ELASTIC SCATTERING AND DIFFRACTION DISSOCIATION

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High energy elastic and inelastic scattering at small t are discussed in terms (where relevant) double pomeron exchange, which allows an almost parameter free description of various elastic processes and of diffraction dissociation. The role of 3-gluon exchange in making pp and pp elastic scattering differ in the dip region at high energy is discussed briefly.

An interesting feature of total cross sections is the additive quark rule. It is found experimentally that to within about 10%

$$\sigma_{\text{Tot}}(\pi p) \simeq \sigma_{\text{Tot}}(\rho p) \simeq \frac{2}{3} \sigma_{\text{Tot}}(pp)$$
(1)

and the rule works equally well for strange mesons and baryons if it is assumed that strange quarks scatter rather more weakly. Thus total cross sections seem to be the incoherent sum of the separate quark-quark cross sections where the participating quarks are the valence quarks of the two particles.

At high energy the total cross section is dominated by pomeron exchange, so the additive quark rule implies that the pomeron couples mainly to the separate quarks of a hadron rather than coherently to the whole hadron. As the coupling counts the number of quarks it is of γ_{μ} type, which means that the pomeron couples to quarks rather like an isoscalar photon with a more-or-less constant γ_{μ} coupling, but with a regge signature factor which gives it even C-parity^{1,2)}. The coupling involves the two Dirac isoscalar form factors $F_1(t)$ and $F_2(t)$, the latter corresponding to helicity flip of the nucleon. However in the isoscalar channel $F_2(t)$ is small, so the experimental fact that the pomeron shows very little helicity flip is correctly predicted.

If we neglect the small helicity flip term, then for pp or \overline{pp} elastic scattering single pomeron exchange gives²

$$\frac{d\sigma}{dt} = \frac{\left\{3\beta F_{1}(t)\right\}^{4}}{4\pi} \left[\frac{s}{m}\right]^{2\alpha_{p}(t)-2}$$
(2)

where β is the strength of the pomeron's coupling to a quark and α_p (t) is the pomeron trajectory. The latter is chosen to be linear

$$\alpha_{\rm p}(t) = 1.08 + 0.25t$$
 (3)

which is sufficient for the values of t being considered³⁾. The value of the intercept $\alpha_n(o)$ gives a good description of the rising total cross section.

In comparisons with accurate data it turns out that double pomeron exchange cannot be neglected even at small t, particularly at collider energies. Although there is no well-founded procedure for calculating the two-pomeron term, the eikonal formalism provides a convenient framework for specifying the t- and s-dependence. The normalisation can be chosen^{3,4)} to provide the dip observed in p-p elastic scattering at ISR energies, this arising primarily from a

cancellation between the imaginary parts of the pomeron and two-pomeron terms.

With the two pomeron term included, the required value of β is given by

$$\beta^2 = 3.43 \text{ GeV}^{-2}$$
 (4)

Using the dipole form for $G_m(t) \simeq \mu G_{\overline{R}}(t)$, then

$$F_{1}(t) = \frac{4m^{2} - 2.79t}{4m^{2} - t} \frac{1}{(1 - t/0.71)^{2}}$$
(5)

Figure 1 shows the calculation⁴⁾ of single-pomeron exchange (broken line) and the effect (solid line) of including two-pomeron exchange at the collider energy, together with the elastic scattering data from UA4⁵⁾. The calculated total cross section is 62.5 mb in good agreement with the latest UA4 measurement⁵⁾ of 62.7 ± 2.1 mb (assuming $\rho = 0.15$).

Formula (2) may be modified to describe single pomeron exchange for any hadron-hadron elastic scattering process. For example, for p-d elastic scattering $4^{(4)}$

$$\frac{d\sigma}{dt} = \frac{\left\{3\beta F_{1}(t)\right\}^{2} \left\{6\beta A(t)\right\}^{2}}{4\pi} \left[\frac{s}{m}\right]^{2\alpha_{p}(t)-2}$$
(6)

where we have made the small-angle approximation in which the deuteron has only one electromagnetic form factor A(t). This has been measured⁶⁾, and using it in equation (6) yields the black points of Fig. 2. The error bars on those points are due to the experimental errors in A(t). The open points in the figure are p-d elastic scattering data from two ISR experiments⁷⁾.

Another example is provided by π -p elastic scattering, for which the single-pomeron exchange contribution is

$$\frac{d\sigma}{dt} = \frac{\left\{3\beta F_{1}(t)\right\}^{2} \left\{2\beta F_{\pi}(t)\right\}^{2}}{4\pi} \left[\frac{s}{m^{2}}\right]^{2\alpha p(t)-2}$$
(7)

where $\textbf{F}_{\pi}\left(t\right)$ is the electromagnetic form factor of the pion. The assumption that this is given by

$$F_{\pi}(t) = \frac{1}{1 - t/0.71}$$
(8)

produces the curve shown in Fig. 3. The data are from reference 8.

Another application of the pomeron-photon analogy is to diffraction dissociation, in which one nucleon scatters elastically while the other breaks up into a system of large invariant mass M. The pomeron-photon analogy relates²⁾ the diffraction dissociation cross section to that of deep inelastic scattering:

$$\frac{s}{\pi} - \frac{d^2 \sigma}{dt \ dM^2} = \frac{9\beta^4 \{F_1(t)\}^2}{4\pi^2} \left[\frac{s}{M^2}\right]^{2\alpha_p(t)-1} \left[1 - \frac{M^2}{s}\right] \tilde{F}_2$$
(9)

 \tilde{F}_{2}^{ν} is related to the deep inelastic structure function vW_{2} :

$$vW_2^{ep} = x\{\frac{4}{9}(u + \overline{u}) + \frac{1}{9}(d + \overline{d}) + \frac{1}{9}(s + \overline{s})\}$$

$$\tilde{F}_2 = x\{u + \overline{u} + d + \overline{d} + \lambda(s + \overline{s})\}$$
(10)

where u, \overline{u} ... are the quark densities and λ measures the reduced strength of the pomeron's coupling to strange quarks. With $-t = \rho^2$, the usual Bjorken variable is defined by

$$\mathbf{x} = \varrho^2 / (\varrho^2 + M^2) \simeq \varrho^2 / M^2$$
 (11)

and we can write

$$xu = S(x) + 2V(x) xd = S(x) + V(x)$$

$$\overline{Xu} = x\overline{d} = S(x) xs = x\overline{s} = \frac{1}{2}S(x)$$
(12)

A combination of electron, muon and neutrino scattering data can be used to obtain a suitable parametrisation of S(x) and V(x), with the small-x behaviour controlled by regge theory. Assuming that the difference in shape between the valence contributions is unimportant at small x, appropriate forms are⁴⁾

$$S(x) = 0.17 x^{-.08} (1 - x)^{5}$$

$$V(x) = 1.33 x^{0.56} (1 - x)^{3}$$
(13)

In addition to needing the quark densities at small x, they are required at small ϱ^2 . Experimental constraints on this are provided by the measurement⁹⁾ of vW_2^{ep} for $o < \varrho^2 < 1.5 \text{ Gev}^2$ and by the real photon-proton cross section¹⁰⁾, since the latter is given by

$$\lim_{Q^2 \to 0} \left\{ \frac{4\pi\alpha}{Q^2} \quad \forall W_2 \right\}$$
(14)

These constraints cam be accomodated by multiplying $S\left(x\right), \, V\left(x\right)$ respectively

$$\Phi_{\rm g}(Q^2) = \left(\frac{Q^2}{Q^2 + 0.36}\right)^{1.08}, \ \Phi_{\rm V}(Q^2) = \left(\frac{Q^2}{Q^2 + 0.85}\right)^{.44}$$
(15)

The contribution from S(x) corresponds to the tripple-regge term $\begin{bmatrix} P & P \\ p \end{bmatrix}$ while that from V(x) corresponds to $\begin{bmatrix} P & P \\ f \end{bmatrix}$. These are non-negligible contributions in which either or both of the upper pomerons is replaced by the f. This can be incorporated by multiplying equation (9) by

$$1 + 2C\left[\frac{M^{2}}{s}\right]^{a(t)} \cos\{\frac{\pi}{2} \ a(t)\} + c^{2}\left[\frac{M^{2}}{s}\right]^{2a(t)}$$
(16)

with C \approx 7.8⁴⁾. Here a(t) is the difference between the pomeron and f trajectories. Typical results of this calculation are shown in Fig. 4, in comparison with ISR¹¹⁾ and collider data¹²⁾.

Finally, let us turn briefly to elastic scattering at larger values of t. At sufficiently high values, say for $|t| > 4 \text{ Gev}^2$, lowest order perturbative QCD works well¹³⁾, the amplitude being dominated by 3-gluon exchange. This is still important in the dip region. At the dip in p-p elastic scattering at ISR energies, while the imaginary parts of the single and double pomeron exchange terms can be made to cancel, the real parts cannot, since the phases are substantially different. The sign of the 3-gluon exchange term in p-p scattering is such that it cancels most of the residual real part from single and double pomeron exchange 3,14 .

However, 3-gluon exchange has negative C-parity, so it has the opposite sign in \overline{p} -p scattering. Thus in \overline{p} -p scattering it does not help to give the dip: in fact it fills it in so that at ISR energies and above it is predicted³⁾ that elastic scattering does not have a dip. The UA4 collaboration finds¹⁵⁾ that there is indeed no dip at the collider, but on this basis alone one cannot say whether \overline{pp} is different from pp. It is conceivable that the lack of a dip is simply because the collider has a higher energy than the ISR¹⁶⁾. The correct interpretation can be determined by a comparison of p-p and \overline{p} -p elastic scattering in the dip region, at the same energy, a test which will be provided soon by the \overline{p} -p data from the ISR.

by

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Figure 1. Single pomeron exchange (broken line) and the effect of including two-pomeron exchange (solid line) at collider energies. The data are from UA4 $^{5)}.$



Figure 3. Prediction of $\pi\text{-}p$ scattering with the data from reference 8.



Figure 4. Typical predictions of diffraction dissociation in comparison with ISR11) and collider data $^{12)}.$