are certainly going to happen beside the afore-mentioned possible repetitions. Our question regarding the number of leptons and quarks might get mired in the confusion, if such repetitions should continue until then.

Let me next turn to the interactions among these constituents. The prevailing assumptions are that

1) All the known interactions are manifestations of gauge fields. A gauge field is characterized by a perfect symmetry principle and long range forces associated with conserved charges.

2) The fact that weak and strong interactions do not seem to show these characteristics is attributed to spontaneous breakdown of symmetry, charge screening (plasma formation), and other special effects. In other words, one regards the vacuum as a complicated medium capable of showing many faces.

3) The gauge fields are considered to be elementary and most desirably renormalizable in the context of quantum field theory, although this last point has not yet been achieved for gravity.

I might also add a fourth and rather popular proposition:

4) It is theoretically desirable, if not necessary, that the different gauge fields be unified under a single large group structure (grand and supergrand syntheses), which is broken down to the observed symmetries in a hierarchy of steps.

The remarkable progress of recent years is certainly due to the success in combining the first three important concepts that are among our theoretical heritages. We have just seen the vindication of the electroweak gauge principle, and the evidence is all pointing towards the validity of the general picture. One can look forward to the next generation of accelerators to produce the weak bosons, follow the QCD predictions, and explore other ingredients of our theoretical framework.

At this point I would like to touch on two different schools of thought regarding strong interactions, although this belongs to the problem of grand synthesis of electroweak and strong interactions to be discussed later. There is a dominant school which postulates

a) Conventional plasma medium for flavor, that is, for the electroweak interactions. The group is $SU(2)_L \times U(1)$.

* One can also ask the hypothetical question: What if the ratio $R = \sigma(e^+e^- \rightarrow X)/\sigma(e^+e^- \rightarrow \mu^+\mu^-)_{QED}$ should drop to a low value after a series of rises?

b) A special symmetric SU(3) medium for color, with asymptotic (or maybe temporary) freedom and quark confinement. This is the standard QCD.

A small minority school, of which Pati and Salam are the most ardent advocates, asserts:

a) Same as above.

b) Color symmetry is also broken in a plasma phase, so flavor and color mix. If this happens for the photon, the quarks become integrally charged.

c) Confinement is naturally imperfect; the leptons are quarks of the fouth color. Quarks and gluons exist as real particles, and their masses may not be very high.

To decide experimentally between the two alternatives is not as easy a task as you might think. The nice properties of gauge theory are already incorporated in both. A crucial test of the second model would be of course to find colored states—quarks and gluons, but such a test has to rely on some details of the theory. My personal position on this matter is somewhat ambiguous because I have a little stake in either of the alternatives. The main problem with me is the confinement question. Recently I have been leaning toward the first alternative because: a) We do not see signs of colored excitations; and b) with plasmatic gluons it seems difficult to achieve an imperfect but high degree of confinement implied by the validity of the string model. But this really depends on how convincing is the theoretical derivation of a confinement mechanism. It is possible to produce models of confinement, like models in lower dimensions, or models using magnetically charged quarks placed in a superconducting medium.[12]

Originally, confinement was suggested to be a result of infrared slavery.[13] But we do not know for sure what exactly happens in QCD at long wave lengths. Basically, we need a magnetic and non-Abelian analog of superconductivity in order to trap the quarks. The difficulties lie in mathematically realizing such a medium, especially within the boundaries of the standard QCD. A recent popular idea is to attribute confinement to the workings of instantons and/or merons that may populate the vacuum, as has been most vigorously pursued by the Princeton group.[14] They do not claim to have proven confinement, but the physical picture is that of an instanton-filled medium in which the dielectric constant tends to zero away from color charges. There is also another model which is closer in spirit to magnetic superconductivity, in a monopole-filled medium. This was originally, advocated by Mandelstam[15] and recently studied by 't Hooft[16] in a quite general context. Unfortunately the relation between this and the Princeton theory based on instanton vacuum is obscure at the moment.

I will next turn to observations of more general nature about gauge theories. One of the remarkable developments in the past few years is the realization that gauge theories are rich in topologically nontrivial configurations. Another related problem which was triggered by the recent work of Gribov,[17] is that non-abelian gauge fields possess a very complex and large phase space, and therefore a very large entropy. By this I mean that the gauge degrees of freedom cannot be factored out in quantum action function by simple gauge fixing, and hence the entropy of the gauge degrees of freedom may play a very important role in determining the nature of the vacuum which corresponds to the minimum of free action density,

$$\Theta = -L - g^2 S,$$

rather than action density $-L$ as would be the case in classical theory. The coupling constant g^2 plays the role of temperature in this thermodynamic analogy. The usual quantum theory starts from the classical vacuum $L=0$, and computes S due to quantum fluctuations around it. But nontrivial topological configurations with $-L>0$, could lead to a lower action because of the large entropy associated with them, especially at high "temperatures." So one can talk about "phase transitions" between different vacua as the temperature varies. The significance of various topological configurations or solitons, however, is still in a very early stage of exploration. Among other physical effects caused by instantons are the problem of CP violation and axion.[18] As for the monopoles and strings, their existence as finite energy objects requires the presence of Higgs fields. Besides, the details of all these phenomena depend sensitively on the gauge group and its representation.

This brings me to ultra high energy physics and the grand unification schemes of electroweak and strong interactions. Here I am particularly concerned about the nature of Higgs fields. In the currently prevailing strategies of model building, the most arbitrary and obscure elements are the Higgs fields, which spoil the compelling simplicity of gauge theories. Right now only one doublet of Higgs is called for, which is simple enough. But their Yukawa couplings to quarks and leptons are purely phenomenological. In a grand synthesis, moreover, one would need a large number of Higgs in order to achieve required patterns of symmetry breaking.

The basic reason for this awkward situation seems to me that we do not yet understand the origin of masses; the masses of leptons and quarks do not yet reveal to us any regularity, as did the energy levels of hydrogen and the Regge trajectories of hadrons. In my view, the Higgs fields represent only a phenomenological way of driving masses in gauge theories. We are only at the level of the Ginzburg–Landau description of superconductivity, but not at the level of the BCS theory. To be sure, the G–L theory is enormously useful; besides, renormalizability of Higgs-type theories is an important element which is unique to the relativistic problems. Nevertheless, to bring in more and more Higgs fields, just to achieve a hierarchy of symmetry breaking, looks to me like drawing more and more epicycles. Even if it turns out that only a few Higgs fields are needed, I think one can rightfully ask whether there is a BCS theory behind it. What is a Higgs field a Cooper pair of? Most naively one would say it is a pair of leptons and quarks, especially of heavy ones since they are more strongly coupled to it, but maybe it is made up of new objects with new interactions and new Regge trajectories, as was recently suggested by Susskind.[19]

Let me therefore indulge in a bit of daydreaming. The time of the scene is not certain, but you can guess from the list* of future accelerators shown by the previous speaker E. L. Goldwasser.—We have already found several flavors of quarks and leptons with the PETRA and PEP machines. An assortment of multi-100 GeV class proton accelerators of various kinds have also begun operation. People are finding heavy vector and scalar mesons, which appear to fit the characteristics of the W, Z and H, with masses in the 100 GeV range. As one goes up to higher energies, however, there is a suprise. Invariant mass distributions of clusters of W's, Z's and H's reveal the existence of a series of massive objects reaching into the TeV's. It looks as if the whole pattern of hadron spectrum is being repeated. Some theorists recall that there was a prediction[20] that topological solitons consisting of monopole and string configurations of the Z^0 and H fields should exist in the form of a Regge sequence of rotating dumbbells and also doughnut states (Fig. 2). Other theorists

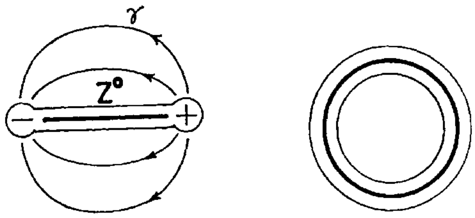

Fig. 2. Dumbbell and Doughnut.

revive Susskind's idea and begin to introduce new heavy constituents with new interactions. Compared to them, the old hadrons and leptons simply become generalized leptons. The H's (there may be several kinds) are the lowest $J=0$ composites in this model. The W's and Z's are $J=1$ composites. Thus one repeats all over again Sakurai's vector dominance game. One may feel uneasy about the smallness of the gauge coupling constants and about the status of the photon, (can it be composite?) but let's leave the problems for the future. The spirit of gauge theory is not spoiled because it is primarily a statement of symmetry principle. One may also repeat the chiral symmetry game with analogs of π and σ, the latter being the H. Are there "low mass" pseudoscalars? Certainly the TeV physics looks exciting.

§III.

Now, let us come back to other theoretical speculations. Actually they encompass a whole hierarchy of theories leading to the ultimate ones which would unify all the known

* See the report of E. L. Goldwasser in this Conference.

and unknown particles and fields in one sweep.[21] One may classify them into three broad categories:

1. Enlargement of flavor group and its representation content. $SU(2)_L \times U(1) \subset G_f$
2. Grand systhesis of color and flavor groups.
3. Supergrand synthesis of all boson and fermion fields from gravity to Higgs.

The first one is partly motivated by the increasing number of flavors. One may also ask the questions: Why do the left and the right behave so differently in the flavor sector? Shouldn't there be some left–right symmetry, and shouldn't there be only one coupling constant for a unified theory?

From a theoretical point of view, probably it is impossible to separate flavor and color; one must go to the grand or supergrand unification scheme in order to understand either of them. There is indeed a possibility of a large unifying group with a single coupling constant, to which all the effective coupling constants converge at a huge unification energy. Minimum theories that have been proposed include SU(5), SU(6), SO(10) and E_6 groups.[21] Here the basic properties of renormalizable field theories, especially the concept of running coupling constants, are pushed to their logical conclusion, as was first done by Landau.[22] The unification energy is usually of the order (on a logarithmic scale) of the Planck mass $\sim 10^{19}$ GeV (or 10^{-5} g), which gives one an incentive to unify gravity as well. In some theories such as the one advocated by Salam and Pati, it is only $\sim 10^4$ GeV. In this case the proponents may have a hope of seeing their dreams come true or be shattered within their lifetimes.

Any such grand unification scheme naturally invites the possibility of baryon number nonconservation. For there is no evidence for a long range gauge field coupled to baryon number, as was once pointed out by Lee and Yang.[23] Thus, the baryon number must correspond to a broken local (gauged) symmetry or a global (non-gauged) symmetry. In either case the conservation may be violated. The present limit of proton lifetime[24] is $\sim 10^{30}$ years. It seems possible to arrange a theory to yield a finite yet long enough lifetime. It should be an exciting event if the lifetime turned out to be indeed finite and measurable. Another intriguing question concerns the total baryon number of the universe. Why does the number appear to have an asymmetry $\sim 10^{80}$, which is numerically huge, but is a small fraction ($\sim 10^{-9}$) of the number of photons. The question may be answerable within the gauge theory framwork.[25]

At this level of unification, what else can one say? The Weinberg angle is calculable because it depends on the way the quarks decompose under the chain $G_{\rm flavor} \to SU(2)_L \times U(1)$, apart from renormalization corrections away from the unification energy. Basically, the value for $\sin^2\theta_W$ should not be too far away from 1/4. If all left-handed fermions form SU(2) doublets and all right-handed fermions are singlets, one has[26]

$$\sin^2\theta_W \approx 3/8 = 0.375,$$

which may be acceptable, considering the renormalization effects. If integer charges are effectively assigned to the four flavors at low energies,[27] one has

$$\sin^2\theta_W \approx 1/4,$$

which looks nice.

As I have already said, the basic problem is our ignorance of the dynamics of mass spectrum generation, that is, why the spectrum looks the way it does, with no obvious regularities. In current gauge theories one is simply trading Higgs parameters for fermion masses. A more satisfying way might be found by considering both fermions and Higgsons in a unified fashion.

Composite models of Higgsons and perhaps also of quarks and leptons are, of course, a possibility which I have already discussed. In particular, all bosons are reduced to fermion composites in the Fermi–Yang–Heisenberg–Sakata type theories. They represent a monistic point of view in contrast to the dualism which separates particles and fields. The prevalent view as well as my own has been along the latter line. This is because the fields have a universal guiding principle, that is, the gauge theory, whereas the material part does not have one, and looks terribly complicated and arbitrary. This situations was already present in Einstein's observation concerning his equation

$$R_{\mu\nu} - 1/2 g_{\mu\nu} R = -T_{\mu\nu}.$$

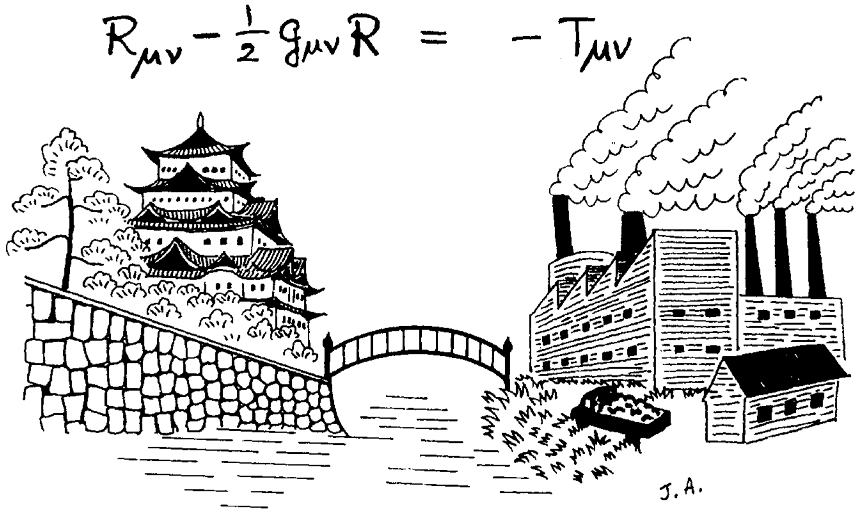

Fig. 3.

To quote: "[the equation] is similar to a building, one wing of which is made of fine marble, but the other wing of which is made of low grade wood."[28] The following is a pictorial rendition of Einstein's theme by Dr. Jiro Arafune, the house cartoonist at KEK (Fig. 3). From this point of view, the Heisenberg–Sakata approach is an attempt to make the whole building symmetric by replacing marble with wood everywhere. But it may have its own appeal, and there are quite a few people pursuing this road. Probably I contributed to this trend unwittingly when Jona-Lasinio and I proposed the superconductivity model[29] borrowing the mathematical techniques of BCS and Heisenberg.

An alternative approach, which amounts to building everything with marble, and about which we have heard the latest developments at this Conference, is the unification via supersymmetry and supergauge principle. This has the capacity to hold all bosons and fermions from spin 2 down to 0, which include gravitons, gravitinos, gauge bosons, quarks and leptons, and Higgsons. The only new appearance is the spin 3/2 gravitino field. One of the attractive features of this framework, beside the obvious ones, has been the possibility of making everything renormalizable, gravity included. Unfortunately, this hope seems to be on rather shaky grounds at the moment. Furthermore, the problem of mass still persists. Since a gauge theory, whether ordinary or supersymmetric, is a theory of massless fields to begin with, it is not easy to predict the patterns of mass spectra that can be dynamically generated. I am not sure that this noble goal of a unification of field and matter, whether in terms of marble, or in terms of wood, can be achieved in a really meaningful way. There is no doubt, however, that the gravity must become an essential ingredient in particle physics, and vice versa. For example, the topological solitons are already being studied in these extended gauge theories. One might speculate that the geometrical richness of gauge principle will lead to interesting and detectable consequences in quantum gravity. I remind you that gravitational waves, not to speak of gravitons, are yet to be detected. Our road is rosy, but surely it will be a long one. I will close my talk with a quotation which I believe should represent the spirit of a gathering such as the one we have just gone through:

> "Our science, which we loved above everything, had brought us together. It appeared to us as a flowering garden. In this garden there were well-worn paths where one might look around at leisure and enjoy oneself without effort, especially at the side of a congenial companion. But we also liked to seek out hidden trails and discovered many an unexpected view which was pleasing to our eyes: and when the one pointed it out to the other, and we admired it together, our joy was complete."

——David Hilbert (memorial address for Hermann Minkowski)[30]

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