ADDENDUM #5 TO P11

THE DELTA PARTICLES.

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ABSTRACT.

This Addendum provides details of the energy distribution of the quarks that make up all Delta sub-atomic particles with an intrinsic angular momentum of $J = 3/2\hbar$. Also presented are the energy translations that take place during their decay.

This is the fifth Addendum to "Derivation of the Quark Energy Distribution and Decay Products of Baryonic Sub-Atomic Particles".

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1.0 Introduction.

There are four Delta particles with an intrinsic angular momentum of $J = 3/2\hbar$. They are Δ^{++}(uuu), Δ^{+}(uud), Δ^{0}(udd) and Δ^{-}(ddd). From this it is seen that Δ^{+} is a high resonance energy version of the Proton and Δ^{0} a high resonance energy version of the Neutron. Δ^{++} and Δ^{-} have $J = 3/2\hbar$ by virtue of their three identical quarks and accordingly their necessity to conform to the Pauli Exclusion Principle. This can only be achieved via one of their quarks possessing an increased intrinsic angular momentum of $J = 3/2\hbar$, while the other two possess intrinsic angular momenta of $J = \pm 1/2\hbar$.

There is only one new decay type introduced by the decay of the Delta particles, that is Decay Type 6 which is a "resonance energy only" decay. This type of decay is due to the extra resonance energy possessed by one of the quarks, and only occurs when the decaying particle with the high resonance energy has the same quark complement as that of the decayed particle., i.e. as stated above for the $\Delta^{+} \rightarrow p^{+}$ and $\Delta^{0} \rightarrow n^{0}$. It is for these two decays that full details are provided in this Addendum, as follows.

(i) The Intrinsic Angular Momentum Tables, (from the generalised tables in [3]).
(ii) The quark energy distributions.
(iii) The decay energy translations.

Note that in this Addendum, only particles with intrinsic angular momentum of $J = 3/2\hbar$ containing quarks with $J = 3/2\hbar$ and $J = \pm 1/2\hbar$ are considered.

Also note that energy will be represented as equivalent mass via the units MeV/c^2 which, for conciseness will be assumed and therefore omitted in the text.

For a full appreciation of this paper it is recommended that [3] and at least one of [4] or [5] be read first.

2.0 Nomenclature.

In this Addendum the following nomenclature will be used.

P	Indicates any Baryon.
P(#)	Indicates the type of intrinsic angular momentum of P.
$q_{\#}$	Indicates the #th quark of P.
E_c	Indicates quark confinement energy.
E_k	Indicated kinetic energy.
$\rightarrow$	Indicates a particle decay.
$\Rightarrow$	Indicates a quark flavour change.

3.0 Initial Discussions.

3.1 Intrinsic Angular Momentum Configurations.

The following brief table shows the number of unique intrinsic angular momentum configurations possible with particles with $J = 3/2\hbar$ as against those with $J = \pm 1/2\hbar$.

Number of Identical Quarks. \ Intrinsic Angular Momentum	$J = 1/2\hbar$.	$J = 3/2\hbar$
3, (i.e. uuu)		6
2, (i.e. uud)	2	6
None, (i.e. uds)	3	6

Table 3.1 – Intrinsic Angular Momentum Configurations.

The reason for the difference in Table 3.1 is evident from the generalised tables in [3]. However, when the number of identical quarks = 3 or 2, for the high resonance energy particles, ($J = 3/2\hbar$), each pair of intrinsic angular momentum configurations will have the same energy distributions, (see Appendix A), but may exhibit different decay modes/types, (see Table 4.1). However, in most cases the decay type will be the same whichever quark possesses the high resonance energy and therefore, in the details presented below, the only configurations shown for the two Type 6 decays, are those in which the quark with the lowest mass has the extra resonance energy, i.e. the first u quark.
Also, because of the extra configurations shown in Table 3.1, it would not be unreasonable to expect that particles with $J = 3/2\hbar$ would exhibit a greater number of decay paths than those with $J = 1/2\hbar$. However, this is not the case, the reason being the manner in which the higher resonance energy of the $J = 3/2\hbar$ particles affects the decay process. The details of this will be addressed in a further paper.

3.2 Decay Distribution Patterns – Overall Summary.

This summary lists the primary decay products of the four Delta Particles according to their intrinsic angular momentum configurations. Included are the branching fractions from [2]. Also included is indication of the two decays for which full details are provided in Section 4.0.

P(1)	P(2)	P(3)	P(4)	P(5)	P(6)	Branching Fraction, %	Full Details Provided
$\Delta^{++}(1)$	$\Delta^{++}(2)$	$\Delta^{++}(3)$	$\Delta^{++}(4)$	$\Delta^{++}(5)$	$\Delta^{++}(6)$		
$P^+(1)$	$P^+(2)$	$P^+(1)$	$P^+(2)$	$P^+(1)$	$P^+(2)$	100	
$\Delta^{+}(1)$	$\Delta^{+}(2)$	$\Delta^{+}(3)$	$\Delta^{+}(4)$	$\Delta^{+}(5)$	$\Delta^{+}(6)$		
$n^0(1)$		$n^0(1)$				50	
	$P^+(1)$		$P^+(1)$	$P^+(1)$	$P^+(1)$	50	√
$\Delta^{0}(1)$	$\Delta^{0}(2)$	$\Delta^{0}(3)$	$\Delta^{0}(4)$	$\Delta^{0}(5)$	$\Delta^{0}(6)$		
$n^0(1)$	$n^0(2)$	$n^0(1)$		$n^0(2)$		50	√
			$P^+(1)$		$P^+(2)$	50	
$\Delta^{-}(1)$	$\Delta^{-}(2)$	$\Delta^{-}(3)$	$\Delta^{-}(4)$	$\Delta^{-}(5)$	$\Delta^{-}(6)$		
$n^0(1)$	$n^0(2)$	$n^0(1)$	$n^0(2)$	$n^0(1)$	$n^0(2)$	100	

Table 3.2 – Overall Summary of Decay Configuration Patterns.

3.3 Types of Decay.

The following table lists the types of decay exhibited by the Delta particles for all intrinsic angular momentum configurations.

Particle Decay	Decay Type	Interim Energy Distribution – Confinement Energy Sign			Quark Flavour Change	
		q_1	q_2	q_3	Down	Up
$\Delta^{++} \rightarrow p^+$	7	+ve	+ve	+ve		√
$\Delta^+ \rightarrow n^0$	7	+ve	+ve	+ve		√
$\rightarrow p^+$	6	+ve	+ve	+ve		
$\Delta^0 \rightarrow n^0$	6	+ve	+ve	+ve		
$\rightarrow p^+$	1	+ve	+ve	+ve	√	
$\Delta^- \rightarrow n^0$	1	+ve	+ve	+ve	√	

Table 3.3 – Types of Decay Exhibited by Delta Particles.

4.0 Intrinsic Angular Momentum Tables, Energy Distribution Tables and Decay Energy Translations.

4.1 The Δ^+ Particle.

4.1.1 Intrinsic Angular Momentum Configurations.

The Δ^+ particle contains two identical quarks but only two intrinsic angular momentum configurations produce unique decay modes.

Δ^+(#)	u_1	u_2	d_1	Decay Modes
1	$\uparrow 3/2$	$\uparrow 1/2$	$\downarrow 1/2$	$\Delta^+(u_1) \rightarrow n^0(d_2)$
2	$\uparrow 3/2$	$\downarrow 1/2$	$\uparrow 1/2$	$\Delta^+(2) \rightarrow p^+(1)$ (Resonance)

Table 4.1 – Intrinsic Angular Momentum Configurations of Δ^+.

In Table 4.1 each arrow indicates the direction of intrinsic angular momentum. Also note that two extra identical configurations, $\Delta^+(3)$ and $\Delta^+(4)$, are obtained by interchanging the intrinsic angular momenta of u_1 and u_2 in $\Delta^+(1)$ and $\Delta^+(2)$ and which have the same decay modes. The same is true of $\Delta^+(5)$ and $\Delta^+(6)$. The decay $\Delta^+ \rightarrow p^+$ (Resonance) is Decay Type 6 and as shown in Table 3.3 is a decay without a quark flavour change.

4.1.2 Energy Distribution Table.

This is determined from the basic theory in [3], is shown in the following table, and is applicable to $\Delta^+(1)$ and $\Delta^+(2)$.

Energy	u_1	u_2	d_1	Total
Matter	2.40	2.40	4.75	9.55
Resonance	377.47	41.94	21.19	440.60
Confinement	196.49	196.49	388.88	781.86
Total	576.36	240.83	414.82	1232.01

Table 4.2 – Energy Distribution for $\Delta^+(1)$ and $\Delta^+(2)$.

Note that similar tables exists for $\Delta^+(3)$, $\Delta^+(4)$, $\Delta^+(5)$ and $\Delta^+(6)$ in which the matter and confinement energies are identical to the above but in which the resonance energy distribution is different with u_2 and d_1 possessing the higher resonance energy respectively. For these configurations while the quark total energies are different, the matter, resonance and confinement energy totals are the same as $\Delta^+(1)$ and $\Delta^+(2)$, as is of course the total particle energy, (see Appendix A).

4.1.3 Decay Energy Translations.

This is the interim energy distribution for the resonance energy only decay of $\Delta^+(2) \rightarrow p^+(1)$.

Energy	u_1	u_2	d_1	Total
Matter	2.40	2.40	4.75	9.55
Resonance	58.63	58.63	29.62	146.87
Confinement	515.33	179.80	380.45	1075.58
Total	576.36	240.83	414.82	1232.01

Table 4.3 – Interim Energy Distribution for $\Delta^+(2) \rightarrow p^+(1)$.

This table shows that, similar to the decay interim energy distributions for $J = 1/2\hbar$ particles, of [3], [4] [5] and [6], in re-balancing the resonance energy of all three quarks to the inverse mass ratio rule, each quark has effected an exchange of resonance and confinement energy in the appropriate direction.
The decay is completed via the following confinement energy translations

$E_c(u_2)$ Increases via absorption from u_1 by 16.69 to 196.49, (the Proton level).
$E_c(d_1)$ Increases via absorption from u_1 by 8.43 to 388.88, (the Proton level).
$E_c(u_1)$ Therefore decreases by 25.12 to 490.21.

Finally u_1 ejects 293.72 in the form of a π^0 plus E_k to reduce to 196.49, the Proton level, to complete the decay.

Note that although this decay is completed via confinement energy translations, it has been called a "resonance energy only decay" because both matter and confinement energies of the decayed particle are identical to their values in the decaying particle so that effectively it is only resonance energy that has been ejected.

4.2 The Δ^0 Particle.

4.2.1 Intrinsic Angular Momentum Configurations.

The Δ^0 particle also contains two identical quarks and also possesses two intrinsic angular momentum configurations with unique decay modes.

$\Delta^+(\#)$	u_1	d_1	d_2	Decay Modes
2	$\uparrow 3/2$	$\downarrow 1/2$	$\uparrow 1/2$	$\Delta^0(2) \rightarrow n^0(2)$ (Resonance)
4	$\downarrow 1/2$	$\uparrow 1/2$	$\uparrow 3/2$	$\Delta^0(d_2) \Rightarrow p^+(u_2)$

Table 4.4 – Intrinsic Angular Momentum Configurations of Δ^0.

Note that similar comments to those under Table 4.1 also apply here.

4.2.2 Energy Distribution Table.

This is the energy distribution table applicable to $\Delta^0(1)$ and $\Delta^0(2)$.

Energy	**u_1**	**d_1**	**d_2**	**Total**
Matter	2.40	4.75	4.75	11.90
Resonance	394.38	22.14	22.14	438.66
Confinement	157.60	311.92	311.92	781.44
Total	554.38	338.81	338.81	1232.00

Table 4.2 – Energy Distribution for $\Delta^0(1)$ and $\Delta^0(2)$.

Similar comments to those under Table 4.2 also apply here.

4.2.3 Decay Energy Translations.

This is the interim energy distribution for the resonance energy only decays of $\Delta^0(2) \rightarrow n^0(2)$.

Energy	**u_1**	**d_1**	**d_2**	**Total**
Matter	2.40	4.75	4.75	11.90
Resonance	72.73	36.75	36.75	146.22
Confinement	479.26	297.31	297.31	1073.88
Total	554.38	338.81	338.81	1232.00

Table 4.6 – Interim Energy Distribution for $\Delta^0(2) \rightarrow n^0(2)$.

Similar comments to those under Table 4.3 also apply here. The decay is completed via the following energy translations.

> $E_c(d_1)$ Increases via absorption from u_1 by 14.61 to 311.92, (the Neutron level).
> $E_c(d_2)$ Increases via absorption from u_1 by 14.61 to 311.92, (the Neutron level).
> $E_c(u_1)$ Therefore decreases by 29.22 to 450.03.

Finally u_1 ejects 292.43 in the form of a π^0 plus E_k to reduce to 157.60, the Neutron level, to complete the decay.

5.0 Conclusions.

There are two aspects of the Delta particles as reviewed here to date that are worthy of discussion. They are (i) while Δ^+ and Δ^0 are resonance excitation versions of p^+ and n^0 respectively, unlike the confinement excitation versions of $J = 1/2\hbar$ Baryons which always only decay by ejection of confinement energy, i.e. no quark flavour change, Δ^+ and Δ^0 can decay via both modes, i.e. with or without a quark flavour change. (ii) While all Delta particles possess a different complement of quarks, and therefore differing levels of total matter energy, they have all been detected with the same overall mass of 1232.00, [1], [2]. These aspects are discussed as follows.

(i) The decay via confinement only energy in $J = 1/2\hbar$ particles occurs because both resonance and confinement energies already conform to their respective mass ratio rules. Consequently their decay does not involve a quark flavour change. If it did, with say $\Sigma^0(s_1) \Rightarrow d_2$, so initiating a decay path towards n^0, the decay process would merely take the particle through a loop back to Σ^0. Therefore the only way in which a confinement energy excitation particle can decay is by all three quarks ejecting confinement energy in the form of secondary particles.
However, when a resonance excitation particle is created, with one of its quarks possessing an intrinsic angular momentum of $J = 3/2\hbar$, and the appropriate resonance energy, as such it does not conform to the inverse mass ratio rule. Consequently, in the process of acquiring

conformance via conversion to/from confinement energy, the quark confinement energy mass ratio rule is disturbed, so enabling a quark flavour change. This aspect will be examined in more detail in a future paper.

(ii) The reason for this feature is that the quark matter energy difference between two particles is variably offset by the difference in the sum of their resonance and confinement energies. This is illustrated in the following two tables.

Particle	Quark Complement	Σq_m	Difference	Particle Mass	Difference
p^+	uud	9.55	2.35	938.28	1.29
n^0	udd	11.90		939.57	
Σ^+	uus	104.80	2.35	1189.38	3.26
Σ^0	uds	107.15		1192.64	
Σ_c^{++}	uuc	1254.80	2.35	2453.98	-1.08
Σ_c^+	udc	1257.15		2452.90	
Σ_b^+	uub	4304.80	2.35	5811.30	-79.18
Σ_b^0	udb	4307.15		5732.12	

Table 5.1 – Variation in Particle Energy vs a Variation in Quark Matter Energy of 2.35 for $J = 1/2\hbar$.

Table 5.1 clearly shows that with $J = 1/2\hbar$ particles of low energy, the offset compensation is small and positive, but becomes large and negative for the high energy particles.

Particle	Quark Complement	Σq_m	Difference	Particle Mass	Difference
Δ^+	uud	9.55	2.35	1232.00	0.00
Δ^0	udd	11.90		1232.00	
Σ^{+*}	uus	104.80	2.35	1382.80	0.90
Σ^{0*}	uds	107.15		1383.70	
Σ_c^{++*}	uuc	1254.80	2.35	2518.00	-0.5
Σ_c^{+*}	udc	1257.15		2517.50	
Σ_b^{+*}	uub	4304.80	2.35	5832.10	-11.83
Σ_b^{0*}	udb	4307.15		5820.27	

Table 5.2 – Variation in Particle Energy vs a Variation in Quark Matter Energy of 2.35 for $J = 3/2\hbar$.

From Table 5.2, for $J = 3/2\hbar$ particles, it is clear that the effect is the same as for $J = 1/2\hbar$ particles but much less pronounced, which must be due to the presence of the high resonance energy. The main point is that at the lower particle energies, i.e. for Δ^+ and Δ^0 the compensation is exact. Consequently, because the difference in quark matter energy between Δ^+ and Δ^{++} and between Δ^0 and Δ^- is also 2.35, it explains why all four particles have been detected with the same mass. However, it is probable that there is a very slight difference in their mass, with Δ^{++} being the lightest and Δ^- the heaviest, but it seems that this difference is too small to be accurately determined experimentally.

APPENDIX A.

The following table provides the intrinsic angular momentum configurations and energy distributions for those particles and particle configurations not covered in the main text.

Particle Angular Momentum Configuration	**Intrinsic Angular Momenta**			**Quark Energy Distributions**				
	$\Delta^{++}(u_1)$	$\Delta^{++}(u_2)$	$\Delta^{++}(u_3)$	Energy	$\Delta^{++}(u_1)$	$\Delta^{++}(u_2)$	$\Delta^{++}(u_3)$	Total
$\Delta^{++}(1)$	$\uparrow_{1/2\hbar}$	$\downarrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	Matter	2.40	2.40	2.40	7.20
				Resonance	365.42	40.60	40.60	446.63
$\Delta^{++}(2)$	$\downarrow_{1/2\hbar}$	$\uparrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	Confinement	259.39	259.39	259.39	778.18
				Total	627.21	302.40	302.40	1232.01
	$\Delta^{+}(u_1)$	$\Delta^{+}(u_2)$	$\Delta^{+}(d_1)$	Energy	$\Delta^{+}(u_1)$	$\Delta^{+}(u_2)$	$\Delta^{+}(d_1)$	Total
$\Delta^{+}(3)$	$\uparrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	$\downarrow_{1/2\hbar}$	Matter	2.40	2.40	4.75	9.55
				Resonance	41.49	377.47	21.19	440.60
$\Delta^{+}(4)$	$\downarrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	$\uparrow_{1/2\hbar}$	Confinement	196.49	196.49	388.88	781.86
				Total	240.83	576.36	414.82	1232.01
	$\Delta^{+}(u_1)$	$\Delta^{+}(u_2)$	$\Delta^{+}(d_1)$	Energy	$\Delta^{+}(u_1)$	$\Delta^{+}(u_2)$	$\Delta^{+}(d_1)$	Total
$\Delta^{+}(5)$	$\uparrow_{1/2\hbar}$	$\downarrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	Matter	2.40	2.40	4.75	9.55
				Resonance	67.29	67.29	306.02	440.60
$\Delta^{+}(6)$	$\downarrow_{1/2\hbar}$	$\uparrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	Confinement	196.49	196.49	388.88	781.86
				Total	266.18	266.18	699.65	1232.01
	$\Delta^{0}(u_1)$	$\Delta^{0}(d_1)$	$\Delta^{0}(d_2)$	Energy	$\Delta^{0}(u_1)$	$\Delta^{0}(d_1)$	$\Delta^{+}(d_2)$	Total
$\Delta^{0}(3)$	$\uparrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	$\downarrow_{1/2\hbar}$	Matter	2.40	4.75	4.75	11.90
				Resonance	72.47	329.57	36.62	438.66
$\Delta^{0}(4)$	$\downarrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	$\uparrow_{1/2\hbar}$	Confinement	157.60	311.92	311.92	781.44
				Total	232.48	646.24	353.29	1232.01
	$\Delta^{0}(u_1)$	$\Delta^{0}(d_1)$	$\Delta^{0}(d_2)$	Energy	$\Delta^{0}(u_1)$	$\Delta^{0}(d_1)$	$\Delta^{0}(d_2)$	Total
$\Delta^{0}(5)$	$\uparrow_{1/2\hbar}$	$\downarrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	Matter	2.40	4.75	4.75	11.90
				Resonance	72.47	36.62	329.57	438.66
$\Delta^{0}(6)$	$\downarrow_{1/2\hbar}$	$\uparrow_{1/2\hbar}$	$\uparrow_{3/2\hbar}$	Confinement	157.6	311.92	311.92	781.44
				Total	232.48	353.29	646.24	1232.01
	$\Delta^{-}(d_1)$	$\Delta^{-}(d_2)$	$\Delta^{-}(d_3)$	Energy	$\Delta^{-}(d_1)$	$\Delta^{-}(d_2)$	$\Delta^{-}(d_3)$	Total
$\Delta^{-}(1)$	$\uparrow_{3/2\hbar}$	$\downarrow_{1/2\hbar}$	$\uparrow_{1/2\hbar}$	Matter	4.75	4.75	4.75	14.25
				Resonance	353.12	39.23	39.23	431.58
$\Delta^{-}(2)$	$\uparrow_{3/2\hbar}$	$\uparrow_{1/2\hbar}$	$\downarrow_{1/2\hbar}$	Confinement	262.06	262.06	262.06	786.18
				Total	619.93	306.04	306.04	1232.01

Table A1 – Intrinsic Angular Momentum Configurations and Energy Distributions for Those Particles and Configurations Not Covered in the Main Text.

Note that in this table the data for $\Delta^{++}(1)$ is also effectively that for $\Delta^{++}(3)$ and $\Delta^{++}(5)$, and the data for $\Delta^{++}(2)$ is also that for $\Delta^{++}(4)$ and $\Delta^{++}(6)$. The same comment applies to Δ^{-}.

The decay interim energy distributions for all of the above configurations can be determined from the process described in [3].

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