This gives

$$\Gamma_{e\bar{e}}\Gamma_h/\Gamma = 2\cdot884\times10^{-3} \quad \text{MeV} \qquad \text{and} \qquad \Gamma_{e\bar{e}}\Gamma_{\mu\bar{\mu}}/\Gamma = 1\cdot96\times10^{-4} \quad \text{MeV}, \quad (17)$$

and assuming $\Gamma_{e\bar{e}} = \Gamma_{\mu\bar{\mu}}$ we also have

$$\Gamma_{\mu\bar{\mu}}/\Gamma_h = 0\cdot0679 \qquad \text{and} \qquad \Gamma = 2\Gamma_{e\bar{e}}+\Gamma_h. \quad (18)$$

The solution of equations (17) and (18) gives

$$\Gamma = 49\cdot4 \quad \text{keV}. \quad (19)$$

Using now the photon trajectory given by equation (12), we get

$$K/\alpha_1' = 15\cdot93\times10^{-6}, \quad (20)$$

and the width of a resonance at $s = s_R$ is given by

$$15\cdot93\times10^{-6}(s_R^{\frac{1}{4}} \text{ GeV}) = \Gamma_R. \quad (21)$$

We can now calculate widths of all resonances on this trajectory and they are given in column 3 of Table 1.

Table 1.   Predicted masses and widths

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$\alpha_1' = 0\cdot104$ (GeV)$^{-2}$			$\alpha_1' = 0\cdot208$ (GeV)$^{-2}$			$\alpha_1(0) \neq \alpha(0)$	
J^P	M (GeV)	Γ (keV)	J^P	M (GeV)	Γ (keV)	J^P	M (GeV)	Γ (keV)
1^-	0	0	1^-	0	0	2^+	2·68	33·81
2^+	3·1	49·4	2^+	2·19	27·63	4^+	4·1	51·73
3^-	4·3	68·5	3^-	3·1	39·11	6^+	5·14	64·85
4^+	5·3	84·4	4^+	3·79	47·81	8^+	6	75·76
5^-	6·2	98·8	5^-	4·38	55·25			

In the case of exchange degeneracy, a further interesting possibility concerns the assignment of spin three to the 3·1 GeV resonance. This leads to a larger slope $\alpha_1' = 0\cdot208$ (GeV)$^{-2}$. In this case the width of a resonance on this trajectory is given by

$$12\cdot61\times10^{-6}(s_R^{\frac{1}{4}} \text{ GeV}) = \Gamma_R. \quad (22)$$

The corresponding mass–width spectrum is given in columns 4–6 of Table 1.

If the photon trajectory is not exchange degenerate with the even signature trajectory, the situation is rather complicated. One can take the attitude that the photon trajectory is like the pomeranchuk trajectory and that the even signature trajectory is like the ρ–f^0 trajectory, having a lower intercept. In such a situation the even signature trajectory will be given by $\alpha(s)$ of equation (13). However, without additional information we have no way of calculating either $\alpha(0)$ or α'. One can only say that $a \approx K$, as both arise from the same interaction. We now choose $\alpha(0) = \frac{1}{2}$ by analogy with the ρ–f^0 trajectory and keep the scale of interaction the same, that is, $\alpha' \approx \alpha_1'$. The predicted masses and widths are given in columns 8 and 9 of Table 1.

5. Conclusions

The interesting feature of the proposed model is that it explains the narrow resonances by a conventional Regge theory. If there is an exchange degeneracy, the model predictions are straightforward. However, if there is no exchange degeneracy, we have two free parameters which cannot be calculated without more resonances in the spectrum. As in the Regge theory of strong interactions, we also have daughter trajectories. The possibility that the new particles belong to the daughter trajectories cannot be ruled out. However, in this case they would have lower spins but their widths would be of the same order of magnitude as those given in Table 1.

Experimentally, it is possible to test exchange degeneracy. If one assumes Gell-Mann's ghost killing mechanism for both even and odd signature amplitudes, then in case I the differential cross section for $e^-e^- \to e^-e^-$ (or $e^+\mu^- \to e^+\mu^-$) would not vanish at $t = -4\cdot81$ (GeV)^2 where $\alpha_1(-4\cdot81) = 0$. However, in case II there would be a dip at $t = -4\cdot81$ (GeV)^2 for these processes.

Finally, we examine whether a slope of the order of $0\cdot2$ to $0\cdot1$ (GeV)$^{-2}$ for the photon trajectory can be tolerated by present experiments. There are deviations from the one-photon exchange contribution of conventional quantum electrodynamics (e.g. the Rosenbluth formula) owing to the exchange of more than one photon and to radiative corrections. These can be calculated to some extent, and it should be possible to separate them from the non-elementary nature of the photon. The deviations from the Rosenbluth formula using a Regge photon were first considered by Freund (1962). In that calculation the detailed structure of the matrix elements was not taken into account and one obtained

$$\rho = \frac{R_{\text{Reg}}}{R_{\text{Ros}}} = \left(\frac{s}{s_0}\right)^{2\{\alpha_1(t)-1\}}, \qquad \text{where} \qquad R = \frac{d\sigma}{d\Omega} \bigg/ \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} \qquad (23)$$

and the subscipts Reg and Ros refer to Regge-photon and Rosenbluth evaluations.

Using $s_0 = 0\cdot4$ (GeV)^2 Freund obtained $\alpha' \leqslant 0\cdot2$ (GeV)$^{-2}$. With the recent accurate data of Kirk *et al.* (1973) we obtain a smaller slope than this. However, as shown by Blankenbecler *et al.* (1962a, 1962b) the real situation is rather complicated. This is because in e–p scattering all six invariant amplitudes contribute for a Regge photon in place of the two form factors which appear for the elementary photon. We thus obtain

$$R_{\text{Reg}} = \beta_0(t)(s/s_0)^{2\{\alpha_1(t)-1\}} + \beta_1(t)(s/s_0)^{\alpha_1(t)+\alpha_\rho(t)-2} + \beta_2(t)(s/s_0)^{\alpha_1(t)+\alpha_\omega(t)-2}$$

$$+ \beta_3(t)(s/s_0)^{2\{\alpha_\omega(t)-1\}} + \beta_4(t)(s/s_0)^{2\{\alpha_\rho(t)-1\}} + \beta_5(t)(s/s_0)^{\alpha_\rho(t)+\alpha_\omega(t)-2}. \qquad (24)$$

At extremely high energies only, the first term dominates. At energies ($s \approx 34$ (GeV)^2) for which accurate experimental data (Coward *et al.* 1968) are presently available one expects contributions from the last five terms. This is because we have five free parameters $\beta_1(t), ...\beta_5(t)$. Furthermore, the scale of the interaction s_0, which is usually taken as $1/\alpha'$, is not completely determined as we have three different slopes α'_ρ, α'_ω and α'_1. Thus s_0 can also be taken as a parameter such that $1/\alpha'_\rho \leqslant s_0 \leqslant 1/\alpha'_1$. Even if ρ–ω exchange degeneracy is assumed, we have three free parameters and we can obviously make a reasonable fit to the data (Kirk *et al.*), although no accurate limit on the slope of the photon trajectory can be calculated. In order to place a limit on

the slope of the photon trajectory, we thus require data on high energy electron scattering from *spin zero* targets. Such data are either available only at low energies or are not accurate enough to rule out a slope of $0 \cdot 2$ to $0 \cdot 1$ $(GeV)^{-2}$.

Acknowledgments

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