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The Regge Pole Model and Forward Elastic Data at High Energies—An Analysis

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Abstract

Using σ_{tot}, Re/Im and relevant forward differential cross-section data up to the highest available energies we determine the P, f, ρ, ω, A_2 intercepts and forward residues in πN, NN and KN scattering. We find evidence for low-lying contributions in the πN and NN non-flip amplitudes including the σ trajectory in the πN case. We also test various phenomenological notions like exchange degeneracy (EXD), ρ universality, ω universality etc. against our parameter values. Comparison is made with other works.

Introduction

The recent measurements of Carroll *et al.* (1979) constitute a substantial extension of the p_{lab} range over which measurements of various hadron–proton total cross sections were previously available. The availability of forward data over an extended p_{lab} range permits more stringent tests of high-energy models and phenomenological prejudices. Thus, it was only after measurements at FNAL had been made that it became possible to establish clearly that ρ–A_2 EXD is definitely broken (Bouquet and Diu 1975; Nakata 1978) and that Regge pole models with $\alpha_P(0) = 1$ are inadequate. Data over a wider energy region can also lead to the detection of hitherto unnoticed systematics and regularities. Thus, Lipkin (1975) noticed systematic departures of higher energy data from a two-component pomeron model and was able to explain all these by adding a third component. Joynson and Nicolescu (1977) have also been able to study regularities and systematics of hadronic total cross sections in a fresh way owing to the availability of new data at higher energies. In addition, new high energy data permit refinements in values of certain basic parameters in certain models such as the trajectory intercepts and residues in the Regge pole model. In this regard, Bouquet and Diu (1975) had attempted a comprehensive determination of the ρ, ω and A_2 intercepts using the then available forward data. However, recent measurements of total cross sections (Carroll *et al.* 1979), πN charge-exchange (Apel *et al.* 1979) and Re/Im data (see e.g. Burq *et al.* 1978) have become available since then necessitating a repetition of their work in the light of the new data. Furthermore, they did not address themselves to a determination of the pomeron (P) and f exchange parameters, which restricted them to only certain total cross-section *combinations*, while the total cross sections as well as Re/Im data remained untouched in their work. In this note we apply the Regge pole model to the total cross section as well as Re/Im measurements from $p_{\text{lab}} \approx 10$ GeV/c up to the highest energies at which data are available. Our main aim will be to test the Regge pole model in a unified way, to refine values of trajectory parameters where the model with conventional Regge contributions works, and to see what new contributions are needed where the conventional exchanges fail to reproduce the data satisfactorily. As a by-product we will also be able to shed light on the status of several phenomenological notions like EXD, universality etc. in the light of our calculations. We will start by determining the various trajectory intercepts by fitting cross-section data and then go over to Re/Im data. Finally we will discuss the various results and their implications for various phenomenological notions.

Trajectory Intercepts and Total Cross Sections

We shall, to begin with, consider the various trajectory intercepts as determined by fitting suitable total cross-section combinations. We note that, as P and f have the same quantum numbers, it is not possible to form total cross-section combinations in which they can be separated. On the other hand, the ρ, ω and A_2 trajectories correspond to different quantum numbers and their contributions to various total cross sections can be isolated by forming suitable combinations of the appropriate total cross sections. In addition, the ρ and A_2 intercepts can also be obtained from the forward differential cross sections for $\pi^-p \to \pi^0 n$ and $\pi^- p \to \eta n$ respectively. We shall first consider the ω, ρ and A_2 intercepts (and residues), since their contributions are easily isolated, and then we shall attempt a determination of the P and f contributions to the various systems.

ω Exchange

In several cases ω exchange can be isolated. The commonly used cases are

$$\Delta\sigma(\mathrm{Kp})+\Delta\sigma(\mathrm{Kn}) = 4\omega^{\mathrm{KN}}, \qquad \Delta\sigma(\mathrm{pp})+\Delta\sigma(\mathrm{pn}) = 4\omega^{\mathrm{NN}}, \tag{1a, b}$$

where

$$\Delta\sigma(x\mathrm{N}) \equiv \sigma_{\mathrm{tot}}(\bar{x}\mathrm{N})-\sigma_{\mathrm{tot}}(x\mathrm{N}). \tag{1c}$$

It is also well known that the ω *intercept* can, to a good approximation, be determined from the combinations (cf. e.g. Bouquet and Diu 1975)

$$\Delta\sigma(\mathrm{pd}) = 2\omega^{\mathrm{Nd}}, \qquad \Delta\sigma(\mathrm{Kd}) = 2\omega^{\mathrm{Kd}}. \tag{1d, e}$$

In these equations we define

$$\omega^{ij} \equiv (0\cdot 3893/2q\surd s)\beta_\omega^{ij}(0)\, s^{\alpha_\omega(0)}. \tag{1f}$$

The factor $0\cdot 3893$ arises because the cross sections are in mb. Here $\beta_\omega^{ij}(0)$ is the residue, at $t = 0$, of the ω contribution to the system ij. For the K(p)–deuteron data however, $\beta_\omega^{id}(0)$ is, strictly speaking, not the residue but the residue and a correction term; this however does not matter because in equations (1d) and (1e) we are interested only in the ω intercept. The relevant cross-section combinations in (1a), (1b), (1d) and (1e) are now available up to 310, 280, 280 and 310 GeV/c respectively (Galbraith *et al.* 1965; Denisov *et al.* 1973; Carroll *et al.* 1976, 1979). We have considered data for $p_{\mathrm{lab}} \geqslant 6$ GeV/c. In determining the ω intercept (and residues) we have first fitted each of the above combinations separately and then taken these data sets simultaneously. Each data set is in excellent agreement with the Regge pole model and yields almost the same intercept in each case. Our results are

		χ^2/pt
$\alpha_\omega(0) = 0\cdot461\pm0\cdot022$	$\beta_\omega^{\mathrm{KN}}(0) = 24\cdot121\pm2\cdot304$	26/25
$\alpha_\omega(0) = 0\cdot445\pm0\cdot017$	$\beta_\omega^{\mathrm{NN}}(0) = 81\cdot53\pm4\cdot57$	5·5/25
$\alpha_\omega(0) = 0\cdot468\pm0\cdot021$	$\beta_\omega^{\mathrm{Kd}}(0) = 63\cdot652\pm6\cdot233$	42·6/25
$\alpha_\omega(0) = 0\cdot450\pm0\cdot011$	$\beta_\omega^{\mathrm{Nd}}(0) = 212\cdot05\pm12\cdot605$	18·8/25

When fitted simultaneously the data yield

$$\alpha_\omega(0) = 0\cdot449\pm0\cdot001 \qquad \beta_\omega^{\mathrm{KN}}(0) = 25\cdot292\pm0\cdot276 \qquad \beta_\omega^{\mathrm{NN}}(0) = 81\cdot106\pm0\cdot131$$
$$\beta_\omega^{\mathrm{Kd}}(0) = 69\cdot833\pm8\cdot287 \qquad \beta_\omega^{\mathrm{Nd}}(0) = 212\cdot05\pm12\cdot605$$
$$\chi^2/\mathrm{pt} = 97\cdot3/100$$

From a somewhat similar analysis in a slightly smaller energy range ($p_{\mathrm{lab}} \leqslant 240$ GeV/c) Bouquet and Diu (1975) obtained $\alpha_\omega(0) = 0\cdot44\pm0\cdot01$. Our results are in close agreement with theirs.

ρ Exchange

There are several ways of determining the ρ intercept, the most obvious and commonly used being via the $\pi^{\pm}$p total cross-section differences and the forward differential cross sections for the charge exchange (CEX) reaction $\pi^-\mathrm{p} \rightarrow \pi^0\mathrm{n}$. In addition to this it is also possible to determine the ρ intercept by isolating the ρ contribution to the various kaon–nucleon and nucleon–(anti)nucleon total cross sections. The relevant expressions for these cases are

$$\Delta\sigma(\pi\mathrm{p}) = 2\rho^{\pi\mathrm{N}}, \tag{2a}$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t}(\pi^-\mathrm{p}\rightarrow\pi^0\mathrm{n})\,|_{t=0} = \frac{389\cdot3}{64\pi sq^2}\Big(\tan^2\{\tfrac{1}{2}\pi\alpha_\rho(0)\}+1\Big)\,2\{\beta_\rho^{\pi\mathrm{N}}(0)\}^2 s^{2\alpha_\rho(0)}, \tag{2b}$$

$$\Delta\sigma(\mathrm{Kp})-\Delta\sigma(\mathrm{KN}) = 4\rho^{\mathrm{KN}}, \qquad \Delta\sigma(\mathrm{pp})-\Delta\sigma(\mathrm{pn}) = 4\rho^{\mathrm{NN}}, \tag{2c, d}$$

where, as in equation (1f),

$$\rho^{ij} = (0\cdot3893/2q\surd s)\beta_\rho^{ij}(0)\,s^{\alpha_\rho(0)}. \tag{3}$$

We have attempted a determination of the ρ intercept by first treating these data sets individually and then collectively, as in the ω case. Both approaches lead to difficulties which are now well known. Further investigation leads us to include an additional contribution ρ' to overcome these difficulties. We discuss our results below.

It is well known (Leader and Nicolescu 1973; Barger and Phillips 1974; Joynson *et al.* 1975; Bouquet and Diu 1975; Nakata 1977, 1978) that problems arise when one considers the $\Delta\sigma(\pi\mathrm{p})$ and $\{\mathrm{d}\sigma(\pi^-\mathrm{p}\rightarrow\pi^0\mathrm{n})/\mathrm{d}t\}\,|_{t=0}$ data together for a determination of the ρ intercept. Taken separately, each of these quantities can be fitted reasonably with a ρ Regge pole but the intercept (and residue) values so obtained are quite different in the two cases (the difference is $\Delta\alpha_\rho \approx 0\cdot1$, a discrepancy of approximately 20%!). It is also now known (Bouquet and Diu 1975; Nakata 1977) that the Serpukhov data on $\Delta\sigma(\pi\mathrm{p})$ (Denisov *et al.* 1973) are out of line with the $\Delta\sigma(\pi\mathrm{p})$ measurements of Foley *et al.* (1967) and the Fermilab data (Carroll *et al.* 1976).

The same is true for the πN CEX data from Serpukhov (Bolotov *et al.* 1974*a*) and from other experiments (Stirling *et al.* 1965; Barnes *et al.* 1976; Apel *et al.* 1978). Initially we considered the various fits twice, firstly including the Serpukhov points and subsequently excluding them. This seemed to make practically no difference to the intercept values but the χ^2 values were inferior when the fits included the Serpukhov points. A similar conclusion was reached by Bouquet and Diu (1975) who then omitted the Serpukhov data in the final phases of their investigation. We shall do likewise. The results of our calculations are as follows, where the first and second lines for each quantity include and exclude the Serpukhov data respectively:

	$\alpha_\rho(0)$	$\beta_\rho^{\pi N}(0)$	χ^2/pt
$\Delta\sigma(\pi p)$	$0\cdot577\pm0\cdot010$	$8\cdot722\pm0\cdot444$	$2\cdot1$
	$0\cdot574\pm0\cdot008$	$8\cdot555\pm0\cdot488$	$1\cdot4$
$\{d\sigma(\pi^- p\to\pi^0 n)/dt\}\vert_{t=0}$	$0\cdot485\pm0\cdot004$	$12\cdot123\pm0\cdot241$	$2\cdot4$
	$0\cdot485\pm0\cdot006$	$12\cdot127\pm0\cdot424$	$1\cdot9$

The $d\sigma/dt$ data here involve extrapolation to $t = 0$. Bolotov *et al.* (1974*a*) have, in an appendix, quoted their values for this quantity (with error bars) and also those of an earlier experiment (Stirling *et al.* 1965). This is done by fitting the $d\sigma/dt$ data in a small range of $|t|$ (say $|t| \lesssim 0\cdot2$ (GeV/c)^2) by the expression, due to Phillips and Rarita (1965),

$$d\sigma/dt = (d\sigma/dt)|_{t=0}\,(1-gct)\,e^{ct}. \tag{4}$$

The physical meaning of g and c need not concern us here. The FNAL group (Barnes *et al.* 1976) do *not* give any error bars on their $(d\sigma/dt)|_{t=0}$ values and in fact have used a Regge pole type fit over a wide range of t to fit their data, as a by-product of which they get $(d\sigma/dt)|_{t=0}$ values. Apel *et al.* (1979) have used equation (4) to give a $(d\sigma/dt)|_{t=0}$ value (with error bars) for their 40 GeV/c measurements but have not quoted any values for their remaining measurements at 15, 20·2, 25 and 30 GeV/c. Therefore we have used (4) to determine the $(d\sigma/dt)|_{t=0}$ values for the remaining measurements of Apel *et al.* (1979) and for all measurements of Barnes *et al.* (1976). As a cross-check we find that our values for the data of Barnes *et al.* (1976) agree with theirs, within errors.

For the kaon–nucleon and nucleon(antinucleon)–nucleon data one has

KN data:	$\alpha_\rho(0) = 0\cdot489\pm0\cdot049$	$\beta_\rho^{KN}(0) = 7\cdot3111\pm1\cdot447$	(χ^2/pt $\approx 1\cdot7$)
N($\bar{N}$)N data:	$\alpha_\rho(0) = 0\cdot501\pm0\cdot005$	$\beta_\rho^{NN}(0) = 4\cdot111\pm1\cdot001$	(χ^2/pt $\approx 0\cdot9$)

These results merely confirm what has already been described and known for some time. The discrepancy in $\Delta\alpha_\rho(0)$ from the $\Delta\sigma$ and $d\sigma/dt$ data is much too large. As a first alternative, by carrying out a simultaneous fit to the various data sets one might hope to achieve a sort of 'compromise' value for $\alpha_\rho(0)$ (and $\beta^{\pi N}(0)$) with which to work. This approach yields:

	Including Serpukhov	Excluding Serpukhov
$\alpha_\rho(0)$	$0\cdot488\pm0\cdot003$	$0\cdot491\pm0\cdot003$
$\beta_\rho^{\pi N}(0)$	$11\cdot933\pm0\cdot211$	$11\cdot753\pm0\cdot173$
$\beta_\rho^{KN}(0)$	$7\cdot627\pm0\cdot427$	$7\cdot526\pm0\cdot200$
$\beta_\rho^{NN}(0)$	$4\cdot293\pm0\cdot141$	$4\cdot302\pm0\cdot149$
χ^2/pt	$2\cdot35$	2

Using the values of $\alpha_\rho(0)$ and $\beta_\rho^{\pi N}(0)$ in the second column yields a value of $\chi^2/\mathrm{pt} \approx 3\cdot6$ for $\Delta\sigma(\pi p)$ (excluding Serpukhov). Despite giving an acceptable overall χ^2/pt for the second column this is not a 'compromise' value in the intended sense as the $\Delta\sigma(\pi p)$ data are not acceptably fitted by this value. Clearly an alternative approach is required. Henceforth we shall omit the Serpukhov points from our calculations following Bouquet and Diu (1975) and Nakata (1977) since their inclusion, while making practically no difference to the various parameter values, affects χ^2 quite adversely.

Difficulties with the ρ-exchange model in πN scattering have led people to add new terms to the non-flip amplitude. These terms either are non-Regge in character (see e.g. Bialkowski *et al.* 1975; Joynson *et al.* 1975) or are additional Regge singularities (Leader and Nicolescu 1973; Nakata 1978). We prefer the second, i.e. to work with Regge singularities, and hence use a $\rho+\rho'$ amplitude instead of the ρ. The ρ' is parametrized in exactly the same form as the ρ in equation (3). We first concentrate on the πN data alone to obtain the ρ and ρ' parameters and then use the resulting ρ intercept to fit the KN and N($\overline{\mathrm{N}}$)N data of (2c) and (2d). No ρ' contribution will be assumed in these latter cases. The ρ' is expected to be a low-lying trajectory whose parameters will hopefully give us some clue to its nature. Using a $\rho+\rho'$ amplitude for the πN data $\big(\Delta\sigma(\pi p)$ and $\{\mathrm{d}\sigma(\pi^- p\to\pi^0 n)/\mathrm{d}t\}|_{t=0}\big)$ resolves the discrepancy observed previously and one obtains

$$\alpha_\rho(0) = 0\cdot485\pm0\cdot001 \qquad \beta_\rho^{\pi N}(0) = 12\cdot184\pm0\cdot063$$
$$\alpha_{\rho'}(0) = -1\cdot745\pm0\cdot047 \qquad \beta_{\rho'}^{\pi N}(0) = -459\cdot28\pm3\cdot93$$
$$\chi^2/\mathrm{pt} = 2\cdot2$$

The χ^2/pt value, though not so good, is still acceptable for now we obtain fits comparable with both the $\Delta\sigma$ and $(\mathrm{d}\sigma/\mathrm{d}t)|_{t=0}$ CEX data and there is no longer a discrepancy in the $\alpha_\rho(0)$ values. Nakata (1978) obtained $\alpha_{\rho'}(0) = -1\cdot80$ which is very close to our value. It is quite tempting to identify our ρ' as a trajectory on which the first particle is $\rho'(1600)$ with an $I^G(J^P)C$ of $1^+(1^-)-$ and the next one T(2190) with quantum numbers $1^+(3^-)-$. Both these mesons are listed in the meson table of the Review of Particle Properties by the Particle Data Group (1978). Their masses are only known approximately and ρ' is quite wide ($\Gamma_{\rho'} \approx 300$ MeV). Allowing for these uncertainties it is possible to put them on a trajectory of intercept $-1\cdot745$ and having the universal slope $\alpha'_{\rho'} = 0\cdot9$. Such a trajectory then yields $m_{\rho'} = 1\cdot75$ and $m_{\mathrm{T}} = 2\cdot3$ GeV; quite close to the experimental values $\sim1\cdot6$ and $2\cdot19$ GeV respectively (the value of m_{T} is, according to the data tables, an 'educated guess'). Nakata (1978) did not make any physical identification of his ρ', probably because at the time of submission of his paper (June 1977) the 1978 review by the Particle Data Group had not appeared. The earlier reviews (see e.g. Particle Data Group 1976) did not regard these as established resonances. However, the physical identification of the ρ' exchange that we have made, although providing additional credibility, is not the reason for invoking it—the need for such a contribution arises in order to restore consistency between the $\alpha_\rho(0)$ values as obtained from the $\Delta\sigma(\pi p)$ and $\{\mathrm{d}\sigma(\pi^- p\to\pi^0 n)/\mathrm{d}t\}|_{t=0}$ data.

Using $\alpha_\rho(0) = 0\cdot485$ then gives the values

$$\beta_\rho^{NN}(0) = 5\cdot41\pm1\cdot0 \qquad \beta_\rho^{KN}(0) = 7\cdot497\pm0\cdot36 \qquad (\chi^2/\mathrm{pt} = 1\cdot5)$$

A_2 Exchange

The A_2 intercept can be determined from $\{d\sigma(\pi^-p\to\eta n)/dt\}|_{t=0}$ as well as from the combinations ($\sigma \equiv \sigma_{tot}$)

$$\sigma(K^+p)-\sigma(K^+n)+\sigma(K^-p)-\sigma(K^-n) = 4A_2^{KN}, \tag{5a}$$

$$\sigma(pp)-\sigma(pn)+\sigma(\bar{p}p)-\sigma(\bar{p}n) = 4A_2^{NN}, \tag{5b}$$

where we write

$$A_2^{ij} = (0\cdot3893/2q\sqrt{s})\beta_{A_2}^{ij}(0)\, s^{\alpha_{A2}(0)}. \tag{5c}$$

Of the combinations (5a) and (5b), the latter has been investigated in great detail in a series of papers by Bouquet *et al.* (1975, 1976) who found that the data on the LHS of (5b) lead to a contradiction between the FNAL and Serpukhov data. This in fact led them to question the procedure used at Serpukhov to extract $\sigma_{tot}(\bar{p}n, pn)$ data from p($\bar{p}$)–d collisions. The upshot of their investigation is that the cross sections have to be corrected, these new values leading to a startling contradiction with the standard Regge pole model. They found that the (corrected) data indicate that the term A_2^{NN} on the RHS of (5b) is *not*, as generally believed, simply the A_2 Regge pole contribution, but rather an ordinary A_2 Regge pole *and* another high-lying $I = 1$ term which contributes in opposition to A_2 and eventually dominates it. In view of this controversy we have confined ourselves to only $\{d\sigma(\pi^-p\to\eta n)/dt\}|_{t=0}$ data (available up to 199·3 GeV/c) and to kaon–nucleon data (now available up to 280 GeV/c). The forward differential cross-section data involve, as in the $\pi^-p\to\eta n$ case discussed earlier, extrapolation to $t = 0$. Bolotov *et al.* (1974*b*) quoted the extrapolated values (with error bars) not only for their measurements but also for some earlier experiments (Guisan *et al.* 1965). The FNAL group (Dahl *et al.* 1976) on the other hand did not quote any error bars on the forward differential cross-section values, which they obtained as a by-product of a Regge pole type fit to the data over the range $|t| \lesssim 1\,(\text{GeV}/c)^2$. We have used equation (4) to calculate the $(d\sigma/dt)|_{t=0}$ values, as for the πN CEX case. In determining the A_2 contribution for $\pi^-p\to\eta n$ at $t = 0$ we then fit the data by

$$\frac{d\sigma}{dt}(\pi^-p\to\eta n)|_{t=0} = \frac{389\cdot3}{64\pi sq^2}\left(\cot^2\{\tfrac{1}{2}\pi\alpha_{A_2}(0)\}+1\right)\{\beta_{A_2}^{\pi N}(0)\, s^{\alpha_{A2}(0)}\}^2. \tag{5d}$$

A simultaneous fit to the data involved in (5a) and (5d) then yields respectively two results of comparable χ^2:

	Solution 1	Solution 2
$\alpha_{A_2}(0)$	0·3475±0·002	0·3618±0·007
$\beta_{A_2}^{KN}(0)$	6·75±0·9	6·31±1·0
$\beta_{A_2}^{\pi N}(0)$	5·67±0·05	5·42±0·14
χ^2/pt	1·4	1·3

Bouquet and Diu (1975) found $\alpha_{A_2}(0) = 0\cdot36\pm0\cdot1$, which agrees with solution 2. Later we find that a better fit is obtained for $S(Kp) \equiv \sigma_{tot}(K^+p)+\sigma_{tot}(K^-p)$ if we employ solution 1. Our results for $\alpha_{A_2}(0)$ and $\alpha_\rho(0)$ indicate that the ρ–A_2 EXD is badly broken (by approximately 20%) so that it is unsafe to use the same intercept for ρ and A_2 as is widely done.

P and f Exchanges

Having determined the ω, ρ and A_2 intercepts, we now turn to the P and f exchanges. As noted earlier, it is not possible to form total cross-section combinations where the P and f are separated. In order to determine their intercepts, we proceed as follows. According to standard ideas one has the following total cross-section combinations where the P and f appear together:

$$S(\pi p) \equiv \sigma_{tot}(\pi^- p)+\sigma_{tot}(\pi^+ p) = 2[P+f]^{\pi N}, \tag{6a}$$

$$S(Kp) \equiv \sigma_{tot}(K^- p)+\sigma_{tot}(K^+ p) = 2[P+f+A_2]^{KN}, \tag{6b}$$

$$S(pp) \equiv \sigma_{tot}(\bar{p}p)+\sigma_{tot}(pp) = 2[P+f+A_2]^{NN}. \tag{6c}$$

One can also add S(pn) data to this list, but on account of the controversy surrounding the A_2 contribution to the NN system, owing to the difficulties with the σ_{tot}(pn) and $\sigma_{tot}(\bar{p}n)$ data referred to earlier (Bouquet *et al.* 1976), we have not done this in our calculations. This is a shortcoming about which we cannot at present do anything, because Bouquet *et al.* (1975, 1976) have not published their corrected values for σ_{tot}(pn) and $\sigma_{tot}(\bar{p}n)$. In equations (6) we write

$$P^{ij} = (0\cdot 3893/2q\sqrt{s})\beta_P^{ij}(0)\, s^{\alpha_P(0)}, \tag{7a}$$

$$f^{ij} = (0\cdot 3893/2q\sqrt{s})\beta_f^{ij}(0)\, s^{\alpha_f(0)}, \tag{7b}$$

while A_2^{ij} is the same as in (5c). We then fit the data on the LHS of equations (6) using the parametrization (5c), (7a) and (7b) for the various terms on the RHS. Here we note that while the A_2^{KN} contribution is known we do not know A_2^{NN} because of the previously mentioned difficulties. Hence we leave $\beta_{A_2}^{NN}(0)$ (cf. equations 5b, 5c) as a free parameter, but with $\alpha_{A_2}(0)$ fixed at a value obtained in the previous subsection (0·3618 or 0·3475). The data ($p_{lab} \geqslant 6$ GeV/c) have been taken from Foley *et al.* (1967), Galbraith *et al.* (1965), Carroll *et al.* (1976, 1979) and Denisov *et al.* (1973). (The πN data from Denisov *et al.* have been excluded.) The $S(\pi p)$ data are available up to 340 GeV/c while the S(Kp) and $S(\bar{p}p)$ data extend to 310 and 280 GeV/c respectively (see Fig. 1*a*). We find, somewhat surprisingly, that it is impossible to fit the $S(h$p) data satisfactorily using equations (6), (7) and (5c). Using $\alpha_{A_2}(0) = 0\cdot 3475$ and the corresponding $\beta_{A_2}^{KN}(0)$ value improves the result (very) slightly but the overall χ^2/d.f. values are still large. The best we could manage was χ^2/d.o.f. = 4·9 with the following values:

$\alpha_P(0) = 1\cdot 0738$	$\beta_P^{\pi N}(0) = 39\cdot 876$	$\beta_P^{KN}(0) = 33\cdot 043$	$\beta_P^{NN}(0) = 61\cdot 781$
$\alpha_f(0) = 0\cdot 434$	$\beta_f^{\pi N}(0) = 88\cdot 78$	$\beta_f^{KN}(0) = 30\cdot 56$	$\beta_f^{NN}(0) = 217\cdot 42$
$\alpha_{A_2}(0) = 0\cdot 3475$		$\beta_{A2}^{KN}(0) = 5\cdot 85$	$\beta_{A_2}^{NN}(0) = 0\cdot 1$

On closer scrutiny the problem seems to lie with the πN and NN data. We have even attempted separate fits to $S(\pi p)$ and S(pp) data allowing for different intercepts in the two cases but satisfactory fits are still not possible. This convinced us that the equations (6) (particularly 6a and 6c) are inadequate for describing $S(h$p) data. Hence the need for a new term on the RHS of (6a) and (6c). In the past a failure of the Regge model was always compensated for either by finding new Regge terms or by invoking non-Regge terms which are then used to either replace or complement

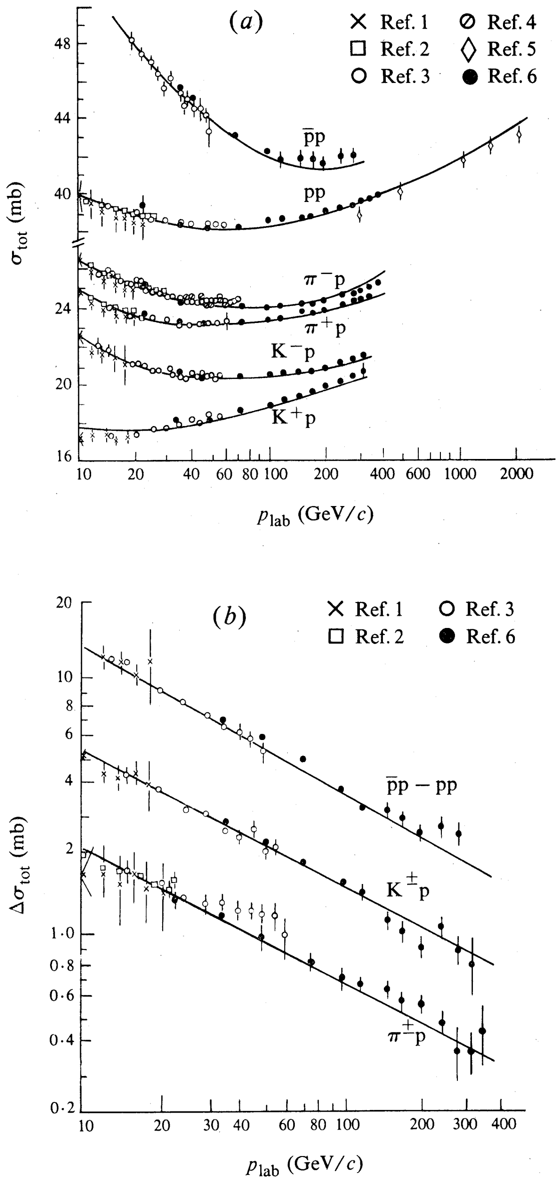

Fig. 1. Fits to (*a*) various hadron–proton total cross sections and (*b*) various total cross-section differences. Ref. 1, Galbraith *et al.* (1965); ref. 2, Foley *et al.* (1969); ref. 3, Denisov *et al.* (1973); ref. 4, Apokin *et al.* (1975); ref. 5, Amaldi *et al.* (1976); ref. 6, Carroll *et al.* (1976, 1979).

the Regge description. We will, as a first step, try to find a new Regge term whose inclusion might solve this difficulty. However, before attempting to do so one could explore the literature on the possibility of the presence of one or more additional Regge singularities in elastic amplitudes. Interestingly enough, Dash and Navelet (1976) proposed a new low-lying $I = 0$ crossing-even trajectory, which they called the σ ($\alpha_\sigma(0) = -0{\cdot}4$), in order to explain the anomalous energy dependence of pp polarization. The contribution of such a term was invoked only in the (single) flip amplitude ϕ_5. Soon afterwards Girardi and Navelet (1976) used a similar term ($\alpha_\sigma(0) = -0\cdot32$) in the πN flip amplitude to explain the departure of πp polarizations from mirror symmetry. Martin and Navelet (1978) have subsequently confirmed the need for such a trajectory (they use $\alpha_\sigma(0) = -0\cdot5$) in the flip amplitudes in elastic scattering. Earlier, Field and Stevens (1975), while analysing nucleon–nucleon data, found that one needs a *pair* of $I = 0$ trajectories of opposite signature and opposite C values ($C = \pm1$). They called these ε ($\tau = +1, C = +1$) and ϖ ($\tau = -1, C = -1$) trajectories ($\alpha_\varepsilon(0) = \alpha_\varpi(0) \approx -0\cdot5$). Their investigations indicated that ϖ couples strongly to the non-flip amplitude while ε couples strongly to the single-flip amplitude. Berger *et al.* (1978), while studying the implications of measurements of various spin observables at ANL, found that the ε and ω' (they denote ϖ by ω') contribute comparably with the non-flip amplitude. They pointed out however that there is some difficulty in reproducing the phase ρ(pp) correctly at lower energies. Irving (1979) has made similar observations on the model of Berger *et al.* It is clear therefore that a low-lying crossing-even isoscalar trajectory is needed in flip amplitudes for various elastic reactions. In addition, there is some mention of a $C = -1$ low-lying exchange of odd signature in the non-flip pp $\to$ pp amplitude. However, a trajectory (or trajectories) contributing to $S(h\mathrm{p})$ must have $C = +1$. We also note that no mention of such a low-lying trajectory in connection with the non-flip πp amplitude appears to have been made. With these points in mind we add another pole (say) $\sigma^{\pi\mathrm{N}}$ and σ^{NN} on the RHS of (6a) and (6c). We must bear in mind that the notation is misleading because we are, in using the same symbol σ in both cases, implying that the same object is exchanged in the πN and NN reactions. However, there is no strong reason to do so and the two terms could turn out to be entirely different in πN and NN scattering (in which case different symbols would have to be used for the two cases). In πN scattering one could expect this to be the crossing-even object σ or ε mentioned previously, but in NN scattering one could expect it to be a more complicated object. Writing

$$\sigma^{ij} = (0\cdot3893/2q\sqrt{s})\beta_\sigma^{ij}(0)\, s^{\alpha_\sigma(0)}, \tag{7c}$$

and fitting $S(\pi\mathrm{p})$, $S(\mathrm{Kp})$ and $S(\mathrm{pp})$ with equations (6) and (7), yields a drastic improvement in the results. We obtain an overall fit with $\chi^2/\mathrm{pt} \approx 1\cdot5$ and the following values ($\alpha_\mathrm{f}(0) \approx \alpha_\omega(0)$ according to these results):

$\alpha_\mathrm{P}(0) = 1\cdot0697$	$\beta_\mathrm{P}^{\pi\mathrm{N}}(0) = 38\cdot652$	$\beta_\mathrm{P}^{\mathrm{KN}}(0) = 33\cdot707$	$\beta_\mathrm{P}^{\mathrm{NN}}(0) = 62\cdot428$
$\alpha_\mathrm{f}(0) = 0\cdot4468$	$\beta_\mathrm{f}^{\pi\mathrm{N}}(0) = 89\cdot134$	$\beta_\mathrm{f}^{\mathrm{KN}}(0) = 31\cdot45$	$\beta_\mathrm{f}^{\mathrm{NN}}(0) = 233\cdot65$
$\alpha_{\mathrm{A}_2}(0) = 0\cdot3475$		$\beta_{\mathrm{A}_2}^{\mathrm{KN}}(0) = 5\cdot85$	$\beta_{\mathrm{A}_2}^{\mathrm{NN}}(0) = 1\cdot83$
$\alpha_\sigma(0) = -0\cdot5919$	$\beta_\sigma^{\pi\mathrm{N}}(0) = -148\cdot89$		$\beta_\sigma^{\mathrm{NN}}(0) = -1399\cdot8$

Since the $\sigma_{\mathrm{tot}}(\mathrm{pp})$ data extend far beyond the $S(\mathrm{pp})$ data ($\sigma_{\mathrm{tot}}(\mathrm{pp})$ extends to $p_{\mathrm{lab}} \approx 2092$ GeV/c compared with 240 GeV/c for $S(\mathrm{pp})$; see Fig. 1*a*), we have checked that our parametrization extrapolates correctly to the higher energy $\sigma_{\mathrm{tot}}(\mathrm{pp})$ data. We find that our parametrization reproduces $\sigma_{\mathrm{tot}}(\mathrm{pp})$ quite well for $6 \leqslant p_{\mathrm{lab}} \leqslant 2092$ GeV/c with $\chi^2/\mathrm{pt} = 1\cdot4$. However, fits to the total cross-section data do not tell us much about the nature of the new term. In particular, they do not tell us anything about its signature or the possibility that it might be made up of more than one pole. It is also quite possible that such a term is an 'effective' parametrization of some low-energy effects. However, one can hope that the various elastic phases $\rho(h\mathrm{p})$ might enable us to deduce something about the crossing property of such a term. Before turning to the Re/Im data though, we check how the various total cross sections $\sigma_{\mathrm{tot}}(h\mathrm{p})$ (where $h = \pi^{\pm}$, $\mathrm{K}^{\pm}$, p, $\bar{\mathrm{p}}$), as well as those combinations not dealt with previously $\big(\Delta\sigma(\mathrm{Kp})$ and $\Delta\sigma(\mathrm{pp})\big)$ are reproduced by our parameter values. We find the following χ^2/pt values for the various quantities:

$\sigma_{\mathrm{tot}}(\pi^+\mathrm{p})$	2·5	$\sigma_{\mathrm{tot}}(\mathrm{K}^+\mathrm{p})$	1·9	$\sigma_{\mathrm{tot}}(\mathrm{pp})$	1·4	$\Delta\sigma^{(\mathrm{Kp})}$	1·2
$\sigma_{\mathrm{tot}}(\pi^-\mathrm{p})$	2·9	$\sigma_{\mathrm{tot}}(\mathrm{K}^-\mathrm{p})$	1·6	$\sigma_{\mathrm{tot}}(\bar{\mathrm{p}}\mathrm{p})$	1·3	$\Delta\sigma^{(\mathrm{pp})}$	1·2

As may be seen the various quantities listed above are reproduced reasonably well except in the πp case, particularly $\sigma_{\mathrm{tot}}(\pi^-\mathrm{p})$. We find $\chi^2/\mathrm{pt} = 90{\cdot}3/31$ for the $\sigma_{\mathrm{tot}}(\pi^-\mathrm{p})$ data. When the actual numbers are analysed we find that χ^2/pt is spoiled by the five $p_{\mathrm{lab}} > 200$ GeV/c points of Carroll *et al.* (1979) whose combined contribution to χ^2 is 57·1. This discrepancy between the higher energy $\sigma_{\mathrm{tot}}(\pi^-\mathrm{p})$ data and our fit might be related to the influence of the odderon. The odderon is an isospin 1 object and is regarded as the odd-signatured partner of the pomeron. The presence of this mysterious high-lying object in hadronic amplitudes has been advocated for sometime now (Bialkowski *et al.* 1975; Joynson *et al.* 1975, 1976; Bouquet and Diu 1977; Diu and Ferraz de Camargo 1977; Leader 1978; Kamran 1980, 1981*a*). The presence of the odderon in πN CEX amplitudes has been advocated by Bialkowski *et al.* (1975) and Joynson *et al.* (1975, 1976). However, since the remaining $\sigma_{\mathrm{tot}}(\pi^-\mathrm{p})$ points are reproduced quite well by our parametrization ($\chi^2/\mathrm{pt} = 33{\cdot}2/26$) and since, in our view, the odderon case needs a separate investigation, we have let the matter rest. As far as $\sigma_{\mathrm{tot}}(\pi^+\mathrm{p})$ is concerned, the overall χ^2/pt is spoilt by two points of Carroll *et al.* (1976), one at 23 GeV/c and the other at 150 GeV/c. The χ^2/pt value for $\sigma_{\mathrm{tot}}(\pi^+\mathrm{p})$ is 56·9/21 out of which these two points alone contribute a χ^2 of 30·6. Excluding these points yields $\chi^2/\mathrm{pt} = 26{\cdot}3/21 = 1{\cdot}25$ which is quite good. It may be noted that for $p_{\mathrm{lab}} > 200$ GeV/c our $\sigma_{\mathrm{tot}}(\pi^+\mathrm{p})$ values are somewhat lower than the mean experimental values, whereas in the π^-p case the theoretical values are higher than the experimental values (see Fig. 1*a*). The identification of the odderon as the cause of this difference may therefore not be too far off the mark as the odderon contribution changes sign in going from π^-p to π^+p scattering.

Phases of Non-flip Amplitudes

We define $\rho \equiv \mathrm{Re}\,T(s,0)/\mathrm{Im}\,T(s,0) \equiv \mathrm{Re/Im}$. The Regge pole phase rule is

$$\mathrm{Re}\,T_{\mathrm{R}}(s,t) = -\cot\tfrac{1}{2}\pi\alpha\,\mathrm{Im}\,T_{\mathrm{R}}(s,t), \qquad \tau = +1 \tag{8a}$$

$$= \tan\tfrac{1}{2}\pi\alpha\,\mathrm{Im}\,T_{\mathrm{R}}(s,t), \qquad \tau = -1, \tag{8b}$$

where T_{R} is the contribution of a Regge pole $\alpha(t)$, with signature τ, to any amplitude T. Here we are concerned with the point $t = 0$ and the trajectories P, f, ρ, ρ', A_2, ω and σ. If we identify the σ as a crossing-even ($\tau = +1$) Regge pole then a satisfactory reproduction of $\rho(\pi^{\pm}\mathrm{p})$ for $p_{\mathrm{lab}} \geqslant 10$ GeV/c can be made, but the $\rho(\mathrm{pp})$ and $\rho(\bar{\mathrm{p}}\mathrm{p})$ values are far too negative. Since the Kp system does not contain any contribution from the σ there is no ambiguity here and the $\rho(\mathrm{K}^{\pm}\mathrm{p})$ data are reproduced quite well. If on the other hand one identifies the low-lying contribution σ in p($\bar{\mathrm{p}}$)–p scattering as a crossing-odd pole (while retaining it as a crossing-even object in πN scattering) a reasonable reproduction of the $\rho(\mathrm{pp})$ and $\rho(\bar{\mathrm{p}}\mathrm{p})$ data is obtained, although

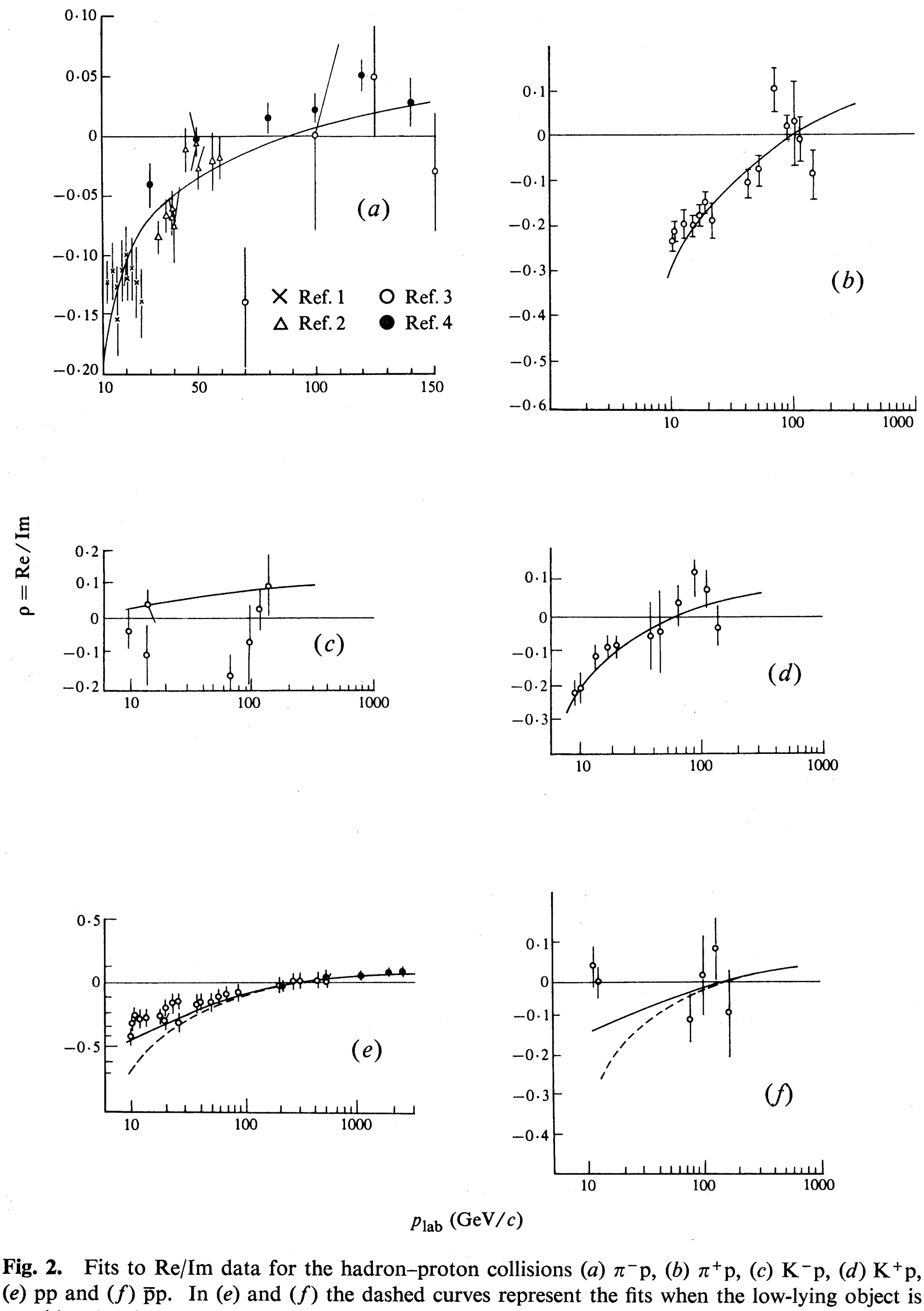

Fig. 2. Fits to Re/Im data for the hadron–proton collisions (*a*) π^-p, (*b*) π^+p, (*c*) K^-p, (*d*) K^+p, (*e*) pp and (*f*) $\bar{\text{p}}$p. In (*e*) and (*f*) the dashed curves represent the fits when the low-lying object is considered to be an even-signatured pole and the solid curves when the low-lying object is regarded as a crossing-odd pole. In (*a*) the data are from ref. 1, Foley *et al.* (1969); ref. 2, Apokin *et al.* (1975); ref. 3, Ankenbrandt *et al.* (1975); ref. 4, Burq *et al.* (1978). Other data are from Foley *et al.* (1967), Beznogikh *et al.* (1972), Amaldi *et al.* (1973, 1977), Bartenev *et al.* (1973), Carnegie *et al.* (1975) and De Boer *et al.* (1976).

at lower energies our $\rho(\mathrm{pp})$ values are somewhat more negative than the data. We have however not attempted any further improvement here because a more careful analysis by Berger *et al.* (1978) revealed the presence at lower energies of other contributions such as those due to the A_1 and Z exchanges. Also there are the earlier results of Field and Stevens (1975) who found that the non-flip NN amplitude contains two low-lying and coincident isoscalar natural parity Regge poles of opposite signature which they called the ϖ and $\tilde{\mathrm{f}}$ (with $\alpha(0) \approx -0{\cdot}5$). In view of the conflict between this and the A_1–Z contribution invoked by Berger *et al.* we have interpreted the low-lying odd-signatured object in the NN non-flip amplitude as an 'effective' parametrization of ill understood effects at low energies. We show the various fits to $\rho(h\mathrm{p})$ data in Fig. 2.

Discussion and Conclusions

By a unified treatment of the relevant forward data we have determined the various trajectory intercepts and the corresponding forward residues. An important conclusion emerging from our analysis of $\sigma_{\mathrm{tot}}(h\mathrm{p})+\sigma_{\mathrm{tot}}(\bar{h}\mathrm{p})$ data is the presence of low-lying contributions in πN and NN scattering. In the πN case the low-lying contribution may be identified with the isoscalar σ trajectory whose presence in the πN, KN and NN *flip* amplitudes has previously been noticed (Dash and Navelet 1976; Girardi and Navelet 1976; Kamran 1981*b*). After completing these calculations we found that Morrow (1978) had already argued for the presence of the σ in the πN *non*-flip amplitude on the basis of an analysis of the behaviour of $|T^0_{+-}/T^0_{++}|$, where the superscript refers to zero isospin in the t channel. The amplitudes used by Morrow are s-channel helicity amplitudes obtained from model independent amplitude analyses. Our analysis is based on consideration of $\sigma_{\mathrm{tot}}(h\mathrm{p})+\sigma_{\mathrm{tot}}(\bar{h}\mathrm{p})$ data over a wide range of p_{lab} and our uncovering of the σ contribution to the πN non-flip amplitude may, in conjunction with the previous work of Morrow, be regarded as providing rather firm evidence for the presence of the σ in the *non*-flip πN amplitude. We believe that this is a new result in πN scattering. As regards the NN case we find that the Re/Im(pp) data for $p_{\mathrm{lab}} \geqslant 10$ GeV/c may be reasonably reproduced by assuming that the low-lying object is odd-signatured. Moreover, because in NN scattering, apart from P, f, ρ, ω and A_2, one expects other contributions at lower p_{lab} values such as A_1, Z, etc., we may regard our low-lying object as an effective phenomenological parametrization of ill understood effects.

Our intercept values indicate that the ρ and A_2 trajectories do not coincide, there being a significant breaking of weak ρ–A_2 EXD with $\alpha_\rho(0)/\alpha_{A_2}(0) \approx 1{\cdot}3$–$1{\cdot}4$. In KN scattering there is a slight breaking of ρ–A_2 EXD at the level of residues with $\beta^{\mathrm{KN}}_\rho(0)/\beta^{\mathrm{KN}}_{A_2}(0) \approx 1{\cdot}4\pm0{\cdot}3$ if we use our favoured value $\alpha_{A_2}(0) = 0{\cdot}3475$, but with $\alpha_{A_2}(0) = 0{\cdot}3618$ the ratio is $1{\cdot}19\pm0{\cdot}25$. In NN scattering the situation is not clear on account of the controversy surrounding the A_2 contribution (Bouquet and Diu 1975) and hence it is difficult to say anything definite about ρ–A_2 EXD breaking at the level of residues in NN scattering, although our residue values show that there is a breaking of ρ–A_2 EXD in this channel.

Our $\alpha_{\mathrm{f}}(0)$ and $\alpha_\omega(0)$ values indicate that f–ω intercepts are equal within errors. Our ω intercept value is equal to that determined by Bouquet and Diu (1975). It may be noted that we do not constrain $\alpha_{\mathrm{f}}(0)$ *a priori* by a consideration of EXD but leave it as a free parameter. It is therefore a new result. Hendrick *et al.* (1975) and Diu and Ferraz de Camargo (1980) on the other hand assume weak f–ω EXD in their calculations. Our $\alpha_f(0)$ and $\alpha_\omega(0)$ values differ from those of Collins and Wright (1979) who used 0·49 and 0·4 respectively. The determination of the ω intercept has been dealt with in detail by Diu and Ferraz de Camargo (1980) who have shown that the value $\alpha_\omega(0) \approx 0\cdot4$, implied by various measurements on scattering neutral K mesons from carbon nuclei, is modified to 0·44 when the data are reanalysed in the light of the Glauber theory. Hence the use of $\alpha_\omega(0) = 0\cdot4$ by Collins and Wright (1979) is inconsistent with the data provided the appropriate rescattering effects are taken into account. We have described the results of our calculations partly for the sake of completeness and partly because they were carried out before the work of Diu and Ferraz de Camargo (1980) appeared. The relevant residues indicate that f–ω EXD is broken in KN and NN scattering at the level of residues, the EXD breaking being particularly severe in the NN case (contrary to the conclusions of Hendrick *et al.* 1975) with $\beta_f^{NN}(0)/\beta_\omega^{NN}(0) \approx 2\cdot9$ instead of 1 as expected from strong EXD considerations. The corresponding number in KN scattering is 1·3.

It may be recalled that ω *universality* predicts $\beta_\omega^{NN}(0)/\beta_\omega^{KN}(0) = 3$. Our values of $\beta_\omega^{NN}(0) = 81\cdot106\pm0\cdot131$ and $\beta_\omega^{KN}(0) = 25\cdot29\pm0\cdot28$ yield the ratio $3\cdot2\pm0\cdot01$. This value shows that there is a significant departure from ω universality. It may be noted that the analysis of Bouquet and Diu (1975) yielded $3\cdot0\pm0\cdot2$ indicating confirmation of the hypothesis. It was also confirmed as being exact by Hendrick *et al.* (1975). In our case the inclusion of the data of Carroll *et al.* (1979) has made the difference and our calculations show that there is *some violation* of this prediction. Bouquet and Diu (1975) have also noted that Nd and Kd residues are expected to be slightly less than twice the NN and KN ones. They obtained $\beta_\omega^{Nd}(0)/\beta_\omega^{NN}(0) \approx \beta_\omega^{Kd}(0)/\beta_\omega^{KN}(0) = 1\cdot83\pm0\cdot2$. This value is not sufficiently precise for a safe conclusion to be drawn. We find that $\beta_\omega^{Nd}(0) = 212\cdot05\pm12\cdot605$ and $\beta_\omega^{NN}(0) = 81\cdot106\pm0\cdot131$, giving the ratio $2\cdot61\pm0\cdot16$, which differs substantially from the Bouquet and Diu value and also indicates that the ratio departs significantly from the expectation that it be slightly less than 2. As regards the Kd and KN case, we have $\beta_\omega^{Kd}(0) = 69\cdot833\pm8\cdot287$ and $\beta_\omega^{KN}(0) = 25\cdot292\pm0\cdot276$, yielding $2\cdot76\pm0\cdot36$, which again departs from the expectation that this ratio be slightly less than 2. However, the two ratios for the N beam and K beam cases are equal within errors as was also the case with the calculations of Bouquet and Diu. These results show that data over a wider range of p_{lab} can sometimes enable us to refine the values of parameters to an extent where definite conclusions can be drawn about various predictions. It is well known that ρ *universality* predicts that the ratio $\beta_\rho^{\pi N}(0):\beta_\rho^{KN}(0):\beta_\rho^{NN}(0)$ should be $2:1:1$. Bouquet and Diu (1975) found that this prediction holds within errors for their parameter values. Here again we find that our results differ from theirs. We have $\beta_\rho^{\pi N}(0) = 12\cdot184\pm0\cdot063$, $\beta_\rho^{KN}(0) = 7\cdot5\pm0\cdot36$ and $\beta_\rho^{NN}(0) = 5\cdot41\pm1\cdot0$. This yields $\beta_\rho^{KN}(0)/\beta_\rho^{NN}(0) = 1\cdot39\pm0\cdot23$, which deviates significantly from the expected value of 1. Similarly $\beta_\rho^{\pi N}(0)/\beta_\rho^{KN}(0) = 1\cdot62\pm0\cdot09$, which departs quite substantially from the value 2 expected from ρ universality. However, we have $\beta_\rho^{\pi N}(0)/\beta_\rho^{NN}(0) = 2\cdot25\pm0\cdot43$, which agrees with the value 2 within errors.

There is a quark model prediction that $\beta_\omega^{KN}(0)/\beta_\rho^{KN}(0) = 3$. Our result is $3\cdot37\pm0\cdot20$ which shows that the fits indicate some departure from this prediction. Bouquet and Diu found $3\cdot6\pm0\cdot3$ for this ratio, which agrees with ours within errors.

Bouquet and Diu found that $\beta_{A_2}^{\pi N}(0) \neq \beta_{A_2}^{KN}(0)$, their value for $\beta_{A_2}^{\pi N}(0)/\beta_{A_2}^{KN}(0)$ being $1\cdot31\pm0\cdot23$. We have two values for $\alpha_{A_2}(0)$ and correspondingly two values for each of the above residues. Our (slightly) favoured value is $\alpha_{A_2}(0) = 0\cdot3475$ which gives

$\beta_{A_2}^{\pi N}(0) = 5 \cdot 68 \pm 0 \cdot 05$ and $\beta_{A_2}^{KN}(0) = 6 \cdot 75 \pm 0 \cdot 94$, yielding the ratio $0 \cdot 84 \pm 0 \cdot 12$, which shows a deviation from the expected value of 1. However, it is interesting to note that our ratio is less than 1 while for Bouquet and Diu this ratio is greater than 1. Our second solution is $\alpha_{A_2}(0) = 0 \cdot 3618$. This gives $\beta_{A_2}^{\pi N}(0) = 5 \cdot 42 \pm 0 \cdot 14$ and $\beta_{A_2}^{KN}(0) = 6 \cdot 31 \pm 1 \cdot 0$ yielding $0 \cdot 86 \pm 0 \cdot 16$. This value agrees with the expected value of 1 within errors but is still less than that of Bouquet and Diu.

Our conclusions may be summarized as follows:

(1) There is strong evidence for low-lying contributions in the πN and NN *non*-flip amplitudes. In the πN case at the low-lying objects are the σ and ρ'. In NN scattering the nature of the low-lying object is fuzzy and needs further investigation. Also there seem to be difficulties with the $\sigma_{\text{tot}}(\pi^- p)$ data for $p_{\text{lab}} > 200$ GeV/c, which might be related to the odderon whose influence in hadronic scattering has been pointed out for some time now.

(2) The ρ and A_2 trajectories have widely differing intercepts. Our favoured solution for $\alpha_{A_2}(0)$ shows that ρ–A_2 EXD is also broken at the level of residues in KN scattering. However, there is another solution for which the two residues are equal within errors. In NN scattering any conclusion about ρ–A_2 EXD at the level of residues is circumspect on account of the controversy surrounding the A_2 contribution. Our residue values show a breaking of ρ–A_2 EXD at the level of residues in NN scattering.

(3) Using $\alpha_f(0)$ as a free parameter we find $\alpha_f(0) = \alpha_\omega(0)$ within errors. However, f–ω EXD is broken at the level of residues in KN and NN scattering, the breaking being very severe in the NN case contrary to the conclusions of Hendrick *et al.* (1975). Also there are substantial departures from the expectation that the ω N(K)d residues are slightly less than twice the N(K)N residues. This conclusion disagrees with the earlier result of Bouquet and Diu (1975).

(4) We find that there are departures from ω- and ρ-universality predictions of the ratios of residues in πN, KN and NN scattering. This conclusion also disagrees with the earlier ones of Hendrick *et al.* (1975) and Bouquet and Diu (1975).

(5) The quark model prediction $\beta_\omega^{KN}(0)/\beta_\rho^{KN}(0) = 3$ is also violated.

(6) Our favoured solution for $\alpha_{A_2}(0)$ shows that $\beta_{A_2}^{\pi N}(0) \neq \beta_{A_2}^{KN}(0)$. However, there is another solution for $\alpha_{A_2}(0)$ which gives $\beta_{A_2}^{\pi N}(0)/\beta_{A_2}^{KN}(0) \approx 1$ within errrors.

Apart from other things the above list of conclusions, when compared with the corresponding conclusions of Hendrick *et al.* (1975) and Bouquet and Diu (1975), justifies the desirability of repeating previous analyses whenever data over an extended p_{lab} range become available.

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