TOTAL ABSORPTION RATE OF MUONS IN CARBON*

F. Russell Stannard
Lawrence Radiation Laboratory, University of California, Berkeley, California

(Received April 20, 1960)

The total absorption rate of muons in carbon has been determined from observations on 2519 muons stopped in a propane bubble chamber. The experimental method employed here leads to a considerable improvement over measurements made thus far with counters. Estimates based on the latter technique have, in fact, been limited to an accuracy of only about ±25%.[1]

A negative muon stopped in propane (C_3H_8) is captured into orbits about a carbon nucleus.[2] The presence or absence of an electron at the end of the meson's track gives a direct indication whether the particle decayed or interacted. Assuming a value τ_d for the decay lifetime of the muon, one expresses the total absorption rate by

$$\Lambda_i = N_i/(N_d \tau_d), \qquad (1)$$

where N_i and N_d are the numbers of mesons interacting and decaying, respectively.

The photographs examined were taken with the 30-inch propane chamber. The muon beam had a background of approximately 1% pions. It was found that, out of a total of 2544 particles stopping in the chamber, 2338 decayed and 206 interacted. The prong distribution of the interactions is given in the first line of Table I.

The pion contamination was estimated from the difference in the prong distributions of pion and muon capture stars. Morinaga and Fry[3] have investigated the characteristics of muon interactions in the light elements of nuclear emulsion and found the maximum energy of the emitted protons to be about 15 Mev. Although many stars were seen to have two or more prongs, the energies of the secondaries were such that only rarely would more than a single prong have been resolvable had the events occurred in a bubble chamber. It follows that any star found in the chamber emitting a proton of energy greater than 15 Mev—or, alternatively, consisting of two or more prongs—is most unlikely to have arisen from muon capture, but rather from the interaction of a pion. In order to be able to estimate the total pion contamination, one needs to know the proportion of pion captures not giving these energetic disintegrations. The second line of Table I shows the prong distribution of a sample of 141 pion-capture stars. The final three columns give a total of 62 energetic stars, and these represent 44% of all pion captures. Hence, the total pion contamination, as estimated from 13 energetic stars, found in the sample of supposed muons becomes 13/0.44 = 30 ± 5. The remaining 176 events are attributed to muon interactions.

Table I. Characteristics of capture stars.

Primary particle	Number of prongs 0	1^a	1^b	2	3
Muons[c]	190	3	9	4	0
Pions	58	21	45	14	3

[a] The prong having an energy <15 Mev.
[b] The prong having an energy >15 Mev.
[c] Uncorrected as yet for pion contamination.

A study of the distribution of events throughout the chamber suggested that some five interactions had escaped detection near the windows and walls. This number then had to be added to the total.

It is expected that about 18% of muon captures[2] lead to the formation of B^{12}. B^{12} subsequently β decays to C^{12}, and some of the electrons from this source will have been photographed if the decay happened to occur between the arrival of the beam and the time of photography. An estimated four captures have been mistaken for decays in this way and consequently have had to be reclassified.

Other observational biases were found to be negligible. A sample of the propane was subjected to mass spectrographic analysis at the completion of chamber operation to test for the presence of impurities in the liquid, but none were found.

The corrected observations yield 185 interactions and 2334 decays from 2519 stopped muons. If one assumes a decay lifetime of 2.22×10^{-6} sec,[4] the estimate of the total capture rate becomes

$$\Lambda_i = (0.36 \pm 0.04) \times 10^5 \text{ sec}^{-1}. \qquad (2)$$

This compares with a previous measurement of 0.45×10^5 sec^{-1}, based on 1000 muons stopped in a propane bubble chamber.[5] Combining these two results with estimates from counter work[1] gives a weighted mean of

$$\Lambda_i = (0.40 \pm 0.03)\times10^5\ \text{sec}^{-1}. \qquad (3)$$

The theoretical value from Primakoff[6] is 0.44×10^5 sec^{-1}. This estimate has recently been modified by Flamand and Ford[7] to account for the effect of the finite nuclear size on the muon wave function. The experimental results are in good agreement with the modified prediction of 0.41×10^5 sec^{-1}.

Finally, it should be mentioned that several measurements recently have been made[8] of the partial rate for the muon-capture process leading to the ground state of B^{12}. These investigations provide a test of the Universal Fermi Interaction theory.[9] Although the value of the total rate, as found in this experiment, is somewhat lower than that previously accepted, the change does not significantly affect the measurements of the partial rate.

The author wishes to thank Dr. Wilson M. Powell, Dr. Robert W. Birge, and the other members of the propane chamber group without whose help this work would not have been possible. He is indebted to the Bevatron crew and staff, and also to Dr. Robert D. Sard for useful discussions.

---

[*] This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. C. Sens, Phys. Rev. 113, 679 (1959); W. E. Bell and E. P. Hincks, Phys. Rev. 88, 1424 (1952).

[2] W. K. H. Panofsky, L. Aamodt, and H. F. York, Phys. Rev. 78, 825 (1950).

[3] H. Morinaga and W. F. Fry, Nuovo cimento 10, 308 (1953).

[4] W. E. Bell and E. P. Hincks, Phys. Rev. 84, 1243 (1951); R. A. Swanson, R. A. Lundy, V. L. Telegdi, and D. D. Yovanovitch, Phys. Rev. Letters 2, 430 (1959); J. Fischer, B. Leontic, A. Lundby, R. Meunier, and J. P. Stroot, Phys. Rev. Letters 3, 349 (1959).

[5] T. H. Fields, R. L. McIlwain, and J. G. Fetkovich, Bull. Am. Phys. Soc. 4, 81 (1959).

[6] H. Primakoff, *Proceedings of the Fifth Annual Rochester Conference on High-Energy Physics* (Interscience Publishers, Inc., New York, 1955), p. 174.

[7] G. Flamand and K. W. Ford, Phys. Rev. 116, 1591 (1959).

[8] T. N. K. Godfrey, Phys. Rev. 92, 512 (1953); W. Love, S. Marder, I. Nadelhaft, R. Siegel, and A. E. Taylor, Bull. Am. Phys. Soc. 4, 81 (1959); J. G. Fetkovich, T. H. Fields, and R. L. McIlwain, Bull. Am. Phys. Soc. 4, 81 (1959); J. O. Burgman, J. Fischer, B. Leontic, A. Lundby, R. Meunier, J. P. Stroot, and J. D. Teja, Phys. Rev. Letters 1, 469 (1958); H. V. Argo, F. B. Harrison, H. W. Kruse, and A. D. McGuire, Phys. Rev. 114, 626 (1959).

[9] A. Fujii and H. Primakoff, Nuovo cimento 12, 327 (1959); L. Wolfenstein, Nuovo cimento 13, 319 (1959).

MODIFIED ANALYSIS OF NUCLEON-NUCLEON SCATTERING. *p*-*p* PHASE SHIFTS AT 210 Mev[*]

Malcolm H. MacGregor and Michael J. Moravcsik
Lawrence Radiation Laboratory, University of California, Livermore, California

(Received April 8, 1960)

The modified phase-shift analysis program[1,2] has been extended to measurements at 210 Mev. We find only two acceptable solutions, which correspond to the two Stapp solutions[2,3] at 310 Mev. This is one of the few instances in which the data[4-7] have been complete enough to yield a definitive result. Since the phase-shift sets thus obtained are of great value in dispersion relation calculations of the energy variation of phase shifts, and since the present analysis indicates what further experiments should be done to eliminate one of the two remaining phase-shift solution sets at 210 Mev (and therefore also at 310 Mev), we feel that the present results are of considerable interest, even though based on some preliminary data.

In the notation of Wolfenstein,[8] we have analyzed the recent Rochester 210-Mev measurements[4-6] of P, R, and A combined with an earlier Rochester 240-Mev measurement[7] of σ. Search problems were run from 30 random sets of phase shifts, using one-pion exchange contribution (OPEC) with a coupling constant $g^2 = 14.4$ for G and higher waves,[1] and searching on the 9 parameters S, P, D, F, ϵ_2. Since 35 pieces of data were used in the search program (the smallest angle cross-section point was excluded), a 9-parameter solution has an expected least-squares sum χ^2 of 26. The 30 random searches yielded 7 solution sets with χ^2 less than 200,