Indian J. Phys., **Vol. 85,** No. 12, pp. 1833-1842, December 2011

Mesonic and baryonic Regge trajectories with quantized masses

N Hothi* and S Bisht
Department of Physics, Kumaun University, Nainital-263 002, Uttrakhand, India

E-mail : hothi.navjot@gmail.com

Abstract : We have constructed some Regge trajectories for mesons and baryons by taking the 70 MeV spinless mass quanta as the ultimate building block for the light hadrons. In order to make masses integral multiples of seventy, small changes in masses has been made with due explanation. We have shown how a linear relationship between J and M^2 is maintained by considering quantized hadron masses , which is a direct consequence of the string model and gives a strong clue for quark confinement. It has also been established that mesons and baryons have different slopes and the slopes of baryons is less than the slope of the mesons. This clearly defies the concept of universality of slopes ($\alpha \approx 1.1$ GeV^2) of hadrons, which can only be achieved if the strings joining the quarks have constant string tension $\alpha = 1/(2\pi\sigma)$ (where σ is the string tension).

Keywords : Regge trajectories; linearity; slopes.

PACS Nos. : 11.55Jy; 12.40Nn; 14.20-c; 14.40.-n

1. Introduction

Regge theory, a phenomenological theory of strong interaction at high energies was initially introduced by Tullio Regge [1,2] in the 1960's. He applied complex angular momentum method [1] in order to generalize the solution for scattering amplitude and introduced the concept of Regge poles. Later on, using these poles it was postulated [3] that all strongly interacting particles lie on Regge trajectories (RTs) [4]. During the past few years, a great deal of interest has been shown by physicists to work in this field because of the availability of large amount of data [5]. As a result various models [6–16] due to different approaches came forward in the last few years. In the present paper, we have tried to find the reason for the deviation of the RTs from linearity and have developed an altogether different scenario.

This paper is based upon the consideration that a large number of hadron masses are integral multiples of the Q = 70 MeV mass quanta [17–19]. The reason

*Corresponding Author

why we observe deviation from this ideal mass formulation may be due to various factors which come into play due to the composite structure of the hadrons. We have come across hadrons which are either exact multiples of Q or show slight deviations from this ideal mass formulation. Thereby, we have scrutinized the effect of this concept on the Regge trajectory phenomenology. We have checked the linearity as well as parallelism conditions for these trajectories.

2. *M*=70 MeV mass quanta : The ultimate hadronic building block

It has been observed [18,19] that the hadron spectrum shows regularity with 70, 140, 210 MeV energy separations. Hadrons do have internal structure, they are not point particles like the leptons. So, like molecules, hadrons have rotational and other excited states which reveal themselves through a sequence of hadronic resonances with increasing energies (masses) and spins J and thus having quantized energy levels (masses). We all are aware of the fact that nature obeys symmetry and we expect it to be evident for largest as well as smallest scales. Just like electrons rotating in orbital shells of an atom have quantized energy levels and even the nucleons in the nucleus follow quantization, we tend to visualize the same in hadrons. Gregor [17–19] has done a pioneering work in this field and has shown that in case of hadrons, there exists a mass band structure in the units of Q = 70 MeV. This mass quanta separates hadron states and there exists a common shell structure.

Quarks are light and have small binding energies. This is evident from both : the quark model behaviour and the experimental hadron behavior. The small binding energies of quarks lead to two types of quanta. First is a 70 MeV spinless quanta Q, which reproduces the pion and the second is a 330 MeV spin ½ quanta S, which reproduces the nucleon. Thereby, the spinless quantum Q = 70 MeV and the spin ½ quantum S = 330 MeV, both serve as the sufficient basis set for light hadrons, where the quark-antiquark binding energies precisely match the nucleon–antinucleon binding energies. Furthermore, when the special relativity is applied to the rotating masses, it is revealed that S is itself composed of three quanta Q in a relativistically spinning configuration, so that Q emerges out as the ultimate hadronic building block. The relativistically spinning mass is $3/2$ times Q.

$$Q = 70\,\text{MeV} \Rightarrow Q_s = 3/2\,Q = 105\,\text{MeV} \tag{1}$$

where Q_s is relativistically spinning mass quanta.

$$3Q_s \approx 330 \text{ MeV} = S \text{ quanta.} \tag{2}$$

The lowest mass particle in the case of mesonic RT is the pion. Its mass is approximately 140 MeV/c^2, which can be viewed as a composite mass of two 70 MeV/c^2 mass quanta. The absolute masses of metastable baryon resonances p, n, Λ, Σ, Ξ, Ω, p-n and the very narrow width meson resonances π, K, η, η' can be reproduced by the light quark basis set Q and S.

We know that $\pi = Q\bar{Q}$, where Q and $\bar{Q}$ are ~70 MeV light mass quanta.

Similarly the *K* meson is 7*Q* that is seven times the mass quantum *Q*. Evidently in the case of mesons the starting member of the mesonic RT is an integral multiple of the 70 MeV and then obviously next particles on the trajectories have mass separations in the integral multiples of *Q*. This is an idealized scenario. Various factors can be accounted for the deviation from this ideal mass structure. Other mesonic resonances which are exact multiple of 70 are :

(1) ρ(770), (2) a_0(980), (3) π_2(2100), (4) a_6(2450), (5) K_1(1400), (6) K_2(1820) *etc.*

From the level spacing observed in the case of baryons [18], it appears that excitations occur in the units of *Q* = 70 MeV, for *eg.* 3 $\equiv$ 3*Q* = 210 MeV, 4 $\equiv$ 4*Q* = 280 MeV *etc*. However the particles and resonances which lie on the baryonic RT, may not be exact multiples of *Q*. In the case of baryonic resonances, following combinations of *S* and *Q* account for their masses.

$$\sum = 330 \oplus \overline{330} \oplus 330 \oplus (4 \otimes \overline{70}) \tag{3}$$

$$\Lambda = 330 \oplus \overline{330} \oplus 330 \oplus (3 \otimes \overline{70}) \tag{4}$$

$$\Omega = 330 \oplus \overline{330} \oplus 330 \oplus (3 \otimes \overline{70}) \oplus (4 \otimes \overline{70}) \oplus (4 \otimes \overline{70}) \tag{5}$$

$$\Xi = 330 \oplus \overline{330} \oplus 330 \oplus (3 \otimes \overline{70}) \oplus (3 \otimes \overline{70}) \tag{6}$$

$$N = 330 \oplus \overline{330} \oplus 330 \tag{7}$$

The existence of the 70 MeV boson was derived from the mass of the classical Dirac Magnetic Monopole [20]. Also the sequel [21] of the above reference provides evidence of this quanta from the findings of the Particle Data Group listings [22]. Moreover, according to Gregor [17–19], all particles more massive than the electron can be constructed from a single mass quantum *Q*.

3. Factors leading to deviation from the hadronic quantised masses

The deviation of masses of hadrons from the integral multiples of *Q* could be attributed to the factors [18] such as Coulomb corrections and spins. Even magnetic moment ratios and charge splitting could be contributory factors. Strangeness quantum number could also be responsible. Constituent quark binding energy is also one of the factor leading to change in mass. Also we know that relativistically spinning configuration of rotating masses leads to deviation of masses of hadrons from the integral multiples of seventy.

The constituent quark binding energies reduce the masses of hadrons by about 3 to 4% [19,21]. The rest of the factors also play important roles in increasing or decreasing the masses.

4. Quantized hadronic masses and the Regge trajectory phenomenology

Now we will discuss the effect of quantized hadronic masses on the Regge trajectory phenomenology and also why linearity is important. A number of models have been formulated regarding these trajectories and majority of them claim non linearity. The linearity of the Regge trajectories is one of the most striking evidence for the string model [23]. The non-perturbative QCD dynamics *i.e.* the long distance regime leads to confinement. In particular, a linear potential between a quark and antiquark for mesons (quark and diquark for baryons) and the linearly rising Regge trajectory are immediate consequences of the string picture. The confinement potential at different length scales [24] is estimated by Cornell potential which is

$$V(R) \approx -(4/3)(\alpha_s/R) + \sigma R \quad \text{(where } \sigma \text{ is the string tension [25])} \tag{8}$$

At long distances the second term is dominant which clearly corresponds to linear potential. The reproduction of linear potentials is one of the earliest and most enthusiastic successes of the lattice gauge theory [26–28]. A linear relationship between J and M^2 ($M^2 = \alpha' J + c$) is a clear manifestation of the strong forces between constituent quarks.

If we consider a different scenario in which the 70 MeV mass quanta to be the ultimate hadronic building block, astonishingly we find almost complete linearity in the RTs. We have subtracted or added small amounts to the masses of mesons and their resonances and made them equal to exact multiples of seventy and then plotted their trajectories. In the case of baryons, we have altered masses, so that baryonic resonances on the same trajectory have mass differences in the integral units of Q. It appears non-linearity is caused by ignoring the various factors contributing to deviation in masses.

Figures 1 to 8 show the RTs which we have plotted, for mesons (Figs. 1 to 4)

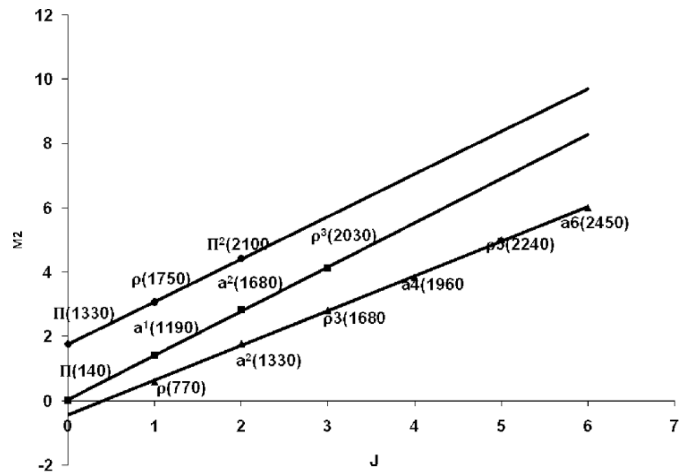

Figure 1. RTs for three separate series of mesons respectively along with their straight line equations.
Π(1330)(+30) – ρ(1750)(+50) – Π_2(2100)(0) M^2 = 1.3206J + 1.7599
Π(140)(0) – a_1(1190)(–70) – a_2(1680)(–20) – ρ_3(2030)(+40) M^2 = 1.371J + 0.0382
ρ(770)(0) – a_2(1330)(+10) – ρ_3(1680)(–10) – a_4(1960)(–80) – ρ_5(2240)(–110) – a_6(2450)(0) M^2 = 1.0804J – 0.4403

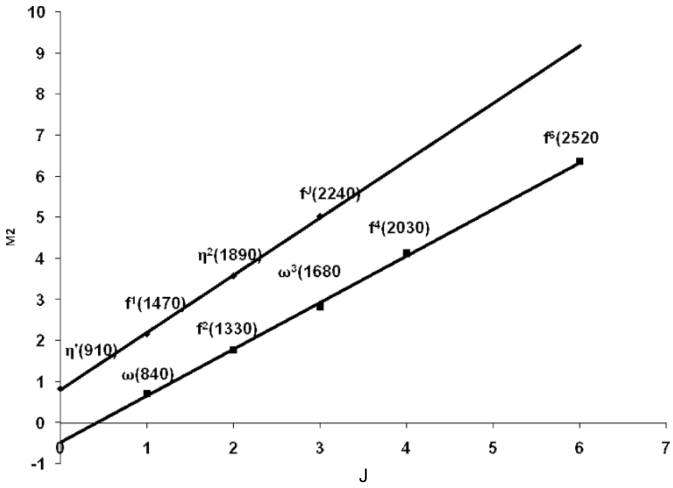

Figure 2. RTs for two separate series of mesons respectively along with their straight line equations.
η'(910)(–48) – f_1(1470)(–40) – η_2(1890)(+20) – f_J(2240)(+20) $M^2 = 1.398J + 0.7977$
ω(840)(+58) – f_2(1330)(+60) – ω_3(1680)(+10) – f_4(2030)(–20) – f_6(2520)(+10) $M^2 = 1.1377J - 0.4871$

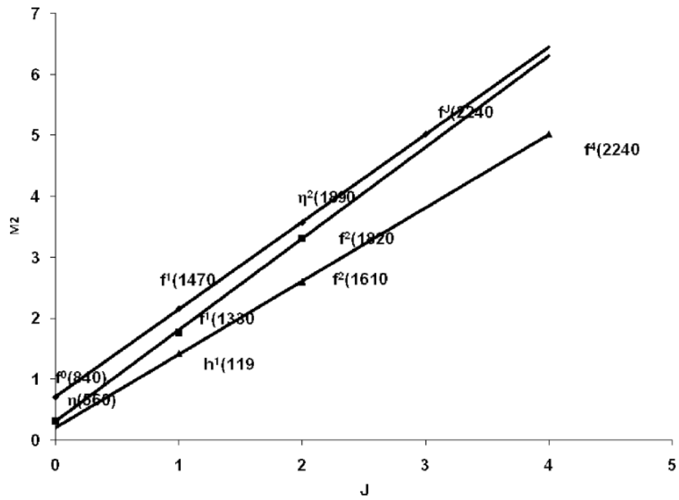

Figure 3. RTs for three separate series of mesons respectively along with their straight line equations.
f_0(840)(–10) – f_1(1470)(+ 50) – η_2(1890)(+20) – f_J(2240)(+20) $M^2 = 1.4347J + 0.712$
η(560)(+13) – f_1(1330)(+45) – f_2(1820)(+10) $M^2 = 1.4994J + 0.2989$
h_1(1190)(+20) – f_2(1610)(–30) – f_4(2240)(–60) $M^2 = 1.2023J + 0.2034$

and baryons (Figs. 5 to 8), with altered masses and quantized energy separations. We have also displayed their straight line equations, which easily give their slopes. In Figs. 9 and 10, we have checked for parallelism of the RTs. Below each figure we have displayed all the particles and resonances which lie on the trajectories with their altered masses along with the amounts which we have added or subtracted from the original values of masses.

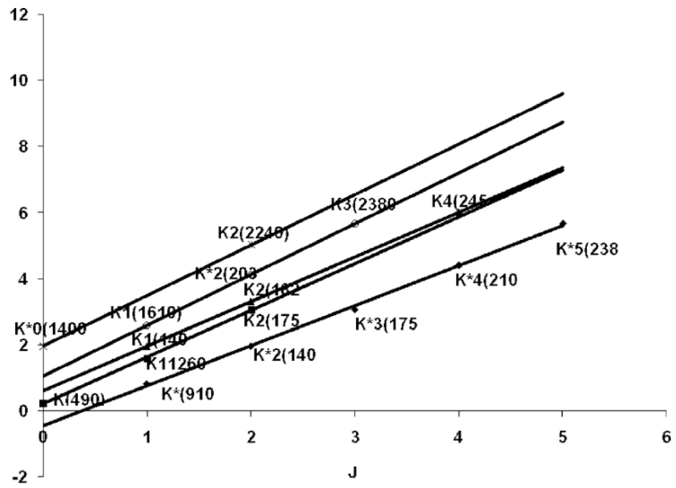

Figure 4. Regge trajectories for five separate series of K mesons.
$K^*_0(1400)(–30)$ – $K_2(2240)(–10)$ $M^2 = 1.5288J + 1.96$
$K_1(1610)(–40)$ – $K^*_2(2030)(+50)$–$K_3(2380)(+60)$ $M^2 = 1.5362J + 1.0535$
$K_1(1400)(0)$ – $K_2(1820)(0)$ – $K_4(2450)(–50)$ $M^2 = 1.3472J + 0.615$
$K(490)(–3)$ – $K_1(1260)(–10)$ – $K_2(1750(–20)$ $M^2 = 1.4112J + 0.2189$
$K^*(910)(+18)$–$K^*_2(1400)(–30)$ – $K^*_3(1750)(–30)$ – $K^*_4(2100)(+55)$ – $K^*_5(2380)(0)$ $M^2 = 1.2123J – 0.4518$.

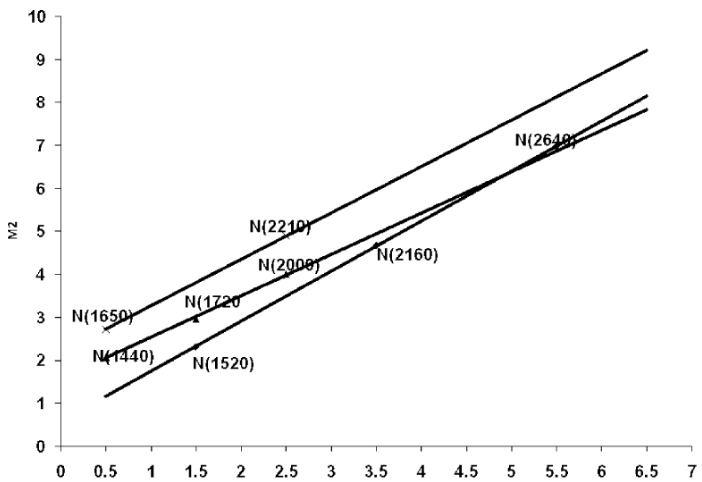

Figure 5. RTs for nucleon baryons with three separate series along with their straight line equations.
$N(1650)(0)$ – $N(2210)(+10)$ $M^2 = 1.0808J + 2.1821$
$N(1440)(0)$ – $N(1720)(0)$ – $N(2000)(0)$ $M^2 = 0.9632J + 1.5649$
$N(1520)(0)$ – $N(2160)(–30)$ – $N(2640)(+40)$ $M^2 = 1.1648J + 0.5717$

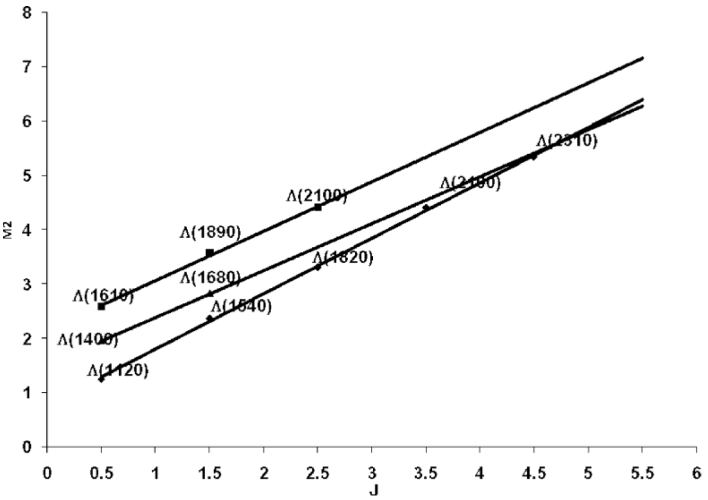

Figure 6. RTs for lambda baryons three separate series along with their straight line equations.
Λ(1610)(+10) – Λ(1890)(0) – Λ(2100)(–10) $M^2 = 0.909J + 2.1613$
Λ(1400)(–5) – Λ(1680)(–10) $M^2 = 0.8624J + 1.5288$
Λ(1120)(+4) – Λ(1540)(+20) – Λ(1820)(0) – Λ(2100)(0) – Λ(2310)(–40) $M^2 = 1.0202J + 0.7865$

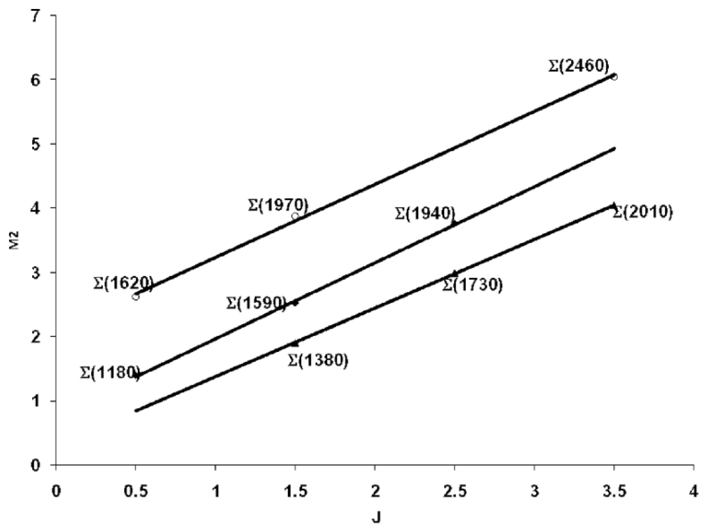

Figure 7. RTs for sigma baryons three separate series along with their straight line equations.
Σ(1620)(0) – Σ(1970)(+30) – Σ(2460)(+5) $M^2 = 1.1343J + 2.1062$
Σ(1180)(–12) – Σ(1590)(+10) – Σ(1940)(+25) $M^2 = 1.1856J + 0.783$
Σ(1380)(–5) – Σ(1730)(+40) – Σ(2010)(–20) $M^2 = 1.0679J + 0.3095$

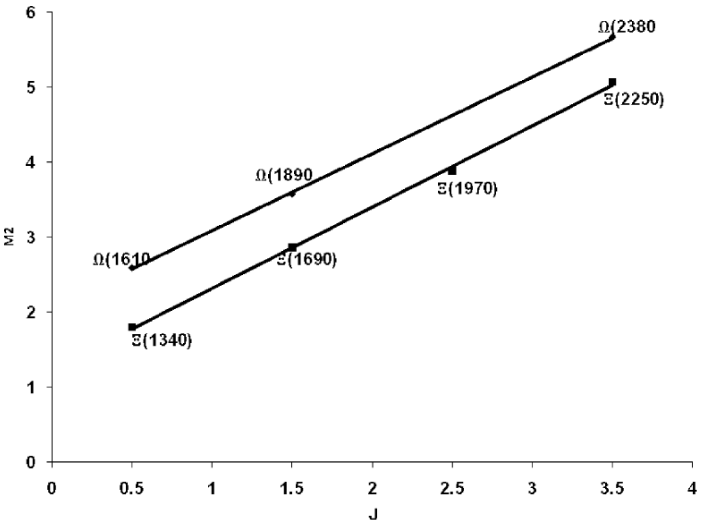

Figure 8. RTs for two separate series of baryons.
$\Omega(1610)(+40) - \Omega(1890)(+22) - \Omega(2380)(0)$ $M^2 = 1.0273J + 2.0596$
$\Xi(1340)(+19) - \Xi(1690)(0) - \Xi(1970)(-60) - \Xi(2250)(0)$ $M^2 = 1.0826J + 1.2337$

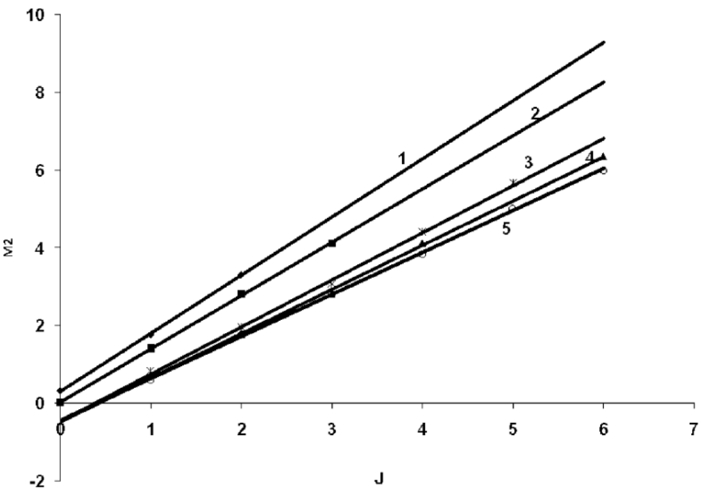

Figure 9. Five separate mesonic Regge trajectories in order to check parallelism.
1 : $- \eta(560) - f_1(1330) - f_2(1820)$ $M^2 = 1 .4994J + 0.2989$
2 : $- \pi(140) - b_1(1190) - \Pi_2(1680) - \rho_3(2030)$ $M^2 = 1.371J + 0.0382$
3 : $- K^*(910) - K^*_2(1400) - K^*_3(1750) - K^*_4(2100) - K^*_5(2380)$ $M^2 = 1.2123J - 0.4518$
4 : $- \omega(840) - f_2(1330) - \omega_3(1680) - f_4(2030) - f_6(2520)$ $M^2 = 1.1377J - 0.4871$
5 : $- \rho(770) - a_2(1330) - \rho_3(1680) - a_4(1960) - \rho_5(2240) - a_6(2450)$ $M^2 = 1.0804J - 0.4403$

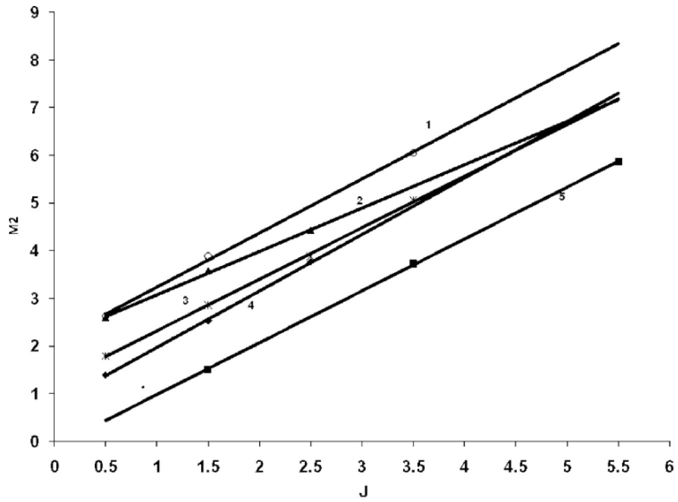

Figure 10. Five separate baryonic Regge trajectories in order to check parallelism.
1 : Σ(1620) – Σ(1970) – Σ(2460)M^2 = 1.1343J + 2.1062
2 : Λ(1610) – Λ(1890) – Λ(2100)M^2 = 0.909J + 2.1613
3 : Σ(1180) – Σ(1590) – Σ(1940)M^2 = 1.1856J + 0.783
4 : Ξ(1340) – Ξ(1690) –Ξ(1970) – Ξ(2250) M^2 = 1.0826J + 1.2337
5 : Δ(1230) – Δ(1930) – Δ(2420)M^2 = 1.0859J – 0.1025

5. Conclusions

From our present work on reconstruction of Regge trajectories taking quantized masses, it becomes quite evident that linearity of Regge trajectories is maintained. We have clearly shown what factors contribute to deviation of masses and thus distort linearity. Moreover, the linear relationship between J and M^2 is a direct consequence of the string model and gives a strong clue for quark confinement.

Taking various set of resonances, we could very well infer that the slopes of baryons is less than the slope of the mesons and the concept of universality of slopes ($\alpha \approx$ 1.1 GeV^2) of mesons and baryons is violated. This can be plausible only if the strings joining the quarks have constant string tension $\alpha = 1/(2\pi\sigma)$, where σ is the string tension). Instead of a universal slope, we have an approximate range (0.9 to 1.5) GeV^2 for the slopes of the mesons and (0.8 to 1.1) GeV^2 for the slope of the baryons masses. Also, from Figs. 9 and 10 we can clearly conclude that the slopes of the various trajectories are different and thereby essential non-parallelism is observed.

Acknowledgment

One of us (NH) gratefully acknowledges the RFSMS (Research fellowship in science for meritorious students) scheme of University Grants Commission, New Delhi, for financial support.

References

[1] T Regge *Nuovo Cim.* **14** 951 (1959)
[2] T Regge *Nuovo Cim.* **18** 947 (1960)

[3] G F Chew and S C Frautschi *Phys. Rev. Lett.* **8** 41 (1962)

[4] S C Frautschi *Regge Poles and S-Matrix Theory* (New York : W. A. Benjamin) (1968)

[5] S Bisht, N Hothi and G Bhakuni *electronic J. Theor. Phys.* **24** 299 (2010)

[6] F Paccanoni, S Stepanov and R Tutik *Mod. Phys. Lett.* **A8** 549 (1993)

[7] S Filipponi and Y Srivastava *Phys. Rev.* **D58** 016003 (1998)

[8] Y Simonov *Phys.Lett.* **B323** 41 (1994)

[9] G S Sharov Talk given at *XI Intt. Conf. : Problems in Quantum field Theroy,* Dubna, Russia, July 13-17 (1998)

[10] L D Soloviev *Phys. Rev.* **D58** 035005 (1998)

[11] M Olsson *Phys. Rev.* **D49** 4675 (1994); *ibid.* **D39** 2751 (1989)

[12] M Fabre de la Ripelle *Phys. Lett.* **B205** 97 (1988)

[13] A Martin *Z. Phys.* **C32** 359 (1986)

[14] G 't Hooft *Nucl. Phys.* **B75** 461 (1974)

[15] A E Inopin hep-ph/0110160 (2001)

[16] A Tang and J W Norbury *Phys. Rev.* **D62** 016006 (2000)

[17] M H Mac Gregor *Nuovo Cim.* **A103** 983 (1990)

[18] M H Mac Gregor *Phys. Rev.* **D9** 1259 (1974)

[19] M H Mac Gregor *Phys. Rev.* **D10** 850 (1974)

[20] D Akers hep-ph/0309075 (2003)

[21] D Akers hep-ph/0303139 (2003)

[22] Particle Data Group *Phys. Rev.* **D66** 010001 (2002)

[23] M Baker and R Steinke *Phys. Rev.* **D63** 094013 (2001)

[24] E Eichten, K Gottfried, T Kinoshita, K D Lane and T M Yan *Phys. Rev.* **D17** 3090 (1978)

[25] N Hothi and S Bisht *Electronic J. Theor. Phys.* (2012)

[26] A S Kronfeld, G Schierholz and U J Wiese *Nucl. Phys.* **B293** 461 (1987)

[27] S Hioki *et. al. Phys. Lett.* **B272** 326 (1991)

[28] S Kitahara, Y Matsubara and T Suzuki *Prog. Theor. Phys.* **93** 1 (1995)