The Quantum Chromodynamics Theory Of Tetraquarks And Mesomesonic Particles

Unfinished draft version

Based on a generalized particle diagram of baryons and anti-baryons which, in turn, is based on symmetry principles, this theory predicts the existence of all the tetraquarks and dimeson molecules (mesomesonic particles) there exist in nature.

by R. A. Frino

Electronics Engineer - Degree from the University of Mar del Plata.

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(see next page)

1. Introduction

Quantum Chromodynamics (QCD) [1, 2, 3, 4] is a quantum mechanical description of the strong nuclear force. The strong force is mediated by gluons [4, 5] which are spin $1\hbar$ bosons (spin is quoted in units of reduced Plank's constant: $\hbar = h/2\pi$). Gluons act on quarks only (only quarks feel the strong force). Colour charge is a property of quarks (and gluons) which is a kind of electric charge (but of a totally different nature) associated with the strong nuclear interactions. There are three distinct types of colour charge: red, green and blue. It is very important to keep in mind that every quark carries a colour charge, while every antiquark carries an anticolour charge (antired, antigreen or antiblue). However colour charge has nothing to do with the real colour of things. The reason, this quark property, is called colour is because it behaves like colour: all known hadrons (baryons and mesons) are "colourless", meaning they are colour neutral particles. Baryons, which are made of three quarks, are "colourless" because each quark has a different colour. Mesons, which are made of a quark and an antiquark, are "colourless" because antiquarks carry anticolour. Thus, a meson with a blue quark and a antiblue quark is a colour neutral particle.

An important point to observe is that the Pauli exclusion principle leads to the existence of colour. This principle may be expressed as follows

Pauli Exclusion Principle

In a system made of identical fermions, no two fermions can have the same set of quantum numbers.

The existence of colour was inferred from the omega-minus particle or Ω^- baryon because it seemed to challenge the above principle. This particle, which was discovered in 1964, is made up of three strange quarks (*s* quarks). Because quarks are fermions, they cannot exist with identical quantum numbers, or in other words, they cannot exist in identical quantum states. So that, the Ω^- particle needed a new quantum number to be able to satisfy the Pauli exclusion principle. Thus, physicists proposed the existence of a new quantum number which was called colour. Having a particle with a red strange quark, a green strange quark and a blue strange quark solved the problem: the Ω^- baryon had all its quarks in different quantum states. So that the property called colour was the one that distinguished each of the quarks of the Ω^- particle when all the other quantum numbers are identical.

Like the electric charge, colour charge is a conserved quantity. Thus, QCD introduced a new conservation law: the conservation of "colour charge". Both quarks and gluons carry colour charge. In contrast, photons which are the mediators or carriers of the electromagnetic force, do not carry electric charge. This is a very important difference between Quantum Electrodynamics (QED) [6] and QCD. Another property of gluons is that they can interact with other gluons. In a certain way, the theory presented here is an extension of the QCD developed independently by Murray Gell-Mann and George Zweig in 1964. Gell-Mann read a James Joyce's novel entitled Finnegan's Wake, which contains the sentence "three quarks for Muster Mark", from where he took the word *quark* and introduced into physics. Gell-Mann predicted the existence of the omega-minus particle from a particle diagram known as the baryon decuplet. In 1969, he received the Nobel Prize in physics for this discovery. The baryon decuplet is shown in FIGURE 1 (see also page 25 of reference [2]). The baryon decuplet contains 10 baryons [4, 7, 8], (shown as blue spheres) which are arranged in a symmetric pattern forming an inverted equilateral triangle. This famous decuplet is also shown on the right hand side of FIGURE 2 through 9. However, in these figures, the baryon decuplet has a slightly different arrangement:

baryons form a right-angled triangle. This will allow us to use a slightly longer horizontal axis representing the electric charge of the particles (from -2 to +2) rather than the isospin. This, in turn, will allow us to add an “antimaterial mirror image” of the 10 baryons so that we can extend the symmetry of the physical system to include not only baryons and antibaryons but also the elusive pentaquarks, mesobaryonic particles (MBPs) and their antiparticles: antipentaquarks and anti-mesobaryonic particles (anti-MBPs).

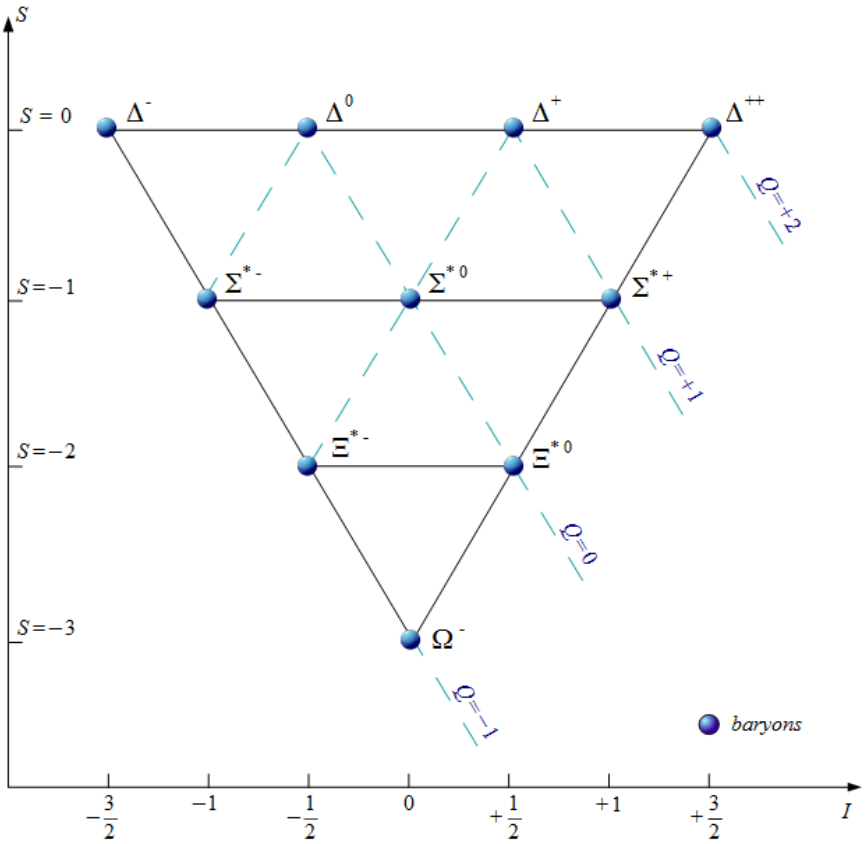


FIGURE 1: ***The Baryon decuplet***. *The diagram shows 10 baryons:* Δ^- , Δ^0 , Δ^+ , Δ^{++} , Σ^{*-} , Σ^{*0} , Σ^{*+} , Ξ^{*-} , Ξ^{*0} *and* Ω^- . *The vertical axis represents the strangeness, S, of the particles while the horizontal axis, I, the isospin. The diagonal lines shown in cyan are lines of equal electric charge. The particles whose names include an asterisk are exited states of the corresponding particles:* Σ^- , Σ^0 , Σ^+ , Ξ^- , Ξ^0 .

Although this theory is intended for experts, it is, from a mathematical point of view, very simple, so that, it is also suitable for those readers with basic knowledge of quarks and equations. Strictly speaking equations are not necessary either. In fact, a number of examples throughout the paper illustrate how to use fractions instead of equations to find the quark contents of exotic particles (pentaquarks and mesobaryonic particles). So that, if you know how to add and subtract fractions you should be able to follow the present analysis. Appendix 1 contains the nomenclature and acronyms used throughout this paper. The expert may skip section 2 as it contains the basic properties of quarks and antiquarks.

2. Summary of the Properties of Quarks and Antiquarks

The following two tables aim to provide a brief overview of the properties of quarks and anti-quarks for non-experts. TABLE 1 is a summary of the properties of quarks while TABLE 2 is a summary of the properties of anti-quarks. The elementary charge, e, is defined as a negative quantity: $e = -1.602\ 176\ 6208 \times 10^{-19} C$, approximately. Thus, the charge of the electron is e and that of the proton is $|e|$ (the absolute value of e).

QUARKS PROPERTIES (see note 1)							
QUARK NAME	SYMBOL	ELECTRIC CHARGE (times $\|e\|$)	SPIN	STRANGENESS	CHARMNESS	BOTTOMNESS	TOPNESS
up	u	$+\frac{2}{3}$	$\frac{1}{2}$	0	0	0	0
down	d	$-\frac{1}{3}$	$\frac{1}{2}$	0	0	0	0
strange	s	$-\frac{1}{3}$	$\frac{1}{2}$	-1	0	0	0
charm	c	$+\frac{2}{3}$	$\frac{1}{2}$	0	$+1$	0	0
bottom	b	$-\frac{1}{3}$	$\frac{1}{2}$	0	0	-1	0
top	t	$+\frac{2}{3}$	$\frac{1}{2}$	0	0	0	$+1$

TABLE 1: *Properties of quarks. The isospin and the isospin z-componet are not shown.*

ANTIQUARKS PROPERTIES (see note 1)							
QUARK NAME	SYMBOL	ELECTRIC CHARGE (times $\|e\|$)	SPIN	STRANGENESS	CHARMNESS	BOTTOMNESS	TOPNESS
Anti-up	$\bar{u}$	$-\frac{2}{3}$	$\frac{1}{2}$	0	0	0	0
Anti-down	$\bar{d}$	$+\frac{1}{3}$	$\frac{1}{2}$	0	0	0	0
Anti-strange	$\bar{s}$	$+\frac{1}{3}$	$\frac{1}{2}$	$+1$	0	0	0
Anti-charm	$\bar{c}$	$-\frac{2}{3}$	$\frac{1}{2}$	0	-1	0	0
Anti-bottom	$\bar{b}$	$+\frac{1}{3}$	$\frac{1}{2}$	0	0	$+1$	0
Anti-top	$\bar{t}$	$-\frac{2}{3}$	$\frac{1}{2}$	0	0	0	-1

TABLE 2: *Properties of antiquarks. The isospin and the isospin z-componet are not shown because are not used by this theory.*

3. The Matter-Antimatter Way For Tetraquarks and Meso-mesonic Particles

The diagram shown on FIGURE 2 is the matter-antimatter way for tetraquarks and dimeson molecules and their corresponding antiparticles. It includes not only tetraquarks and mesomesonic particles on the symmetry axis but also tetraquarks and mesomesonic particles in each and every labelled point of the diagram whose strangeness is:

a) particles side $-2 \leq S \leq 0$ in other words S = -2, -1, and 0.

b) antiparticles side $0 \leq S \leq 2$ in other words S = +2, +1, and 0.

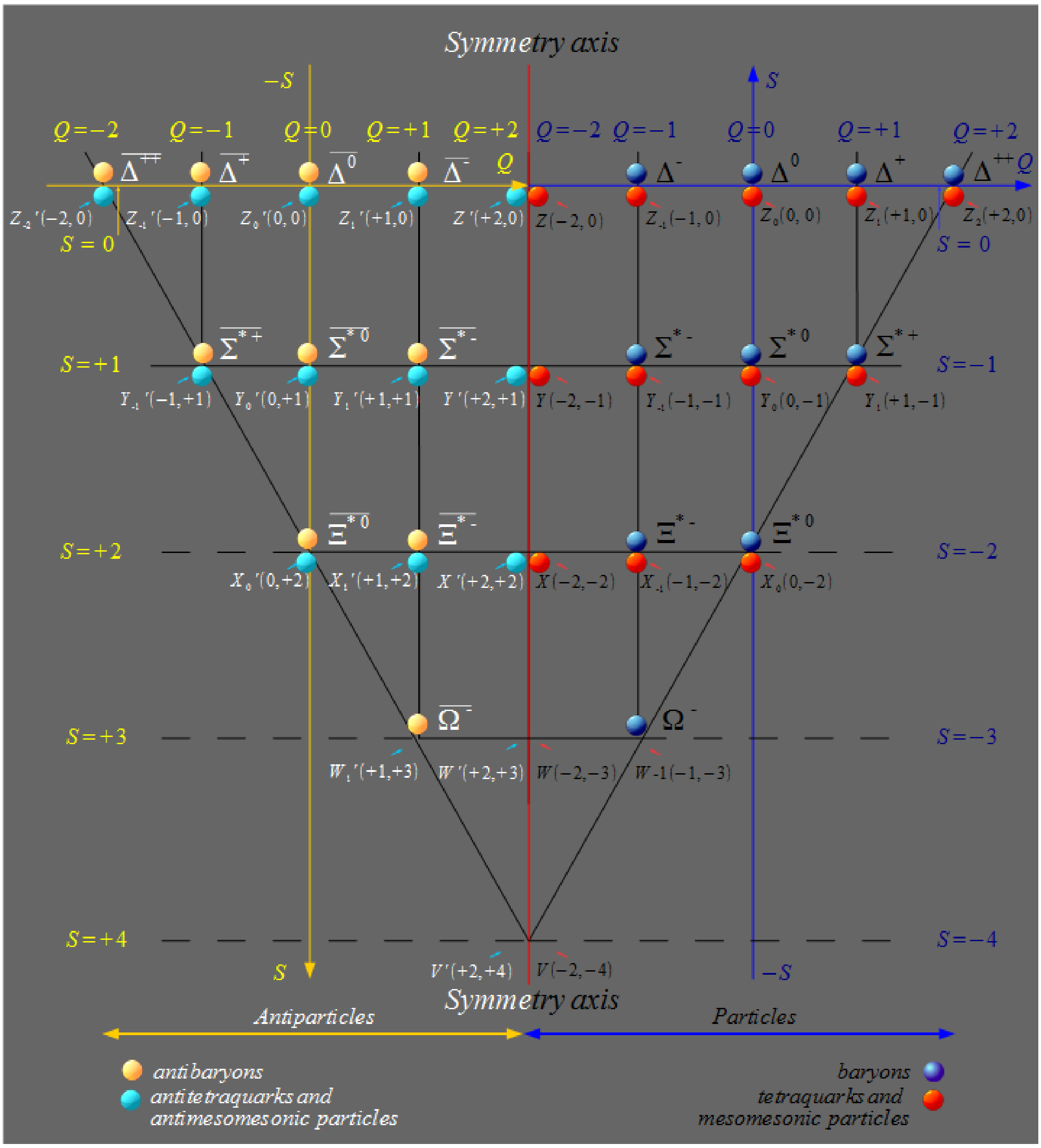


FIGURE 2: ***The Matter-Antimatter Way***. *This theory predicts the existence of tetraquarks and mesomesonic "molecules" (dimeson "molecules") and their antiparticles. Each red circle represents a set of tetraquarks and dimeson "molecules" while each cyan circle represents the corresponding set of antiparticles. The blue circles represent the baryon decuplet while the yellow circles represent the corresponding anti-baryon decuplet.*

The analysis shows that there exist the following tetraquarks/mesomesonic molecules and their antiparticles (tables 4 and 5, respectively).

Point X **tetraquarks/dimeson molecules**		
PARTICLE COMPOSITION (quark contents)	ELECTRIC CHARGE (times $\|e\|$)	STRANGENESS
$(s\,s\,\bar{u}\,\bar{u})$	-2	-2
$(s\,s\,\bar{u}\,\bar{c})$	-2	-2
$(s\,s\,\bar{u}\,\bar{t})$	-2	-2
$(s\,s\,\bar{c}\,\bar{u})$	-2	-2
$(s\,s\,\bar{c}\,\bar{c})$	-2	-2
$(s\,s\,\bar{c}\,\bar{t})$	-2	-2
$(s\,s\,\bar{t}\,\bar{u})$	-2	-2
$(s\,s\,\bar{t}\,\bar{c})$	-2	-2
$(s\,s\,\bar{t}\,\bar{t})$	-2	-2

TABLE 4: *Some of the properties of the particles predicted by this theory at point* X .

Point X ' **antitetraquarks/anti-dimeson molecules**		
PARTICLE COMPOSITION (quark contents)	ELECTRIC CHARGE (times $\|e\|$)	STRANGENESS
$(\bar{s}\,\bar{s}\,u\,u)$	$+2$	$+2$
$(\bar{s}\,\bar{s}\,u\,c)$	$+2$	$+2$
$(\bar{s}\,\bar{s}\,u\,t)$	$+2$	$+2$
$(\bar{s}\,\bar{s}\,c\,u)$	$+2$	$+2$
$(\bar{s}\,\bar{s}\,c\,c)$	$+2$	$+2$
$(\bar{s}\,\bar{s}\,c\,t)$	$+2$	$+2$
$(\bar{s}\,\bar{s}\,t\,u)$	$+2$	$+2$
$(\bar{s}\,\bar{s}\,t\,c)$	$+2$	$+2$
$(\bar{s}\,\bar{s}\,t\,t)$	$+2$	$+2$

TABLE 5: *Some of the properties of the antiparticles predicted by this theory at point* X' .

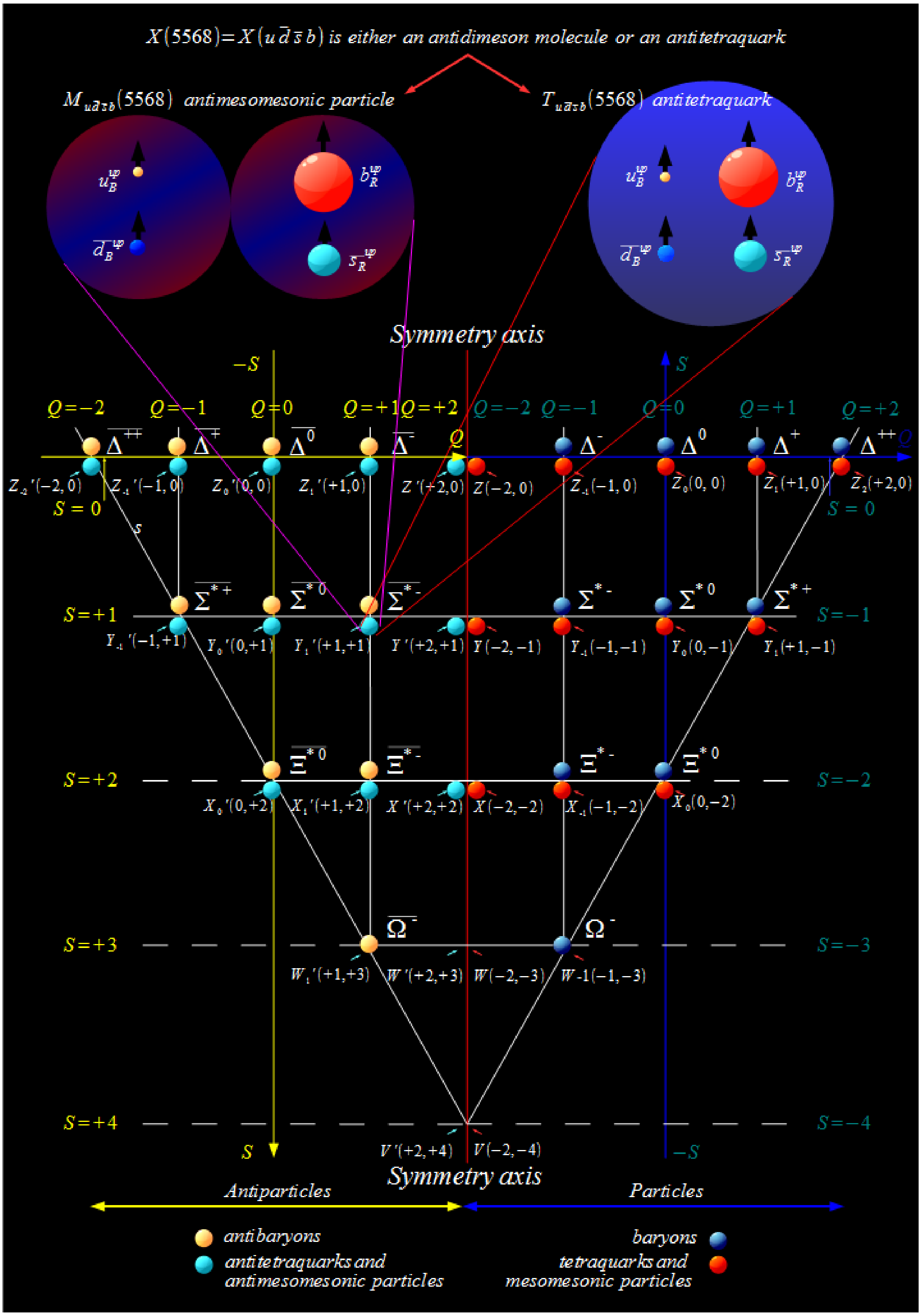
4. The Discovery of the $X(5568)$ Particle

On 25 February this year (2016) FERMILAB scientists announced the discovery the $X(5568)$ state with a mass of $5567.8 \pm 2.9(stat) + 0.9/-1.9(syst)\ MeV/c^2$ and composition $(u\,\bar{d}\,\bar{s}\,b)$. The theory presented in this paper predicts both tetraquarks and dimeson molecules states with exactly this composition. These particles are found at point $Y_1'(+1,+1)$, on the antiparticles side of the matter-antimatter way (see FIGURE 3). Therefore the discovered X state corresponds to an antiparticle, not to a particle.

FERMILAB'S NOMENCLATURE (Observed)	AUTHOR'S NOMENCLATURE antitetraquark/ antidimesonic molecule (Predicted)	PARTICLE COMPOSITION (valence quark contents)	ELECTRIC CHARGE (times |e|)	STRANGENESS
$X(5568)$	$\bar{T}_{u\bar{d}\bar{s}b}(5568)$ $\bar{M}_{u\bar{d}\bar{s}b}(5568)$	$(u\,\bar{d}\,\bar{s}\,b)$	+1	

TABLE 3: *The discovered tetraquarks/dimesonic particle (either one or the other) and some of their properties. It should be noted that this theory predicts the existence of both tetraquarks and dimesonic molecules.*

If the discovered particle were a tetraquark then it would be a strongly bound state of 4 quarks. On the other hand, if the discovered particle were a di-meson "molecule", then it would be a weakly bound state of two mesons. Whatever the new discovered particle turns out to be, it is a new type of exotic matter and this will, sooner or later, open the doors to some of the mysteries of nature with implications that will extend not only to particle physics but also to astrophysics and cosmology. FIGURE 3 shows the location of the discovered antiparticle on the diagram.



FIGIRE 3: The matter-antimatter way for tetraquarks showing the two possibilities (either tetraquark or dimeson molecule) for the discovered *X*(5568) antiparticle. Note that the points *V*, *W*, W_{-1} (particles side) do not contain any tetraquarks or dimeson molecules. Likewise, the points *V'*, *W' and* $W_1{}'$ (antiparticles side) do not contain any antitetraquarks or anti-dimeson molecules either. This is so because 4 quarks cannot produce a total strangeness of -4 or -3 (particles side) and cannot produce a total strangeness of +4 or +3 (antiparticles side) and still satisfy the charge requirements for each point.

5. Conclusions

The theory I propose in this paper is based on a symmetry principle between matter and antimatter, which in its graphic form, is what I have called - the matter-antimatter way -. The diagram suggests it's possible that there exist:

a) tetraquarks and mesomesonic molecules, and
b) pentaquarks and mesobaryonic molecules. Pentaquarks have been analysed in another article that I wrote [9].

In summary, this formulation:

(a) predicts the existence of all the tetraquarks and dimeson molecules there exist in the universe (along with their corresponding antiparticles).

(b) predicts, in particular, the existence of tetraquarks and the existence of mesomesonic particles made of four different flavours. For example the antitetraquark $(u\,\bar{d}\,b\,\bar{s})$ contains four different flavours: up, anti-down, anti-strange and bottom (this means that we consider the strange flavour and the anti-strange "flavour" as two distinct flavours). Thus, it seems appropriate to group together these types of tetraquarks and these types of mesomesonic particles under the name of **quadruply flavoured tetraquarks** and **quadruply flavoured mesomesonic particles (quadruply flavoured dimeson molecules)**, respectively. This is a feature we cannot find in baryons because, as the reader knows, baryons are made of three quarks only.

(c) predicts, in particular, the existence of tetraquarks and the existence of mesomesonic particles made of two different flavours. For example the $(u\,\bar{u}\,u\,\bar{u})$ is made of two up quarks and two anti-up quarks (provided that an anti-flavour to be considered a different flavour).

(d) defines tetraquarks and dimeson molecules as those particles that are found on the right-hand side (particles side) of the matter-antimatter way, while the formulation defines antitetraquarks and antidimeson molecules as those particles that are found on the left-hand side (antiparticles side) of the matter-antimatter way. Without the diagram the classification seems to be arbitrary.

When this theory is finalized it will show the quark contents of all the tetraquarks and mesomesonic molecules (and their antiparticles) there exist in nature.

Appendix 1: Acronyms and Nomenclature

ACRONYMS

The following are the acronyms used in this paper

LHC = large hadron collider
QED = quantum electrodynamics
QCD = quantum chomodynamics
MAW = matter-antimatter way
MMP = *MMM* = mesomesonic particle (or mesomesonic molecule, dimeson molecule).

$\overline{MMP} = \overline{MMM}$ = anti-mesomesonic particle (anti-mesomesonic molecule, anti-dimeson molecule).

NOMENCLATURE

The following are the symbols used in this paper

$P_{vwxy\bar{z}}$ = pentaquark. The subindex $vwxy\bar{z}$ represents the particle composition where *v*, *w*, *x*, *y* and *z* are quark flavours.
$M_{vwxy\bar{z}}$ = mesobaryonic particle (or mesobaryonic molecule, baryomesonic particle, baryomesonic molecule). The subindex $vwxy\bar{z}$ represents the particle composition where *v*, *w*, *x*, *y* and *z* are quark flavours.
$\bar{P}_{\bar{v}\bar{w}\bar{x}\bar{y}z}$ = anti-pentaquark. The subindex $\bar{v}\bar{w}\bar{x}\bar{y}z$ represents the particle composition where *v*, *w*, *x*, *y* and *z* are quark flavours.
$\bar{M}_{\bar{v}\bar{w}\bar{x}\bar{y}z}$ = anti-mesobaryonic particle (or anti-mesobaryonic molecule, anti-baryomesonic particle, anti-baryomesonic molecule). The subindex $\bar{v}\bar{w}\bar{x}\bar{y}z$ represents the particle composition where *v*, *w*, *x*, *y* and *z* are quark flavours.
$P_{vwxy\bar{z}}(m_0)$ = pentaquark of rest mass m_0 .
$M_{vwxy\bar{z}}(m_0)$ = mesobaryonic molecule of rest mass m_0 .
$\bar{P}_{\bar{v}\bar{w}\bar{x}\bar{y}z}(m_0)$ = anti-pentaquark of rest mass m_0 .
$\bar{M}_{\bar{v}\bar{w}\bar{x}\bar{y}z}(m_0)$ = anti-mesobaryonic molecule of rest mass m_0 .
Q = electric charge of the unknown particle (pentaquark/mesobaryonic particle). Also, in the diagram of FIGURE 2, *Q* is the electric charge of a baryon or the electric charge of an antibaryon
q_u = electric charge of the up quark
q_d = electric charge of the up quark
q_s = electric charge of the strange quark
q_c = electric charge of the charm quark
q_b = electric charge of the bottom quark
q_t = electric charge of the top quark
$q_{\bar{u}}$ = electric charge of the antiup quark
$q_{\bar{d}}$ = electric charge of the antidown quark
$q_{\bar{s}}$ = electric charge of the antistrange quark
$q_{\bar{c}}$ = electric charge of the anticharm quark

$q_{\bar{b}}$ = electric charge of the antibottom quark
$q_{\bar{t}}$ = electric charge of the antitop quark
q_5 = electric charge of one of the constituents (quark) of the unknown particle (pentaquark/mesobaryonic particle) (cannot be an *s* quark). This quark will be called the fifth quark.
q_4 = electric charge of one of the constituents (quark) of the unknown particle (pentaquark/mesobaryonic particle) (cannot be an *s* quark). This quark will be called the forth quark.
q_3 = electric charge of one of the constituents (quark) of the unknown particle (pentaquark/mesobaryonic particle) (cannot be an *s* quark). This quark will be called the third quark.
q_2 = electric charge of one of the constituents (quark) of the unknown particle (pentaquark/mesobaryonic particle) (cannot be an *s* quark). This quark will be called the second quark.
q_1 = electric charge of one of the constituents (quark) of the unknown particle (pentaquark/mesobaryonic particle) (cannot be an *s* quark). This quark will be called the first quark.
Δ^- = Delta-minus particle – composition: *ddd*
Δ^0 = Delta-zero particle – composition: *udd*
Δ^+ = Delta-plus particle – composition: *uud*
Δ^{++} = Delta-plus-plus particle – composition: *uuu*
Σ^- = Sigma-minus particle – composition: *dds*
Σ^0 = Sigma-zero particle – composition: *uds*
Σ^+ = Sigma-plus particle – composition: *uus*
Ξ^- = Xi-minus particle – composition: *dss*
Ξ^0 = Xi-zero particle – composition: *uss*
Ω^- = Omega-minus particle – composition: *sss*
$\overline{\Delta^-}$ = Delta-minus antiparticle – composition: $\bar{d}\,\bar{d}\,\bar{d}$
$\overline{\Delta^0}$ = Delta-zero antiparticle – composition: $\bar{u}\,\bar{d}\,\bar{d}$
$\overline{\Delta^+}$ = Delta-plus antiparticle – composition: $\bar{u}\,\bar{u}\,\bar{d}$
$\overline{\Delta^{++}}$ = Delta-plus-plus antiparticle – composition: $\bar{u}\,\bar{u}\,\bar{u}$
$\overline{\Sigma^-}$ = Sigma-minus antiparticle – composition: $\bar{d}\,\bar{d}\,\bar{s}$
$\overline{\Sigma^0}$ = Sigma-zero antiparticle – composition: $\bar{u}\,\bar{d}\,\bar{s}$
$\overline{\Sigma^+}$ = Sigma-plus antiparticle – composition: $\bar{u}\,\bar{u}\,\bar{s}$
$\overline{\Xi^-}$ = Xi-minus antiparticle – composition: $\bar{d}\,\bar{s}\,\bar{s}$
$\overline{\Xi^0}$ = Xi- zero antiparticle – composition: $\bar{u}\,\bar{s}\,\bar{s}$
$\overline{\Omega^-}$ = Omega-minus antiparticle – composition: $\bar{s}\,\bar{s}\,\bar{s}$
Σ^{*-} = Excited state of the Sigma-minus particle – composition: *dds*
Σ^{*0} = Excited state of the Sigma-zero particle – composition: *uds*
Σ^{*+} = Excited state of the Sigma-plus particle – composition: *uus*
Ξ^{*-} = Excited state of the Xi-minus particle – composition: *dss*
Ξ^{*0} = Excited state of the Xi-zero particle – composition: *uss*
$\overline{\Sigma^{*-}}$ = Excited state of the Sigma-minus antiparticle – composition: $\bar{d}\,\bar{d}\,\bar{s}$
$\overline{\Sigma^{*0}}$ = Excited state of the Sigma-zero antiparticle – composition: $\bar{u}\,\bar{d}\,\bar{s}$
$\overline{\Sigma^{*+}}$ = Excited state of the Sigma-plus antiparticle – composition: $\bar{u}\,\bar{u}\,\bar{s}$
$\overline{\Xi^{*-}}$ = Excited state of the Xi-minus antiparticle – composition: $\bar{d}\,\bar{s}\,\bar{s}$
$\overline{\Xi^{*0}}$ = Excited state of the Xi-zero antiparticle – composition: $\bar{u}\,\bar{s}\,\bar{s}$
u = up quark

$d =$ down quark
$s =$ strange quark
$c =$ charm quark
$b =$ bottom quark
$t =$ top quark
$\bar{u} =$ antiup quark or anti-up quark
$\bar{d} =$ antidown quark or anti-down quark
$\bar{s} =$ antistrange quark or anti-strange quark
$\bar{c} =$ anticharm quark or anti-charm quark
$\bar{b} =$ antibottom quark or anti-bottom quark
$\bar{t} =$ antitop quark or anti-top quark
$u_R =$ up quark carrying red colour
$u_G =$ up quark carrying green colour
$u_B =$ up quark carrying blue colour
$d_R =$ down quark carrying red colour
$d_G =$ down quark carrying green colour
$d_B =$ down quark carrying blue colour
$s_R =$ strange quark carrying red colour
$s_G =$ strange quark carrying green colour
$s_B =$ strange quark carrying blue colour
$c_R =$ charm quark carrying red colour
$c_G =$ charm quark carrying green colour
$c_B =$ charm quark carrying blue colour
$b_R =$ bottom quark carrying red colour
$b_G =$ bottom quark carrying green colour
$b_B =$ bottom quark carrying blue colour
$t_R =$ top quark carrying red colour
$t_G =$ top quark carrying green colour
$t_B =$ top quark carrying blue colour
$u_R^{up} =$ up quark carrying red colour and spin up
$u_G^{up} =$ up quark carrying green colour and spin up
$u_B^{up} =$ up quark carrying blue colour and spin up
$d_R^{up} =$ down quark carrying red colour and spin up
$d_G^{up} =$ down quark carrying green colour and spin up
$d_B^{up} =$ down quark carrying blue colour and spin up
$s_R^{up} =$ strange quark carrying red colour and spin up
$s_G^{up} =$ strange quark carrying green colour and spin up
$s_B^{up} =$ strange quark carrying blue colour and spin up
$c_R^{up} =$ charm quark carrying red colour and spin up
$c_G^{up} =$ charm quark carrying green colour and spin up
$c_B^{up} =$ charm quark carrying blue colour and spin up
$b_R^{up} =$ bottom quark carrying red colour and spin up
$b_G^{up} =$ bottom quark carrying green colour and spin up
$b_B^{up} =$ bottom quark carrying blue colour and spin up
$t_R^{up} =$ top quark carrying red colour and spin up
$t_G^{up} =$ top quark carrying green colour and spin up
$t_B^{up} =$ top quark carrying blue colour and spin up

u_R^{down} = up quark carrying red colour and spin down
u_G^{down} = up quark carrying green colour and spin down
u_B^{down} = up quark carrying blue colour and spin down
d_R^{down} = down quark carrying red colour and spin down
d_G^{down} = down quark carrying green colour and spin down
d_B^{down} = down quark carrying blue colour and spin down
s_R^{down} = strange quark carrying red colour and spin down
s_G^{down} = strange quark carrying green colour and spin down
s_B^{down} = strange quark carrying blue colour and spin down
c_R^{down} = charm quark carrying red colour and spin down
c_G^{down} = charm quark carrying green colour and spin down
c_B^{down} = charm quark carrying blue colour and spin down
b_R^{down} = bottom quark carrying red colour and spin down
b_G^{down} = bottom quark carrying green colour and spin down
b_B^{down} = bottom quark carrying blue colour and spin down
t_R^{down} = top quark carrying red colour and spin down
t_G^{down} = top quark carrying green colour and spin down
t_B^{down} = top quark carrying blue colour and spin down
$\overline{u_R}$ = antiup quark carrying antired colour
$\overline{u_G}$ = antiup quark carrying antigreen colour
$\overline{u_B}$ = antiup quark carrying antiblue colour
$\overline{d_R}$ = antidown quark carrying antired colour
$\overline{d_G}$ = antidown quark carrying antigreen colour
$\overline{d_B}$ = antidown quark carrying antiblue colour
$\overline{s_R}$ = antistrange quark carrying antired colour
$\overline{s_G}$ = antistrange quark carrying antigreen colour
$\overline{s_B}$ = antistrange quark carrying antiblue colour
$\overline{c_R}$ = anticharm quark carrying antired colour
$\overline{c_G}$ = anticharm quarkv carrying antigreen colour
$\overline{c_B}$ = anticharm quark carrying antiblue colour
$\overline{b_R}$ = antibottom quark carrying antired colour
$\overline{b_G}$ = antibottom quark carrying antigreen colour
$\overline{b_B}$ = antibottom quark carrying antiblue colour
$\overline{t_R}$ = antitop quark carrying antired colour
$\overline{t_G}$ = antitop quark carrying antigreen colour
$\overline{t_B}$ = antitop quark carrying antiblue colour
$\overline{u_R}^{up}$ = antiup quark carrying antired colour and spin up
$\overline{u_G}^{up}$ = antiup quark carrying antigreen colour and spin up
$\overline{u_B}^{up}$ = antiup quark carrying antiblue colour and spin up
$\overline{d_R}^{up}$ = antidown quark carrying antired colour and spin up
$\overline{d_G}^{up}$ = antidown quark carrying antigreen colour and spin up
$\overline{d_B}^{up}$ = antidown quark carrying antiblue colour and spin up
$\overline{s_R}^{up}$ = antistrange quark carrying antired colour and spin up
$\overline{s_G}^{up}$ = antistrange quark carrying antigreen colour and spin up
$\overline{s_B}^{up}$ = antistrange quark carrying antiblue colour and spin up

$\overline{c}_R^{up} =$ anticharm quark carrying antired colour and spin up
$\overline{c}_G^{up} =$ anticharm quark carrying antigreen colour and spin up
$\overline{c}_B^{up} =$ anticharm quark carrying antiblue colour and spin up
$\overline{b}_R^{up} =$ antibottom quark carrying antired colour and spin up
$\overline{b}_G^{up} =$ antibottom quark carrying antigreen colour and spin up
$\overline{b}_B^{up} =$ antibottom quark carrying antiblue colour and spin up
$\overline{t}_R^{up} =$ antitop quark with carrying antired colour and up
$\overline{t}_G^{up} =$ antitop quark with carrying antigreen colour and up
$\overline{t}_B^{up} =$ antitop quark with carrying antiblue colour and up
$\overline{u}_R^{down} =$ antiup quark carrying antired colour and spin down
$\overline{u}_G^{down} =$ antiup quark carrying antigreen colour and spin down
$\overline{u}_B^{down} =$ antiup quark carrying antiblue colour and spin down
$\overline{d}_R^{down} =$ antidown quark carrying antired colour and spin down
$\overline{d}_G^{down} =$ antidown quark carrying antigreen colour and spin down
$\overline{d}_B^{down} =$ antidown quark carrying antiblue colour and spin down
$\overline{s}_R^{down} =$ antistrange quark carrying antired colour and spin down
$\overline{s}_G^{down} =$ antistrange quark carrying antigreen colour and spin down
$\overline{s}_B^{down} =$ antistrange quark carrying antiblue colour and spin down
$\overline{c}_R^{down} =$ anticharm quark carrying antired colour and spin down
$\overline{c}_G^{down} =$ anticharm quark carrying antigreen colour and spin down
$\overline{c}_B^{down} =$ anticharm quark carrying antiblue colour and spin down
$\overline{b}_R^{down} =$ antibottom quark carrying antired colour and spin down
$\overline{b}_G^{down} =$ antibottom quark carrying antigreen colour and spin down
$\overline{b}_B^{down} =$ antibottom quark carrying antiblue colour and spin down
$\overline{t}_R^{down} =$ antitop quark carrying antired colour and spin down
$\overline{t}_G^{down} =$ antitop quark carrying antigreen colour and spin down
$\overline{t}_B^{down} =$ antitop quark carrying antiblue colour and spin down

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