8. Naming Scheme for Hadrons

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In the 1986 edition [1], the Particle Data Group introduced an extended and systematized naming scheme for mesons and baryons. The extensions were necessary in order to name the new particles containing c or b quarks that were then rapidly being discovered. The 1986 naming scheme has been retained in all subsequent editions, including this one. However, a number of particles were since discovered that could not be accommodated in the 1986 scheme. These include, for example the meson state originally named $Z_c(3900)^+$ (now $T_{c\bar{c}1}(3900)^+$) containing $c\bar{c}$ but with isospin $I = 1$ [2,3]. Because of such discoveries, in the 2017 edition [4] the 1986 naming scheme was extended to cover $c\bar{c}$ and $b\bar{b}$ states with $I = 1$, including the Z_c and Z_b states.

The further discovery of various exotic hadron states—including in particular tetraquarks and pentaquarks containing $qq\bar{q}\bar{q}$ and $q\bar{q}qqq$ minimal quark content, respectively—has rendered the 2017 extension insufficient. These include, for example: the meson state $T_{cc}(3875)^+$ containing two charm quarks and with unknown isospin [5]; and the baryon state originally named $P_c(4312)^+$ (now $P_{c\bar{c}}(4312)^+$) containing minimal quark content $c\bar{c}uud$ [6]. In this edition, the 2017 scheme is revised and extended to cover all experimentally known states.

The naming scheme as a whole provides a name for each hadron, driven primarily by consideration of its quantum numbers, its minimal quark content—the smallest combination of quarks required to produce a color singlet with the required isospin, parities, strangeness, and open or hidden-heavy flavor—and its mass. While much of the naming scheme has been developed within the context of the naive quark model, a hadron name does *not* designate the internal structure of a state per se: we make no attempt, for example, to distinguish meson states that are "mostly gluonium" from those that are "mostly $q\bar{q}$." (Other reviews within the RPP discuss our current understanding of the nature of various hadron states). While the naming scheme conventions aim to be comprehensive, exceptions to the scheme are occasionally made for historical reasons (e.g. J/ψ, p, or n) or in cases where the spectroscopic identity of a state is considered established (e.g. $\Upsilon(1S)$). Note also 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 decides on a case-by-case basis whether to revise the mass label, taking into account the updated information.

8.1 Light unflavored, $c\bar{c}$, and $b\bar{b}$ mesons

Unflavored mesons—also referred to as "neutral-flavor" mesons—have zero strangeness and all heavy-flavor quantum numbers are equal to zero. Their minimal quark content is denoted $q\bar{q}$, with the understanding that for $q = u$ or d, such states may carry unit isospin: the "light unflavored" nomenclature is understood to encompass all states furnishing an isospin-1 multiplet that contains a $q\bar{q}$ neutral meson. Mesons composed of $c\bar{c}$ or $b\bar{b}$ are said to have hidden-heavy flavor.

Within the naive quark model, a neutral $q\bar{q}$ bound state has quantum numbers $P = (-1)^{L+1}$ and $C = (-1)^{L+S}$, where $S(= 0,\, 1)$ and L are the spin and orbital angular momentum of the $q\bar{q}$ system, respectively. The total angular momentum J satisfies $|L - S| \le J \le L + S$ as usual. There is thus a selection rule between the angular-momentum state ${}^{2S+1}L_J$ and the PC configuration, such that

$$PC \quad = \quad -+\,, \qquad +-\,, \qquad --\,, \qquad ++\,, \tag{8.1}$$

corresponds to

$$^{2S+1}L_J \quad = \quad {}^1(L\text{ even})_L\,,\quad {}^1(L\text{ odd})_L\,,\quad {}^3(L\text{ even})_{|L-1|\leq J\leq L+1}\,,\quad {}^3(L\text{ odd})_{L-1,L,L+1}\,. \tag{8.2}$$

Table 8.1 describes the naming scheme for unflavored mesons. The scheme is categorized by isospin and hidden-heavy flavor (rows) and parity/charge-conjugation configurations (columns); the first few allowed J^{PC} combinations for each column are shown in the header. Note C-parity is only well-defined for neutral unflavored mesons; the states furnishing an isospin-1 multiplet instead have a well-defined G-parity$= (-1)^{L+S+I}$; see the review on the quark model. The angular momentum J is included as a subscript to the base symbol for most unflavored mesons, but is omitted for various pseudoscalar, vector, and axial vector mesons whenever disambiguation by the J subscript is deemed superfluous. 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.

Table 8.1: Base symbols for unflavored mesons (zero strangeness and heavy-flavor quantum numbers equal to zero). Each base symbol is uniquely determined by the isospin/hidden-heavy flavor and PC configuration.

$J^{PC} =$ Minimal quark content	0^{-+} 2^{-+} ⋮	1^{+-} 3^{+-} ⋮	1^{--} 2^{--} ⋮	0^{++} 1^{++} ⋮
$u\bar{d}, u\bar{u}-d\bar{d}, d\bar{u}$ ($I=1$)	π	b	ρ	a
$d\bar{d}+u\bar{u}$, $s\bar{s}$ and/or gluons ($I=0$)	η,η'	h,h'	ω,ϕ	f,f'
$c\bar{c}$ ($I=0$)	η_c	h_c	ψ [*]	χ_c
$b\bar{b}$ ($I=0$)	η_b	h_b	Υ	χ_b

[*] With the exception of the J/ψ.

For light unflavored mesons—i.e. those unflavored mesons formed from u, d, and s quarks—there can be two isospin-0 mesons: a prime is used to distinguish one from the other (e.g. η and η'), with the exception that vector mesons comprised of $u\bar{u}+d\bar{d}$ and $s\bar{s}$ (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.

Determination of the quark content (where relevant) and the quantum numbers I, J, P, and C (or G) of an unflavored meson thus determine its symbol. For example, the light unflavored isospin-1 2^{--} meson would be the ρ_2. Conversely, these properties may be inferred unambiguously from the symbol. The name X is used for states with still unknown quantum numbers. In some cases names are assigned when quantum numbers have not been strictly measured but have instead been inferred from a broader context. These cases typically include an explanation in the header, such as "Quantum numbers shown are quark-model predictions." One example is the $\psi_2(3823)$, for which the $I^G(J^{PC}) = 0^-(2^{--})$ assignment needs confirmation. Since the top quark is so heavy that it decays too rapidly to form bound states, no name is assigned to structures like $t\bar{t}$.

The selection rules in Eq. (8.2) impose restrictions on the J^{PC} quantum numbers that are allowed for $q\bar{q}$ states. These do not apply to more complicated structures such as tetraquarks, hybrid mesons, or glueballs. In particular, unflavored mesons with quantum numbers $J^{PC} = 0^{--}$, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}, …cannot be $q\bar{q}$ bound states, but might be glueballs or $q\bar{q}g$ etc. (This is distinct from light unflavored mesons with $I \geq 2$ or hidden-heavy flavor mesons with $I \geq 1$, which could be interpreted as tetraquarks). For such a "manifestly exotic" unflavored meson, the naming scheme nonetheless assigns the same base symbol as solely determined by the isospin/hidden-heavy flavor and PC in Tab. 8.1. For example, an isospin-0 light unflavored 1^{-+} meson would be denoted η_1 while an isospin-1 0^{--} light unflavored meson would be denoted ρ_0. The exotic nature of the meson can be inferred from its PC quantum numbers—given by the symbol—and the spin J—given by the subscript.

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

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 (the $\psi(4230)$) apparently 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. These states were originally named X, Y, or Z, with their masses added in parentheses. This nomenclature differs from the conventions 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.

Since their original discovery, the properties of some of these states have become better understood and it has become possible to include them in the Listings as well as Summary Tables using the name assigned according to this review. The X-, Y-, or Z-based names used at the time of the discovery are also reported in the Listings and Summary Tables from the 2018 edition onwards as a sub-header (listed are only some examples of the particles that appear in the Summary Tables),

- the state originally named $X(3872)$ appears as '$\chi_{c1}(3872)$ also known as $X(3872)$';
- the state originally named $Z_c(3900)$ appears[1] as '$T_{c\bar{c}1}(3900)$ also known as $Z_c(3900)$';
- the state originally named $Y(4260)$ appears[2] as '$\psi(4230)$ also known as $Y(4230)$';

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 $q\bar{q}$ state. A candidate for an exotic structure. See the review on ⟨name of the proper review⟩.

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*

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[1] The name $T_{c\bar{c}1}(3900)$ derives from the scheme outlined in a later section.

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

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.
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.

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 minimal 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.[3]
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) on the base symbol. For example, $\bar{p}$ for the antiproton, or $\bar{\Lambda}_c^-$ for the antiparticle of Λ_c^+. Alternatively, particle and antiparticle can be distinguished by including only a charge-label superscript, so long as the flavor structure of the baryon is defined solely by the base symbol (and subscripts). Thus one may also write Λ_c^- or p^- for the antiparticles of the Λ_c^+ and p^+, but the Σ^- is not the antiparticle of Σ^+, which is called $\bar{\Sigma}^-$.

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 Hadrons with a minimal quark content of $qq\bar{q}\bar{q}$ or $q\bar{q}qqq$

The naming scheme described above does not accommodate various $qq\bar{q}\bar{q}$ mesons and $q\bar{q}qqq$ baryons. In such cases, the 1986 naming scheme must be extended. Following discussion initiated by the proposal made by the LHCb collaboration [7], we adopt the notation

$$T^{(*)}_{\text{quarks}\,J}(\text{mass})^q \qquad \text{for tetraquarks,} \tag{8.3a}$$

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[3] See the "Charmed and Bottom Baryons" section of the "Quark Model" review.

$$P_{\text{quarks}}(\text{mass})^q \ J^P \qquad \text{for pentaquarks,} \tag{8.3b}$$

according to the following rules:

1. The basename T or P is chosen in cases where the minimal quark content of a state is $qq\bar{q}\bar{q}$ (tetraquark) or $q\bar{q}qqq$ (pentaquark), respectively.
2. The bottom, charm, and strange quark content (b, $\bar{b}$, c, $\bar{c}$, s, $\bar{s}$) is explicitly listed as a subscript, in order from the heaviest quarks and antiquarks to the lightest and listing quarks before antiquarks. The hidden-flavor $c\bar{c}$ and $b\bar{b}$ combinations are listed explicitly when their presence can be inferred from production or decay patterns.
3. The approximate mass of a state, in MeV/c^2, is given in parentheses.
4. The electric charge (q) can be specified as a superscript after the mass, for example when referring to a specific member of an isospin multiplet.
5. Antibaryons are marked with an overline ($\overline{P}$). The antiparticle of a meson can be specified either with an overline or by the quark content label (e.g. the charge conjugate of $T_{cc}(3875)^+$ is $\overline{T}_{cc}(3875)^-$, which is equivalent to $T_{\bar{c}\bar{c}}(3875)^-$).
6. For pentaquarks, as in the case of ordinary baryons, when known the spin-parity, J^P, of the state is included as a suffix.
7. For tetraquarks, similarly to the naming scheme for mesons, the spin J is appended as a subscript after the quark content. When the spin-parity is in the natural series, $J^P = 0^+, 1^-, 2^+, \cdots$, a superscript "$*$" is added.

Table 8.2 summarizes PDG name changes with respect to the 2022 edition [8]. We acknowledge that experiments might choose to add $I^{(G)}J^{P(C)}$ information to hadron names using experiment-specific conventions that differ from the one utilized by the PDG.

Table 8.2: Names used from the 2024 edition onward compared to those in the 2022 edition. Whenever the C-parity of a charged tetraquark is specified in the Particle Listings, it refers to the C-parity of the prospective/observed neutral isospin partner. Only one member per isospin multiplet is shown (see the Listings for more information).

2024 Name	minimal quark content	$I^{(G)}(J^{P(C)})$	2022 Name	2024 Name	minimal quark content	$I^{(G)}(J^{P(C)})$	2022 Name
$T^*_{cs0}(2870)^0$	$cs\bar{u}\bar{d}$	$?(0^+)$	$X_0(2900)$	$T_{c\bar{c}1}(4430)^+$	$c\bar{c}u\bar{d}$	$1^+(1^{+-})$	$Z_c(4430)^+$
$T^*_{cs1}(2900)^0$	$cs\bar{u}\bar{d}$	$?(1^-)$	$X_1(2900)$	$T_{c\bar{c}\bar{s}1}(4000)^+$	$c\bar{c}u\bar{s}$	$1/2(1^+)$	$Z_{cs}(4000)^+$
$T^*_{c\bar{s}0}(2900)^{++}$	$c\bar{s}u\bar{d}$	$1(0^+)$		$T_{c\bar{c}\bar{s}1}(4220)^+$	$c\bar{c}u\bar{s}$	$1/2(1^+)$	$Z_{cs}(4220)^+$
$T_{cc}(3875)^+$	$cc\bar{u}\bar{d}$	$?(?^?)$		$T_{b\bar{s}}(5568)^+$	$b\bar{s}\bar{u}d$	$1(?^?)$	$X(5568)^+$
$T_{c\bar{c}1}(3900)^+$	$c\bar{c}u\bar{d}$	$1^+(1^{+-})$	$Z_c(3900)^+$	$T_{b\bar{b}1}(10610)^+$	$b\bar{b}u\bar{d}$	$1^+(1^{+-})$	$Z_b(10610)^+$
$T_{c\bar{c}}(4020)^+$	$c\bar{c}u\bar{d}$	$1^+(?^{?-})$	$X(4020)^+$	$T_{b\bar{b}1}(10650)^+$	$b\bar{b}u\bar{d}$	$1^+(1^{+-})$	$Z_b(10650)^+$
$T_{c\bar{c}}(4050)^+$	$c\bar{c}u\bar{d}$	$1^-(?^{?+})$	$X(4050)^+$	$T_{cc\bar{c}\bar{c}}(6900)^0$	$cc\bar{c}\bar{c}$	$0^+(?^{?+})$	$X(6900)$
$T_{c\bar{c}}(4055)^+$	$c\bar{c}u\bar{d}$	$1^+(?^{?-})$	$X(4055)^+$	$P_{c\bar{c}}(4312)^+$	$c\bar{c}uud$	$1/2(?^?)$	$P_c(4312)^+$
$T_{c\bar{c}}(4100)^+$	$c\bar{c}u\bar{d}$	$1^-(?^{?+})$	$X(4100)^+$	$P_{c\bar{c}}(4380)^+$	$c\bar{c}uud$	$1/2(?^?)$	$P_c(4380)^+$
$T_{c\bar{c}1}(4200)^+$	$c\bar{c}u\bar{d}$	$1^+(1^{+-})$	$Z_c(4200)^+$	$P_{c\bar{c}}(4440)^+$	$c\bar{c}uud$	$1/2(?^?)$	$P_c(4440)^+$
$T_{c\bar{c}0}(4240)^+$	$c\bar{c}u\bar{d}$	$1^+(0^{--})$	$R_{c0}(4240)^+$	$P_{c\bar{c}}(4457)^+$	$c\bar{c}uud$	$1/2(?^?)$	$P_c(4457)^+$
$T_{c\bar{c}}(4250)^+$	$c\bar{c}u\bar{d}$	$1^-(?^{?+})$	$X(4250)^+$	$P_{c\bar{c}s}(4459)^0$	$c\bar{c}uds$	$0(?^?)$	

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