GLUE BALLS, QUARKS, AND THE POMERON-f

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ABSTRACT

I present three issues related to s-channel unitarity which argue in favor of the P-f identity model of diffraction of Chew, Rosenzweig, and Chan, and which argue against the traditional P+f model. These are (1) The violation of two component duality in modern P+f fits, (2) Threshold effects due to strangeness, charm, and baryon production (flavoring), and (3) Quark-loop renormalization of the QCD glueball, consistent with observed hadron multiplicities and dominant short range order. I also review P-f identity phenomenology.

Je vous présente des considérations ayant pour origine l'unitarité dans la voie s , qui favorisent le modèle de diffraction incorporant l'identité P-f et qui posent des problèmes aigus pour le modèle à deux composantes P+f. Seront traités (1) la dualité à deux composantes, (2) les problèmes liés aux seuils pour la production de parfums (flavoring), et (3) l'unitarisation de la glueball de QCD, d'une façon compatible avec les multiplicités de hadrons observées et avec l'ordre à courte portée. Je rappelle aussi la phénoménologie basée sur l'identité P-f.

I. INTRODUCTION

It has become habitual to associate the concept of diffraction with the two component Pomeron (P) + f model. The Harari-Freund [1] notion of two-component duality and the theoretical possibility of quarkless excitations (QCD glueball, dual closed string) is often cited as evidence for the separate existence of a Pomeron and f. The Pomeron, dual to the background, is supposed to be the glueball or closed string. The f, dual to resonances, is supposed to be nearly exchange degenerate, ideally mixed, and planar. More recently a different idea has developed, due to Chew, Rosenzweig [2], Chan [3], and others, called the "Pomeron-f identity". Here there is only one high-lying trajectory- the P-f. The P-f trajectory goes through the f-meson and is curved in t in a manner which involves the transition to a nearly planar amplitude at timelike t from a dominantly cylindrical amplitude at $t = 0$. These two schemes clearly differ in concept, and my purpose here will be to contrast them on a phenomenological level. The crucial aspect will be s-channel unitarity.

I will focus on three points which argue strongly in favor of the P-f identity and against the traditional P+f model [4].

(1). Two component duality, in contrast to the situation in 1969, is badly violated. Typically the f pole amplitude from P+f modern fits is dual to the resonances plus one-half the background.

(2). The P-f identity is quite successful in describing data. It not only has passed all important phenomenological tests (including several specific challenges directed against it), but it works better than the P+f model in one very important respect. The point can only be seen if one tries to build up the diffractive amplitude using s-channel unitarity. Called "flavoring" [5], the effect is due to the successive excitation of particles with different quantum numbers (flavors - strangeness, charm; and baryon number) in inelastic states. Within a dominant short range order picture, as exists at current energies, these threshold effects must "renormalize the Pomeron". This means that the bare Pomeron scaling law changes from $s^{\hat{\alpha}(t)}$ to $s^{\alpha(t)}$ with $\alpha > \hat{\alpha}$ in a well-defined way, both mathematically and phenomenologically.

Flavoring renormalization is analogous to the change in the scaling law on either side of a threshold for exciting a new quantum number in $e^+e^- \to$ hadrons. The details are different, but the effects are just as dramatic.

Actually, the "correct" theory of diffraction, built up as it is by unitarity, must be consistent with the observed multiplicities $\langle n_i \rangle$ ($i = K\bar{K}$, $B\bar{B}$, ...) of individual species of hadrons. That is, flavoring is not so much

a complication as a constraint on any model of diffraction that claims to be right.

The reason that I have so strongly emphasized this point here is that the P-f identity is in fact consistent with this important aspect of unitarity and short range order. Flavoring is a necessary ingredient in a successful P-f phenomenology [5]. In contrast, the traditional P+f model most probably fails this test.

(3). The last point involves the common idea of the association of a glueball at $\alpha^{*} = 1$ with the Pomeron separate from the f . I will argue that, on the contrary, the existence of an $\alpha^{*} = 1$ glueball in quarkless QCD does not imply the standard P+f scheme. Indeed, I shall argue that once quark-loop unitarization of such an object is included, the P-f identity is favored over the P+f model. The t-channel content of the Pomeron-f is made of $q\bar{q}$. Any possible t-channel glue content of the output Pomeron will be shown to be negligible.

II . THE FAILURE OF TWO COMPONENT DUALITY

The reason why the situation now is different from what it used to be is the discovery that total cross sections rise. Roughly, rising σ means that the P part σ_P rises, i.e. σ_P decreases as we go to lower energies. But then the f part $\sigma_f = \sigma - \sigma_P$ is bigger at lower energies that it would be if σ_P were constant. The bigger σ_f now tends to be too high to average the resonances.

In Fig. 1 I exhibit the experimental $I_t = 0$ πN amplitude $\mathrm{ImA'}^{+}(\nu, 0)$ corresponding to the resonances, and also to the resonances plus one-half the background. Here $\mathrm{ImA'}^{+}(\nu, 0) = \frac{1}{2}(\nu^2 - m_\pi^2)^{1/2}(\sigma_{\pi^+p} + \sigma_{\pi^-p})$ where $\nu = E_{lab}$. Also plotted are the $t = 0$ absorptive f pole amplitudes taken from several "conventional" P+f published fits [6] performed after 1974. By a "conventional" fit I mean that the P is basically a pole plus small cuts at $t = 0$, consistent with dominant short range order. Although the authors of these fits differ in their philosophy toward exchange degeneracy, the results are quite uniform. It is clear that, instead of averaging the resonances, the f actually averages the resonances plus one-half of the background, in contradiction to the idea of two component duality.

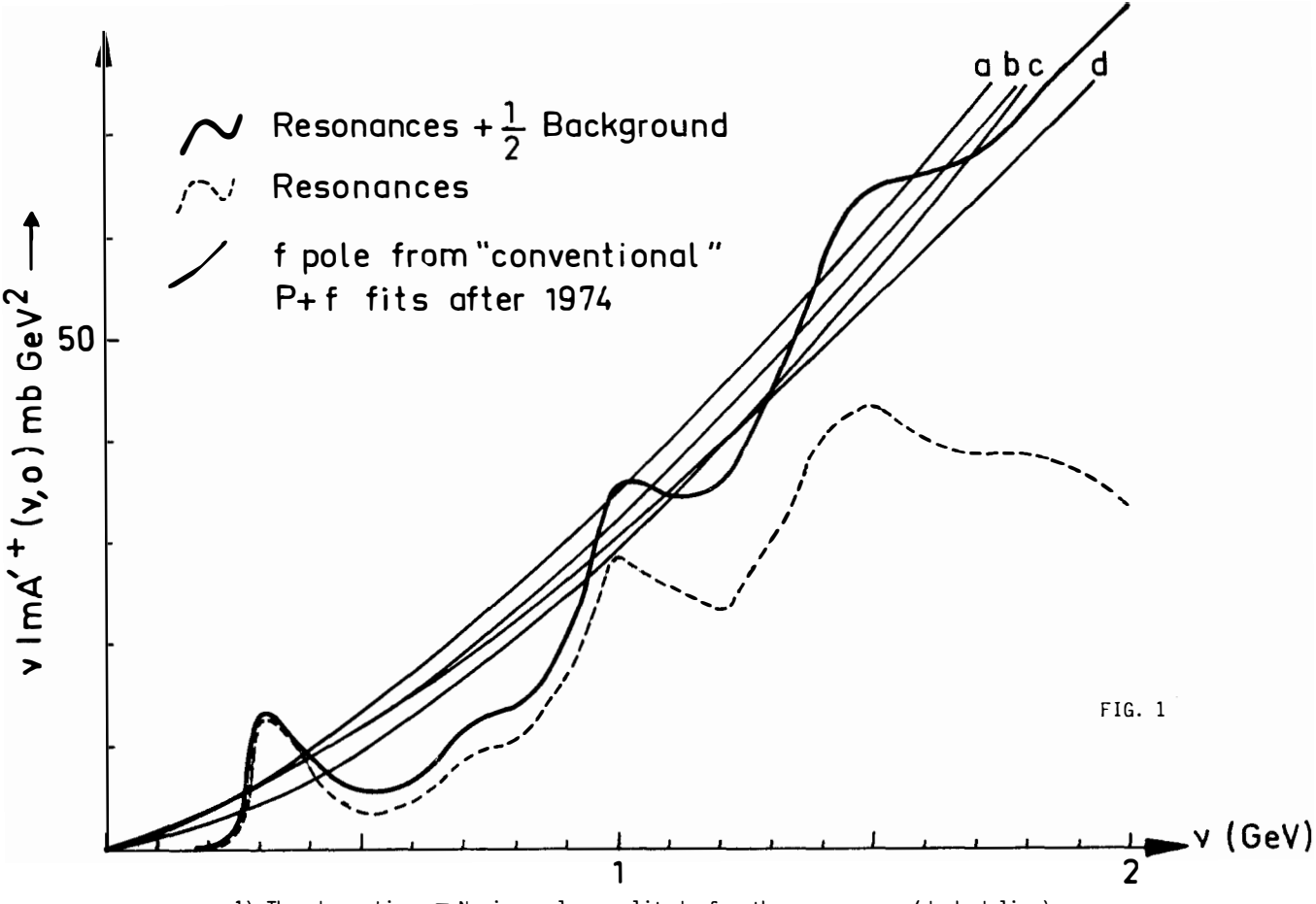


FIG. 1

1) The absorptive πN isoscalar amplitude for the resonances (dashed line), the resonances plus one-half the background (solid line), and the absorptive f-pole amplitudes from four recent conventional P+f fits. See ref.(6).

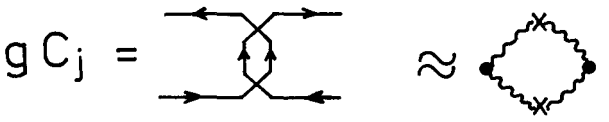
The failure of the P+f model to satisfy its own "postulate" is not shared by the P-f identity. A model dependent test of two-component duality within the P-f identity of the form Im T (planar) $\cong \langle$Im (resonances)$\rangle$, Im T (cylinder) $\cong \langle$Im (background)$\rangle$ has been performed. The reader is referred to Ref. (4) for a description of this as well as more details for the P+f case.

III. THE P-f IDENTITY

The P-f identity is based on a specific realization of Veneziano's topological expansion [7]. To the planar + cylinder level, the $I_t = 0$, $C = +$ amplitude T can be written as $T = T^{Pl} + T^{Cyl}$ as in the P+f model. In contrast, however, the partial wave amplitude T_j only has one high lying pole instead of two. (This statement will be refined in a moment when we discuss flavoring). The planar f, a pole in T_j^{Pl} at $j = \alpha_{Pl} \cong \frac{1}{2}$, is shifted upward by the cylinder amplitude according to the partial wave equation

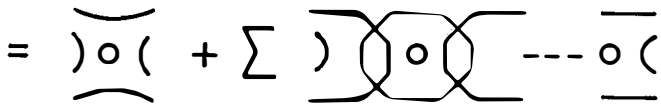
$$T_j = T_j^{Pl} + T_j^{Pl}\, g\, C_j\, T_j \qquad (1)$$

The cylinder kernel C_j is taken as a nonsingular function of j near $j = 1$. This is quite sensible. In Regge models [3], the leading C_j singularity is a Regge-Regge cut at $j \lesssim 0$, as shown below :



THE NONSINGULAR CYLINDER KERNEL C_j OF EQ. 1

Upon iterating eq.(1), the C_j kernel changes the direction of circulation of the quark loops between neighboring planar amplitudes. That is, the cylinder kernel produces transitions between the "back" and "front" of the cylinder on which quark loops circulate in opposite directions. Note that every t-channel cut (vertical line) on the cylinder cuts through quarks. Pictorially T_j is given by the iteration



THE PARTIAL WAVE AMPLITUDE T_j OF THE P-f IDENTITY

The solution of eq.(1) is elementary,

$$T_j = T_j^{Pl}(1 - g\, C_j\, T_j^{Pl})^{-1} \qquad (2)$$

The fact that C_j is nonsingular near $j = 1$ means that there is only one high lying pole, the P-f. This is the P-f identity [2].

IV . FLAVORING

I next discuss flavoring, which as mentioned earlier, plays a most important role in distinguishing the P-f identity from the conventional P+f model. Here I can only mention the highlights ; the reader is referred to ref. 5 for a complete review.

The basic idea follows the old observation that the rise in σ seems correlated with the rise of $B\bar{B}$ production, which is an obvious threshold-like effect. This same sort of behavior is also observed for $K\bar{K}$ production, though at somewhat lower energies (the effective threshold is around $s = 30\ GeV^2$). Charm and possible other new flavors clearly will also exhibit such behavior at large s , though at present energies these effects are negligible. The experimental fact that the multiplicities $\langle n_i \rangle (i = K\bar{K}\ ,\ B\bar{B}\ ,\ldots)$ exhibit strong threshold-like behavior produces the flavoring effect on diffraction through s-channel unitarity.

In general unitarity constraints are very difficult to implement. Here we are fortunate. The existence of dominant short range order at present energies allows us to conclude that the dominant production amplitudes are multiperipheral, probably in clusters. Now any multiperipheral model with its kinematics properly treated contains t_{min} effects for production of $K\bar{K}$, $B\bar{B}$, ...

pairs. Independent of details, one always obtains partial wave amplitudes of the following (strong-coupling) form [5] :

$$T_j = \beta_j \left[j - \hat{\alpha} - g_K^2 e^{-b_K j} - g_B^2 e^{-b_B j} - \ldots \right]^{-1} \qquad (3)$$

The decaying $\exp(-bj)$ exponentials are just the kind that arise from the Froissart-Gribov formula due to thresholds in s-channel discontinuities at $\ln s = b$. These terms do two things. They produce smooth threshold modifications of cross section behavior (which, contrary to lore need not be oscillatory). They also renormalize the Pomeron (j-plane description). Denote

$\hat{\alpha}$ = unflavored pomeron $\hat{P}$ intercept. [$\hat{P}$ = pole in $\hat{T}_j$ where $\hat{T}_j = T_j(g_K = g_B = 0)$.]

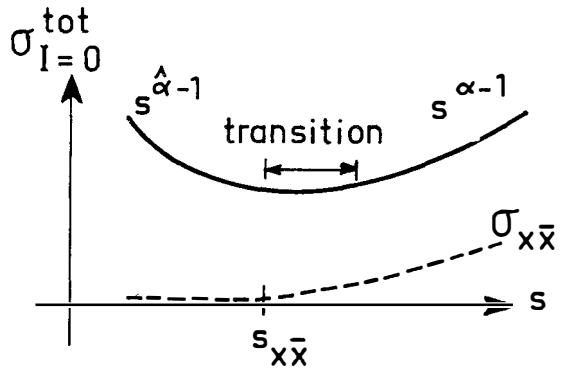
α = flavored Pomeron P intercept (P = leading pole in T_j)

The unflavored $\hat{P}$ is built up from pion production alone. It is a pole in the "unflavored" partial wave amplitude $\hat{T}_j$. It is an auxiliary, though extremely useful object. The flavored Pomeron P is the leading pole in the full partial wave amplitude T_j. It is the bare Pomeron of the Reggeon Field Theory. The reader should note carefully that there are no "energy dependent trajectories". $\hat{\alpha}$ and α are numbers (or at $t \neq 0$ functions of t). Further the flavored intercept α is calculated from knowing the unflavored intercept $\hat{\alpha}$ and the threshold parameters which are fixed by data.

Now by (a) expanding T_j in a series in g_K, g_B ; or (b) by picking up the poles of T_j in the Sommerfeld-Watson transform, one is lead to two completely equivalent descriptions of σ.

$$\sigma = \begin{cases} \text{either} & \hat{\beta}\, s^{\hat{\alpha}-1} + \sum_{i=K,B,\ldots} g_i^2 f_I(s)\, \theta(\ln s - b_i) + \ldots \\ \text{or} & \beta\, s^{\alpha-1} + \sum_{i=1}^{\infty} \text{(complex pole terms)} \end{cases} \qquad (4)$$

Note that at low s, σ is given simply by the unflavored $\hat{P}$ scaling law $s^{\hat{\alpha}-1}$. At high s, σ is given simply by the flavored P scaling law $s^{\alpha-1}$. This is the flavoring renormalization of the (bare) Pomeron. This is shown pictorially below for the simple case of one $X\bar{X}$ flavoring threshold :

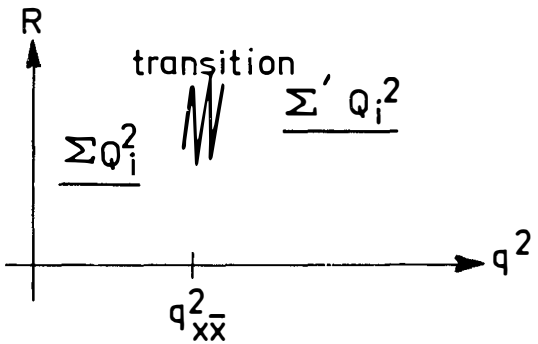


FLAVORING RENORMALIZATION EFFECT ON σ BY $X\bar{X}$ PRODUCTION

Here $s_{X\bar{X}}$ is around BNL (FNAL) energies for $K\bar{K}$ ($B\bar{B}$) production, and is determined by the experimental point at which $X\bar{X}$ production "takes off".

I stress again that the flavoring renormalization of the Pomeron is not model dependent. It occurs because (1) threshold-like behavior of $K\bar{K}$, $B\bar{B}$,... production exists, and (2) dominant short range order in rapidity exists.

The existence of flavoring in hadron scattering is rather like the now-familiar idea that the famous ratio R in e^+e^- annihilation approximately obeys one scaling law (ΣQ_i^2) below the threshold for exciting a new flavor and a different scaling law ($\Sigma' Q_i^2$) above that threshold, with a complicated transition region in between (e.g. the Ψ family at the charm threshold). Of course there are dynamical differences. In hadron physics the excitation thresholds are kinematically delayed. Moreover baryon number counts as a "flavor" because no $q^2 \to \infty$ argument is around to break up the qqq system. Pictorially $e^+e^- \to h$ flavoring due to a new $X\bar{X}$ flavor excitation looks like this :



EFFECT ON $R(e^+e^- \longrightarrow h)$ DUE TO A NEW FLAVOR

The scaling law change from $\sum Q_i^2$ to $\sum' Q_i^2$ in R is analogous to the flavoring renormalization of the bare Pomeron scaling law from $s^{\hat{\alpha}}$ to s^{α} in hadron-hadron scattering.

Numerically, flavoring in hadron-hadron scattering is a very important effect. A detailed analysis yields [5]

$$\alpha - \hat{\alpha} \approx 0.2 \tag{5}$$

As we shall see in the next section this has quite important consequences.

V. P-f IDENTITY PHENOMENOLOGY

Here I shall list important phenomenological results within the P-f identity framework, concentrating only on $t \leq 0$ physics.

A. THE DUAL UNITARIZATION PROGRAM OF CHAN

The comprehensive dual unitarization program of Hong-Mo Chan and collaborators [3] has all been carried out within the context of the P-f identity. This was not, however, recognized at the outset.

B. TWO-BODY PHENOMENOLOGY

(1). The first major work incorporating the P-f identity was ref. 8 which contains one of the two existing global fits to all $0^- \frac{1}{2}^+ \to 0^- \frac{1}{2}^+$ data at and below BNL energies. This was done with what is now recognized to be the unflavored bare Pomeron $\hat{P}$, and the unflavored $\hat{P}$ intercept $\hat{\alpha}$ was taken at $\hat{\alpha} = 0.85$. The existence of a separate ideally mixed "f" was allowed for in the fit, but its intercept was consistent only with a value of around zero. The $\hat{P}$ intercept below one solves the enigmatic "phase problem" of absorption models, known to two-body phenomenologists, in an elegant way. Standard P+f treatments suffer from the problem that Regge-Regge cuts should vanish in an exchange-degenerate world, which gives incorrect phases if the P is a pole around 1 plus small cuts.

(2). Rising cross sections above BNL energies are quite consistent with the P-f identity and the above global fit. As mentioned several times, flavoring plays the key role. The flavored P has the calculated intercept $\alpha = 1.08$. Using the same flavoring in πN, KN, and NN scattering produces the correct shapes of all these cross sections through FNAL-ISR energies [5].

(3). Specific challenges to the P-f identity have all ignored the crucial aspect of flavoring. These include [6a] the observed increasing behavior of $2\sigma_{KN} - \sigma_{\pi N}$ and the ratio of forward real to imaginary amplitudes[9]. These data are well described within the P-f identity, as shown in ref. 5.

(4). Inelastic two body reactions have not been systematically analyzed, other than the $0^- \frac{1}{2}^+ \rightarrow 0^- \frac{1}{2}^+$ case. The assertion [10a] that K^* production poses a serious problem for the P-f identity has been reanalyzed by Tan, Tow, and Tran Than Van [10b] and shown to be false. However a complete analysis of vector meson production as well as reactions like $np \rightarrow pn$ where diffraction enters through absorption still needs to be performed.

C. MULTIPARTICLE PHENOMENOLOGY

(1). Mueller analysis is different in the P-f identity because at subenergies s_i which are below flavoring thresholds it is the unflavored $\hat{P}$ which controls the leading s_i dependence as $s_i^{\hat{\alpha}}$. In addition the $\hat{P} \times \hat{P}$ cut and unflavored $j \approx 0$ singularities can be present, as in the global fit [8]. Triple-Regge $pp \rightarrow pX$ and $\pi p \rightarrow Xp$ phenomenology using triple $\hat{P}\hat{P}\hat{P}$ and $\pi\pi\hat{P}$ terms was performed in ref. 11, where the $\hat{P}$ was first introduced. The existing data were indeed consistent with this description. However newer data exist that should be analyzed, with appropriate attention to flavoring renormalization in subenergies.

(2). The rising rapidity plateau has been analyzed by Jones [12], who concludes that flavoring may be a key issue here too. Flavoring can introduce new Mueller couplings which can make the rise of $d\sigma/dy$ occur at the same s as σ, instead of later. Further work along this line would be welcome.

(3). All flavoring phenomenology has been performed using the $pp \rightarrow K\bar{K}X$, $p\bar{p}X$ tabulation [13], assuming that the flavoring renormalization is universal for ap scattering ($a = p, \pi, K$) as it should be in a short range

order framework. This should be checked explicitly by tabulating $\pi p \to K\bar{K}X$, etc. data.

The overall conclusion is that the P-f identity, while not exhaustively tested, has passed all major phenomenological tests as well as a number of minor tests. The P-f identity moreover has the advantage of being consistent with flavoring.

On the other hand, the large flavoring effect is clearly inconsistent with the traditional P+f picture, at least within the conventional framework. For example, the flavoring renormalization of 0.2 required by the data for $K\bar{K}$ and $B\bar{B}$ production would renormalize an unflavored Pomeron $\hat{P}$ at one to a flavored P with intercept 1.2, which is much too high to fit total cross sections. Conversely, the complex poles in the flavoring-renormalized spectrum of T_j (eq.(3)) cannot approximate the f of the P+f model. This is because (1) the complex poles are complex, and anyway nowhere near $\frac{1}{2}$, and (2) they contain substantial strange $s\bar{s}$ and diquark $qq\,\bar{q}\bar{q}$ components, whereas the standard f is ideally mixed ; i.e. it supposedly contains only $u\bar{u}$ and $d\bar{d}$ components.

VI . WHY THE POSSIBLE EXISTENCE OF A GLUEBALL WITH INTERCEPT ONE DOES NOT IMPLY THE P+f MODEL

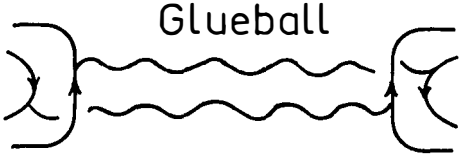
The major theoretical motivation for the P+f picture has been taken from the possibility of new quarkless effects ; a glueball in quarkless QCD [14, 15] or a closed string in dual models, which could produce a pole with intercept one. It is important first of all to remind the reader that this possibility suggestive as it may be, is unproven [14]. However, what I wish to point out is, even given the existence of such an object, the demonstration of the standard P+f picture is by no means guaranteed. The glueball concept, formulated as it is in a world without quarks, violates unitarity. The imposition of unitarity by adding quarks loops can substantially modify what one might naïvely believe to be the case. Specifically, I will show that

(1). The P-f identity is in fact consistent with the existence of a glueball in quarkless QCD, even with intercept one ;

(2). The P-f identity is not only a consistent result but the

preferred result over a possible P+f result. This will follow only from internal consistency, short range order and the total particle multiplicity $\langle n \rangle$ which increases roughly like $a \ln s$, where a is a big number ($a \gtrsim 3$). The P+f model results generally imply [16] particle multiplicities $\langle n \rangle$ which increase like $\epsilon \ln s$, where ϵ is a small number (e.g. $\epsilon \approx 1/6$).

I begin by considering the standard picture for the QCD glueball Pomeron, first introduced by Low and Nussinov [15]. There are no quarks at this stage, other than the external quarks. (Technically, the number of colors N_c has been taken to infinity) :



THE f-DOMINATED GLUEBALL POMERON IN QUARKLESS QCD

The two external quark loops fit on a cylinder topologically since they circulate in opposite directions. They produce a double planar f pole (f-dominated residues), and they exchange colored gluons to produce the glueball. The two gluons in the above drawing are only suggestive. Actually we expect the full content of quarkless QCD to enter and, in an as yet unknown way, perhaps lead to the j-plane result

$$C_j^{glue} = \frac{\beta_j^*}{j - \alpha^*} \qquad (6)$$

with $\alpha^* = 1$ or at least something close to one. The t-channel discontinuity away from the external quarks cuts through only glue.

Now the s-channel discontinuity of this amplitude is obtained by considering the two gluons in the figure as the s-channel discontinuity line. Clearly only two $q\bar{q}$ pairs are present, and in fact each has a "mass" on the order of $s^{1/2}$. This unphysical result is because the dynamics has not yet been regarded as including quark loops, which produce $q\bar{q}$ pairs in the s-channel unitarity sum. However, even at this stage, one sees a hint of what is to come. Any explicit glueball (associated with a t-channel discontinuity that does not cut through quarks) will produce a large rapidity gap and lead to a lack of $q\bar{q}$ pairs. This will ultimately produce problems with hadron multiplicities for the P+f model, though not for the P-f identity.

When quark loops are added, the cylinder topology will still dominate. This is because higher order topologies generate j-plane cuts, which are small effects. Because of short range order, there is a multiperipheral structure on the cylinder. Moving along the cylinder, a planar amplitude with quark loops circulating in one direction on the "back" of the cylinder undergoes a transition by means of a "cylinder kernel" to another planar amplitude with quark loops circulating in the other direction on the "front" of the cylinder (and conversely). Iterations of planar-cylinder-planar ... transitions along the cylinder generate the multiperipheral structure, consistent with a j-plane pole output. (Technically, nonsense zeros kill the cuts). So far I have done nothing unconventional, and in fact I am merely following Veneziano's suggestion that each of the original high "mass" $q\bar{q}$ pairs "decays" into a planar jet [17]. To go further I have to specify the "cylinder kernel".

Suppose that the cylinder kernel is chosen as C_j, the nonsingular function of eq. (1). Then the multiperipheral equation for the cylinder, with the planar amplitude added, is exactly eq.(1). Every t-channel cut goes through quarks. Since eq.(1) is the equation that generates the P-f identity, I have shown my first claim. THE POMERON-f IDENTITY IS CONSISTENT WITH THE EXISTENCE OF A GLUEBALL IN QUARKLESS QCD. What has happened is that the unitarization of this glueball has been chosen in such a way as to produce the P-f identity. Specifically, the unitarization of the cylinder turns the double planar f pole due to the f-dominated residues of the original glueball Pomeron into a planar f pole with a negative residue, which cancels the planar f in T_j^{Pl}. Technically, one should take note of the fact that it is the physical s-channel discontinuity which builds up the physical j-plane amplitude through the Froissart-Gribov formula. Because the non-unitarized and unitarized cylinder discontinuities are different (containing two $q\bar{q}$ pairs and many $q\bar{q}$ pairs, respectively), the non-unitarized glueball partial wave amplitude is different from the physical partial wave amplitude T_j. Thus there are important details which must depend on the quark loop dynamics, like the above negative residue planar pole in the cylinder. Another example is flavoring, which I have argued must occur and is clearly a quark-mass dependent effect. Those who would like to use color confinement to argue that the leading cylinder j-plane pole intercept shouldn't change much under unitarization have a built-in argument for saying that the P-f intercept should be around one. I do not believe that argument is a-priori reasonable, simply from the above observation regarding the Froissart-Gribov formula. Therefore I must rely on counting arguments like those of H. Lee and Veneziano or the more sophisticated computer calculations of Chan et al. [3] to say that the output P-f intercept should be around one,

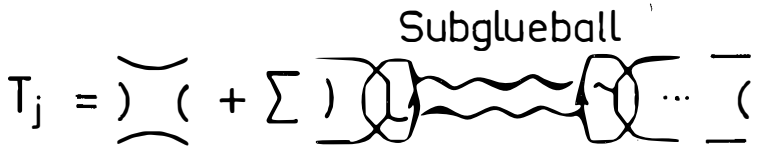
the details being fixed by the necessity of being consistent with both low energy BNL data [8] and with flavoring [5] as described in the previous section on P-f phenomenology.

So far I have shown that one can have the QCD glueball in one limit, the nonunitarized quarkless limit, and the P-f identity in the real world once quarks are added. I will now argue that this is in fact the most reasonable solution. While it is formally possible to construct solutions that look rather like the P+f model, I will show that something always goes wrong - particle multiplicities are too small, the f does not have the properties that would be expected in the P+f model, short range order is violated, or double counting errors are committed.

To construct a solution that looks like the P+f model is at first glance easy. Instead of choosing the cylinder kernel as the nonsingular C_j kernel which generates the P-f identity, one chooses to have the possibility that some transitions between planar amplitudes on the cylinder take place through the intermediary of glueball transitions across the appropriate subenergies, leading to t-channel cuts through glue. To avoid confusion in terminology, I will call these transitions subglueball transitions. By consistency, the partial wave projection of each subglueball transition is just C_j^{glue} with its pole at $j = \alpha^x$. The relevant partial wave equation is now

$$T_j = T_j^{Pl} + T_j^{Pl}(g\, C_j + g_{glue}\, C_j^{glue})\, T_j \qquad (7)$$

Upon iteration T_j now looks like this :



THE AMPLITUDE T_j OF THE SINGULAR EQUATION (7)

It is trivial to see that T_j indeed has two high lying poles. The glueball has been iterated through subglueball transitions interspersed between nonsingular C_j transitions, and the result is just a splitting of the two input glueball and planar poles to form two output poles that one may be tempted to call the P and f. This possibility, raised by a number

of authors, is formally similar to the old Schizophrenic Pomeron model of Chew and Snider [18]. We now point out the problems associated with this point of view.

P+f PROBLEM ONE : THE HADRON MULTIPLICITY IS TOO SMALL IF $\alpha^* = 1$.

Suppose that the glueball - and subglueball - intercept α^* is one (or around one). The problem, as hinted at before, is that each subglueball transition requires a lot of phase space. Given the total cross section $\sigma \approx \beta s^{\alpha-1}$, it is easy to see that the average number of subglueball transitions $\langle n_{sgb} \rangle$ satisfies

$$\langle n_{sgb} \rangle \approx (\alpha - \alpha^*) \ln s < 1/10 \ln s \qquad (8)$$

where I have used the experimental information that $\alpha < 1.1$. Thus at present energies, internal consistency and the total cross section requires there to be mostly only one (!) subglueball, which generates a large rapidity gap across the entire kinematic region. Thus, little phase space is available to produce $q\bar{q}$ pairs on either side of the subglueball transition. This means that the hadron multiplicity $\langle n \rangle$ is much too small, i.e. $\langle n \rangle \approx \epsilon \ln s$ where $\epsilon << 3$, the experimental value.

There are at least three examples of this of which I am aware. The first is the Schizophrenic Pomeron model [18], where the subglueball formally is a logarithmic cut near $j = 1$. Many calculations were done, typically producing $\langle n \rangle / \ln s \approx \frac{1}{2}$ [18,19]. A second example is the QED - based model of Cheng, Wu, and Walker [20]. Here the glueball is composed of two photons. Hence $\alpha^* = 1$, there are two hadrons between each subglueball, $\alpha = 1.08$, and so $\langle n \rangle / \ln s \approx 1/6$. A third example [16] is the phenomenology done by Pinsky and Snider [21], who fit σ using eq.(7) with $g = 0$. If we take one particle between subglueball transitions, then $\langle n \rangle / \ln s \approx 1/7$. In this last example the subglueball intercept was well below one ($\alpha^* = 0.85$), but even so the particle multiplicity is too small. Finally, Nussinov's "dressing-up of the Pomeron" [15] is also given by eq.(7), but as he did not bother to calculate multiplicities, he did not see the problem.

This $\langle n \rangle$ problem shows that the t-channel unitarity content of the Pomeron cannot contain any substantial pure-glue component if $\alpha^* \approx 1$, as is the case for the P+f model. Instead, the t-channel content of diffraction must be made up predominately of quarks, as is the case in the P-f identity. Calculations [3] show that no $\langle n \rangle$ difficulties are encountered in the P-f

identity.

P+f PROBLEM TWO : The f DOES NOT LOOK LIKE THE f OF THE P+f MODEL.

This problem arises under the following hypotheses. One imagines, that regardless of the possible value $\alpha^* = 1$ of the original glueball, the subglueball intercept is not 1 , but less than one. This may occur, because there may be additional renormalization effects of the quarkless QCD glueball due to quark loops which are not cut by the s-channel discontinuity [22], and so have not been explicitly included so far. How big this effect can be is a matter of conjecture in one sense, but we can be pretty sure from the above argument about multiplicities that if the subglueball really exists as a separate cylinder kernel its intercept must be $\alpha^* < \frac{1}{2}$. Still eq.(7) generates two poles. Now, however, the Pomeron is mostly the shifted planar f shifted using C_j as in the P-f identity and is mostly made up of quarks in the t-channel, while the putative output "f" will have a large glue component [17].

However, an "f" with a large glue component has all the wrong properties. The f of the P+f model is supposed to be planar and ideally mixed to a good approximation. However glue is inherently a cylindrical concept and a flavor singlet. It is also worth pointing out that an output "f" intercept near $\frac{1}{2}$ would, under the circumstances, be accidental. Actually it is quite unlikely since the input planar pole in T_j^{pl} at $\frac{1}{2}$ will repel any output pole in T_j well away from $\frac{1}{2}$.

In fact I believe that the only sensible result of this kind is an output glueball trajectory, after quark mixing, with intercept below zero. This is then quite consistent with the P-f identity.

P+F PROBLEM THREE : SHORT RANGE ORDER IS VIOLATED OR MULTIPLE COUNTING ERRORS ARE COMMITTED.

These errors are to be found in at least two papers [23, 24].

First, imagine that what I have called a "subglueball", composed only of glue (and perhaps uncut quark loops) is actually an intermediate quantity like a big "glueball resonance" which "later" decays into quark pairs which appear in the s-channel unitarity sum. Such a "decay" will of course have to be multiperipheral and cylindrical topologically in order to retain short range order. Hence, "subglueball decay" is indistinguishable in character

from the multiperipheral cylindrical structure which came from the original glueball and on which I have been basing the whole discussion. Thus one obtains nothing new by letting subglueballs "decay". If subglueballs "decay" into iterates of C_j then all final states are obtained by iterating C_j, and this simply produces eq.(1) and the P-f identity. If subglueball decays also include glue (as "sub-subglueballs"), one merely obtains eq.(7) as generating all final states. Hence there is really nothing to discuss ; the earlier treatment is complete.

However, ref.(23) imagines all $\alpha^* \approx 1$ subglueball decays to occur nonmultiperipherally, and so irreducibly with respect to C_j iterations. This is accomplished technically with the aid of a "minimum rapidity length" which stretches across the subglueball, and is introduced to avoid double counting. Double counting is indeed avoided. However, because each subglueball uses up so much phase space, the assumed nonmultiperipheral subglueball decay immediately results in all final states being dominated by non-multiperipheral configurations. But nonmultiperipheral final states are tantamount to dominant long range order, violating the data.

A second (and related) way that short range order can be violated is not to recognize that topologies of higher order than the cylinder generate j-plane cuts. These higher order topologies are also responsible for producing all the correct analyticity properties of multiparticle amplitudes, but dominant short range order (and the topological expansion) tells us that these are small effects at current energies. Clearly, if one is investigating the properties of the bare Pomeron pole before adding cuts (as we are), one should make sure not to include these higher topologies.

I close with a discussion of multiple counting errors. These occur under the following situation. Imagine starting with final states on the cylinder, all generated by C_j iteration. As I have said, this produces eq.(1) and the P-f identity. However, ref.(24) effectively tries to reorganize these final states as if they originated from $\alpha^* \approx 1$ subglueball decays, which makes eq.(7) and a P+f solution look relevant. The point is, this identification cannot be done uniquely, and multiple counting errors are thus committed. Technically, ref.(24) divides C_j into contributions from low and high rapidity gaps in its defining Froissart-Gribov integral, but this does not prevent the multiple counting errors. The point is simple. A nonsingular equation like eq.(1) cannot generate solutions to a singular equation like eq.(7) regardless of how one tries to rearrange things.

SUMMARY OF SECTION VI

There may indeed be a glueball in quarkless QCD with intercept one. However, because of unitarity the final result for the diffractive amplitude can be different from what one might expect. I have argued that after unitarization due to quark loops that a possible result -and the most plausible result- is the P-f identity, and not the traditional P+f model.

VII. CONCLUSIONS

QCD may or may not provide the fundamental theory of strong interactions. Unfortunately, present techniques preclude a realistic QCD calculation of diffraction scattering. Regardless, the ultimate character of diffraction must pass the test of unitarity. While this is notoriously difficult to incorporate, a major step forward has been taken with the topological expansion.

I have argued that the model of diffraction best consistent with unitarity is the Pomeron-f identity model. The quark loop unitarization of a QCD glueball is formally consistent with the P-f identity. Phenomenologically, the P-f identity is in good shape. An especially important point in this regard is the flavoring renormalization of the P-f , which arises from the requirement of consistency through unitarity with inelastic production of particles with different quantum numbers.

The P+f model, though steeped in tradition, suffers from three major flaws. These are (1) Modern P+f fits strongly violate two component duality, (2) The usual P+f model is incompatible with flavoring, and (3) Quark-loop unitarization of a QCD glueball probably cannot produce the P+f model (with the P containing glue in the t-channel) and be consistent with short range order and with observed hadron multiplicities.

I have concentrated in this paper on the short range order amplitude, whose j-plane projection is pole dominated. J-plane cut corrections, provided by the Reggeon Field Theory, are small effects at accessible accelerator energies. At superasymptotic energies where local scales, like the flavoring scales, become negligible the RFT scaling laws could become applicable. However, we should avoid complacency. Hints of big surprises at cosmic ray

energies exist. It may be that all present concepts of diffraction scattering are relevant only in a limited energy regime [25]

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