Mass Spectra and Semileptonic Decays of Doubly Heavy Ξ and Ω Baryons

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Introduction

•研究对象：doubly heavy Ξ and Ω baryons

•研究方法：hypercentral constituent quark model

•研究结果：

①给出了对双重重子Ξ 和 Ω基态和轨道激发态的质量预测，发现$M_{\Omega}-M_{\Xi}=\Delta_{M}\approx 178\mathrm{MeV}$

②给出了其部分的半轻衰变宽度和分支比的数值结果

Theoretical framework

$$E_\gamma = (2\gamma + 6)\frac{w}{2} - \frac{2mc^2}{(2\gamma + 5)^2}$$

$$\psi_\gamma(x) = N_\gamma x^{-\frac{5}{2}}\phi_\gamma(x) = N_\gamma x^\gamma exp(-\frac{mw}{2}x^2 - \frac{2mc}{(2\gamma + 5)}x),$$

$$H_S = \Sigma_{i<j} A_S(\frac{1}{\sqrt{\pi}\sigma_S})^3 exp(\frac{-x^2}{\sigma_S})(\overrightarrow{s_i}.\overrightarrow{s_j}),$$

$$M_{\text{baryon}} = \sum_{i=1} m_i + E_\gamma + < H_S > .$$

Theoretical framework

$$\Gamma_{\frac{1}{2}\to\frac{1}{2}} = \frac{G_F^2|V_{bc}|^2 M_i^5 r^4}{12\pi^3}\int_1^{\omega_{\max}} d\omega\sqrt{\omega^2-1}(l_1^+(\omega)\eta^2(\omega)+l_1^-(\omega)\eta^2(\omega)), \tag{10}$$

$$\Gamma_{\frac{1}{2}\to\frac{3}{2}} = \frac{G_F^2|V_{bc}|^2 M_i^5 r^4}{12\pi^3}\int_1^{\omega_{\max}} d\omega\sqrt{\omega^2-1}l_2(\omega)\eta^2(\omega), \tag{11}$$

$$\Gamma_{\frac{3}{2}\to\frac{1}{2}} = \frac{G_F^2|V_{bc}|^2 M_i^5 r^4}{24\pi^3}\int_1^{\omega_{\max}} d\omega\sqrt{\omega^2-1}l_3(\omega)\eta^2(\omega), \tag{12}$$

$$\Gamma_{\frac{3}{2}\to\frac{3}{2}} = \frac{G_F^2|V_{bc}|^2 M_i^5 r^4}{24\pi^3}\int_1^{\omega_{\max}} d\omega\sqrt{\omega^2-1}(l_4^+(\omega)\eta^2(\omega)+l_4^-(\omega)\eta^2(\omega)), \tag{13}$$

Theoretical framework

where $r = M_2/M_1$, $\omega_{\rm max} = (1+r^2)/2r$,

$$l_1^{\pm}(\omega) = (\omega \mp 1)(3\omega_{\rm max} \pm 1 - 2\omega), \tag{14}$$

$$l^2(\omega) = 2(\omega+1)(\omega_{\rm max} - \omega + \frac{\omega^2-1}{6r}), \tag{15}$$

$$l^3(\omega) = 2(\omega+1)(\omega_{\rm max} - \omega + \frac{(\omega^2-1)r}{6}), \tag{16}$$

and

$$l_4^{\pm}(\omega) = \frac{4}{9}(l_1^{\pm}(\omega)\frac{3+2\omega^2}{2} \pm (\omega_{max} \pm 1)(\omega^2-1)). \tag{17}$$

The parameter G_F is the Fermi Coupling constant, V_{bc} is the CKM matrix element and its value is $V_{bc} = 0.04$, M_1 and M_2 are the initial and final state baryon masses, respectively. We take the following values of $\omega_{\rm max}$ for different transitions:

$$\omega_{\rm max}[\Xi_{bb} \to \Xi_{bc}] = 1.07, \quad \omega_{\rm max}[\Omega_{bb} \to \Omega_{bc}] = 1.07, \tag{18}$$

$$\omega_{\rm max}[\Xi_{bc} \to \Xi_{cc}] = 1.22, \quad \omega_{\rm max}[\Omega_{bc} \to \Omega_{cc}] = 1.20. \tag{19}$$

Numerical results

TABLE II: Masses of the ground states of doubly heavy baryons (in GeV). The sign "*" refers to the $s = \frac{3}{2}$ baryons.

Baryon	Content	Our results	RQM [47]	HQSS [48]	QCDSR [49]	NRQM [50]	NRQM [51]
Ξ_{cc}	qcc	3.620	3.620	3.613		3.676	3.685
Ξ_{cc}^*	qcc	3.653	3.727	3.707	3.690	3.753	3.754
Ξ_{bc}	qbc	6.958	6.933	6.928		7.020	
Ξ_{bc}^*	qbc	6.991	6.980	6.996	7.250	7.078	
Ξ_{bb}	qbb	10.322	10.202	10.198		10.340	10.314
Ξ_{bb}^*	qbb	10.355	10.237	10.237	10.400	10.367	10.339
Ω_{cc}	scc	3.798	3.778	3.712		3.815	3.832
Ω_{cc}^*	scc	3.831	3.872	3.795	3.780	3.876	3.883
Ω_{bc}	sbc	7.137	7.088	7.013		7.147	
Ω_{bc}^*	sbc	7.170	7.130	7.075	7.300	7.191	
Ω_{bb}	sbb	10.500	10.359	10.269		10.456	10.447
Ω_{bb}^*	sbb	10.533	10.389	10.307	10.500	10.486	10.467

Numerical results

TABLE III: Masses of the orbitally excited states of doubly heavy baryons (in GeV).

State	Baryon	Our results	NRQM [52]	EFT [53]	Baryon	Our results	NRQM [54]	NRQM [51]
P-wave	Ξ_{cc}	3.928	3.853	4.028	Ω_{cc}	4.106	3.964	4.086
	Ξ^*_{cc}	3.961	3.862	4.079	Ω^*_{cc}	4.139	3.972	4.199
	Ξ_{bc}	7.266	7.140		Ω_{bc}	7.4457	7.375	
	Ξ^*_{bc}	7.299	7.157		Ω^*_{bc}	7.478	7.381	
	Ξ_{bb}	10.631	10.502	10.386	Ω_{bb}	10.808	10.634	10.607
	Ξ^*_{bb}	10.664	10.510	10.404	Ω^*_{bb}	10.841	10.636	10.796
D-wave	Ξ_{cc}	4.237	4.026	4.321	Ω_{cc}	4.414	4.133	4.263
	Ξ^*_{cc}	4.269	4.035	4.376	Ω^*_{cc}	4.474	4.141	4.265
	Ξ_{bc}	7.575	7.307		Ω_{bc}	7.754	7.807	
	Ξ^*_{bc}	7.607	7.312		Ω^*_{bc}	7.786	7.812	
	Ξ_{bb}	10.939	10.658	10.585	Ω_{bb}	11.1177	10.783	10.723
	Ξ^*_{bb}	10.972	10.660	10.610	Ω^*_{bb}	11.150	10.785	10.730
F-wave	Ξ_{cc}	4.545	4.185	4.569	Ω_{cc}	4.723	4.287	4.555
	Ξ^*_{cc}	4.577	4.216	4.644	Ω^*_{cc}	4.755	4.313	4.600
	Ξ_{bc}	7.883	7.451		Ω_{bc}	8.062	7.702	
	Ξ^*_{bc}	7.916	7.468		Ω^*_{bc}	8.095	7.721	
	Ξ_{bb}	11.274	10.797	10.757	Ω_{bb}	11.425	11.136	11.028
	Ξ^*_{bb}	11.280	10.805	10.792	Ω^*_{bb}	11.458	11.142	11.059

Numerical results

TABLE IV: Semileptonic decay widths of doubly heavy baryons in units of 10^{-14} GeV and their variations.

Decay	Our results	RCQM [37]	NRQM [58]	RQM [47]	HQSS [32]	LFQM^a [59]
$\Xi_{bb} \to \Xi_{bc}\ell\bar{\nu}_\ell$	1.75 ± 0.73	1.33 ± 0.61	1.37	1.63	$1.92^{+0.25}_{-0.05}$	3.30
$\Xi_{bc} \to \Xi_{cc}\ell\bar{\nu}_\ell$	4.39 ± 0.83	4.01 ± 1.21	5.07	2.30	$2.57^{+0.26}_{-0.03}$	4.50
$\Xi^*_{bb} \to \Xi_{bc}\ell\bar{\nu}_\ell$	0.49 ± 0.18	0.25 ± 0.10	0.66	0.28	$0.35^{+0.03}$	
$\Xi^*_{bc} \to \Xi_{cc}\ell\bar{\nu}_\ell$	1.00 ± 0.16	0.58 ± 0.14	1.16	0.38	$0.43^{+0.06}$	
$\Xi_{bb} \to \Xi^*_{bc}\ell\bar{\nu}_\ell$	1.07 ± 0.43	0.61 ± 0.15	1.45	0.53	$0.61^{+0.04}$	
$\Xi_{bc} \to \Xi^*_{cc}\ell\bar{\nu}_\ell$	2.82 ± 0.52	1.39 ± 0.34	3.32	0.72	$0.75^{+0.06}$	
$\Xi^*_{bb} \to \Xi^*_{bc}\ell\bar{\nu}_\ell$	1.10 ± 0.48	1.62 ± 0.73		1.92	$2.09^{+0.16}$	
$\Xi^*_{bc} \to \Xi^*_{cc}\ell\bar{\nu}_\ell$	3.12 ± 0.62	4.63 ± 1.23		2.69	$2.63^{+0.40}$	
$\Omega_{bb} \to \Omega_{bc}\ell\bar{\nu}_\ell$	1.87 ± 0.76	1.92 ± 1.15	2.48	1.70		3.69
$\Omega_{bc} \to \Omega_{cc}\ell\bar{\nu}_\ell$	4.70 ± 0.83	4.12 ± 1.10	5.39	2.48		3.94
$\Omega^*_{bb} \to \Omega_{bc}\ell\bar{\nu}_\ell$	0.53 ± 0.19	0.26 ± 0.10	0.69	0.29		
$\Omega^*_{bc} \to \Omega_{cc}\ell\bar{\nu}_\ell$	1.09 ± 0.16	0.59 ± 0.13	1.23	0.40		
$\Omega_{bb} \to \Omega^*_{bc}\ell\bar{\nu}_\ell$	1.14 ± 0.45	0.57 ± 0.23	1.53	0.55		
$\Omega_{bc} \to \Omega^*_{cc}\ell\bar{\nu}_\ell$	2.99 ± 0.52	1.78 ± 0.64	3.52	0.74		
$\Omega^*_{bb} \to \Omega^*_{bc}\ell\bar{\nu}_\ell$	1.17 ± 0.50	1.72 ± 0.77		2.00		
$\Omega^*_{bc} \to \Omega^*_{cc}\ell\bar{\nu}_\ell$	3.32 ± 0.62	4.95 ± 1.26		2.88		

Numerical results

TABLE V: The calculated branching fractions of semileptonic decays of doubly heavy baryons.

Process	Our results	NRQM [58]	LFQM [59]
$\Xi_{bc} \to \Xi_{cc} \ell \bar{\nu}_\ell$	1.63×10^{-2}	1.11×10^{-2}	1.67×10^{-2}
$\Xi_{bb} \to \Xi_{bc} \ell \bar{\nu}_\ell$	0.98×10^{-2}	0.28×10^{-2}	1.86×10^{-2}
$\Omega_{bc} \to \Omega_{cc} \ell \bar{\nu}_\ell$	1.57×10^{-2}	1.10×10^{-2}	1.32×10^{-2}
$\Omega_{bb} \to \Omega_{bc} \ell \bar{\nu}_\ell$	2.27×10^{-2}		4.49×10^{-2}

Summary

◆在超中心方法中考虑了双重重子Ξ 和 Ω的三体问题，得到了双重重子Ξ和Ω的基态和激发态的质谱，并发现了$M_{\Omega} - M_{\Xi}=\Delta_M \simeq 178\mathrm{MeV}$

◆研究了bb→bc和bc→cc重子跃迁接近零反冲点的半轻子衰变宽度和分支比，并将结果与其他的理论计算结果进行了比较。

谢谢！