TABLES OF Λ, K⁰, Σ± LIFETIMES AND Λ⁰, K⁰ DECAY BRANCHING RATIOS

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These tables of lifetimes and branching ratios are not necessarily a comprehensive list but are based on the information supplied to the Rapporteur of Session 9 (D. A. Glaser) of the 1958 Annual International Conference on High Energy Physics.

In calculating the mean values of Λ^0 and K^0 lifetimes, and the Λ^0-decay branching ratio, the individual values are weighted in proportion to the number of events upon which they were based. The errors given to the mean values are discussed by Glaser.

In computing mean values for the Σ^+- and Σ^--lifetimes and the K^0 decay branching ratios, the errors were symmetrised by taking the inverse of the quoted values and errors. The squares of these new " inverse errors " were used to weight the reciprocals of the quoted values in obtaining a mean value. The errors on this mean were formed from the r.m.s. of the " inverse errors ".

The following abbreviations are used :

- H.B.C. Hydrogen Bubble Chamber
- P.B.C. Propane Bubble Chamber
- C.C. Cloud Chamber
- C.R. Cosmic Ray measurement
- (p) F Σ-decays in Flight were taken, the proton track was measured.
- (p, π) F Σ-decays in Flight were taken, the proton and/or pion tracks were measured.
- (p) F, R Σ-decays in Flight or at Rest were taken, the proton track was measured.

TABLE I

Λ^0-Lifetime

Group	Technique	No. of events	Lifetime × 10^{10} sec.
BERKELEY (K^- capture)	H. B. C.	76	2.95 ± 0.4
BERKELEY (Assoc. prodn.)	H. B. C.	340	3.05 ± 0.35
COLUMBIA, PISA, BOLOGNA	H. B. C. P. B. C.	454	$2.29 {}^{+0.15}_{-0.13}$
COLUMBIA	C. C.	74	$2.75 {}^{+0.45}_{-0.38}$
JUNGFRAUJOCH	C. C.	40	$3.04 {}^{+0.78}_{-0.51}$
MICHIGAN	P. B. C.	61	$2.08 {}^{+0.46}_{-0.31}$
M. I. T.	C. C.	200	2.4 ± 0.2
MEAN LIFETIME			$2.60 {}^{+0.16}_{-0.14}$

TABLE II

Σ^--Lifetime

Group	Technique	Measurement	Lifetime × 10^{10} sec	
BERKELEY	H. B. C.	(π) F, R	1.60 ± 0.2	
COLUMBIA, PISA, BOLOGNA	P. B. C.	(π) F	$1.89 {}^{+0.33}_{-0.25}$	$1.72 {}^{+0.17}_{-0.10}$ Mean
MICHIGAN	P. B. C.	(π) F	$1.67 {}^{+0.40}_{-0.28}$	
LIVERMORE	Emulsion	(π) F	$0.34 {}^{+0.37}_{-0.07}$	
WISCONSIN	Emulsion	(π) F, R	2.5 ± 0.8	

TABLE III

Σ^+-Lifetime

Group	Technique	Measurement	Lifetime × 10^{10} sec.	
BERKELEY	H. B. C.	(p, π) F	0.69 ± 0.1	$0.75 {}^{+0.10}_{-0.09}$ Mean
MICHIGAN	P. B. C.	(p, π) F	$0.95 {}^{+0.37}_{-0.23}$	
BERKELEY	Emulsion	(p) F, R	$0.94 {}^{+0.23}_{-0.15}$	
EUROPEAN COLLAB.	Emulsion	(p) F, R selected	$0.84 {}^{+0.20}_{-0.15}$	
LIVERMORE	Emulsion	(p) F, R	$0.61 {}^{+0.18}_{-0.11}$	
N. R. L.	Emulsion	(p) F, R	$1.25 {}^{+0.51}_{-0.28}$	$0.93 {}^{+0.10}_{-0.08}$ Mean
ROCHESTER	Emulsion	(p) F, R	0.95 ± 0.16	
WISCONSIN	Emulsion	(p) F, R	$0.96 {}^{+0.37}_{-0.21}$	
EUROPEAN COLLAB.	Emulsion	(p) F	$0.86 {}^{+0.57}_{-0.25}$	
LIVERMORE	Emulsion	(p) F	$0.54 {}^{+0.58}_{-0.11}$	
LIVERMORE	Emulsion	(p) F, cut-off	$0.12 {}^{+0.07}_{-0.04}$	
LIVERMORE	Emulsion	(π) F	$0.16 {}^{+0.08}_{-0.03}$	
ROCHESTER	Emulsion	(p) F	$0.81 {}^{+0.75}_{-0.15}$	
WISCONSIN	Emulsion	(p) F	$0.47 {}^{+0.44}_{-0.15}$	

TABLE IV

$\Sigma^{\pm}$-Lifetime

Group	Technique	Measurement	Lifetime × 10^{10} sec.
BERKELEY	Emulsion	$(\pi^{\pm})\ F$	0.51 ± 0.2
EUROPEAN COLLAB.	Emulsion	$(\pi^{\pm})\ F$	$0.81 {}^{+0.22}_{-0.15}$
LIVERMORE	Emulsion	$(\pi^{\pm})\ F$	$0.33 {}^{+0.11}_{-0.04}$
DAVIES ET AL.	Emulsion (C. R.)	$(\pi^{\pm})\ F$	$0.35 {}^{+0.15}_{-0.11}$
N. R. L.	Emulsion	$(\pi^{\pm})\ F$	$0.31 {}^{+0.32}_{-0.10}$
WISCONSIN	Emulsion	$(\pi^{\pm})\ F$	$0.32 {}^{+0.11}_{-0.07}$

TABLE V

K^0 Lifetime

Group	Technique	No. of events	Lifetime × 10^{10} sec.
BERKELEY	H. B. C.	228	$0.93 {}^{+0.10}_{-0.06}$
COLUMBIA PISA BOLOGNA	P. B. C.	259	$1.06 {}^{+0.08}_{-0.06}$
COLUMBIA	C. C.	39	$1.15 {}^{+0.40}_{-0.25}$
JUNGFRAUJOCH	C. C.	29	$0.84 {}^{+0.35}_{-0.19}$
MICHIGAN	P. B. C.	62	$0.81 {}^{+0.23}_{-0.15}$
M. I. T.	C. C.	90	1.07 ± 0.13
MEAN LIFETIME			$0.99 {}^{+0.08}_{-0.06}$

TABLE VI

Λ^0-Decay branching ratio, $\dfrac{\Lambda^0 \rightarrow p + \pi^-}{\text{All } \Lambda^0}$

Group	Technique	No. of events	Branching ratio
BERKELEY (K^- CAPTURE)	H. B. C.	130	0.61 ± 0.05
BERKELEY (ASSOC. PRODN.)	H. B. C.	450	0.59 ± 0.04
COLUMBIA, PISA, BOLOGNA	P. B. C.	528	0.68 ± 0.05
MICHIGAN	P. B. C.	91	0.57 ± 0.10
M. I. T.	C. C.	200	0.69 ± 0.06
MEAN BRANCHING RATIO			0.63 ± 0.03
EXPECTED BRANCHING RATIO IF $\Delta I = \frac{1}{2}$			$\frac{2}{3} = 0.67$

TABLE VII

K^0 decay branching ratios

Group	Technique	No. of events	Branching Ratios		
			$\dfrac{\pi^+ + \pi^-}{\text{All } \theta^0}$	$\dfrac{\pi^0 + \pi^0}{\text{All } \theta^0}$	$\dfrac{\theta_1^0}{\text{All } \theta^0}$
BERKELEY	H. B. C.	450	0.35 ± 0.03		
COLUMBIA, PISA, BOLOGNA	P. B. C.	528	0.42 ± 0.05	0.07 ± 0.03	0.49 ± 0.075
MICHIGAN	P. B. C.	91	0.46 ± 0.10		
M. I. T.	C. C.		(0.47)	0.03	
MEAN BRANCHING RATIO			0.39 ± 0.03		
EXPECTED RATIOS IF $\Delta I = {}^1/_2$			${}^1/_3 = 0.33$	${}^1/_6 = 0.17$	${}^1/_2 = 0.50$

DISCUSSION

Discussion of Lifetimes

Fowler: I have a question about the Λ^0-lifetime. Those of us who have small bubble chambers live in the hope that we will some day get hundreds of events. If I take your table and combine the Cosmotron bubble chamber results I see a lifetime of 2.26×10^{-10} sec but if I take the Berkeley Bevatron results I see a lifetime of 3.04×10^{-10} sec, based on 515 and 416 events respectively. This seems to be a significant difference. I wonder if, for the sake of completeness, we could hear some details?

D. A. Glaser: As can be seen from Table I, the lowest value of 2.29×10^{-10} sec comes from the Columbia, Pisa, Bologna chamber, and the highest, 3.05×10^{-10} sec, from the Berkeley chamber, which is indeed quite a variation. Those chambers were the same size. The Berkeley chamber was 10 inches and the other one 12 inches. The Michigan chamber was also 12 inches, and the cloud chambers were quite different in size, the M.I.T. one being a few feet. The difficulty with the experiment is that one must take into account wall effects which result from escape of Λ^0's, and I regret to say that there has not been a very precise meeting between us as to how one should do that. Each of us did this quite independently and I think, that if the discrepancy is more than statistical, then that is its origin. I have no answer except that we have to get together and argue out how we should correct for the fact that the chambers are not really 12 inches but only 8 inches, because you have to produce the Λ^0 and then see it. It is an experimental question which has to be settled; I am sure we would have settled it if there was some theoretical prediction that the value is 2.3×10^{-10} sec!

Crussard: About the short value of Σ-lifetime found in emulsion from decays in flight only, I want to mention values which were found last year in Göttingen. I say " mention ", because unfortunately I do not have them here but they have been given at the 1957 Venice - Padua Conference. They are comfortably large values — something like 2 or 3×10^{-10} sec with a large error; the large error is quite normal for Σ's resulting from K^- capture due to the fact that the time of flight of the hyperons is short compared with their lifetime. I also wanted to remark that the Σ's from K^- capture are slow, and have therefore an average time of flight shorter than the " normal " Σ-lifetimes, so that any loss of decays near the end of the range should result in a calculated lifetime of the order of the mean time of flight of such hyperons; that is $\sim 0.5 \times 10^{-10}$ sec.

D. A. Glaser: I know about this difficulty because you told me! I am not an expert on this question, but I asked other emulsion people about it. They were aware of this trouble and in many cases corrected their data by putting in a cut-off.

Crussard: Of course this is not true when a cut-off has been made.

Rochester: Could I ask what errors are quoted in the tables? May I ask that the type of error will be stated in the final report of the conference?

D. A. Glaser: That is a very embarrassing question because in compiling the data we did not know in many cases what errors were being given to us. In most cases the experimenters had used the maximum likelihood method of Bartlett and therefore asymmetric errors were given, but in some cases symmetric errors were given. In computing the mean values of the Λ^0 and K^0 lifetimes, and the Λ^0-branching ratio, we were therefore afraid to try to weight the values according to the errors quoted on the individual results, and instead we weighted them according to the number of events. This is really not more scientific but the answer seemed more reasonable to us. The final error quoted was put roughly at the least error quoted from all the contributions but was not made smaller than that, because, as you see by the question of Fowler, there is the possibility of a systematic error which is more serious at this moment, I think, than the statistical error.

For the Σ^+- and Σ^--lifetimes and the K^0 branching ratio, the errors on the mean values were calculated from the errors quoted by the experimental groups.

W. Wenzel: Glaser stated that in measurements on the lifetime of the K^- there were no counter experiments. I would like to mention that there was one counter measurement done two years ago at the Bevatron. The result is in agreement with the measurements by other techniques.

Okun': Are there any new results on the spectra and angular distribution in leptonic decay of K^+ and K^0 mesons?

D. A. Glaser: No contributions were given to me on these subjects, and that is why I omitted them.

Discussion on Branching Ratios

Feld: Once when the experimental situation on the θ_1^0 decays seemed a little more definite, I tried to estimate an upper limit for the $2\pi^0$ decay fraction of the θ_1^0 by assuming that the same fraction of γ's were missed in detecting the neutral decay mode of the Λ^0 as for the θ^0. In those days, that estimate agreed fairly reasonably with one-third. Now, again, you tell me that π^0's seem to be missed in the Λ-decay. If one makes the same kind of estimate (that is, assumes that one gets a reasonable upper limit for the $2\pi^0$ decay mode of the θ^0 by taking the efficiency of detection of π^0's from the Λ^0 experiment, assuming that the Λ^0-decay ratio is known), do you have any idea whether one would get agreement with $\Delta T = \frac{1}{2}$ or whether one would still be off?

D. A. Glaser: I do not know exactly how your correction would go. There is a difficulty in doing that owing to the fact that the θ^0 generally makes a wider angle in its decay than the Λ^0. In a multiplate chamber I would think the efficiency for seeing the γ from the Λ, might be rather good. However, in the case of the θ^0 it may be a very wide angle decay and the γ's may escape between the plates. The geometric argument would be different for the bubble chamber, so I am not sure that an efficiency calculation, based on that assumption, is more useful than that we have already.

Chairman: I would just like to ask one question. What is the best statement one can make now about the branching ratios from K_2^0 into the muon mode, the electron mode and the τ mode?

D. A. Glaser: I would like to beg off; that is a leptonic mode and I have not studied the situation!

Chairman: Well, would anybody like to make a statement on that?

Ledermann: The nicest statement one can make is about the things you do not see. Out of 180 θ_2^0 events, no two-body modes were observed so you can say the branching ratio into 2 π's, or any other two-particle mode you like, are absent to better than 1%. As to the modes you do see, very little is known. You do know that there are 3 modes (i.e. the τ^0 mode, and counterparts of the K^+ mode, namely π-e-ν and π-μ-ν), and the ratios are not really known. Probably they are consistent with equal amounts π-μ-ν and π-e-ν but the 3π mode is present less than 20% of the time [1].

Gatto: About branching ratios, may I know about the τ'/τ ratio?

D. A. Glaser: I do not know anything new about it either.

Chairman: Does anyone have any information on the ratio τ'/τ? I guess that just means there is no new information.

Discussion of spins

Good: I would like to say one thing which may have been said in the talk, but I am not quite sure whether it was or not, and that is on the Adair analysis of the spin of the Λ^0. This is subject to the assumption that the spin of the K^0 is zero; conversely the Adair analysis of the spin of the K^0 is subject to the assumption that the spin of the Λ^0 is $\frac{1}{2}$. This is more or less the experimental situation with respect to the Adair analysis; if you can assume one of the spins then you can use all the events in which you have the other particle. You do not even have to see the particle whose spin has been assumed. This enables you to use single V's as well as double V's and to say something with a moderate degree of confidence about the spin of one particle subject to this assumption about the spin of the other, so the nice thing about the Lee - Yang trick is that it enables you to say something about the spin of the Λ^0 without any assumption whatever. So I think a nice approach to follow is to nail down the Λ^0-spin and go after the K^0 spin by the Adair analysis.

Chairman: Any further questions on the spins? If not, we can go on to the parity violation problem.

Burhop: Just to get the record straight, there was one point about an event that you showed of a $\Sigma \rightarrow p$ decay with a Dalitz pair coming from it. This is not the first example of this kind of event as was stated. The European collaboration had such an event and they showed it at the Padua conference last year.

Nataf: About the $(a\overline{P})_{\Lambda^0}$ you mentioned, I have not understood the connection between the polarization of Σ^0 and Λ^0.

D. A. Glaser: This was the experimentally observed asymmetry of Λ^0 which came from Σ^0.

Telegdi: There is a semi-experimental point concerning the sign of the α in the Λ^0-decay. Dalitz has an argument where I believe he can extract this sign from certain branching ratios in the decay of hyperfragments, and maybe he cares to tell you what he gets.

Chairman: Are you sure it is the sign of α, or the ratio of the p to s amplitudes?

Telegdi: As far as I recall he gets both but I could not give you the argument.

Chairman: I thought it was just $\frac{p}{s}$.

Treiman: Yes, I think it is just p to s.

LIST OF REFERENCES

1. Bardon, M., Fuchs, M., Lande, K., Lederman, L.M., Chinowsky, W. and Tinlot, J. Phys. Rev., *110*, p. 780, 1958.