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THE WHYs OF SUBNUCLEAR PHYSICS

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The first "Why?" of this Conference refers to the Parallel sessions: Why have they been eliminated? Because if we want to have a chance of selecting something relevant from the bulk of theoretical models or from the bulk of experimental data, we ought to know both.

The Conference will proceed through Plenary sessions in order to mix not only Regge-ologists with Gauge-field theorists, but theorists with experimentalists, irrespective of their specialization.

Only if we look into a special corner can we have the impression that either an experiment or a theoretical work is the only driving force towards an understanding of a peculiar phenomenon. Experiment and theory in every specialized field both contribute to the development of our Science. Let me elaborate this point further.

As we all know, the first discovery of modern Science, the universality of motion, is due to Galilei and it is of an experimental nature. He proved that the theory of Aristotle (for 2,000 years believed to be correct), that there are two types of motion, one proper to the sub-lunar world (the linear) and the other proper to the celestial bodies (the circular motion), was not supported by experimental evidence. Again, without the accurate and systematic measurements of Tycho Brahé, it would have been impossible for Kepler to discover his famous three laws, unified later by Newton in his law of universal gravitation. But how could Newton have known that the gravitational attraction Moon-Earth was the same as that of a material body in the Earth (once account is taken of the $1/r^2$ effect) if it was not for the measurements of Galilei? On the other hand, Neptune is a theoretical discovery, Astronomers were asked to point their telescopes at a precise region of the sky, and Neptune was indeed seen. Pluto was discovered in a similar way, and its observation was again based on a theoretical prediction. Somebody could question the validity of referring to such old events. So let me jump to 1947.

The Lamb shift was theoretically suggested to be -27 MHz and experimentally measured to be +1,000 MHz. The first-order radiative shift (the key to all self-interaction effects) is therefore an experimental discovery. The pion was theoretically predicted but the muon is an experimental discovery and remains one of the greatest puzzles of subnuclear physics. The strange particles were theoretically unwanted, but experimentally discovered; the Ω^- is like Pluto, and with it SU(3) is a theoretical goal.

In the field of weak interactions, theorists are at the forefront with P and C violations, with (V-A), and finally with the famous Cabibbo angle, which allowed the universality principle of weak interactions to be saved. The existence of the K_2^0 was theoretically suggested, even if its lifetime could not (even nowadays) be theoretically predicted. The "two neutrinos" is a sort of fifty-fifty case. On the experimental side we had some mysteriously forbidden decay modes of the μ, in particular ($\mu \to e\gamma$), and on the theoretical side an estimate of the ($\mu \to e\gamma$) rate which was many orders of magnitude above the experimental limits; thus the suggestion of a new leptonic quantum number. But the 2π decay mode of the K_2^0 is unquestionably an experimental achievement; even if the experiment was motivated by the suspected (and false) anomalous regeneration of K_2^0. It was certainly not motivated by a theoretical model of T-violation or of superweak forces. These models came later. And so we arrive at the weak neutral currents, suggested by Salam and Weinberg, in their attempt to unify weak and electromagnetic interactions. However the experimental discovery of the non-existence of strangeness changing neutral currents ($K_L^0 \not\rightarrow \mu^+\mu^-$) has motivated the introduction of a new quantum number. The "charm".

In the field of electromagnetic interactions the hope that radiative effects, in phenomena involving hadrons, would be damped by the hadron structure, was seriously questioned in the celebrated work of Bjorken; and this is the starting point of the deep inelastic physics discovered at SLAC. However, what is probably a strongly connected phenomenon, the discovery at Frascati of the large (e^+e^-) annihilation cross-section into hadrons, had no theoretical motivation -- more precisely, zero theoretical support -- the expectation being the vanishing tails of the known vector mesons.

The discovery of the antibaryons was theoretically motivated (Dirac). However, it should be emphasized that in so far as we do not understand strong forces we cannot take for granted that "protons" should have antiparticles as electrons do. This is why the existence of the antibaryons lies behind the predictive power of the Dirac theory.

In strong interactions the search for and the discovery of mesonic and baryonic resonances started with experimental motivation, thanks to the work of Alvarez and collaborators; its development was, however, motivated by theory: the SU(3) of Gell-Mann and Ne'eman. The first observation of shrinkage in (p-p) elastic scattering was due to Reggeology; all subsequent experiments on shrinkage, antishrinkage, etc., including spin-dependent effects, were and still are all motivated by the various versions of the Regge theory. It should, however, be pointed out that the spin-dependence in (π^--p) charge exchange was theoretically unexpected (because only the ρ trajectory was supposed to play a role in the above process), and was immediately cured by *ad hoc* theoretical models. Here we come to a typical feature of strong interaction theoretical physics: the incredible rate of model production by theorists. In spite of this high production rate only two basic features are really understood in strong interactions: i) the existence of a symmetry higher than isospin, SU(3); ii) the fact that the spin of a virtual particle should not be thought of as being untouchable; it changes as function of the four-momentum transfer q^2. If we now go to the very high energy phenomena (those investigated at the CERN ISR), we find two experimental discoveries: the rate of large p_T events; and the rising (p-p) total cross-section; however, according to Francis Low, only the constancy of this cross-section would have been a challenge to theoretical Physics.

We finally arrive at the great and unexpected discovery by Sam Ting and collaborators of the J-particle, followed by the remarkable series of ψ's and other new phenomena discovered at SLAC: all without any hint from theory.

The above examples show that finding keys to the new, is a field which is open to both experimenters and theorists. If you are an experimentalist, in order to find these keys you need to know as much as possible about what is going on in theoretical physics (think of the Ω^-, the K_2^0, and the neutral currents); if you are a theorist you need to know not only those results relevant to your daily model, but all experimental results, because in some corner you can find a new key. For example, in spite of the tremendous number of theoretical models available on the market, there are many "Whys" which stand up as permanent challenges to all of us. These 'Whys" are the best proof that our field of research is far from seeing the end. Nevertheless, some contributors appear to have forgotten these problems, and this is why I want to list them.

The Whys of Subnuclear Physics (as at June 1975)

1) Why are S- and P-waves in non-leptonic decays correlated?

2) Why is the elastic scattering imaginary at high energy, or in Regge-language, Why do even-signatures dominate and odd signatures become negligible?

3) Why is the Pomeron slope so small?

4) Why is $\frac{\sigma(pp)_{\text{elastic}}}{\sigma(pp)_{\text{total}}} \simeq \frac{1}{5}$?

5) Why does $\frac{\nu W_2^n}{\nu W_2^p} \to \frac{1}{4}$ as $\omega \to 1$?

6) At relatively low energies (few GeV's) we observe that the inclusive electromagnetic coupling of the hadrons is point-like. Is this because the hadrons are made of super-elementary constituents? and if so, Why they do not show up?

7) Why is $\frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$ not 2, but most likely between 5 and 6 at the highest SLAC energy?

8) Why are the weak non-leptonic decay rates 3 orders of magnitude greater than the weak leptonic decays, i.e.:
$\frac{\Lambda \to \beta}{\Lambda \to \text{all}} \simeq 10^{-3}$?

9) Why is the inclusive ratio $e/\pi \sim 10^{-4}$?

10) Why does not $K_L^0 \to \mu^+ + \mu^-$ go as it should, while $\nu + p \to \nu +$ anything goes; or more generally, why are weak neutral non-strange currents there and weak neutral strange currents NOT there? Is the answer: charm, heavy leptons, or something else?

11) Why are the J and ψ particles there? Is the answer: charm, colour, or something totally different?

12) Why does $K_L \to 2\pi$ go? Or, more generally, why is CP violated? Is this because a new interaction -- superweak -- is at work?

13) Why is the Cabibbo angle $\sim 20°$? Can the answer be found via spontaneous symmetry breaking?

14) Why is SU(3) there? Is this because the so-called elementary particles are made of quarks?

15) We observe regularities which go beyond SU(3). Is this because unitary spin and Dirac spins are correlated?

16) Why do single quark transitions dominate? i.e. Why is it so easy to have spectator quarks?

TABLE I. Guide to inconclusive experiments and hypothetical particles.

Particle	Who needs it?	If not found, so what?	Craziness index	Signature
I. PEDAGOGICAL EXAMPLES				
Ω^-	MGM & YN	Kills SU(3)	No	Good
$M^0(150) \rightarrow 5\gamma$	Nobody, but why not?	Nobody cares	Not particularly	Missing mass
II. PROPOSED SEARCHES AT NAL				
Tachyons	Nobody, but why not?	Nobody cares. Try harder	Very	Good
Quarks	Dalitz	Try harder	Fair	Good (fractional charge)
Monopoles	Dirac-Schwinger	Try harder	Moderately	Good
Intermediate bosons	Yukawa	Try harder, but credibility falls	No	Good
Heavy leptons	Nobody, but why not?	Look elsewhere (spectroscopy)	No	Good
Partons	Bjorken-Paschos	Ask Bjorken-Paschos	No	Good
Han-Nambu triplets	Dalitz might settle for these	Try harder	Less than quarks	Missing mass best
Superheavy nuclei	Nuclear physicists	Try harder	No	Chemistry. Not clean
III. THE REALLY EXCITING SEARCH				
?	Nobody has thought of it	It will be found; it's there	Who knows, the theorists have not thought of it yet	

17) Why have quarks so far not been found? Is it because the confinement theories predict the truth; or because the production process is peculiar, or because quarks do not exist in Nature at all?

18) Why is the muon there? Should other leptonic states (heavy leptons of the old type) exist?

19) We do not observe any of the processes predicted by theory to have infinite rates, such as all higher-order weak interaction reactions. Are we sure that something physically relevant is not missing, which causes all attempts to have a renormalizable theory of weak interactions to fail?

20) Why is the weak charge universal?

21) Why is the electric charge universal?

22) The bare electric charges of the electron and the proton are equal. Is this related to their $(1 + \gamma_5)$ coupling as particle states in weak interactions?

23) Why are the proton, the neutron, the Λ^0, as examples of baryonic states, and the e^-, μ^-, ν_e, as examples of leptonic states, all left-handed when they interact weakly? Is this due to the fact that they transform each other?

24) We observe six types of fundamental interactions. Are these all orthogonal to each other, or have they a common origin?

25) Why is the proton so stable? i.e. Why do we exist at all?

With these "Whys" I would like to close this introductory note -- but not before rendering justice to a great theorist who is here with us in this lecture hall. I have said, and everybody believes, that the "new" particles were totally unexpected. Table 1 is taken from the Proceedings of the Irvine Conference on Particle Physics, December, 1971, three years before the first rumour on the J-particle started to circulate. The last rows of the table show that Harry Lipkin indeed predicted its existence -- so let me open this Conference by applauding his foresight.