The Quantum Chromodynamics Theory Of Quadruply Strange Pentaquarks

Based on a generalized particle diagram of baryons and antibaryons which, in turn, is based on symmetry principles, this theory predicts the existence of three quadruply strange pentaquarks: $s\,s\,s\,s\,\overline{u}$, $s\,s\,s\,s\,\overline{c}$, *and* $s\,s\,s\,s\,\overline{t}$ *, and their antiparticles:* $\overline{s}\,\overline{s}\,\overline{s}\,\overline{s}\,u$, $\overline{s}\,\overline{s}\,\overline{s}\,\overline{s}\,c$, *and* $\overline{s}\,\overline{s}\,\overline{s}\,\overline{s}\,t$ *. The theory only requires basic mathematical knowledge and therefore may be understood by the non-expert.*

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Keywords: *mirror symmetry, parity, P symmetry, charge conjugation, C symmetry, time reversal, T symmetry, CP symmetry, CPT symmetry, quantum electrodynamics, quantum chromodynamics, quark, antiquark, up quark, down quark, strange quark, charm quark, bottom quark, top quark, pentaquark, quadruply strange pentaquark, quadruply bottom pentaquark, colour charge, anticolour, anticolour charge, strangeness, charmness, bottomness, topness, fermion, hadron, baryon, meson, boson, photon, gluon, Pauli exclusion principle, force carrier, omega-minus particle, LHC (Large Hadron Collider).*

Contents

1. Introduction

Quantum Chromodynamics (QCD) is a quantum mechanical description of the strong nuclear force. The strong force is mediated by gluons which are spin 1 bosons. They 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 colours: all known hadrons (baryons and mesons) are “colourless” (meaning 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.

The Pauli exclusion principle leads to the existence of colour. According to this principle, no two fermions can have all the same quantum numbers. The existence of colour was inferred from the omega-minus particle or Ω^- baryon. 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. 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) and QCD. Another property of gluons is that they can interact with other gluons.

The theory presented here is, in certain way, 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 the word quark was taken and introduced into physics. Gell-Mann predicted the existence of the omega-minus particle from a particle diagram known as baryon decuplet. This diagram, which contains 10 baryons, is shown in blue on the right hand side of FIGURE 1. Appendix 1 contains the nomenclature used throughout this paper.

2. Summary of the Properties of Quarks and Antiquarks

Before I explain the details of this theory, we need to understand some of the properties of quarks and antiquarks. In order to do this I have included the following two tables. TABLE 1 is a summary of the properties of quarks while TABLE 2 is a summary of the properties of antiquarks. There are other properties that have been left out because they are not relevant to this paper.

QUARKS PROPERTIES							
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							
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 QCD Theory of Strange Pentaquarks (The 26-Particles Matter-Antimatter Way)

The particle diagram showed below (FIGURE 1), that I call Matter-Antimatter Way of 26 Particles (other suitable names are: The 26-Particle Matter-Antimatter Way, Matter-Antimatter Triangle, Matter-Antimatter Symmetry Diagram, Double Decuplet+6 Diagram, 26-Particles Triangle, etc.) suggests that pentaquarks are real physical entities. The reason is explained further below. But first, I would like to explain the diagram which is from where we shall be able to predict the existence of new particles (pentaquarks) which have not been observed yet. An innovative feature of this diagram is that contains two QS coordinate systems (charge-strangeness coordinate system which is like an xy coordinate system). One QS coordinate system is for particles (shown in blue) while the other one is for their antiparticles (shown in green). Thus, one of the horizontal Q axes represents the electric charge of particles while the other one represents the electric charge of antiparticles. Similarly, one of the vertical S axis represents the strangeness of particles ($+S$ points up the page) while the other vertical S axis represents the strangeness of antiparticles ($+S$ points down the page).

It is important to observe that Q=-2 belongs to the particles' Q axis while Q=+2 belongs to the antiparticles' Q axis. Thus the points (-2, 0) and (+2,0) are QS points that overlap. The only way of explaining this overlapping is if there are both pentaquarks and antipentaquarks on the lower vertex of the triangle.

This particle diagram is symmetrical about the vertical axis, which is called: the symmetry axis (the symmetry axis has no arrows and is shown in red). On the right hand size of the symmetry axis we have 10 baryons, known as the baryon decuplet (this was the original decuplet discovered by Gell-Mann). This decuplet is shown in blue. On the left hand side of the symmetry axis we have the antibaryon decuplet containing the 10 corresponding antibaryons (shown in red) The left hand side of the diagram (where antiparticles are placed) can be obtained simply by placing a mirror along the symmetry axis (with the reflecting side facing the material side) and replacing the reflection of the particles by their corresponding antiparticles. Thus, our mirror is a kind of magic mirror because in addition to reflecting images (mirror symmetry, parity (P) or P symmetry) it must also be able to replace the reflected particles by their corresponding antiparticles (charge conjugation (C) or C symmetry). If additionally, we consider, as Richard Feynman did [1], that antiparticles are particles moving backward in time[1], this is, if we consider time reversal (T, or T symmetry) as well, then our mirror would be even stranger: a "magical CPT mirror".

The Gell-Mann decuplet diagram is a special case of the 26-particles matter-antimatter way shown on FIGURE 1. As I shall show, this generalization allow us to predict the existence of pentaquarks of composition:

(quark, quark, quark, quark, antiquark), and
(antiquark, antiquark, antiquark, antiquark, quark)

The coordinates of the lower vertex of this diagram are shown on TABLE 3.

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(1) "*the fundamental idea is that the "negative energy" states represent the state of electrons moving backward in time. In a classical equation of motion...reversing the direction of proper time s amounts to the same as reversing the sign of the charge so that the electron moving backward in time would look like a positron moving forward in time.*" [1]

QS COORDINATE SYSTEM	LOWER VERTEX COORDINATES	MEANING
MATERIAL (For particles. Right hand side coordinate system)	$(-2,0)$	$Q=-2$ and $S=-4$
ANTIMATERIAL (For antiparticles. Left hand side coordinate system)	$(+2,0)$	$Q=+2$ and $S=+4$

TABLE 3: *Coordinates of the lower vertex of the triangle of FIGURE 1 (The* 26-particle *matter-antimatter way).*

If pentaquarks were not real, no particle would occupy the lower vertex of the diagram (e.g. there would be an empty circle). This would contradict our belief which states that, in general, nature is governed by symmetry principles (by the way, the standard model has been built around symmetry principles). According to the values of the coordinates of this vertex the new particles must be pentaquarks (This will be analysed in subsection 3.1). Therefore I shall interpret the lower vertex of the triangle, as evidence of the existence of the following particles

(i) 3 pentaquarks: $s\,s\,s\,s\,\bar{u}$, $s\,s\,s\,s\,\bar{c}$ and $s\,s\,s\,s\,\bar{t}$
(ii) 3 antipentaquarks: $\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,u$, $\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,c$ and $\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,t$

Consequently, the diagram shows 6 pentaquarks in the lower vertex instead of an empty circle. The reader should keep in mind that, for clarity reasons, these 6 pentaquarks are represented by a single particle (in green colour) in the diagram. These pentaquarks are labelled: P_1, P_2, P_3, P_4, P_5 and P_6 (I'm also going to use more sophisticated names later on, however we have to keep in mind that names are not important). The reader who is interested in the composition of all the particles and antiparticles (baryons and antibaryons) shown in FIGURE 1 may find them in Appendix 1.

(see next page)

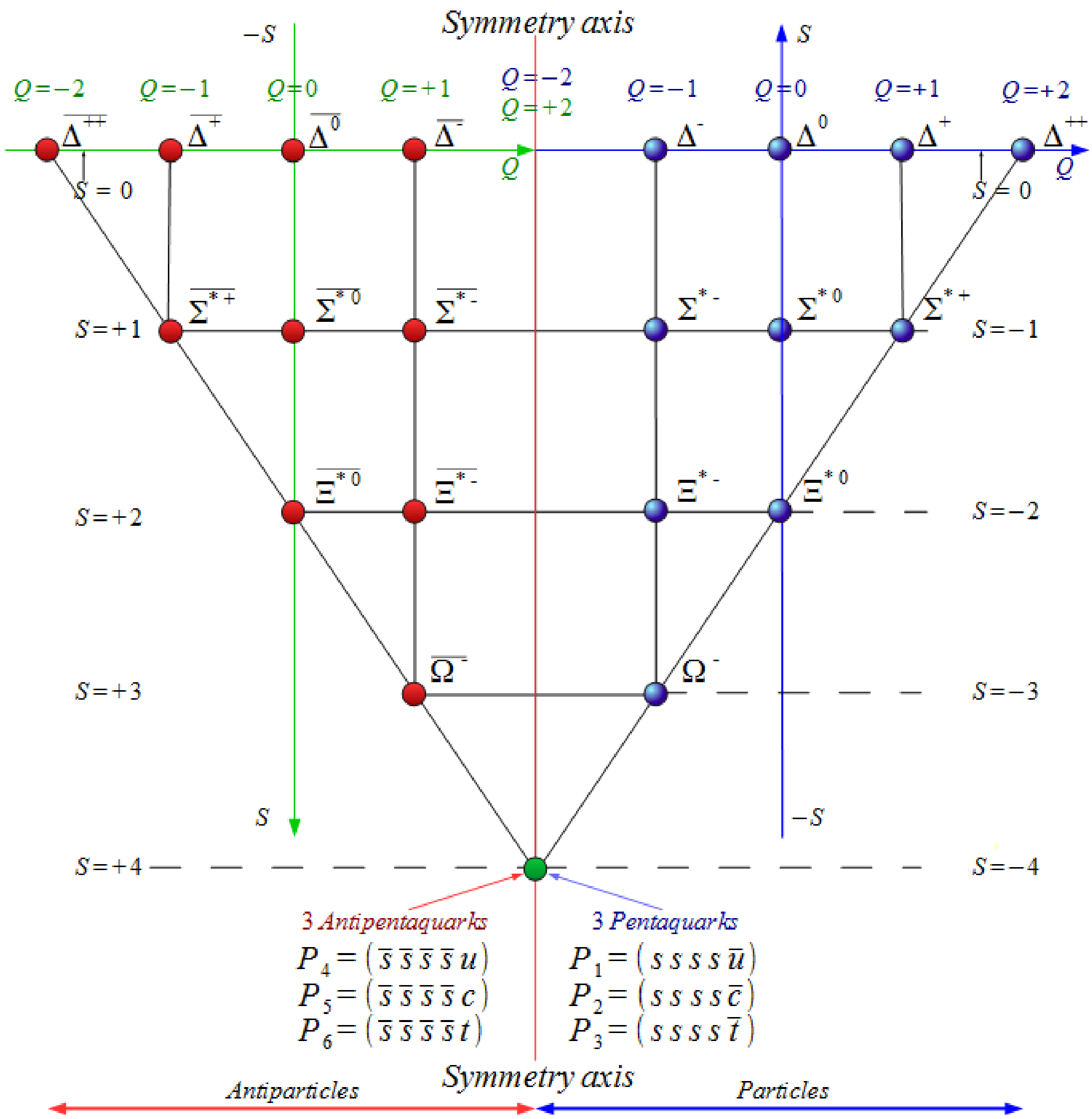

FIGURE 1: *The "Matter-Antimatter Way of 26 Particles": a pattern of 10 baryons (blue circles), 10 anti-baryons (red circles) and 6 pentaquanks and antipentaquarks (green circle). If the green circle in the lower vertex of the triangle wouldn't have been drawn, the vertex would be "empty" suggesting that there are new particles yet to be discovered (according to the values of the coordinates of this vertex these particles must be pentaquarks). For this reason the vertex shows a green circle representing the six pentaquarks this formulation predicts. It is important to observe that two QS coordinate systems have been used. One QS coordinate system is for particles while the other one is for their antiparticles. Thus, one of the horizontal Q axes represents the electric charge of particles while the other one represents the electric charge of antiparticles. It is important to observe that Q=-2 belongs to the particles' Q axis while Q=+2 belongs to the antiparticles' Q axis. One of the vertical S axis represents the strangeness of particles while the other vertical S axis represents the strangeness of antiparticles. The isospin property of the particles and antiparticles is not used in this formulation, therefore is not shown in this diagram. The composition of all the particles and antiparticles shown in this diagram are given in Appendix 1. The particles whose names include an asterisk:* Σ^{*-} , Σ^{*0} , Σ^{*+} , Ξ^{*-} , Ξ^{*0} *are exited states of the corresponding particles:* Σ^{-} , Σ^{0} , Σ^{+} , Ξ^{-} , Ξ^{0} *. In the particles with exited states, the spins of the constituent quarks are aligned so that the total spin of these particles is ½ + ½ + ½ = 3/2.*

3.1. Analysis of the Electric Charge and Strangeness

Analysis for Particles

In this analysis we only consider the *QS* coordinate system for particles which is shown in blue colour on the right hand side of FIGURE 1. The predicted particles must satisfy the following two conditions:

(a) According to FIGURE 1, the first condition the unknown particle (pentaquark) must satisfy is that its electric charge must be -2 ($Q=-2$) (meaning $-2e$, where *e* is the absolute value of the elementary charge).

(b) The second condition the unknown particle (pentaquark) must satisfy is that its strangeness must be -4 ($S=-4$). Because strange quarks are the only particles which possess the strangeness property, and because the value of this property is -1 (TABLE 1 of section 2), the only way a particle can have a strangeness of -4 is if the particle were composed by 4 strange quarks.

Taking into account these two conditions and the fact that each strange quark carries an electric charge of $-1/3$, the electric charge equation for this particle should be

$$Q = 4\,q_s + q \qquad (3.1.1)$$

Where

Q = total electric charge of the unknown particle (-2)
q_s = electric charge of the strange quark ($-1/3$)
q = electric charge of another quark (different from an *s* quark) so that the total charge of the unknown particle is -2 . This quark will be called the fifth quark.

We solve equation (3.1.1) for *q*. This gives

$$q = Q - 4\,q_s \qquad (3.1.2)$$

The electric charge of the four strange quarks is

$$4\,q_s = 4\times\left(-\frac{1}{3}\right) = -\frac{4}{3} \qquad (3.1.3)$$

Then, according to equation (3.1.2) the value of the electric charge, *q,* of the fifth quark should be

$$q = -2-\left(-\frac{4}{3}\right) = -2+\frac{4}{3} = -\frac{2}{3} \qquad (3.1.4)$$

So that the fifth quark must have an electric charge of $-2/3$. Looking at TABLE 2 of section 2 (antiquark properties) we see that there are only three antiquarks that satisfy this condition. These antiquarks are:

(i) the antiup quark, $\bar{u}$,
(ii) the anticharm quark, $\bar{c}$, and
(iii) the antitop quark, $\bar{t}$,

Because equation (3.1.1) is satisfied by three antiquarks we have three equations

$$Q = 4\, q_s + q_{\bar{u}} \tag{3.1.5}$$
$$Q = 4\, q_s + q_{\bar{c}} \tag{3.1.6}$$
$$Q = 4\, q_s + q_{\bar{t}} \tag{3.1.7}$$

Where

$q_{\bar{u}} =$ electric charge of the antiup quark = $-2/3$
$q_{\bar{c}} =$ electric charge of the anticharm quark = $-2/3$
$q_{\bar{t}} =$ electric charge of the antitop quark = $-2/3$

This, in turn, means that the pentaquarks must have the following composition

Pentaquark P_1 $$(s\,s\,s\,s\,\bar{u}) \tag{3.1.8}$$
Pentaquark P_2 $$(s\,s\,s\,s\,\bar{c}) \tag{3.1.9}$$
Pentaquark P_3 $$(s\,s\,s\,s\,\bar{t}) \tag{3.1.10}$$

Analysis for Antiparticles

In this analysis we only consider the *QS* coordinate system for antiparticles which is shown in green colour on the left hand side of FIGURE 1. The predicted particles must satisfy the following two conditions:

(a) According to FIGURE 1, the first condition the unknown particle (antipentaquark) must satisfy is that its electric charge must be +2 (Q = +2) (meaning +2*e*, where *e* is the absolute value of the elementary charge).

(b) The second condition the unknown particle (antipentaquark) must satisfy is that its strangeness must be +4 (S = +4). Because strange quarks are the only particles which possess the strangeness property, and because the value of this property for anti-strange quarks is +1 (TABLE 2 of section 2), the only way a particle can have a strangeness of +4 is if the particle were composed by 4 anti-strange quarks.

Taking into account these two conditions and the fact that each anti-strange quark carries an electric charge of $+1/3$, the electric charge equation for this particle should be

$$Q = 4\, q_{\bar{s}} + q \tag{3.1.11}$$

Where

Q = total electric charge of the unknown particle ($+2$)
$q_{\bar{s}}$ = electric charge of the anti-strange quark ($+1/3$)
q = electric charge of another quark (different from a anti-strange quark) so that the total charge of the unknown particle is $+2$. This quark will be called the fifth

quark.

We solve equation (3.1.11) for q. This gives

$$q = Q - 4\,q_{\bar{s}} \tag{3.1.12}$$

The electric charge of the four anti-strange quarks is

$$4\,q_{\bar{s}} = 4\times\left(+\frac{1}{3}\right) = +\frac{4}{3} \tag{3.1.13}$$

Then, according to equation (3.1.12) the value of the electric charge, q, of the fifth quark should be

$$q = +2 - \left(+\frac{4}{3}\right) = +2 - \frac{4}{3} = +\frac{2}{3} \tag{3.1.14}$$

So that the fifth quark must have an electric charge of $+2/3$. If we look at TABLE 1 of section 2 (quark properties) we shall see that there are only three quarks that satisfy this condition. These quarks are:

(i) the up quark, u,
(ii) the charm quark, c, and
(iii) the top quark, t

Because equation (3.1.11) is satisfied by three quarks we have three equations

$$Q = 4\,q_{\bar{s}} + q_u \tag{3.1.15}$$
$$Q = 4\,q_{\bar{s}} + q_c \tag{3.1.16}$$
$$Q = 4\,q_{\bar{s}} + q_t \tag{3.1.17}$$

Where

$q_u =$ electric charge of the up quark = $+2/3$
$q_c =$ electric charge of the charm quark = $+2/3$
$q_t =$ electric charge of the top quark = $+2/3$

This, in turn, means that the antipentaquarks must have the following composition

Pentaquark $P_4 = \overline{P_1}$ $\qquad \bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,u\,,$ (3.1.18)

Pentaquark $P_5 = \overline{P_2}$ $\qquad \bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,c\,,$ (3.1.19)

Pentaquark $P_6 = \overline{P_3}$ $\qquad \bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,t\,,$ (3.1.20)

3.2. Analysis of the Colour Charge and Spin

Analysis for Particles

Because all known baryons and mesons are colourless, meaning they are neutral in terms of colour charge, the predicted pentaquarks should also be colourless. Also because of the Pauli exclusion principle there shouldn't be two quarks of the same type with all the same quantum numbers. This means that the two strange quarks of identical colour (because there are 4 strange quarks and because there are only three flavours of the colour charge, there must be two strange quarks of the same colour) should have opposite spins (one with spin up and the other one with spin down). For example the following pentaquark should be allowed by nature

$$s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{u}_R^{up} \tag{3.2.1}$$

It is worthwhile to observe that the anti-quark up could have spin up or down. Because the antiquark up is antired, the combination $s_R^{down}\ \overline{u}_R^{up}$ will be colourless. Also the combination $s_R^{up}\ s_G^{up}\ s_B^{up}$ will be colourless. This means that the entire pentaquark will be colourless. As an additional example, the following pentaquarks should be allowed

$$s_R^{down}\ s_G^{down}\ s_B^{down}\ s_R^{up}\ \overline{u}_R^{up} \tag{3.2.2}$$

$$s_R^{up}\ s_G^{up}\ s_B^{down}\ s_R^{down}\ \overline{u}_R^{up} \tag{3.2.3}$$

etc.

The interested reader could find more allowed combinations.

Analysis for Antiparticles

Carrying out a similar analysis we find that

$$\overline{s}_B^{up}\ \overline{s}_G^{up}\ \overline{s}_B^{up}\ \overline{s}_R^{down}\ u_R^{up} \tag{3.2.4}$$

3.3. Quadruply Strange Pentaquarks Naive Diagrams

In order to illustrate pentaquarks graphically, I have included a set of naive diagrams. The diagrams are naive because they do not include all the constituents of the particles in question (such as quark-antiquark pairs and gluons). Although these graphics have limitations, they are good enough to illustrate the principles outlined in this paper.

The set (FIGURES 2, 3 and 4) shows three strange quarks on the left of the picture while the other strange quark and the antiquark are shown on the right. The reason of having this set of drawings is to facilitate the visualisation of the colourless (neutral) nature of each particle. The diagrams shown on FIGURES 2, 3 and 4 correspond to the $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{u}_R^{up}$ pentaquark, the $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{c}_R^{up}$ pentaquark, and the $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{t}_R^{up}$ pentaquark, respectively. The indices indicate the spin of the quark. The graphics for the corresponding antipentaquarks are not shown.

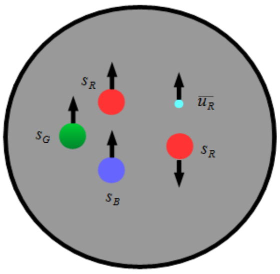

FIGURE 2: *The* $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{u}_R^{\,up}$ *pentaquark.*
Both quark-antiquark pairs and gluons are not shown.

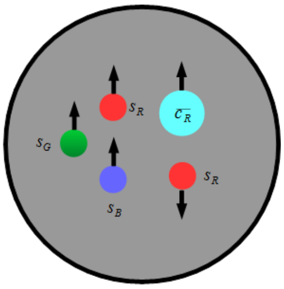

FIGURE 3: *The* $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{c}_R^{\,up}$ *pentaquark.*
Both quark-antiquark pairs and gluons are not shown.

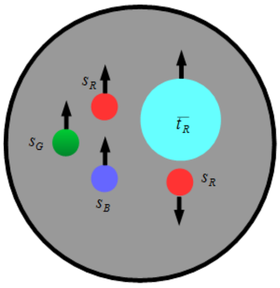

FIGURE 4: *The* $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{t}_R^{\,up}$ *pentaquark.*
Both quark-antiquark pairs and gluons are not shown.

(see next page)

4. Summary of the Properties of the Quadruply Strange Pentaquarks

The following table shows some of the properties of the pentaquarks predicted by this theory

	PREDICTED PARTICLE (symbol)	PARTICLE COMPOSITION (quark contents)	ELECTRIC CHARGE (times the elementary charge: $\lvert e \rvert$	STRANGENESS	SPIN
PARTICLES	P_1 or $P^{--}_{4s\bar{u}}$	$(s\,s\,s\,s\,\bar{u})$	-2	-4	$\frac{3}{2}$
	P_2 or $P^{--}_{4s\bar{c}}$	$(s\,s\,s\,s\,\bar{c})$	-2	-4	$\frac{3}{2}$
	P_3 or $P^{--}_{4s\bar{t}}$	$(s\,s\,s\,s\,\bar{t})$	-2	-4	$\frac{3}{2}$
ANTI-PARTICLES	P_4 or $P^{++}_{4\bar{s}u}$	$(\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,u)$	$+2$	$+4$	$-\frac{3}{2}$
	P_5 or $P^{++}_{4\bar{s}c}$	$(\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,c)$	$+2$	$+4$	$-\frac{3}{2}$
	P_6 or $P^{++}_{4\bar{s}t}$	$(\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,t)$	$+2$	$+4$	$-\frac{3}{2}$

TABLE 4: *Some of the properties of the quadruply strange pentaquarks.*

5. Conclusions

This theory which is based on a symmetry principle between matter and antimatter (translated into the matter-antimatter way for 26-particles), suggests it's possible that there exist pentaquarks. In particular, this formulation predicts the existence of three quadruply strange pentaquarks: $(s\,s\,s\,s\,\bar{u})$, $(s\,s\,s\,s\,\bar{c})$, $(s\,s\,s\,s\,\bar{t})$ and three quadruply strange antipentaquarks: $(\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,u)$, $(\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,c)$, $(\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,t)$. This theory, as all theories, have advantages and limitations. One advantage of this formulation is that the isospin property is not used. On the other hand, the limitation is that it does not predict the masses of the six predicted pentaquarks. This, however, has nothing to do with the correctness or potential of this formulation. In summary, based on this formulation, I strongly believe that pentaquarks are real which impulsed me to write this article. I also believe that soon the LHC will confirm these findings.

Appendix 1
NOMENCLATURE

The following are the symbols used in this paper

Q = electric charge of the unknown particle (pentaquark). Also, in the diagram of FIGURE 1, Q is the electric charge of a baryon or the electric charge of an antibaryon

q_s = electric charge of the strange quark

$q_{\bar{u}}$ = electric charge of the antiup quark

$q_{\bar{c}}$ = electric charge of the anticharm quark

$q_{\bar{t}}$ = electric charge of the antitop quark

q = electric charge of another quark (different from an b quark) so that the total charge of the unknown particle is -2. This quark will be called the fifth quark

Ω^- = omega-minus particle

P_1 or $P_{4s\bar{u}}^{--} = (s\,s\,s\,s\,\bar{u})$ pentaquark

P_2 or $P_{4s\bar{c}}^{--} = (s\,s\,s\,s\,\bar{c})$ pentaquark

P_3 or $P_{4s\bar{t}}^{--} = (s\,s\,s\,s\,\bar{t})$ pentaquark

P_4 or $P_{4\bar{s}c}^{++} = (\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,u)$ antipentaquark

P_5 or $P_{4\bar{s}u}^{++} = (\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,c)$ antipentaquark

P_6 or $P_{4\bar{s}u}^{++} = (\bar{s}\,\bar{s}\,\bar{s}\,\bar{s}\,t)$ antipentaquark

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: $\bar{b}\,\bar{s}\,\bar{s}$

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*

$\Xi^{*0}=$ 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

Notes

Note 1

The composition of all the particles shown on FIGURE 1 of this paper are included in Appendix 1

REFERENCES

[1] R. P. Feynman, *Quantum Electrodynamics*, Benjamin Publishers, p. 67, (1961).