The Quantum Chromodynamics Theory Of The 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. The composition of these particles is $s\,s\,s\,s\,\bar{u}$, $s\,s\,s\,s\,\bar{c}$, *and* $s\,s\,s\,s\,\bar{t}$.

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Contents

1. Introduction

Quantum Chromodynamics (QCD) is a quantum mechanical description of the strong nuclear force. The strong force is mediated by gluons ("balls of glue") 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 1969, 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.

(see next page)

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 Pentaquarks (The "Double Decuplet" Diagram)

The particle diagram showed below (figure 1), known as the matter-antimatter way, ("double decuplet" diagram[1] or 23-particles triangle) suggests that pentaquarks are real physical entities. The reason is explained further below. But first, I would like to explain the diagram. The horizontal axis, *Q*, represents the electric charge of the particle while the vertical axis, *S*, represents its strangeness. For clarity reasons, both the positive *Q* semi-axis and the positive *S* semi-axis are shown in green while the negative *Q* semi-axis and the negative *S* semi-axis in black. A point to observe is that the negative *Q* semi-axes end in *Q=-2* (but both axes include this value). Another point to observe is that the diagram uses two vertical *S* axes. One of the *S* axis is for particles and the other one for antiparticles. This was done this way for both symmetry and clarity reasons.

This particle diagram is symmetrical about the vertical axis, which is called: the symmetry axis (shown in red). On the right hand size of the symmetry axis we have 10 baryons, known as the baryon decuplet (due to 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. This decuplet is shown in orange-yellow. 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[2], 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, which comprises the 10 particles on the right, is part of the more general diagram shown below. This generalization allow us to predict the existence of pentaquarks of composition: "quark, quark, quark, quark, antiquark". If pentaquarks were not real, no particle would occupy the lower vertex of the diagram (corresponding to an electrical charge of $Q = -2$ and a strangeness of $S = -4$). 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). Thus, we interpret the lower vertex of the triangle, as evidence of the existence of 3 pentaquarks: $s\,s\,s\,s\,\bar{u}$, $s\,s\,s\,s\,\bar{c}$, *and* $s\,s\,s\,s\,\bar{t}$. Consequently, the diagram shows 3 pentaquarks in the lower vertex instead of an empty circle (which would indicate the absence of a particle). The reader should keep in mind that, for clarity reasons, these 3 pentaquarks are represented by a single particle (in red colour) in the diagram. These pentaquarks are labelled: P_1, P_2 and P_3 (the names are not important).

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(1) *The diagram shown on figure 1 consists of 23 particles: 10 baryons, 10 antibaryons and 3 pentaquarks. The name "double decuplet" is a simplified name for a diagram that, in fact, consists of 23 particles (double decuplet+3 diagram does not look or sound nice enough).*

(2) "*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]

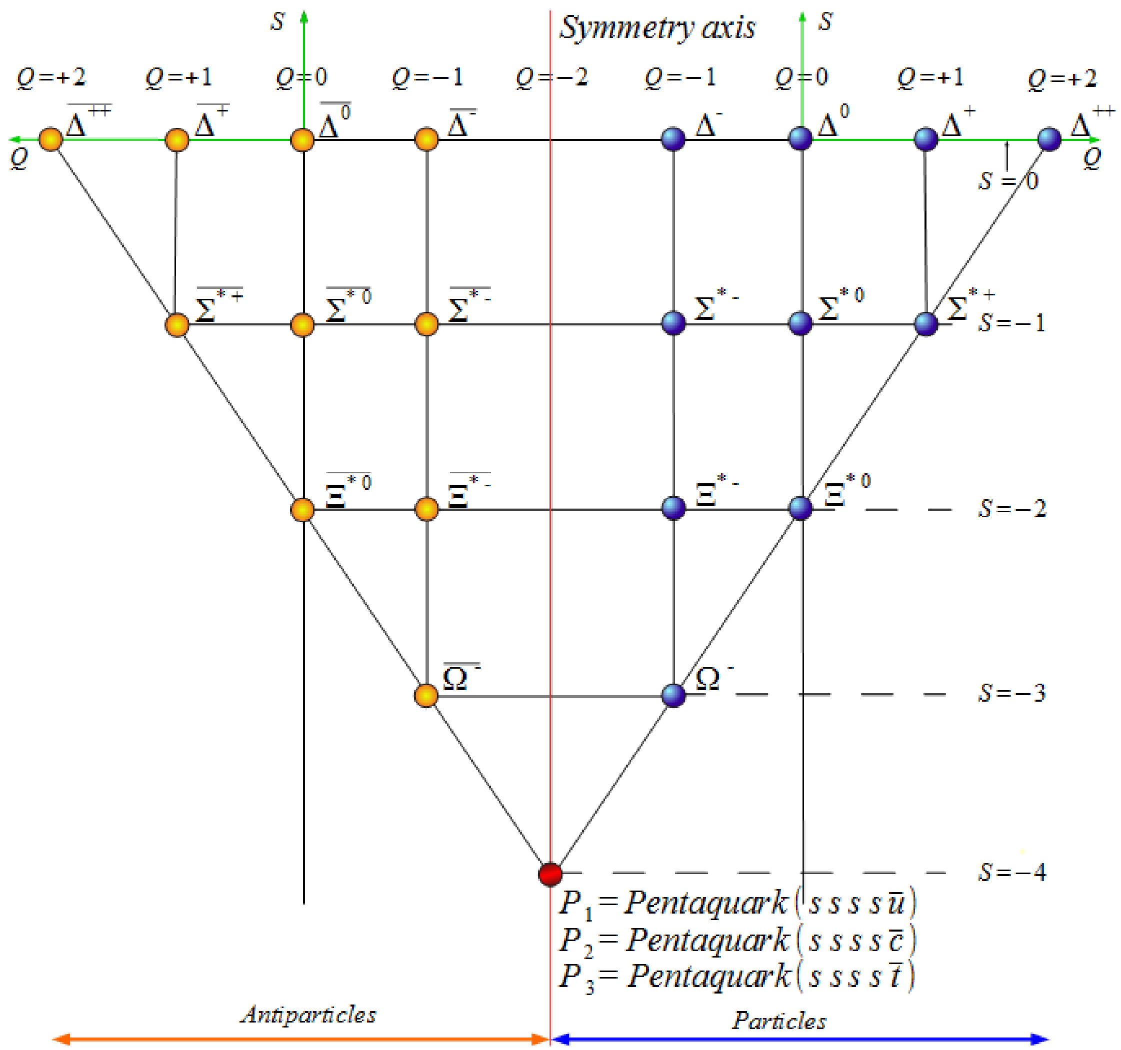


FIGURE 1: *The "Matter-Antimatter Way": a pattern of 10 baryons (blue), 10 anti baryons (orange-yellow) and 3 pentaquanks (red). The absence of a particle in the lower vertex of the "inverted" triangle suggests that there are new particles yet to be discovered. These three particles are probably pentaquarks which are represented with only one red circle. The horizontal axis, Q, represents the electric charge of the particle while the vertical axis, S, represents its strangeness. It is worthwhile to observe that two vertical S axes have been used, one for the material world and another one for the antimaterial world. It is also worthwhile to observe that the isospin property is not used in this formulation.*

3.1. Analysis of the Electric Charge

The first condition the predicted pentaquark must satisfy is that its electric charge must be -2 (meaning -2*e*, where *e* is the absolute value of the elementary charge). According to figure 1 the unknown particle should have a strangeness of -4 (S = -4) because the particle should contain 4 strange quarks to fit in the vertex. Also, according to figure 1, the total electric charge of this unknown particle, should be -2. Because each strange quark carries an electric charge of -1/3, the charge equation for this particle (pentaquark) should be

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

Or

$$q = Q - 4q_s \tag{3.1.2}$$

Where

Q = electric charge of the unknown particle
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.

Because

$$4q_s = 4\times(-\frac{1}{3}) = -\frac{4}{3} \tag{3.1.3}$$

The value of the electric charge, *q,* of the fifth quark is

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

So that the fifth quark must have an electric charge of -2/3. If we look at table 2 of section 2 (antiquark properties) we shall see that there are only three antiquarks that satisfy this condition. These quarks are: the antiup quark, the anticharm quark and the antitop quark. Thus equation (3.1.1) is satisfied by three antiquarks. This means that we have one equation for each of them

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

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 $(s\,s\,s\,s\,\bar{u})$ (3.1.8)

Pentaquark P_2 $(s\,s\,s\,s\,\bar{c})$ (3.1.9)

Pentaquark P_3 $(s\,s\,s\,s\,\bar{t})$ (3.1.10)

3.2. Analysis of the Colour Charge and Spin

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.

3.3. Pentaquarks Naive Diagrams

In order to illustrate pentaquarks graphically, I have included a set of naive diagrams. The diagrams are naïve 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 or neutral nature of each particle. The diagrams shown on figure 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.

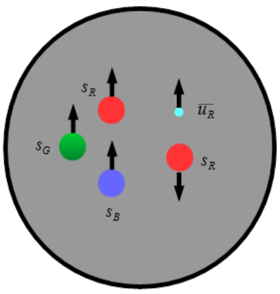


FIGURE 2: *The* $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{u_R}^{up}$ *pentaquark. Both quark-antiquark pairs and gluons are not shown.*

(see next page)

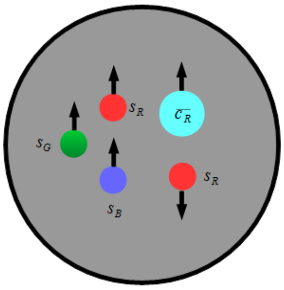


FIGURE 3: *The* $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{c}_R^{up}$ *pentaquark. Both quark-antiquark pairs and gluons are not shown.*

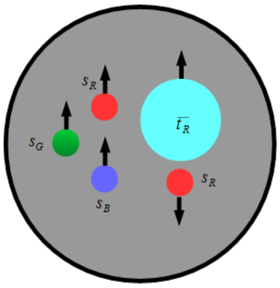


FIGURE 4: *The* $s_R^{up}\ s_G^{up}\ s_B^{up}\ s_R^{down}\ \overline{t}_R^{up}$ *pentaquark. Both quark-antiquark pairs and gluons are not shown.*

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

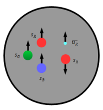
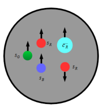
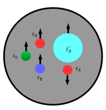
NAIVE DIAGRAM	PREDICTED PARTICLE (symbol)	PARTICLE COMPOSITION (quark contents)	ELECTRIC CHARGE (times the elementary charge: $\|e\|$)	STRANGENESS	SPIN
	P_1 or $P_{4s\overline{u}}^{--}$	$(s\,s\,s\,s\,\overline{u})$	-2	-4	$\frac{3}{2}$
	P_2 or $P_{4s\overline{c}}^{--}$	$(s\,s\,s\,s\,\overline{c})$	-2	-4	$\frac{3}{2}$
	P_3 or $P_{4s\overline{t}}^{--}$	$(s\,s\,s\,s\,\overline{t})$	-2	-4	$\frac{3}{2}$

TABLE 3: *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 a generalized "double decuplet" diagram or matter-antimatter way), suggests it's possible that there exist pentaquarks. In particular, the theory predicts the existence of three quadruply strange pentaquarks with the following compositions: $(s\,s\,s\,s\,\bar{u})$, $(s\,s\,s\,s\,\bar{c})$ and $(s\,s\,s\,s\,\bar{t})$. This theory, as all theories, have advantages and limitations. One advantage of this formulation is that the isospin property was not needed and consequently it was not used. On the other hand, the limitation is that it does not predict the masses of pentaquarks. This, however, has nothing to do with the correctness or potential of this formulation. The formulation also indicates the existence of other pentaquarks such as the quadruply bottom pentaquarks: $(b\,b\,b\,b\,\bar{u})$, $(b\,b\,b\,b\,\bar{c})$ and $(b\,b\,b\,b\,\bar{t})$. I shall analyse these pentaquarks in another paper that will be published under the name: *The Quantum Chromodynamics Theory Of The Quadruply Bottom Pentaquarks*. In summary, based on this formulation, I believe that pentaquarks exist and I also that soon the LHC (Large Hadron Collider) will confirm my 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 s 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
u = up quark
d = down quark
s = strange quark
c = charm quark
b = bottom quark
t = top quark
$\bar{u}$ = antiup quark
$\bar{d}$ = antidown quark
$\bar{s}$ = antistrange quark
$\bar{c}$ = anticharm quark
$\bar{b}$ = antibottom quark
$\bar{t}$ = antitop 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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