DETERMINATION OF THE μ^- TOTAL CAPTURE RATE IN LIQUID HYDROGEN

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(presented by C. Rubbia)

We are reporting here a measurement of the total μ^- capture rate in liquid hydrogen. The process:

$$\mu^- + p \rightarrow n + \nu \qquad (1)$$

occurring in the liquid H_2 is recognized by the absence of the decay electron and by the energy of the emitted neutron (5.2 MeV). Events in which the neutron emitted scatters in the liquid hydrogen of the chamber giving rise to a sizeable ($\geqq 1$ mm) proton recoil are selected. The neutron energy is then worked out from the scattering angle and the proton range. The measurement of the neutron energy is mainly required to make sure that no contribution to the recorded capture rate is coming from captures due to impurities which may be present in the liquid or from the π-meson contamination present in the beam. In fact, measurements by Schiff [1] and calculations by Gershtejn [2] show that if $\sim 3 \times 10^{-8}$ parts of impurities of $Z \gg 2$, (for instance, air) were dissolved in the liquid hydrogen, recognizing the capture events by the absence of the decay electron *only*, would give an apparent increase of the capture rate of the order of the presently quoted error (15%). We do not know of any " a priori " way of assuring that such a degree of purity from O_2 or N_2 has been actually achieved in our chamber.

Preliminary results based on about 80 000 pictures are reported here. Pictures were scanned first by looking for non-decaying stops. Whenever such an event was found, proton recoil tracks of $\geqq 0.8$ mm of projected length were carefully searched for. All pictures have been scanned at least twice. In evaluating the muon capture rate only capture events satisfying the following conditions have been retained:

(a) the proton recoil has a projected length along the plane normal to the optical axis of the cameras $\geqq 1$ mm.

(b) the distance between the muon capture and the recoil is smaller than 5 cm.

Such conditions have been chosen in order to ensure a scanning efficiency as high as possible in finding the proton recoils ($>99\%$ for a double scanning) and a low background due to uncorrelated proton recoils and capture events. This background has been obtained by connecting proton recoils by hypothetical neutron paths to capture events of *different* pictures. The condition that the (projected) length of the recoil should be longer than 1 mm corresponds for (5.3 MeV neutrons) to a maximum angle $\vartheta_{\max}$ for the scattered proton of about 35°. It has been actually checked that the final results on the capture rate, after accidental background subtraction, do not depend on the choice of $\vartheta_{\max}$.

A Monte Carlo calculation of the over-all detection efficiency was made, starting from the actual distribution of capture events in the chamber. The hydrogen density was determined experimentally from the range of muons which undergo the fusion reaction $(p\mu d) \rightarrow He^3 + \mu + 5.5$ MeV. The main uncertainty in evaluating the detection efficiency comes from the error (± 0.07 mm) in the measurement of the projected proton recoil length. A change of 0.1 mm of the minimum accepted projected recoil length changes the detection efficiency by about 12%. Therefore the error in the knowledge of the detection efficiency is certainly much smaller than the statistical error in the number of presently recorded events.

The hydrogen used has " natural " D_2 concentration. In order to subtract out D_2 and He^3 contributions, pictures have been taken with 0.6% of D_2 added to the H_2 of the chamber. The fusion reaction $(p\mu d) \rightarrow He^3 + \mu$ offers a convenient monitor for the fraction of μ^- transferred to deuterium. It turns out that because the neutron energy is measured, μ^--captures by deuterium or He^3 will not contribute appreciable ($\leqq 10\%$) to the recorded effect. However, only a fraction ($\sim 2/3$) of μ^-'s will end up bound in $(p\mu)$ or $(p\mu p)$ molecular states.

Results are summarized in Table I. Our present result, indicating a capture rate $R_{H_2} = (420 \pm 75)$ sec^{-1}, is in quite good agreement with the number (435 ± 100)sec^{-1} given by R. Hildebrand in the preceding paper. Because the techniques used in the two experiments are very similar it is meaningful to combine the two results, to yield the capture rate in hydrogen $R_{H_2} = (425 \pm 60)$ sec^{-1}.

TABLE I

Pictures examined	80 000
μ^- stops in the useful part of the chamber	1 087 656
Rejuvenation probability { H_2 run	$(7.42 \pm 0.05) \times 10^{-3}$
Rejuvenation probability { H_2+D_2 run	$(1.94 \pm 0.1\ ) \times 10^{-2}$
μ^- expected to end up bound in a (μp) atom or $(p\mu p)$ molecule (deuterium effects subtracted)	$(671 \pm 40\ ) \times 10^3$
Detection probability for events: (*a*) projected recoil length $\leqslant 1$ mm (*b*) proton recoil at less than 5 cm from μ^- stop	8.2×10^{-2}
Good events found, after background subtractions	46 ± 8.5
Scanning efficiency	0.90
Total number of events corrected for scanning efficiency	51 ± 9.3
Capture probability in H (μp) and $(p\mu p)$ states	$(9.25 \pm 1.70) \times 10^{-4}$
Capture rate (experimental)	(420 ± 75) sec^{-1}
Capture rate (theoretical) Primakoff	~ 560 sec^{-1}

LIST OF REFERENCES

1. M. Schiff, Nuovo Cimento *22*, 66 (1961); Erratum **ib.** *23*, 661 (1962).
2. S. S. Gershtejn, Dubna Preprint, P— 942 (1962).

DISCUSSION

HILDEBRAND: We should add to our list the Columbia results, which are (515 ± 85) sec^{-1}. The results are not exactly comparable since the Columbia capture events were detected after a time delay, so that presumably all the μ's were captured from the molecular $(p\mu p)$ state. In the bubble chamber experiments the capture is from a mixture of $\sim \frac{1}{4}(\mu p)$ and $\sim \frac{3}{4}(p\mu p)$ states. The capture rate in the mixture is expected to be about 4% higher than for pure $(p\mu p)$.

LEDERMAN: I would like to comment on the question of the total spin F in the $p\mu p$ system. The question posed by Weinberg is whether the hyperfine interaction mixes states of total spin $F = 3/2$ and those of spin $F = 1/2$. The various hyperfine interaction terms were calculated by Halpern and Kroll at Columbia. The mixing is in fact very small and the state is $F = 1/2$ with an uncertainty of a few per cent. I hope the calculation will be published soon.

As for the Columbia experiment on muon capture (Anderson, Bleser, Meyer, Rosen, Rothberg, Wang), no result beyond what is on the board is yet available although we have now counted several thousand events. This illustrates the weak as well as the strong points of the counter experiment as opposed to the Bubble Chamber one. Much calibration running must still be done. However, it is the only way of determining the ortho $(p\mu p)$ to para conversion rate. If this is significant it damps the neutron yield and could possibly decrease the difference between the theory and the average of the Hildebrand-Rubbia results.

WOLFENSTEIN: Your result on the muon capture rate of course is not in disagreement with the theoretical number 565. The bubble chamber result is a slightly different measurement. Am I right in saying that in so far as there is any difference the bubble chamber people should have an even slightly larger capture rate because they have some atomic capture mixed in?

RUBBIA: If we consider the (μp)-capture we have 636 sec^{-1} from the atom. As far as the lifetime for $(\mu p) \rightarrow (p\mu p)$ is concerned we have got new data at CERN which are slightly lower than the Columbia results but still in agreement with them. Our result is $(5 \pm 2) \times 10^{-7}$ sec^{-1}, which leads to a little less than a quarter of (μp) involved in the capture. This would tend to increase the rate, as you say, by a few per cent (about 4%).

LEDERMAN: How big a pseudoscalar term do you need in order to get down to 425 sec^{-1}?

RUBBIA: 16 G_A.

LEDERMAN: Could this be in agreement with the very large asymmetries observed in the neutron emission from complex nuclei after μ capture? I think this would require a large pseudoscalar term as well.

WOLFENSTEIN: The neutron asymmetry is of course not easy to evaluate because it occurs in a complex nucleus. It cannot be regarded as evidence for or against as large a pseudoscalar term as mentioned by Rubbia, but certainly a big pseudoscalar contribution would make the explanation of the neutron asymmetry easier.

TELEGDI: There are two sets of data (besides this experiment) from which one can extract the pseudoscalar term. The asymmetry data are most useful for getting the sign which is in agreement with theory. But there is the series of experiments on the μ capture in C^{12} and the decay back, which have been done in a number of places and recently with great accuracy at Carnegie Tech. The results there are quite sensitive to the magnitude of the pseudoscalar term. I think if you double the pseudoscalar term from 8 to 16 G_A the $C^{12} \to B^{12}$ ground state capture rate would no longer agree with the experiments.

WOLFENSTEIN: There are actually two slightly different things. The pseudoscalar term enters into the neutron asymmetry in a rather unique way, that distinguishes it from the other contributions to the Gamow-Teller coupling. But what one is really thinking of here, in the case of the Rubbia-Hildebrand experiment as well as in the C^{12} capture, is simply to decrease the effective Gamow-Teller coupling by increasing the pseudoscalar contribution. The statement then is that increasing the pseudoscalar term too much would lead to disagreement with the observed C^{12} rate.

TELEGDI: And we wish to maintain the axial vector at least temporarily at its standard strength because of the $(\pi\mu)/(\pi e)$ decay ratio, which is at least a plausible if not a totally convincing argument.

WOLFENSTEIN: Well, whether one considers a change in the axial vector or the pseudoscalar coupling the question is one of form factors, since one knows the one-pion-contribution to the pseudoscalar quite well.

YAMAGUCHI: I have a naive question. Is it possible to calculate the nuclear matrix element for $\mu^- + C^{12} \to B^{12} + \nu$ to such an accuracy as to make it possible to distinguish between the two different strengths of pseudoscalar coupling constant under discussion: 8 versus 16?

WOLFENSTEIN: The estimate I made of the uncertainty of the theory is of the order of 20%, which is about the same as the difference in the capture rate between 8 and 16.

HILDEBRAND: The theoretical rates for capture in hydrogen are based on Primakoff's figures. There has been another estimate by Adams which predicts a higher capture rate.

SENS: This estimate was later corrected, there was an error. The new number is in good agreement with Primakoff's calculation, if the same experimental G_A/G_V ratio is used.

SEARCH FOR THE $\mu \to 3e$ DECAY

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In the modern theory of weak interactions with one neutrino there is no strict interdiction for $\mu \to e + \gamma$ and $\mu \to 3e$ decays simultaneously. Reliable quantitative relations between them are not obtained, too. That is why the study of each of these reactions is of independent interest. Up to now, however, none of them was found experimentally [1, 2].

In our previous report [1], a search for the $\mu \to e + \gamma$ decay was carried out and an upper limit for this reaction of 4×10^{-7} (90% confidence) was obtained. In the present paper, a search for the $\mu \to 3e$ decay is described with an arrangement very close to the one described in [1]. The experimental set-up is represented in Fig. 1. A 70 MeV π^+ beam was defined by