

# Charmed baryon spectroscopy

Mat Charles (Oxford)  
Ruslan Chistov (ITEP)

# People

- Ruslan has taken over from Roman Mizuk on the Belle side and has already written a chunk of text on baryon weak decays (see his slides).
- Agreement from Pat Burchat to read/edit later.
- Otherwise, not much bench depth.

# Section

- Basic structure looks like:
  - Spectroscopy
    - Introduction [Mat]
    - Theory review [who?]
    - Experimental review [Mat]
  - Weak decays [Ruslan]
  - Applications to light baryon spectroscopy

# Section

- Basic structure looks like:
  - Spectroscopy
    - Introduction [Mat] ← Decent chunk of this written
    - Theory review [who?]
    - Experimental review [Mat] ← Not written... but plan to base it on a review by me from a couple of years back.
  - Weak decays [Ruslan]
  - Applications to light baryon spectroscopy
    - Have some experts on BABAR; should try again to rope them in. (Otherwise it's me writing this too...)

16.4 Charmed baryon spectroscopy and decays

Editors:
Matthew Charles (BABAR)
Roman Mizuk (Belle)

16.4.1 Spectroscopy

16.4.1.1 Introduction

Overview The spectroscopy of charmed baryons is beautiful and intricate. With three quarks there are numerous degrees of freedom, giving rise to many more states than in the charmed meson sector. At the same time, the large difference in mass between the charm quark and the light quarks provides a natural way to classify and understand these states: Heavy Quark Effective Theory (HQET). The spectrum of known singly charmed states can be thought of in three broad regimes: the ground states, which are a vindication of the constituent quark model; the low-lying excited states, which are described well by HQET; and higher excited states, where the situation is murkier.

The naming convention for charmed baryons is to take a light baryon, replace one or more s quarks with c quarks, and add a c subscript for every quark replaced. Isospin is unchanged. For example, Λ denotes a sud baryon with isospin zero and so Λ\_c^+ denotes a cud baryon with isospin zero. Likewise, Ξ\_c^0 denotes a csd baryon and Xi\_cc^+ denotes a ccd baryon. Following the PDG convention, we mark strongly decaying states such as the Ξ\_c(2645) with their approximate mass.

Quark model for ground states In the constituent quark model, baryons composed of u, d, s, c quarks can be classified into SU(4) multiplets according to the symmetry of their flavor, spin, and spatial wavefunctions. All states in a given SU(4) multiplet have the same angular momentum J, and parity P, but can have different quark flavours. For excited states with multiple units of orbital angular momentum the number of possible multiplets becomes large, but for the ground states the picture is much simpler. This framework is not exact—different states with the same conserved quantum numbers will mix, and baryons are not pure three-quark objects—but it works remarkably well for the ground states.

A baryon is a fermion and therefore must have a wavefunction that is overall antisymmetric under quark interchange<sup>1</sup>. Baryons are color singlets, and so have an antisymmetric color wavefunction. In the ground state, the

<sup>1</sup> Strictly, it only needs to be symmetric under interchange of equal-mass quarks, but in order to build the model we assume

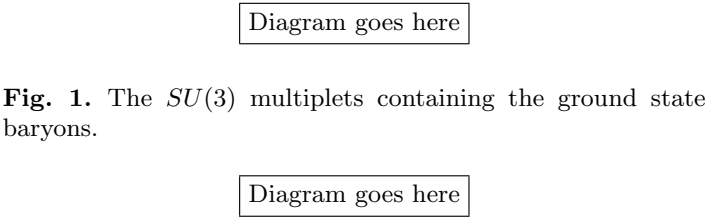


Fig. 1. The SU(3) multiplets containing the ground state baryons.

Fig. 2. The SU(4) multiplets containing the ground state baryons.

spatial wavefunction is symmetric. Therefore, the product of the spin and flavor wavefunctions must also be symmetric for ground-state baryons. There are two ways this can be accomplished: both wavefunctions can be fully symmetric, or both can have mixed symmetry with the product being symmetric.

In concrete terms, we can consider a singly charmed baryon to consist of a heavy c quark and a light diquark with spin-parity j^P. Assuming isospin symmetry and letting q denote a u or d quark, there are four possibilities for the flavour content of the diquark:

– qq with isospin 0 (flavour antisymmetric);
– qq with isospin 1 (flavour symmetric);
– sq with isospin 1/2 (either);
– ss with isospin 0 (flavour symmetric).

These correspond to the Λ\_c, Σ\_c, Ξ\_c, and Ω\_c states, respectively. The diquark is a boson and its spatial and color wavefunctions are symmetric, so it may be either flavor-symmetric and spin-symmetric (j^P = 1^+) or flavor-antisymmetric and spin-antisymmetric (j^P = 0^+). Combining the diquark with the charm quark gives rise to the possible states set out in Table 1 and illustrated in Fig. 1. Those with J^P = 1/2^+ are all members of the same multiplet as the proton, and those with J^P = 3/2^+ are all members of the same multiplet as the Δ and Ω (Fig. 2).

The constituent quark model predicts relations between the masses of these states as well as their existence and quantum numbers. These were expressed for the light baryons as Gell-Mann-Okubo sum rules (see Gell-Mann (1962); Okubo (1962)):

(m\_N + m\_Ξ)/2 = (3m\_Λ + m\_Σ)/4,
m\_Σ\* - m\_Δ = m\_Ξ\* - m\_Σ\* = m\_Ω - m\_Ξ\*.

Generalize to charmed baryons. (Use Gasiorowicz-Rosner instead?)
Mention lovely agreement of Ω\_c\* with prediction.

Phenomenological predictions for higher states Theory input (or at least sanity-checking) needed.

It is beyond the scope of this book to try to describe the current suite of phenomenological predictions for excited charmed baryon states—not to mention a moving target. Instead, we will focus on HQET, which is conceptually simple and enables us to understand the properties and decays of the lower tiers of excited states. We consider

singly charmed baryons to be composed of a heavy, slow-moving charm quark plus a light, fast-moving diquark—not precisely the same as a hydrogen atom, but similar. ... transitions between states by action of diquark ... conserve quantum numbers separately ...

16.4.1.2 Λ\_c, Σ\_c families

Experimental results and interpretation

- BABAR: Λ\_c^+ ground state mass
- BABAR: Λ\_c(2880)^+ and Λ\_c(2940)^+ mass, width
- Belle: Spin/parity of Λ\_c(2880)^+; mass and width of Λ\_c(2880)^+ and Λ\_c(2940)^+
- BABAR: Σ\_c resonances in B^- → Λ\_c^+ p̄ π^-
- Belle: Properties of Σ\_c(2800)

16.4.1.3 Ξ\_c family

Experimental results and interpretation

- Belle: Masses of Ξ\_c^0, Ξ\_c^+
- BABAR: Mass, spin of Ξ\_c'^0
- Belle: Ξ\_c(2980), Ξ\_c(3077); search for Ξ\_cc
- Belle: Ξ\_c(2645), Ξ\_c(2815), Ξ\_c(2980) masses, width of Ξ\_c(2980)
- BABAR: Ξ\_c(2980), Ξ\_c(3055), Ξ\_c(3077), Ξ\_c(3123) properties
- BABAR: Possible Ξ\_c(2930) in B^- c+ c K

16.4.1.4 Ω\_c family

Experimental results and interpretation

- BABAR: Ω\_c^\*0 mass
- Belle: Masses of Ω\_c^0, Ω\_c^\*0

16.4.1.5 Searches for Ξ\_cc

Experimental results and interpretation

- BABAR: Search for Ξ\_cc

16.4.1.6 Conclusions

Text goes here

16.4.2 Weak decays

16.4.2.1 Introduction

16.4.2.2 Results and discussion

- Λ\_c^+
- Belle: Weak decay BRs of Λ\_c
  - BABAR: Weak decay BRs of Λ\_c

**Table 1.** Summary of the ground state singly charmed baryons.  $S$  denotes a wavefunction that is fully symmetric under interchange of any two quarks;  $M_S$  and  $M_A$  denote mixed overall symmetry with interchange of the two light quarks being symmetric or asymmetric, respectively; and  $A$  would denote a fully asymmetric wavefunction.

Baryon	Diquark	Diquark $I$	Diquark $j^P$	Baryon flavor symmetry	Baryon spin symmetry	Baryon $J^P$
$\Lambda_c$	$qq$	0	$0^+$	$M_A$	$M_A$	$1/2^+$
$\Sigma_c$	$qq$	1	$1^+$	$M_S$	$M_S$	$1/2^+$
$\Sigma_c^*$	$qq$	1	$1^+$	$S$	$S$	$3/2^+$
$\Xi_c$	$sq$	1/2	$0^+$	$M_A$	$M_A$	$1/2^+$
$\Xi_c'$	$sq$	1/2	$1^+$	$M_S$	$M_S$	$1/2^+$
$\Xi_c^*$	$sq$	1/2	$1^+$	$S$	$S$	$3/2^+$
$\Omega_c$	$ss$	0	$1^+$	$M_S$	$M_S$	$1/2^+$
$\Omega_c^*$	$ss$	0	$1^+$	$S$	$S$	$3/2^+$

$\Xi_c^0$  and  $\Xi_c^+$

- BABAR: Weak decay BRs of  $\Xi_c^0$
- Belle: Weak decay BRs of  $\Xi_c^0, \Xi_c^+$

$\Omega_c^0$

- BABAR: Weak decay BRs of  $\Omega_c$

#### 16.4.2.3 Comments on absolute branching fractions

### 16.4.3 Applications to light baryon spectroscopy

#### 16.4.3.1 Introduction

#### 16.4.3.2 Spin of the $\Omega^-$

- BABAR: Spin of  $\Omega$

#### 16.4.3.3 Properties of $\Xi(1530)$ and $\Xi(1690)$

- BABAR: Spin of  $\Xi(1530)^0$
- BABAR: Mass, width, spin of  $\Xi(1690)^0$

#### 16.4.3.4 Conclusions

### 16.4.4 Outlook