

*Short note***On the $\Delta I=1/2$ rule in the $\Lambda N \rightarrow NN$ reaction**Z. Rudy¹, W. Cassing², L. Jarczyk¹, B. Kamys¹, P. Kulesa^{1,3}, O.W.B. Schult³, A. Strzałkowski¹¹ M. Smoluchowski Institute of Physics, Jagellonian University, PL-30059 Cracow, Poland² Institut für Theoretische Physik, Universität Giessen, D-35392 Giessen, Germany³ Institut für Kernphysik, Forschungszentrum Jülich, D-52425 Jülich, Germany

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Abstract. It is shown that the mass dependence of the Λ -lifetime in heavy hypernuclei is sensitive to the ratio of neutron-induced to proton-induced non-mesonic decay rates R_n/R_p . A comparison of the experimental mass dependence of the lifetimes with the calculated ones for different values of R_n/R_p leads to the conclusion that this ratio is larger than 2 on the confidence level of 0.75. This suggests that the phenomenological $\Delta I=1/2$ rule might be violated for the nonmesonic decay of the Λ -hyperon.

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It is well known that weak, pionic decays of strange mesons and hyperons strongly favour $\Delta I=1/2$ amplitudes over *a priori* comparable $\Delta I=3/2$ amplitudes [1]. This phenomenological rule may be interpreted on the level of a simple quark model as an indication that decays proceed via a transformation of the s-quark (with $S=-1, I=0$) into a u-quark (with $S=0, I=1/2$) whereas all other quarks play the role of spectators. The question arises whether the same, simple picture also holds in strangeness changing, weak interaction between two baryons, such as a Λ -hyperon and a nucleon. Since it is difficult to realize hyperon - nucleon scattering experimentally, the only practical way to study the weak YN interaction is to examine the non-mesonic decays $\Lambda p \rightarrow np$ and $\Lambda n \rightarrow nn$ of hyperons bound in hypernuclei. The current theoretical models of the YN weak interaction, which rely on the validity of the $\Delta I=1/2$ rule, have achieved a reasonable agreement with data on the total non-mesonic decay rates but they are not able to reproduce ratios of partial decay rates, i.e. neutron-induced to proton-induced decays [2]. Thus the applicability of the $\Delta I=1/2$ rule to the non-mesonic decay mode is an open question. The analysis of existing data on non-mesonic decays of the lightest hypernuclei [3] suggests that the $\Delta I=1/2$ rule might be violated in the weak hyperon-nucleon interaction. It was also recently shown [4] that the theoretical analysis of the shape of proton spectra from the decay of ${}_{\Lambda}^{12}\text{C}$ leads to the conclusion that the $\Delta I=1/2$ rule is not preserved in the non-mesonic decay.

The present letter examines another method of testing the validity of the $\Delta I=1/2$ rule in the non-mesonic decay.

It is based on the fact that the mass dependence of the lifetime of hypernuclei is sensitive (for heavy hypernuclei) to the ratio R_n/R_p of the neutron - induced (R_n) to proton - induced (R_p) decay rates of the Λ -hyperon. Furthermore, it is known that the R_n/R_p ratio should be less or equal to 2 if the $\Delta I=1/2$ rule holds for the non-mesonic decay [1]. Thus an experimental evidence for $R_n/R_p > 2$ obtained from the investigation of the mass dependence of the Λ -lifetime in heavy hypernuclei would imply a violation of the $\Delta I=1/2$ rule.

We recall that the mass dependence of the Λ -lifetime in hypernuclei may be due to several effects:

- i) The Pauli blocking strongly affects the mesonic decay mode ($\Lambda \rightarrow N\pi$) and depends on the mass of the hypernuclei, but practically does not influence the non-mesonic decay process. This is caused by the different energy release in mesonic (≈ 40 MeV) and non-mesonic (≈ 180 MeV) decays. Furthermore, this energy is almost equally shared among both nucleons emerging from the non-mesonic decay, whereas the pion - due to momentum conservation - carries most of the energy released in the mesonic decay. Thus the nucleon in the final state from the mesonic decay is coming from far below the Fermi energy whereas the final nucleons from the non-mesonic decay are both highly above the Fermi energy.
- ii) Another source for the lifetime dependence on the mass of hypernuclei is the variation of the hyperon - nucleus potential with mass A of hypernuclei and a resulting variation of the hyperon wave function. This depen-

dence in turn will affect both, the mesonic and non-mesonic decay rates.

- iii) The last effect is the variation of the ratio N/Z with the mass of hypernuclei. This is the most important effect for our purposes because such a variation can lead to a mass dependence of the Λ -lifetime in hypernuclei only if the ratio R_n/R_p deviates from unity. Thus the mass dependence of the lifetime of heavy hypernuclei appears to be sensitive to the R_n/R_p ratio.

In order to estimate the decay width of the mesonic decay a phase-space model has been used in line with the Coupled - Channel - Boltzmann - Uhling - Uhlenbeck approach [5]. The decay width in units of the free Λ -hyperon decay width including Pauli blocking is given by:

$$\Gamma_{mesonic}/\Gamma_{free} = \frac{1}{(2\pi)^3} \int d^3r \int d^3p \int d^3p' f_{\Lambda}(\mathbf{r}, \mathbf{p})(1 - f_N(\mathbf{r}, \mathbf{p}'))\delta(\mathbf{p} - \mathbf{p}_{\pi} - \mathbf{p}') \quad (1)$$

with $p_{\pi} = 102MeV/c$, where $f_{\Lambda}(\mathbf{r}, \mathbf{p})$ is approximated by a Gaussian s-state phase-space density from the harmonic oscillator model

$$f_{\Lambda}(\mathbf{r}, \mathbf{p}) = \frac{1}{\pi^3} \exp\left(-\frac{\mathbf{r}^2}{\gamma^2}\right) \times \exp(-\gamma^2 \mathbf{p}^2);$$

$$\gamma = \sqrt{\frac{\hbar}{\mu\omega}}; \quad \hbar\omega = 41A^{-1/3}[MeV] \quad (2)$$

normalized to unity, whereas the nucleon phase-space distribution is taken in the semiclassical limit, i.e.

$$f_N(\mathbf{r}, \mathbf{p}') = \Theta(p_F(\mathbf{r}) - p') \quad (3)$$

with $p_F(\mathbf{r})$ denoting the local Fermi momentum defined by the experimental density for the nucleus of interest, $p_F(\mathbf{r}) = (\frac{3}{2}\pi^2\rho(\mathbf{r}))^{1/3}$ and $\Theta(x)$ is the step - function, i.e. $\Theta(x)=1$ for $x \geq 0$ and $\Theta(x)=0$ for $x < 0$.

The same conceptual approach is applied to the non-mesonic decay and leads to the following width that also includes the blocking of the final nucleon states [5]:

$$\Gamma_{non-mesonic} \approx R_N \frac{4}{(2\pi)^6} \int d^3r \int d^3p \int d^3p_N \int d^3p'_1$$

$$\int \frac{d\Omega}{4\pi} |v_{\Lambda N}| \frac{d\sigma_{\Lambda N \rightarrow \Lambda N}}{d\Omega} (\sqrt{s}) f_{\Lambda}(\mathbf{r}, \mathbf{p}) f_N(\mathbf{r}, \mathbf{p}_N) \times$$

$$(1 - f_N(\mathbf{r}, \mathbf{p}'_2))(1 - f_N(\mathbf{r}, \mathbf{p}'_1))\delta(\mathbf{p} + \mathbf{p}_N - \mathbf{p}'_1 - \mathbf{p}'_2), \quad (4)$$

where the phase-space distributions are the same as in (1) and the differential cross section $d\sigma_{\Lambda N \rightarrow NN}/d\Omega$ has been approximated by $R_N d\sigma_{\Lambda N \rightarrow \Lambda N}/d\Omega$ [5] with a weak decay constant R_N . The latter is the squared ratio of the weak transition matrix element to that for the strong interaction $\Lambda N \rightarrow \Lambda N$. The quantity $v_{\Lambda N}$, furthermore, is the relative velocity of the Λ -hyperon and the nucleon in their collision. The constant R_n for the process $n + \Lambda \rightarrow n + n$ might have a different value from the constant R_p for the $p + \Lambda \rightarrow p + n$ channel. This is due to the fact that the final NN system can have both isospin $I_{NN} = 0$ or $I_{NN} = 1$ in

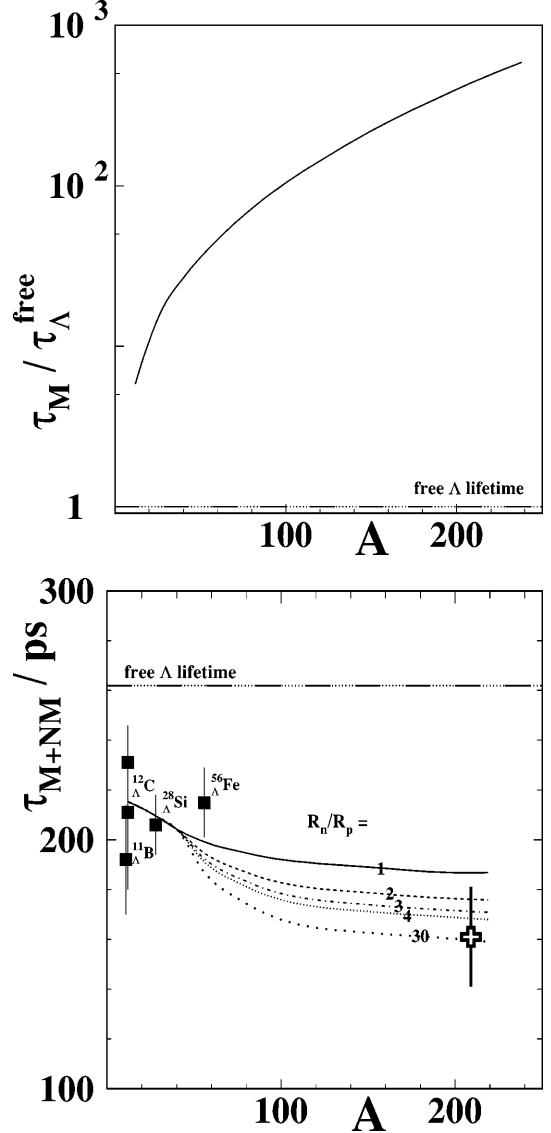


Fig. 1. Upper part: phase-space model calculation of the lifetime τ_M of the Λ -hyperon due to the mesonic decay inside the hypernucleus of mass A according to (1) presented in units of the lifetime of the free Λ -hyperon $\tau_{\Lambda}^{free} = 263$ ps; Lower part: calculations of the Λ -lifetime τ_{M+NM} due to the mesonic and nonmesonic decay as a function of hypernucleus mass A in comparison to the data of [7,8,11]. The COSY-13 collaboration result for a Bi target [11] is marked by the cross. In the theoretical calculations both mesonic and non-mesonic decay modes are taken into account whereas the unknown ratio of the weak decay rates R_n/R_p in equation (4) is varied assuming the values: $R_n/R_p = 1, 2, 3, 4$ and 30

case of neutron-proton final states and only $I_{NN} = 1$ in case of two final neutrons. Anyway, one can always write $\Gamma_{non-mesonic} = \Gamma_n + \Gamma_p$, where Γ_n and Γ_p can be separately calculated via formula (4) using instead of R_N the effective strength equal to $N \cdot R_n/A$ or $Z \cdot R_p/A$ for neutrons and protons, respectively.

The lifetime $\tau_M = \hbar/\Gamma_{mesonic}$ of the Λ -hyperon due to the pure πN decay channel evaluated according to for-

mula (1) is displayed in the upper part of Fig. 1 as a function of the mass A of the hypernucleus. It shows a dramatic increase of τ_M due to Pauli-blocking what contradicts the tendency of the experimental mass dependence of the lifetime depicted in the lower part of Fig. 1. This indicates clearly that the non-mesonic decay dominates for medium-mass and heavy hypernuclei.

The results for $\tau_\Lambda = \hbar/(\Gamma_{mes} + \Gamma_{non-mesonic})$, where $\Gamma_{non-mesonic} = \Gamma_n + \Gamma_p$ are shown in the lower part of Fig. 1 as a function of the mass A . The calculations were performed for several ratios R_n/R_p while keeping $R_{av} = (R_n + R_p)/2$ constant. R_{av} was fixed by the requirement that the constructed model has to describe the lifetime data for light hypernuclei, i.e. ${}^1_1\text{B}$ and ${}^1_6\text{C}$ [7,8].

The lifetimes calculated for hypernuclei in the neighbourhood of mass number $A=200$ are equal to ≈ 175 ps for the ratio $R_n/R_p=2$, i.e. the limiting value which is still compatible with the $\Delta I=1/2$ rule. Smaller values of the lifetime for these heavy hypernuclei correspond to ratios $R_n/R_p > 2$ and therefore they imply a violation of the $\Delta I=1/2$ rule. It should be noted, that in order to obtain a convincing conclusion about the violation of the $\Delta I=1/2$ rule the errors of the lifetime measurements should be very small.

Recently, the COSY-13 collaboration [11] has measured the lifetime for heavy hypernuclei produced in the p+Bi interaction with experimental errors distinctly smaller than other published results [9,10]. This value for the lifetime $\tau_\Lambda = (161 \pm 21)$ ps leads to the conclusion that the R_n/R_p ratio is larger than 2 on the confidence level of 0.75. This suggests that the phenomenological $\Delta I=1/2$ rule may be violated for the non-mesonic decay of the Λ -hyperon. It should be noted that the lines displayed in Fig. 1 have been obtained for the average N/Z ratio as expected [6] for the cold hypernuclei produced in the p+Bi experiment [11].

The estimation of the confidence level was performed taking into account both, the inaccuracy of the R_{av} due to the experimental errors for the lifetime of light hypernuclei and the inaccuracy of the experimental determination of the lifetimes for heavy hypernuclei. It was assumed that the distribution of R_{av} as well as the distribution of the experimental lifetime of heavy hypernuclei are described by normal distributions, i.e. $N(\langle R_{av} \rangle, \sigma(R_{av}))$ and $N(\langle \tau_\Lambda \rangle, \sigma(\tau_\Lambda))$, respectively. The parameters $\langle R_{av} \rangle$, $\sigma(R_{av})$ were found from a fit of the theoretical curve to the lifetimes of the light hypernuclei, i.e. ${}^1_1\text{B}$ and ${}^1_6\text{C}$ [7,8] whereas $\langle \tau_\Lambda \rangle$ and $\sigma(\tau_\Lambda)$ are known from the p+Bi experiment [11]. Then the con-

fidence level has been evaluated by convolution of these two distributions according to:

$$P = \int_{-\infty}^{+\infty} dR_{av} N(\langle R_{av} \rangle, \sigma(R_{av})) \cdot \int_{-\infty}^{\tau_{max}(R_{av}, \frac{R_n}{R_p}=2)} d\tau_\Lambda N(\langle \tau_\Lambda \rangle, \sigma(\tau_\Lambda)), \quad (5)$$

where $\tau_{max}(R_{av}, \frac{R_n}{R_p}=2)$ is the theoretical lifetime evaluated for heavy hypernuclei with the proper value of R_{av} and limiting value of the R_n/R_p ratio.

In order to put more stringent limits to the R_n/R_p ratio and thus to test further the validity of the $\Delta I=1/2$ rule on a higher confidence level it is necessary to obtain new precise data on the lifetime of medium-mass and heavy hypernuclei. Such experiments are planned both by the COSY-13 collaboration at Forschungszentrum Jülich [12] for heavy hypernuclei and by the E369 collaboration at KEK for ${}^{89}_\Lambda\text{Y}$ [7].

It should be emphasized, that the origin of the $\Delta I=1/2$ rule is not fully understood at present [13], though theoretical calculations in most cases rely on the validity of this rule [2]. Therefore, experimental results which indicate a violation of this rule will have relevant implications for all theoretical models of the weak interaction of baryons.

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References

1. Block, M. M., Dalitz, R. H., Phys. Rev. Lett. **11**, 96 (1963)
2. Cohen, J., Prog. in Part. and Nucl. Phys. **25**, 139 (1990)
3. Schumacher, R. A., Nucl. Phys. **A547**, 143c (1992)
4. Ramos, A., et al., Phys. Rev. **C55**, 735 (1997); Alberico, W.M., et al., **nucl-th/9902023**
5. Rudy, Z., et al., Z. Phys. **A351**, 217 (1995)
6. Rudy, Z., et al., Z. Phys. **A354**, 445 (1996)
7. Bhang, H. C. et al., Phys. Rev. Lett. **81**, 4321 (1998)
8. Szymanski, J.J., et al., Phys. Rev. **C43**, 849 (1991)
9. Armstrong, T. A., et al., Phys. Rev. **C47**, 1957 (1993)
10. Ohm, H., et al., Phys. Rev. **C55**, 3062 (1997)
11. Kulessa, P., et al., Phys. Lett. **B427**, 403 (1998)
12. Borgs, W., et al., Proposal submitted to the Physical Advisory Committee of COSY, Jülich, 1998
13. Parreño, A., et al., Phys. Lett. **B435**, 1 (1998)