In many ways the pomeron is like the photon, but there are important differences. Factorisation allows us to define a pomeron structure function, even though the pomeron is not a particle. Although we have a model for the light-quark content of the pomeron, which led to the prediction that a surprisingly large fraction of events at HERA would have an extremely-fast final-state proton, its charm and gluon content will have to be got from experiment. Because the pomeron is not a particle, we cannot derive a momentum sum rule.

Definition of the pomeron structure function

This introduction to the pomeron structure function applies to the soft pomeron, whose exchange is responsible for the $s^{0.08}$ rise in total cross-sections\cite{1}. See for example figure 1, which shows the $\gamma p$ cross-section: the curve is the sum of an $s^{0.08}$ term corresponding to the soft pomeron and an $s^{-0.45}$ term corresponding to $(\rho, \omega, f_2, a_2)$ exchange. I do not know to what extent my discussion may apply to any other pomeron, whether it be a less soft one\cite{2}\cite{3} or a hard one\cite{4}.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{$\gamma p$ total cross-section.}
\end{figure}

The data for elastic scattering and diffraction dissociation in $pp$ and $\bar{p}p$ collisions are described extremely well\cite{5} by supposing that soft pomeron exchange is similar to photon exchange. For photon exchange between a pair of quarks, the amplitude is

$$\gamma \cdot \gamma e^2 \left[ \frac{1}{t} \right]$$

while for soft pomeron exchange it is

$$\gamma \cdot \gamma \beta_0^2 \left[ (\alpha'(s)^{\alpha'(t)-1} \xi_{\alpha(t)} \right]$$

Thus the charge $e$ is replaced by a constant pomeron coupling $\beta_0 \approx 2\text{GeV}^{-1}$, and the photon propagator is replaced by the expression in square brackets which is something like a pomeron propagator. Here

$$\alpha(t) = 1 + \epsilon + \alpha't$$

\*Based on talks given in April 1995 at Photon '95 (Sheffield) and DIS '95 (Paris)
and $\xi_0$ is a phase factor $-e^{\frac{1}{2}i\pi\alpha}$.

Although photon and pomeron exchange have similarities, there is a crucial difference. The photon propagator has a pole at $t = 0$ because there is a real zero-mass photon, but there is no pole at $t = 0$ in the pomeron propagator because the pomeron is not a particle. We do expect to find a $2^{++}$ particle, probably a glueball, with mass $m$ such that $\alpha(m^2) = 2$, but this particle would have $m \approx 1.9$ GeV and so it has no direct influence on the properties of pomeron exchange near $t = 0$. (However, it is interesting that the WA91 collaboration has reported a $2^{++}$ glueball candidate with just this mass$^6$.)

Consider now the proton structure function $F_2^\text{proton}$. Being related to the total $\gamma^*p$ cross-section, it corresponds to a sum over all possible final states. In some small fraction of events, there is an extremely fast proton in the final state$^7$. Such events contribute to $F_2^\text{proton}(x, Q^2)$ a part which we call $F_2^\text{diss}(x, Q^2)$. In order to define this we must decide what we mean by an “extremely fast” proton, that is we must specify the maximum fraction $\xi$ of its longitudinal momentum we allow it to lose to include the event. Alternatively, rather than summing over $\xi$ up to some maximum value, we may introduce $\xi$ as an extra variable into $F_2^\text{diss}$, and in fact it is useful to introduce also the momentum transfer $t$ between the initial and final protons: $F_2^\text{diss} = F_2^\text{diss}(x, Q^2, \xi, t)$.

This definition of $F_2^\text{diss}$ does not mention the pomeron. By interpreting it in terms of pomeron exchange we find that it has some simple properties: it is leading twist (and so varies only slowly with $Q^2$), and it factorises$^8$.

![Figure 2](image-url)

Figure 2: The parton model: (a) $F_2^\text{proton}$ (b) $F_2^\text{diss}$ and (c) $F_2^\text{pomeron}$. The black lines represent the pomeron.

In the simple parton model$^9$, which is a good approximation at not-too-large $Q^2$, $F_2^\text{proton}$ corresponds to the diagram in figure 2a. The lower bubble is the amplitude that gives the probability of finding a quark in the proton. It includes all possible nonperturbative contributions. In drawing figure 2a I have used the optical theorem: if we cut the diagram down the middle we reveal the final states. A part of the bubble corresponds to those final states that contain an extremely fast proton, and if we take that part we obtain the diagram of figure 2b. As I have said, this part is leading twist.

The thick lines represent the pomeron. The momentum it carries away from the proton is just $\xi p + \ldots$. In recognition of this it is nowadays usual to rename $\xi$ and instead call it $x_P$. Soft pomeron exchange has a factorisation property, which yields

$$\frac{d^2}{dt dx_P} F_2^\text{diss}(x, Q^2, x_P, t) = F_{EP/p}(t, x_P) F_2^\text{pomeron}(\beta, Q^2, t)$$

$$\beta = x / x_P$$

$$F_{EP/p}(t, x_P) = \frac{9\beta_0^2}{4\pi^2} [F_1(t)]^2 x_P^{1-2\alpha(t)}$$

Here $F_1$ is the Dirac elastic form factor of the proton.
Momentum sum rule

We may regard $F_{p/P}(t, x_P)$ as the flux of pomeron emissions by the proton, and $F_{pomeron}^2$ as the structure function of the pomeron. In the parton model, $F_{pomeron}^2$ is just the upper part of figure 2b, drawn in figure 2c. Figure 2c looks just like figure 2a, with the initial-state proton apparently replaced by an initial-state pomeron. However, there is no particle called the pomeron; figure 2c rather makes sense because of the factorisation property (3).

In fact, because there is no pomeron particle near $t = 0$, this factorisation is not uniquely defined. I think that (3) is the most natural way to define it[8], but we could just as well multiply one of the factors in (3) by any number $N$ and the other by $1/N$. Indeed, the choice $N = 1/\pi$ is found in the literature[10][2]. Because of this ambiguity, one cannot derive a momentum sum rule for $F_{pomeron}^2$: if such a sum rule were to be satisfied for some choice of $N$, obviously it would not be for any other choice. One cannot derive a momentum sum rule because the pomeron is not a particle.

Simple model for the pomeron structure function

I have said that the pomeron in some ways resembles the photon, and so one expects that it has a quark structure function something like that of the photon, in that it consists of two pieces at not-too-large $Q^2$: one that can be calculated from a simple box diagram and another that is not calculable and is most important at small $\beta$.

![Figure 3: (a) box contribution to $F_{pomeron}^2$. The black lines represent the pomeron. (b) the equivalent when pomeron exchange is modelled by two-gluon exchange.](image-url)

The box contribution corresponds to figure 3a. The simplest model for pomeron exchange is that it corresponds to the exchange of a pair of nonperturbative gluons[11]. Then figure 3a becomes the sum of the two diagrams in figure 3b. Together these give[8][12]

$$\beta q_{pomeron}^2(\beta) = C \beta (1 - \beta)$$

(5)

where $C \approx 0.2$ for each light quark and each light antiquark. This formula provided the remarkable prediction, nearly 10 years ago[8], that some 10% of HERA events would have a very fast final-state proton.

The other piece[8] of the pomeron quark structure function resembles the $q$-like contribution to the photon structure function, and so is most important for small $\beta$, where it behaves as $\beta^{-\epsilon}$. If $\beta$ is not too small, one expects that $\epsilon = 0.08$, as for the proton structure function[13]. But for extremely small $\beta$ one would expect the same to happen as with $F_{proton}^2$, and see a marked increase in the effective value of $\epsilon$.

Scaling violation and related issues

Even though the pomeron is not a particle, the factorisation that leads to figure 2c makes it natural[8][14] to write an evolution equation for $F_{pomeron}^2$ similar to that for $F_{proton}^2$, as if the pomeron were the initial state. For this, one needs an input gluon distribution $q_{pomeron}^2(\beta)$ at some initial $Q^2$ value. One might guess that its shape is not too different from that of $q_{pomeron}^2(\beta)$, but this is just a guess. Further, we have no model that tells us how large it is. Experiment will be important here, for example high-$p_T$ jet production in real-photon diffractive events, the analogue of the UA6 experiment at the CERN $\bar{p}p$ collider[15].
We also need to know what is the initial charmed-quark content of the pomeron. Again we have no reliable model, and so experiment will be important. The coupling of the pomeron to quarks could be rather flavour-blind, so that the c-quark content might be quite large even at quite small $Q^2$, but even if the coupling is flavour-blind there may be a suppression because of the mass$^{[12]}$. We do not know.

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