THE DEPENDENCE OF THE COMPOSITE MEAN LIFE OF MU-MESONS ON THE ATOMIC NUMBER OF THE ABSORBER

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ABSTRACT. The measurements of the mean life of the composite beam of μ-mesons (both positive and negative) at sea level in the absorbers of C, Al, S and Pb have been reported previously. The same experiment has been conducted with water and NaF absorbers. In water (only oxygen is effective, since a hydrogen atom rarely captures a μ-meson), the composite mean life is found to be 1.95 ± 0.08 micro-seconds. Choosing the thickness of water absorber to be equivalent to the sulphur absorber in respect to the stopping power of the μ-mesons, the decay curve of the positives in S has been taken to represent the same in water and hence by subtraction, the mean life of the negative μ-mesons in water has been determined to be equal to 1.80 ± 0.19 microseconds. In the case of NaF ($Z_{eff} = 10.1$) absorber, the experimental points have been found to represent a composite decay curve giving the mean life equal to 1.82 ± 0.09 microseconds.

The Z dependence of the composite mean life has been found to fit an empirical relation,

$$\tau\pm = 2.50 - 0.065\ Z \text{ microseconds.}$$

in the interval $Z = 6$ to $Z = 16$.

INTRODUCTION

The mean life of the positive μ mesons is the same in all absorbers, but that of the negatives is dependent on the absorbing element. From the K-orbit, negative mesons can either be captured by the atomic nucleus or distintegrate spontaneously, Their decay constant should, therefore, be $\lambda + \Lambda$. where $\lambda = 1/\tau_+$, τ_+ being the mean life of free decay and Λ the probability per second for capture, The decay electrons arising from the decay of negative muons should follow a dis-integration curve with the decay constant $\lambda+\Lambda$. Hence one can write

$$N^-_{(t)} = n^-_{(0)} \exp[-(\lambda+\Lambda)t] \qquad \ldots (1)$$

where $n^-_{(0)}$ and $N^-_{(t)}$ are the number of negative mesons disintegrating between $t=0$ to $t=\infty$ and $t=t$ to $t=\infty$ respectively: Now, $n^-_{(0)} = \frac{\lambda}{\lambda+\Lambda} N^-_{(0)}$ where $N^-_{(0)}$ is the number of negative mesons available for decay and capture at $t=0$.

The capture constants can, therefore, be measured by determining the apparent mean life $1/(\lambda+\Lambda)$ of negative muons, If the experiment is carried out without differentiating between the positive and negative mesons, a small change of the disintegration constant should still be observed in materials of suitable atomic numbers, This 'change' of the disintegration constant is due to the fact that the experimental data really represent a superposition of two decay curves. one produced by the positives with the mean life $1/\lambda$ and the other produced by the negative with a mean life $1/(\lambda+\Lambda)$. Hence the total decay curve is represented by

$$N_{(t)} = N^{+}_{(o)} \exp[-\lambda t] + \lambda/(\lambda+\Lambda) \times N^{-}_{(o)} \exp[-(\lambda+\Lambda)t] \quad \dots \quad (2)$$

It is clear that in such investigations particular attention must be paid to very short decay times, specially if the capture constant is large, for the effect of the negative mesons at large time intervals after stopping will be almost nil,

EXPERIMENTAL DETAILS AND RESULTS

With a view to observing the variation of the mean life of the composite mixture of μ mesons available at sea level with the atomic number of the absorbing element, a set of experiments was carried out in this laboratory. The delayed coincidence technique was utilised to register the decay electrons arising out of the decay of the stopped μ-mesons. The details of the electronic circuits and the arrangement of the G.M. counters have been reported before (1954*a*). The experi. mental results with the C, Al, S and Pb absorbers have been communicated previously (1954*b*). Since then we have made measurements with water and NaF absorbers. Here we shall report these results.

(1) *Water Absorber.*

The thickness of the water absorber was so chosen that it was equivalent to the sulphur absorber (results reported before) with respect to the stopping power of the μ-mesons. 13.5 gms of water per square centimeter were used in thin galvanized iron containers of area $2'' \times 20''$.

The results with this absorber have been plotted in figure. 1 on a semi-logarithmic scale. The points fit a single straight line which represents the decay curve of a composite beam of mesons in the absorbing material, It is known from the works of Panofosky, Aamodt and Hadley (1951) that the D^{+} π^{-} as well as μ^{-} mesons, are very rarely captured by the hydrogen nucleus and hence oxygen is the only effective element in the case of water absorber. It is noted that the nature of the curves in the cases of absorbers of low atomic numbers, such as carbon, (reported earlier) and oxygen, is the same, as in both the cases the composite decay curves are registered upto the last point. This is expected since the apparent mean lives of the negatives in these materials are not much less than that of the positives which implies that the negatives were still available for decay at 4.0 microseconds.

The composite mean life of the mesons is found to be 1.95 ± 0.08 microseconds. As the thicknesses of the sulphur and water absorbers were equivalent as regards the stopping power of the mesons, the same number of the positive mesons decayed in both the cases in a definite time interval. The numbers of decay electrons on account of such decays were also the same in the two cases, since the thicknesses of the absorbers and the number of G.M. counters in the delayed coincidence did not alter. Any correction for the solid angle need not be considered and hence the positive decay curve of sulphur has been drawn in figure 1 to represent the same in water. By subtraction, the decay curve of the negative μ-mesons in water has been obtained. The negative mean life comes out to be 1.80 ± 0.19 microseconds. The calculated capture probability is $(0.90 \pm 0.85) \times 10^5$ per second.

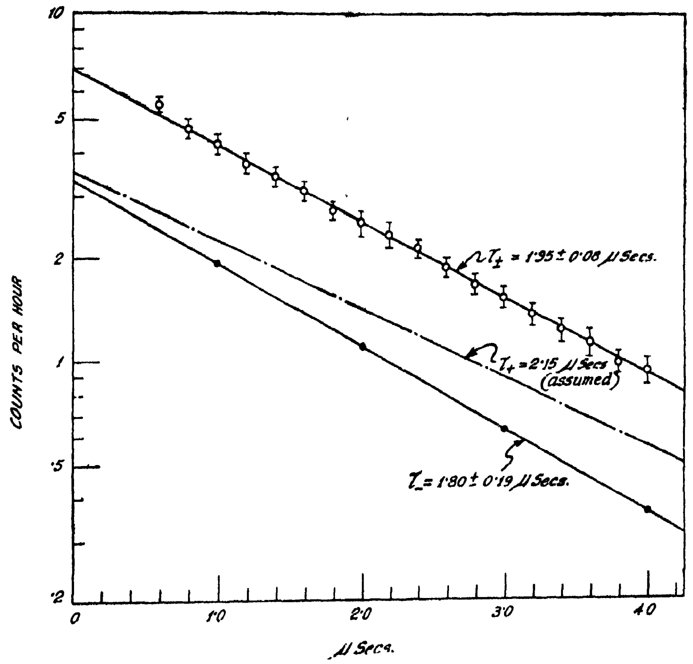

Fig. 1. The decay curve of the composite and the negative μ mesons in water.

If the observed integral decay curves are extrapolated to the zero time, one obtains the number of mesons available for decay in the time interval $t = 0$ to $t = \infty$. Corresponding to the positive decay curve, it represents the number of mesons stopped in the material. In the case of the negatives, however, a fraction of the stopped particles is captured by the nucleus and hence to get the number of the stopping mesons a multiplication factor $\frac{\lambda + \Lambda}{\lambda} = \frac{\tau_+}{\tau_-}$ is to be introduced. Since both the negative and the positive decay curves are known in this case, we have been able to find the ratio of the positive to the negative 'slow' mesons and the value is 0.90 ± 0.16.

(2) *NaF Absorber.*

The arrangement of the apparatus was slightly altered for this absorber and a single absorber was used because large quantities of the compound were not available in the laboratory. The configuration of the G.M. counters is shown in figure 2. The number of counters in the delayed coincidence was reduced to six (instead of nine in the case of other absorbers) contained in two trays and the absorber was placed in between. Fifteen pounds of powdered sodium fluoride was taken in a thin galvanized iron container of area $2'' \times 20''$ square inches, for meson absorption.

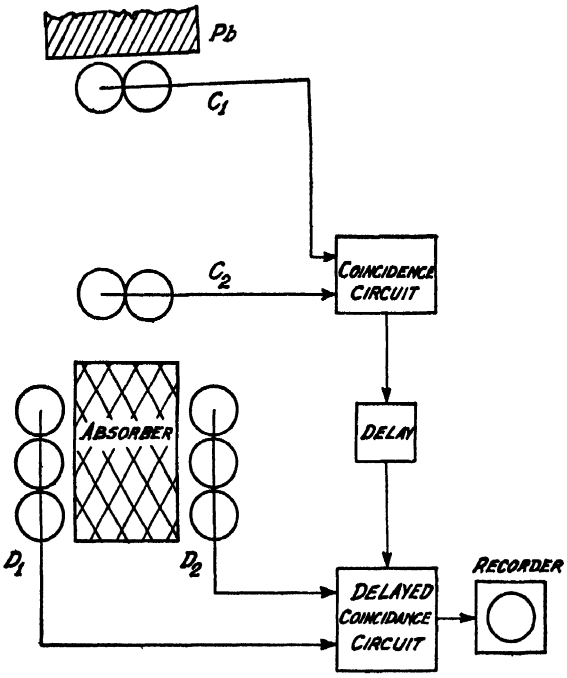

Fig. 2. The experimental arrangements of G. M. counters in the case of NaF absorber.

The plot of the data on a semi-logarithmic scale as shown in figure 3 yields the composite mean life of the μ-mesons stopped in the material. It is seen from the figure that the points corresponding to the delays of 3.8 and 4.0 microseconds lie above the composite decay curve even within the statistical errors shown. It is possible that the contribution of the negative mesons to the decay electron counting rates at these time delays is not so significant as it is for smaller values of delay times. The composite mean life is 1.82 ± 0.09 microseconds.

The relative number of captures of the negative mesons in a chemical mixture should, according to Fermi and Teller, be proportional to the atomic number of the element. The validity of the Z law has been assumed by Ticho (1948) for the Na and F atoms and he gives the effective Z value of the NaF compound

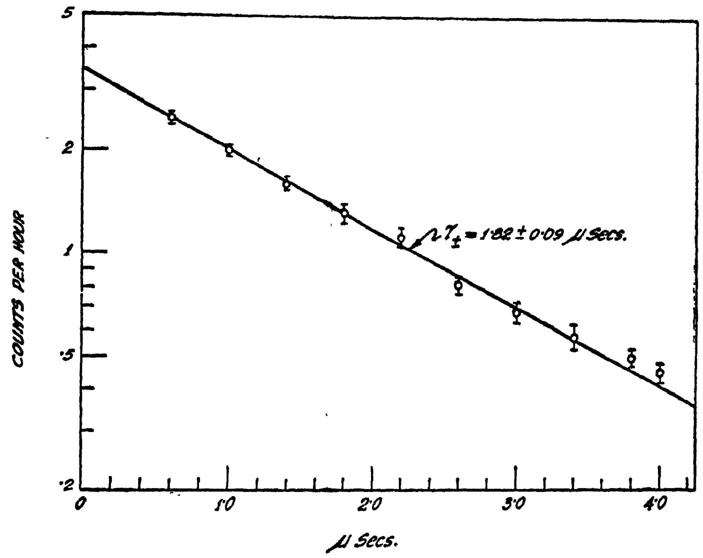

Fig. 3. The decay curve of the composite beam of μ mesons in NaF absorber.

to be equal to 10.1 on this assumption. Thus the decay curve in this absorber is expected to yield practically the same as in an element of $Z = 10$.

CONCLUSION

The dependence of the composite mean life of mesons at sea level is obvious from Table I, where our results, along with those of others are tabulated for comparison.

TABLE I

Composite mean life of mesons in different absorbers

Z	Composite mean life of mesons $\tau\pm$ in microseconds at — sea level	Composite mean life of mesons $\tau\pm$ in microseconds at — 3,500 meters height	Authors
16	1.48 ± 0.08	—	Biswas and Sinha (1945b)
13	1.58 ± 0.07	—	,,
13	—	1.78 ± 0.10	Ticho (1947)
12	—	1.70 ± 0.10	Bonado and Sard (1949)
10	1.82 ± 0.09	—	Present Experiment
8	1.95 ± 0.08	—	,,
6	2.06 ± 0.03	—	Morewitz and Shamos (1953)
6	2.12 ± 0.02	—	Bell and Hincks (1952)
6	2.15 ± 0.09	—	Biswas and Sinha (1954b)
4	2.15 ± 0.02	—	Bell and Hincks (1952)
3	2.20 ± 0.02	—	,,

For $Z \leqslant 16$, the value of the composite mean life increases as the atomic number of the absorbing medium decreases and tends to attain a value equal to the mean life of the positive mesons, 2.22 microseconds for $Z<6$. This shows that for $Z<6$, the apparent mean life of the negative μ mesons is approximately the same as the mean life of the positives.

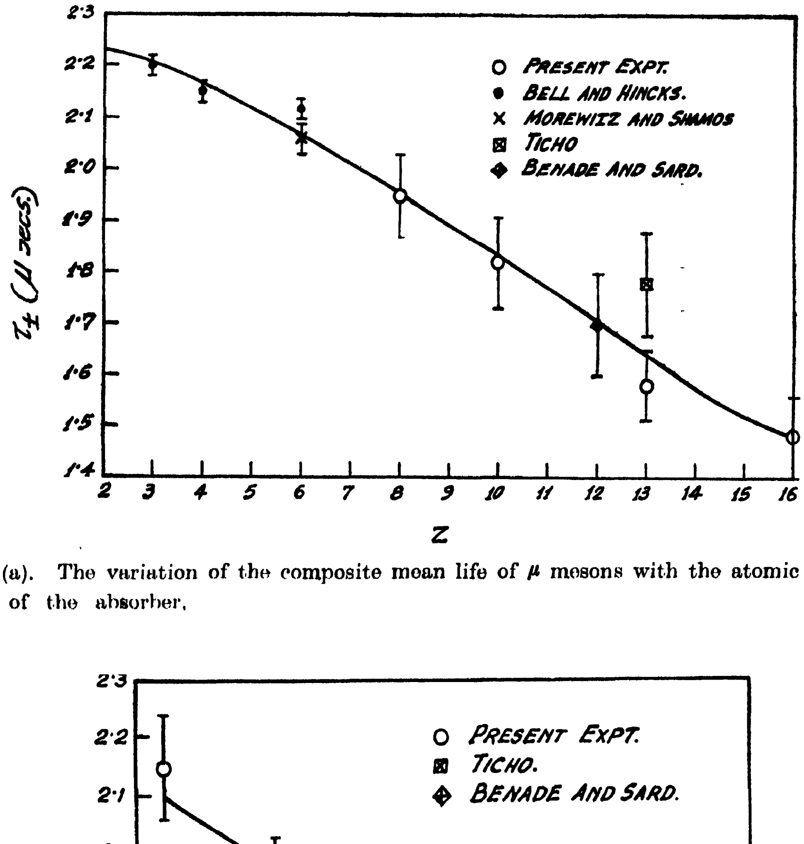

Fig. 4 (a). The variation of the composite mean life of μ mesons with the atomic number of the absorber.

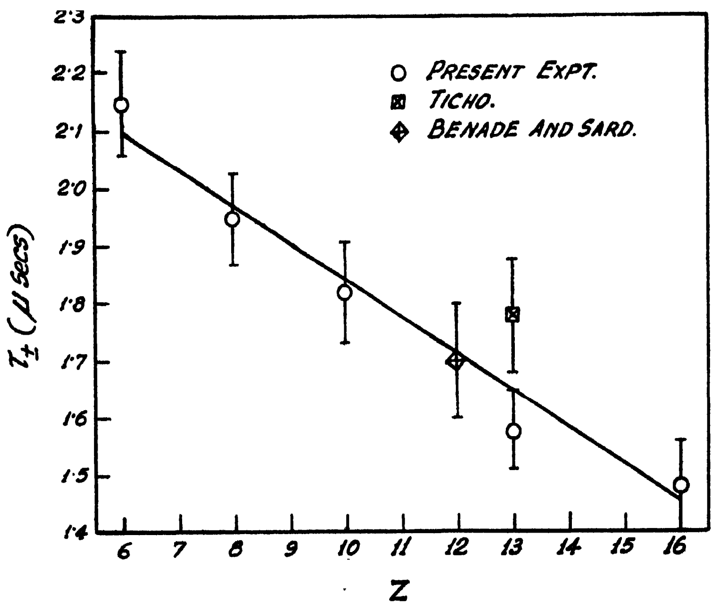

Fig. 4 (b). Empirical relation of $\tau_{\pm}$ with Z.

It is seen that our results are in good agreement with those of others. In figure 4(a), a curve has been drawn showing the Z dependence of the composite mean life upto the values of $Z = 16$ (sulphur). In Fig. 4(b), only the results of our experiments have been plotted against Z in the interval $Z = 6$ to $Z = 16$, and it is shown that a straight line can be drawn through the points suggesting the empirical formula

$$\tau \pm = 2.50 - .065Z, \text{ microseconds in the range } 6 \leqslant Z \leqslant 16.$$

The composite mean lives as determined by Ticho (1948) and by Benade and Sard (1949) in aluminium and magnesium respectively also fit the line as shown in figure 4(b). Their results favour the empirical relation as obtained from our data.

As the experiments of Ticho and of Benade and Sard were carried out at an altitude of 3,500 metres above sea level and since their results for the composite beam are consistent with our findings, it is possible that the positive/negative ratio at a height of 3,500 metres may not be much different from that at the sea level; otherwise the composite mean life which is dependent on this ratio would not have followed a systematic variation as has been shown here. Hence it can be mentioned that the phenomenological theory of Puppi and Dallaporta (1952) on the assumption of the constancy or a slow variation of the ratio with altitude gets a support from these observations.

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