8. Naming Scheme for Hadrons

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In the 1986 edition [1], the Particle Data Group extended and systematized the naming scheme for mesons and baryons. The extensions were necessary in order to name the new particles containing c or b quarks that were rapidly being discovered. With the discoveries of particles that are candidates for states with more complicated structures than just $q\overline{q}$ or qqq, it is necessary to extend the naming scheme again.

8.1 "Neutral-flavor" mesons

The naming of mesons is based on their quantum numbers. Although wherever possible we use names established within the naive quark model, the name does *not* necessarily designate a (predominantly) $q\overline{q}$ state. In other words, the name provides information on the quantum numbers of a given state and not about its dominant component, which might well be $q\overline{q}$ (if allowed) or tetraquark, molecule, etc. In many cases, exotic states will be difficult to distinguish from $q\overline{q}$ states and will likely mix with them, and we make no attempt to, e.g., distinguish those that are "mostly gluonium" from those that are "mostly $q\overline{q}$."

Table 8.1: Symbols for mesons with strangeness and heavy-flavor quantum numbers equal to zero. States that do not (yet?) appear in the RPP are listed in parentheses.

$J^{PC} = \{$	0^{-+}, 2^{-+}, $\vdots$	1^{+-}, 3^{+-}, $\vdots$	1^{--}, 2^{--}, $\vdots$	0^{++}, 1^{++}, $\vdots$
Minimal quark content				
$u\bar{d}, u\bar{u}-d\bar{d}, d\bar{u}$ $(I=1)$	π	b	ρ	a
$d\bar{d}+u\bar{u}$ and/or $s\bar{s}$ $(I=0)$	η,η'	h,h'	ω,ϕ	f,f'
$c\bar{c}$	η_c	h_c	ψ^*	χ_c
$b\bar{b}$	η_b	h_b	Υ	χ_b
$I=1$ with $c\bar{c}$	(Π_c)	Z_c	R_c	(W_c)
$I=1/2$ with $sc\bar{c}$	(Π_{cs})	Z_{cs}	(R_{cs})	(W_{cs})
$I=1$ with $b\bar{b}$	(Π_b)	Z_b	(R_b)	(W_b)
$I=1/2$ with $sb\bar{b}$	(Π_{bs})	(Z_{bs})	(R_{bs})	(W_{bs})

*The J/ψ remains the J/ψ.

Table 8.1 shows the names for mesons having strangeness and all heavy-flavor quantum numbers equal to zero. The rows of Table 8.1 give the minimal $q\overline{q}$ content. The columns give the possible parity/charge-conjugation states,

$$PC = -+,\ +-,\ --,\ \text{and}\ ++\ .$$

Within the naive quark model, these combinations correspond one-to-one to the angular-momentum state ${}^{2S+1}L_J$ of the $q\overline{q}$ system being

$${}^1(L\ \text{even})_J,\ {}^1(L\ \text{odd})_J,\ {}^3(L\ \text{even})_J,\ \text{or}\ {}^3(L\ \text{odd})_J\ ,$$

respectively. Here S, L, and J are the spin, orbital, and total angular momenta of the $q\overline{q}$ system. Within the naive quark model, the quantum numbers are related by $P = (-1)^{L+1}$, $C = (-1)^{L+S}$, and G parity $= (-1)^{L+S+I}$, where the quantum number C is only relevant to neutral mesons with neutral-flavor quantum numbers and G extends to isovector mesons; see the review on the quark model. These expressions impose restrictions on the quantum numbers that are allowed for $q\overline{q}$ states. However, they do not apply to more complicated structures such as tetraquarks.

The spin J is added as a subscript in the name except for pseudoscalar, vector, and axial vector mesons when there is no risk of ambiguity. Moreover, the mass is added in parentheses for mesons that decay strongly. However, for some of the familiar mesons (e.g. η', ϕ, ω), we omit the mass.

Measurements of the mass, quark content (where relevant), and quantum numbers I, J, P, and C (or G) of a meson thus determine its symbol. Conversely, these properties may be inferred unambiguously from the symbol. The name X is used for states with still unknown quantum numbers.

The mass label used in particle names is chosen using the best information available when a name is assigned. A more accurate value of a particle mass may become available at a later time. PDG will decide on a case-by-case basis whether to revise the mass label, taking into account the updated information.

With u, d, and s quarks, there are two isospin-0 mesons. A prime is used to distinguish one from the other (e.g. η and η'). Vector mesons decoupling to $u\overline{u} + d\overline{d}$ and $s\overline{s}$ (ideal mixing) are labeled ω and ϕ, respectively. As usual, we assign the spectroscopic name (e.g. $\Upsilon(1S)$) as the primary name to most of those ψ, Υ, and χ states whose spectroscopic identity is known. We use the form $\Upsilon(9460)$ as an alternative, and as the primary name when the spectroscopic identity is not known.

Since the top quark is so heavy that it decays too rapidly to form bound states, no name is assigned to structures like $t\bar{t}$.

Mesons with quantum numbers $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}$, etc. cannot be $q\overline{q}$. For such a "manifestly exotic" meson, we use the same symbol as for a $q\overline{q}$ meson; the exotic nature of the meson can be inferred from the values of the P and C quantum numbers (given by the symbol), and the spin J (given by the subscript). For example, an isospin-0 1^{-+} meson containing only u, d, and s quarks and antiquarks would be denoted η_1 and an isospin-1 0^{--} meson containing only u, d, and s quarks and antiquarks would be denoted ρ_0.

The last two lines of Table 8.1 list isospin-1 states that also contain hidden heavy flavor, i.e. whose minimal quark content includes $c\overline{c}$ or $b\overline{b}$. We have assigned new names to these states, in keeping with the practice in the light-quark sector, where the $I = 0$ and $I = 1$ states have distinct names. The currently established $I = 1$ states in the heavy-quark sector have quantum numbers $J^{PC} = 1^{+-}$ and the proposed scheme keeps their original names Z.

Recently two experiments claimed evidence for states with 1^{+-} decaying into final states containing $sc\bar{c}$ and a light quark calling them Z_{cs}. We therefore extended Tab. 8.1 by allowing also for multiquarks containing strangeness.

8.2 Remarks on "neutral-flavor" mesons with hidden charm or bottom not classified as $q\overline{q}$

In the heavy-quark sector, there are several states with properties – such as masses, decay patterns, and widths – that are in disagreement with predictions from the naive quark model. For example, the vector state at 4230 MeV does not decay into $D\overline{D}$, although within the naive quark model its quantum numbers would call for this decay channel to be dominant. In recent literature, these states have been called X, Y, or Z, with their masses added in parentheses. This nomenclature conflicts with the rules outlined in the previous section, since the meson names are not related to their quantum numbers. However, these states have properties in conflict with the naive quark model and therefore deserve some special labeling.

Therefore in the Review of Particle Physics we will keep two names, one that carries the quantum number information and the other the original name. However, the former name will be given priority. In particular, it will be used when the particle appears as a decay product. Thus, in the Listings as well as Summary Tables from the 2018 edition onwards (listed are only some examples of the particles that appear in the Summary Tables),

- $X(3872)$ will appear as '$\chi_{c1}(3872)$ also known as $X(3872)$';
- $X(3900)^{\pm}$ will appear as '$Z_c(3900)^{\pm}$';
- $X(4260)$ will appear as '$\psi(4230)$ also known as $Y(4230)$'[1];

In addition, states with quantum numbers allowed by the naive quark model but showing some peculiarities, such as an unusual decay pattern, will have the following information in the header:

> This state shows properties different from a conventional $q\overline{q}$ state. A candidate for an exotic structure. See the review on ⟨name of the proper review⟩.

The states that cannot be classified as $q\overline{q}$ states (such as charged states with strong decays to heavy quarkonia) will have in the header:

> Properties incompatible with a $q\overline{q}$ structure (exotic state). See the review on ⟨name of the proper review⟩.

The names Z_c and Z_b used in the literature for isovector states in the $c\overline{c}$ and $b\overline{b}$ sector, respectively, will now also be the official PDG names. No heavy isovector $PC = -+, --$, or $++$ states have yet been confirmed, but provisional names for such states – $\mathit{\Pi}$, R, and W, respectively – are listed in Table 8.1. Note that the heavy isovector $PC = ++$ states were predicted to exist as spin partners of the Z states in [2], where the name W was also introduced.

By analogy to the light-quark sector, states with quantum numbers that are in conflict with the naive quark model are labeled according to their I, P, C, and spin J. The exotic nature can be inferred from the quantum numbers.

Table 8.2 maps the names now used in the PDG to former commonly used names.

8.3 Mesons with nonzero S, C and/or B

Mesons with nonzero strangeness S or heavy flavor C and/or B are not eigenstates of charge conjugation, and in each of them one of the quarks is heavier than the other (as above, states containing top quarks are not considered). The rules have been and remain:

1. The main symbol is an upper-case italic letter indicating the heavier quark as follows:

   $$s \to \overline{K} \qquad c \to D \qquad b \to \overline{B},$$

   We use the convention that *the flavor quantum number and the charge of a quark have the same sign.* Thus the strangeness of the s quark is negative, the charm of the c quark is positive, and the bottomness of the b quark is negative. The effect of this convention is as follows: *any flavor carried by a charged meson has the same sign as its charge.* Thus the K^+, D^+, and B^+ have positive strangeness, charm, and bottomness, respectively, and all have positive I_3. The D_s^+ has positive charm *and* strangeness. Furthermore, the Δ(flavor) = ΔQ rule, best known for the strange kaons, applies to every flavor.
2. If the lighter quark is not a u or a d quark, its identity is given by a subscript. The D_s^+ is an example.

[1] This is one example where the mass label needed to be shifted given improved experimental information

3. When the spin-parity is in the natural series, $J^P = 0^+, 1^-, 2^+, \cdots$, a superscript "*" is added.
4. The spin is added as a subscript except for pseudoscalar or vector mesons.

Table 8.2: A comparison of current PDG names to former names commonly used in the literature.

Mesons with complete $I^G J^{PC}$ assignment	
PDG Name	Former Common Name(s)
$\psi_2(3823)^*$	$X(3823)$
$\chi_{c1}(3872)$	$X(3872)$
$Z_c(3900)$	$Z_c(3900)$
$\chi_{c2}(3930)^\dagger$	$\chi_{c2}(2P)$, $Z(3930)$
$\chi_{c1}(4140)$	$Y(4140)$
$Z_c(4200)$	$Z_c(4200)$
$\psi(4230)$	$Y(4230)$, $Y(4260)$
$R_{c0}(4240)$	$Z_c(4240)$
$\chi_{c1}(4274)$	$Y(4274)$
$\psi(4360)$	$Y(4360)$
$Z_c(4430)$	$Z_c(4430)$
$\chi_{c0}(4500)$	$X(4500)$
$\psi(4660)$	$X(4630)$, $Y(4660)$
$\chi_{c0}(4700)$	$X(4700)$
$Z_b(10610)$	$Z_b(10610)$
$Z_b(10650)$	$Z_b^{(\prime)}(10650)$
Mesons with incomplete $I^G J^{PC}$ assignment	
PDG Name	Former Common Name(s)
$X(3915)^\ddagger$	$\chi_{c0}(3915)$, $X(3915)$, $Y(3940)$
$X(3940)$	$X(3940)$
$X(4020)$	$Z_c^{(\prime)}(4020)$
$X(4050)^\pm$	$Z_1(4050)$
$X(4055)^\pm$	$Z_c(4055)$
$X(4160)$	$X(4160)$
$X(4250)^\pm$	$Z_2(4250)$
$X(4350)$	$X(4350)$

*The 2016 edition used $\psi(3823)$.
†The 2016 edition used $\chi_{c2}(2P)$. The mass is now used in the name following the current prescription.
‡The 2016 edition used $\chi_{c0}(3915)$. The J^{PC} have since been questioned.

8.4 Baryons with ordinary quantum numbers

All baryons having quantum numbers consistent with a minimal quark content of three quarks are denoted by the symbols N, Δ, Λ, Σ, Ξ, and Ω introduced more than 50 years ago. These symbols are followed by J^P signifying their spin J and parity P. For those where the minimal content involves one or more heavier quarks than the light (u, d, and s) quarks, subscripts are added to their symbols, (c and b) as appropriate. The rules are:

1. Baryons with miminal content of *three* u and/or d quarks are N's (isospin 1/2) or Δ's (isospin

3/2).

2. Baryons with *two* u and/or d quarks are Λ's (isospin 0) or Σ's (isospin 1). If the third quark is a c or b quark, its identity is given by a subscript.
3. Baryons with *one* u or d quark are Ξ's (isospin 1/2). One or two subscripts are used if one or both of the remaining quarks are heavy: thus Ξ_c, Ξ_{cc}, Ξ_b, etc.*
4. Baryons with *no* u or d quarks are Ω's (isospin 0), and subscripts indicate any heavy-quark content.
5. A baryon that decays strongly has its mass in parentheses. Examples are the $\Delta(1232)\ 3/2^+$, $\Sigma(1385)\ 3/2^+$, $N(1440)\ 1/2^+$, $\Xi_c(2645)\ 3/2^+$.
6. If individual states of isospin multiplets are addressed, the electric charge is specified as a superscript. The electric charge is not necessary for isospin-0 states (Λ and Ω), as there is no ambiguity, but may still be included.
7. Antibaryons are labeled by an overline (bar) (e.g. $\bar{p}$ for the antiproton). Alternatively, particle and antiparticle can be distinguished by including a charge-label superscript. For example using Λ_c and $\bar{\Lambda}_c$ is equivalent to Λ_c^+ and Λ_c^-.

In short, the minimal number of u plus d quarks together with the isospin determine the main symbol, and subscripts indicate any content of heavy quarks. A Σ always has isospin 1, an Ω always has isospin 0, etc.

8.5 Exotic baryons

In 2003, several experiments reported finding a strangeness $S = +1$, charge $Q = +1$ baryon, and one experiment reported finding an $S = -2$, $Q = -2$ baryon. Baryons with such quantum numbers cannot be made from three quarks, and thus they are exotic with respect to the naive quark model. However, these "discoveries" were then ruled out by many experiments with far larger statistics: See our 2008 *Review* [3].

More recently, the LHCb collaboration found a series of candidates for pentaquark states in the $J/\psi p$ system extracted from data on $\Lambda_b^0 \to J/\psi K^- p$ [4,5].** These have the quantum numbers of excited nucleons, but have a minimal quark content of $c\bar{c}uud$. Following the name established by the LHCb collaboration, we label these $P_c^+(\text{mass})J^P$, with the mass given in parentheses.

Footnotes:

* See the "Note on Charmed Baryons" in the Charmed Baryon Listings.

** See our review "Pentaquarks" in the 2016 Edition.

References

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