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Publication Date
1975-02-01

LBL-3697 c.1
UC-34d
TID-4500-R62

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Prepared for the U. S. Energy Research and Development Administration under Contract W-7405-ENG-48

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $4.00; Microfiche $2.25

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LBL-3697

Strong Interactions, Zweig's Rule, and Weaker Interactions

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ABSTRACT

This paper will attempt to connect five notions: 1) Strong interaction scattering amplitudes do not involve the action of a Hamiltonian and are only Clebsch-Gordan coefficients. 2) The four momentum $\vec{P}$ is an SU(something) operator. 3) The four momentum of a quark does not change in a strong interaction scattering. 4) Zweig's rule 5) Gluons should not be drawn in strong interaction scattering diagrams. Finally, a simple explanation will be offered for the weak interaction of leptons amongst themselves and with hadrons.

I. No Hamiltonian in Strong Interactions

Consider the amplitude that two initial states (1 and 2) look like two final states (3 and 4) after the passage of a time t.

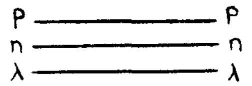
$$\text{Amplitude} = \langle 3 \langle 4 | e^{itH} | 1 \rangle 2 \rangle$$
$$= \langle 3 \langle 4 | 1 + itH + \frac{(itH)^2}{2} + \ldots | 1 \rangle 2 \rangle \qquad (1)$$

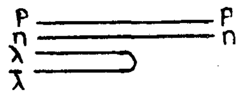
The notion to be presented here is that the "strong" interaction does not involve the action of the Hamiltonian except for getting the two initial particles on top of one another. The strong interaction amplitude is just the amplitude $\langle 3 \langle 4 | 1 \rangle 2 \rangle$ arising from the 1 in the above expansion of e^{itH}. The expression $\langle 3 \langle 4 | 1 \rangle 2 \rangle$ is the amplitude for $| 1 \rangle 2 \rangle$ to be $| 3 \rangle 4 \rangle$. This idea is consistent with the 10^{-23} second time scale of strong interactions. It takes 10^{-23} seconds for two 1 F diameter particles going at velocity c to get on top of one another, from which position there are just amplitudes to be other things with no time dependence.

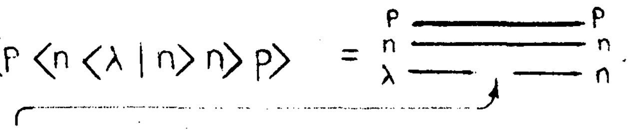
Weaker interactions (eg. electromagnetic, weak, gravitational) involve the action of H in the expansion of eqn. (1).

In the back of ones mind there is the notion that the states in eqn. (1) will be to some future physicist the states in a representation of SU(something). The operator H will be expressed in terms of the SU(something) generators and hence the amplitude in eqn. (1) will be rigorously calculable. The symbol $\langle 3 \langle 4 | 1 \rangle 2 \rangle$ will be an SU(something) Clebch-Gordon coefficient.

The assumption that strong interaction scattering amplitudes are CG coefficients explains why the lines in strong amplitude quark diagrams never change their names. When the states in a CG coefficient are expanded in the states of the fundamental representation, the CG coefficient is only non-zero if the bra and ket states match up in a one-to-one fashion. For example in SU(3)

$$\langle p \langle n \langle \lambda | \lambda \rangle n \rangle p \rangle =$$  $$= 1$$

$$\langle p \langle n \langle \lambda \langle \bar{\lambda} | n \rangle p \rangle =$$  $$= 1$$

$$\langle p \langle n \langle \lambda | n \rangle n \rangle p \rangle =$$  $$= 0$$

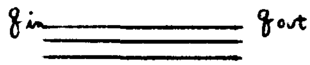
For this non-continuous quark line a Hamiltonian is required to convert $\lambda \to n$, hence this is not a strong diagram.

II. $\vec{P}$ is an SU(something) Operator

Eventually one expects the commutation relations between all generators of interest to physics to be written down. This will merge both the symmetry group generators (eg. I, U, V, Q, Y, B, L) and the dynamical group generators (eg. $\underset{\sim}{J}$, $\underset{\approx}{K}$, $\vec{P}$) into one group here assumed to be SU(something). The members of the fundamental representation of this group will be called quarks. If the group is SU(N), then there are N quarks.

III. Quark Momentum Doesn't Change

Since every SU(N) "in" quark has to go unchanged over to an "out" quark in order for the CG coefficient to be non-zero, and since $\vec{P}$ is an SU(N) operator, it is obvious that the expectation of momentum for each quark doesn't change.



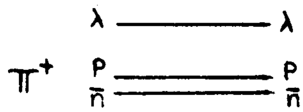
q stands for quark (not momentum)

Consider

$$\langle q_{in} | \vec{P} | q_{in} \rangle = \langle q_{out} | \vec{P} | q_{out} \rangle \quad \text{because } q_{in} = q_{out}$$

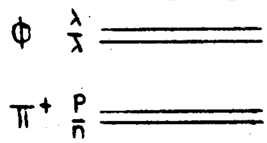
IV. Zweig's Rule

Given that the expectation of the four momentum of a quark can't change then Zweig's rule follows. Consider



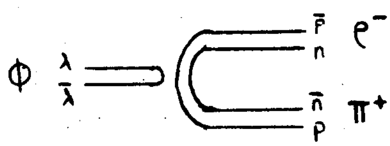
$= 1$ only when $\vec{P}_{\lambda\,in} = \vec{P}_{\lambda\,out}$

However, we define as a scattering only those events for which the momentum of λ changes. Hence the strong $\lambda\pi^+ \rightarrow \lambda\pi^+$ scattering amplitude is zero. Similarly the strong amplitude $\phi\pi^+ \rightarrow \phi\pi^+$ is zero.



$= 1$ only when $\vec{P}_{\phi\,in} = \vec{P}_{\phi\,out}$

Finally, consider $\phi \rightarrow \rho^- \pi^+$



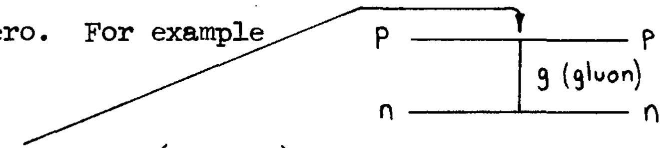
$\vec{P}_\phi = \vec{P}_\lambda + (-\vec{P}_\lambda) = 0$ is necessary since the λ quark does not change its momentum. Since $m_\phi \neq 0$, $\vec{P}_\phi \neq 0$ for a real ϕ. Hence the strong decay amplitude is zero. The measured $\phi \rightarrow \rho\pi$ must be due to an admixture of $p\bar{p}$ and $n\bar{n}$ in the ϕ.

Thus we arrive at the statement of Zweig's rule. Disjoint quark diagrams have zero strong amplitude. The set of quarks may of course be expanded from the traditional three $(p\, n\, \lambda)$ to N of SU(N), where the value of N is a future problem.

V. No Gluons in Strong Interaction Scattering Diagrams

Since quarks do not change their momenta in strong scatterings, it is pointless to put in gluons to carry changes in momentum between the quarks.

A related argument against gluons in strong scattering quark diagrams is as follows. If the gluon is a composite particle, then draw it in all diagrams as being made of its composite quarks. Thus no diagrams with gluons appear. If the gluon is not a composite particle but instead belongs to the fundamental representation, then diagrams with gluons being exchanged are zero. For example



This vertex = $\langle p \langle g \mid p \rangle = 0$ if p and g belong to the fundamental representation.

Furthermore, the exchange of a particle means that a Hamiltonian has acted. The p current has interacted with the n current with a gluon pole. This is the H = current x current picture. Since strong interaction scattering diagrams do not involve the action of H, there are no gluons.

VI. Leptons and Weak Interactions

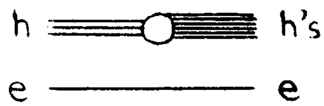
Assume

a) The electron, muon, and neutrino belong to the fundamental representation of SU(N) (ie. they are quarks). This is consistent with the point like nature of the electron and muon. They do not appear to be made up of any smaller building blocks.[1]

b) Electrons, muons, and neutrinos are not the quarks of which hadrons are built.

Why do electrons only weakly interact with hadrons ?

The only quark diagram which can be drawn for $e + h \rightarrow e + h$'s is

Amplitude = 

By Zweig's rule this strong amplitude is zero because it has a disjoint free quark line (the electron!). The same argument can be made for μ and ν interacting with hadrons and for $e\mu\nu$ interacting amongst themselves. Hence the leptons are called weakly interacting, even though they are quarks! Do electrons ever exhibit strong interaction size cross sections ?

Yes, consider $e + H \rightarrow e + H$ H = hydrogen atom

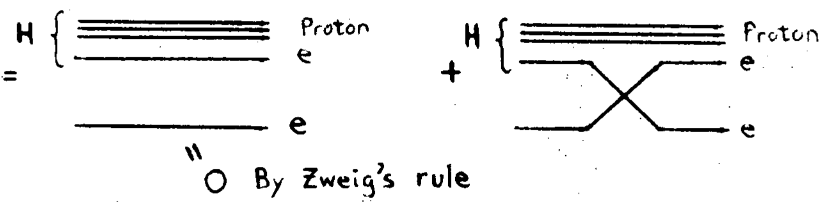
Amplitude = 

Figure 1 shows the $e + H$ total cross section between 0 and 10 ev kinetic energy of the electron.

$$\ell_{max} \approx \frac{1}{\hbar c}\sqrt{2 m_e c^2 (10\,ev)}\;(1\,\text{Å}) \approx 1$$

Hence only ℓ =0,1 partial waves enter the problem. As can be seen from the curve $4\pi\bar{\lambda}^2$, both partial wave cross sections must be near their unitarity limits (ie. not down by 1/137 or some other large factor). This is a characteristic of a strong interaction.

VII. Conclusions

I have attempted to connect together five things: strong interaction scattering amplitudes do not involve the action of a Hamiltonian and are Clebsch-Gordan coefficients, the four momentum $\vec{P}$ is an operator of the total group of physics, the expectation of the four momentum of a quark does not change in a strong scattering, Zweig's rule, and gluons should not be drawn in strong scattering diagrams. The leptons e, μ, ν are conjectured to be quarks.

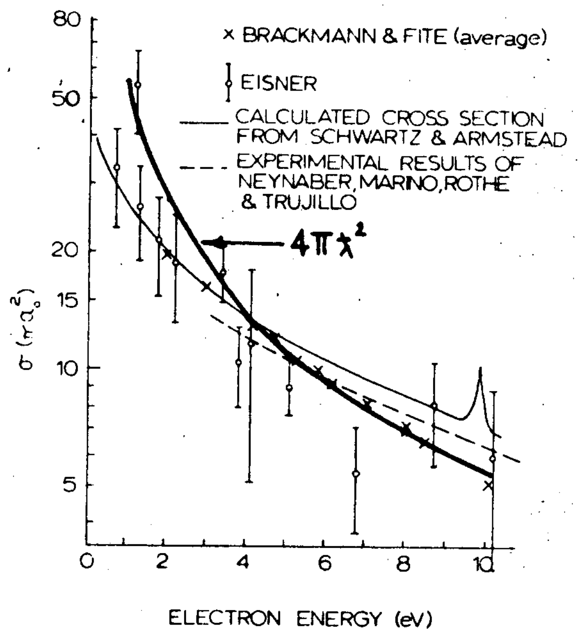
Special thanks go to Jim Wiss for a very clarifying discussion.

References

1) Gary L. Godfrey, Lawrence Berkeley Laboratory Report No. LBL-3612 (1974) unpublished.

2) B. Bederson and L. J. Kieffer, Rev. Mod. Phys. 43, 626 (1971).

Fig. 1. Summary of crossed-beam determinations of total electron-atomic hydrogen cross sections from reference 2. The heavy curve is $4\pi\lambda\!\!\!^{-2}$.



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