OBSERVATION OF THE "ISOTOPE EFFECT" IN THE NUCLEAR CAPTURE OF NEGATIVE MUONS BY CHLORINE*†

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Theoretical calculations by various authors[1-3] of the muon capture rates in nuclei have shown that a strong "isotope effect" is to be expected. Primakoff,[1] using a closure approximation, has found that

$$\lambda_c(a) = (Z_{\text{eff}})^4(\langle\eta\rangle_a)^2(272\ \text{sec}^{-1})\left(1 - \frac{A-Z}{2A}\delta_a\right),$$

where $\delta_a = 3.0$. This formula predicts a quite large isotope effect, e.g., $\lambda_c(Cl^{37})/\lambda_c(Cl^{35}) = 0.83$. Primakoff's calculations are intended to give an idea of the general behavior of the capture rate over all ranges of Z and A, and do not predict the exact value for any particular nucleus. In fact, δ_a is only independent of Z and A in the first approximation.

Tolhoek and Luyten,[2] using the shell model of the nucleus, have explicitly evaluated the transition probabilities between the various nuclear energy levels, and performed the summation appropriate to each nucleus.

We have measured the "isotope effect" in separated chlorine isotopes using the physical arrangement shown in Fig. 1. The composition of the beam from the CIT synchrocyclotron was about 70% muons, and 30% electrons, with a negligible amount of pions. The lead wall collimated the beam to a size $1\frac{1}{2}$ in. × $1\frac{1}{2}$ in., and helped to reduce the random counting rate in the electron telescope. The Helmholtz coils were adjusted to buck out the fringing field of the cyclotron. This eliminated the sinusoidal modulation of the decay curve due to precession of the muon spin about the field direction.

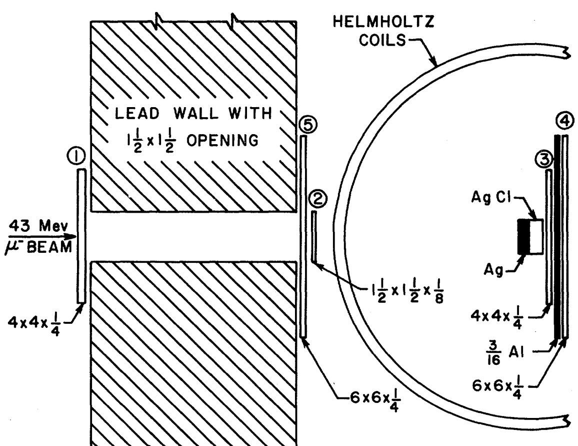

FIG. 1. Experimental arrangement.

The targets used consisted of enriched isotopes of chlorine in the form of AgCl. They were 1-inch diameter cylinders of length 1/4 in. and 5/8 in., respectively, for the Cl^{37} and the Cl^{35} isotopes. The enriched abundances were 76% Cl^{37} and 96.8% Cl^{35}. An amount of silver absorber, sufficient to maximize the number of stopped muons, was placed directly in front of the target.

A muon which stopped in the target was indicated by a coincidence $(1+2+\bar{3})$, where the bar indicates that the counter is in anticoincidence. The lack of a monitor directly in front of the target did not appreciably increase the random background, but did significantly reduce the background arising from muons which would stop in such a counter. A decay electron was indicated by a coincidence $(3+4+\bar{5})$. Counter 5, in anticoincidence, prevented particles which came through the collimator from being counted as electrons. In order to reduce the random background arising from gamma rays and neutrons, 3/16 in. of aluminum was placed between counters 3 and 4.

The "start" pulses $(1+2+\bar{3})$ opened a fast rising gate, which was closed by the "stop" pulses $(3+4+\bar{5})$. If no electron was detected within 15 μsec, the gate was closed by the delayed "start" pulses. The pulses from a precision 10-Mc/sec oscillator passed through the gate and were counted by a 10-Mc/sec scaler. After 15 microseconds the number of counts in the 10-Mc/sec scaler, corresponding to the time difference between "start" and "stop" pulses, was stored in the memory of an RCL 256-channel pulse-height analyzer.

The data from the time analyzer form a histogram which is fitted by

$$Y_n = e^{-n\lambda_b}\Big[Ae^{-n\lambda_t(\text{Ag})} + B\Big(\alpha_{35}e^{-n\lambda_t(35)} + \alpha_{37}e^{-n\lambda_t(37)}\Big) + Ce^{-n\lambda_t(\text{C})} + D\Big],$$

where A, B, C, D are constants, and n is an integer corresponding to the channel number. λ_t is the disappearance rate of muons bound to nuclei of a given type, and λ_b is the rate of random counts in the electron telescope. In this experiment $\lambda_b \leq 0.005\times10^5$ sec^{-1}, and the multiplicative factor $e^{-n\lambda_b}$ could be approximated by one. The values of the coefficients α_{35} and α_{37} are derived from the isotopic concentrations in the targets and take into account the effects of the finite channel width in the time analyzer and the random phasing between the "start" pulse and the 10-Mc/sec wave train. For the Cl^{35} target, $\alpha_{35} = 0.966$ and $\alpha_{37} = 0.034$; for the Cl^{37} target, $\alpha_{35} = 0.23$ and $\alpha_{37} = 0.77$. λ_t(Ag) has been measured using a pure silver target and found to be (10.92 ± 0.27) per μsec. λ_t(C) has been measured by Reiter et al.[4] and found to be $(4.899 \pm 0.007)\times10^5$ sec^{-1}.

The quantities A, B, C, D, $\lambda_t(35)$, and $\lambda_t(37)$ were calculated using an iterative least-squares program written for the IBM-650 computer. A plot of the data, along with the calculated function, is shown in Fig. 2.

The disappearance rates obtained in this experiment are:

$$\lambda_t(35) = (22.54 \pm 0.52)\times10^5 \text{ sec}^{-1},$$

$$\lambda_t(37) = (17.03 \pm 0.49)\times10^5 \text{ sec}^{-1}.$$

The measurements of Yovanovitch[5] show that in the region of chlorine, the decay rate λ_d is the same as the decay constant of the free muon. Using the value for the decay constant of the positive muon of 4.52×10^5 sec^{-1},[4] we obtain for the capture rates of negative muons in chlorine isotopes:

$$\lambda_c(35) = (18.02 \pm 0.49)\times10^5 \text{ sec}^{-1},$$

$$\lambda_c(37) = (12.51 \pm 0.52)\times10^5 \text{ sec}^{-1}.$$

The ratio $\lambda_c(37)/\lambda_c(35)$ is 0.694 ± 0.034, and the ratio of the difference in the capture rates to the mean value is $[\lambda_c(35) - \lambda_c(37)]/\bar{\lambda} = (36.1 \pm 4.6)\%$.

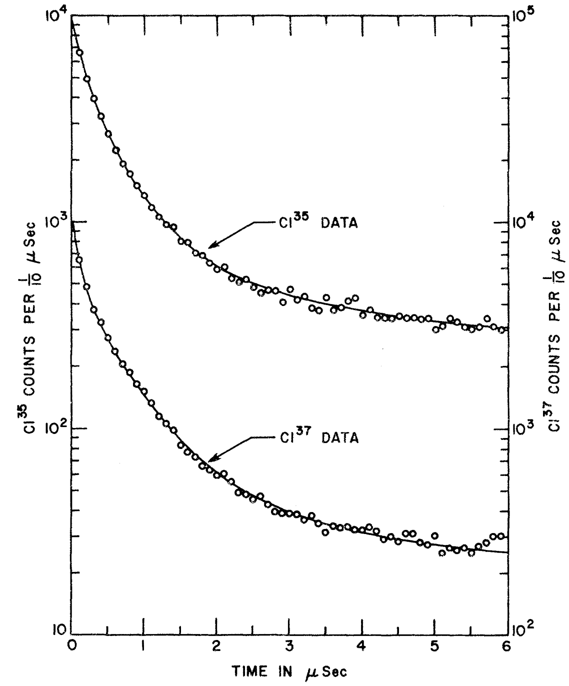

FIG. 2. Decay curves of μ^- mesons in separated chlorine isotopes. The curve is the function obtained by a least-squares fit to the data. Statistical deviations are not shown, but are the square root of the indicated count.

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