Half-Life of O^{14}†

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(Received September 26, 1960)

The half-life of O^{14} has been remeasured and found to be (70.91 ± 0.04) seconds. The corresponding partial half-life for the $0^+ \rightarrow 0^+$ beta transition is found to be (71.34 ± 0.08) seconds. These results are about 1.6% less than reported earlier. The new half-life is combined with the O^{14} end-point energy as recently determined by Bardin *et al.* to re-evaluate the Fermi coupling constant for beta decay. From this, the mean life of the μ meson is calculated. The predicted mean life is greater than the observed value by $(3.3\pm0.4)\%$ if the radiative corrections of Kinoshita and Sirlin are used, and by $(1.4\pm0.4)\%$ if the radiative corrections of Durand *et al.* are used.

THE vector coupling constant of the beta-decay interaction is determined most directly[1] from the *ft* value for the $0^+ \rightarrow 0^+$ transition in the decay of O^{14}. The conserved current theory of weak interactions advanced by Feynman and Gell-Mann[2] is based on the assumption that this coupling constant is identical to the corresponding constant in μ decay. Accordingly, it is now of considerable interest to determine these constants with the best experimental precision possible. The two experimental measurements needed to determine the O^{14} *ft* value are the decay energy and the partial half-life for the $0^+ \rightarrow 0^+$ transition. We have made a new measurement of the latter and have obtained for the partial half-life (71.34 ± 0.08) seconds. This value differs significantly from the value (72.5 ± 0.5) seconds reported earlier by Gerhart.[1] It is in good agreement with the value (71.5 ± 0.2) seconds recently obtained by Bardin *et al.*[3]

I. EXPERIMENTAL METHOD

O^{14} was produced by the $N^{14}(p,n)O^{14}$ reaction on N_2 gas (containing approximately 0.03% O_2 carrier) using 22-Mev H_2^+ ions from the University of Washington 60-inch cyclotron. Activated gas was drawn from the cyclotron target in a continuous flow N_2 gas system. C^{11}, produced by the competing $N^{14}(p,\alpha)C^{11}$ reaction, was removed by passing the active gases through hot CuO (to oxidize CO to CO_2) and then through Ascarite (to remove CO_2). Hydrogen was then introduced into the gas stream and the mixture passed over a hot platinum catalyst to convert oxygen into H_2O vapor. The activity was piped approximately 100 feet to the experimental apparatus where the gas stream was passed over one end of a copper rod kept at liquid N_2 temperature. The active H_2O frozen onto this rod served as the O^{14} source. The remaining gases were exhausted to the atmosphere.[4]

During half-life measurements the source chamber (see Fig. 1) was isolated by valves located as close as possible to the source and the flow of active gas from the cyclotron was diverted through a by-pass about 25 feet from the source. The pipes joining the source chamber to the by-pass were exhausted before beginning a measurement of the O^{14} decay and were pumped continuously during the measurements. The source chamber was free of leaks so that no active gas could either enter or leave during the half-life measurements.

The O^{14} source contained an impurity of O^{15} made by the $N^{15}(p,n)O^{15}$ reaction on the 0.37% abundant N^{15} in the target gas. To ensure that this O^{15} positron activity did not interfere with the O^{14} half-life measurement,[5] the decay of the 2.3-Mev N^{14} *gamma ray* was observed. The detector was a 1.5-inch diameter by 1-inch NaI(Tl) crystal mounted on a Dumont 6292 photomultiplier. The detector was heavily shielded with lead. In addition to the shielding shown in Fig. 1, there were 3.5 inches of lead between the O^{14} source and the pump located at the bypass. Gamma rays from the source entered the scintillator through a collimator arranged so that only the cold copper rod was exposed to the counter and not the entire source chamber. Preliminary measurements, in some of which the collimator was removed to expose the entire source chamber to the scintillator, showed there was no detectable migration of the activity to or from the cold rod during the time of measurement.

Pulses from the photomultiplier were amplified and simultaneously fed to a 20-channel pulse-height analyzer and an integral discriminator. A typical pulse-height spectrum is shown in the inset of Fig. 2. Also indicated in this figure is the setting of the integral discriminator used for the half-life measurements.

The output of the integral discriminator was fed to two scalers which were activated by a timing circuit

† This work was supported in part by the U. S. Atomic Energy Commission.
* National Science Foundation Predoctoral Fellow, 1960–61.
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[2] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).
[3] R. K. Bardin, C. A. Barnes, W. A. Fowler, and P. A. Seeger, Phys. Rev. Letters **5**, 323 (1960).
[4] J. B. Gerhart, F. H. Schmidt, H. Bichsel, and J. C. Hopkins, Phys. Rev. **114**, 1095 (1959). The O^{14} source chamber used in the present work was designed originally for use in the experiment reported in this reference.
[5] Annihilation-in-flight photons from O^{15} positrons contributed only negligibly to the observed counting rates. There are no nuclear gamma rays emitted in the O^{15} decay.

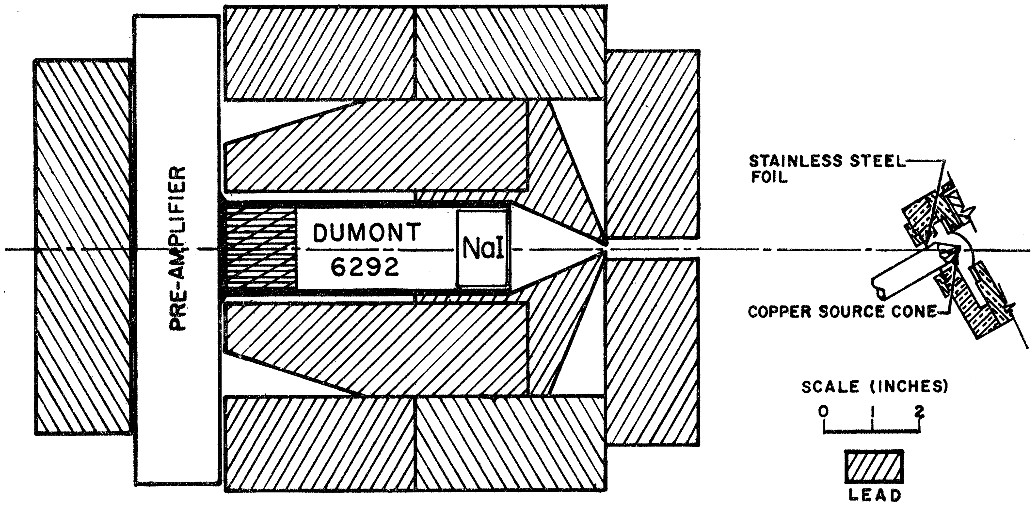

FIG. 1. Schematic diagram showing the O^{14} source chamber and the NaI(Tl) detector.

driven by a synchronous motor. This circuit alternately activated each scaler for about 10 seconds and in addition controlled an electric clock which recorded the total counting time. The accuracy of the clock was checked against the line-frequency records of the Seattle City Light Department and the U. S. Department of Interior's Columbia Basin Project. Corrections were made for line-frequency variations during the time data was collected, the largest frequency correction being 0.05%. The line frequency itself is monitored and checked against the Naval Observatory time at the Columbia Basin Project. During the time our data was accumulated the average absolute frequency did not differ from 60 cps by more than two parts in 10^6.

In a typical decay measurement the total counting rate detected had a maximum value of about 2×10^4 counts per second, and the counting rate after integral discrimination had a maximum value of about 4×10^3 counts per second. Under these conditions we estimate that the opposing effects of pileup and counting loss combined so as to alter even the highest counting rate by at most 0.2% and thus were negligible.

In each decay measurement the gain of the counter system was monitored at about 30-second intervals by observing the pulse height of the 2.3-Mev photopeak with the 20-channel pulse-height analyzer. We observed a gain reduction at high counting rates which was reproduced from run to run. The gain shift was less than 5% at the highest counting rates used and negligible when the integral discriminator counting rates were less than 750 counts per second. From our data on this gain shift and the known pulse-height distribution an empirical correction was made for this counting rate effect.

Background in the integral discriminator was 0.23 count per second when the cyclotron beam was turned off, and 0.37 count per second when O^{14} activity was brought as far as the bypass. In the half-life measurements the ratio of initial counting rate to background was ordinarily 10^4 so that in a typical measurement such as shown in Fig. 2 the O^{14} activity was observed for 12 or 13 half-lives before dropping to background. In each measurement the integral discriminator counting rate at the beginning of the decay was about 4000 counts per second. A total of 40 measurements were made and analyzed.

II. ANALYSIS OF DATA

The O^{14} half-life was determined for each measurement by fitting a weighted-least-squares straight line to the logarithm of the net counting rate plotted against time. Each point was weighted by the reciprocal of its relative statistical uncertainty. 80 to 90 points were used in each determination. The calculations were performed on an IBM-650 computer. The possibility of curvature in the decay curves was investigated by making least-squares fits to several portions of the decay curve. In all cases where this was tried there was no significant difference in the half-lives determined from various sets of points.

The average of the 40 half-life measurements is 70.91 seconds. The standard deviation[6] of each of the 40 least-squares fits was calculated and in each case we obtained a value close to ±0.19 second (which is the average of these 40 calculations). The standard deviation about their average of the 40 different half-life determinations was also calculated directly. The latter calculation gave ±0.23 second. The good agreement of these calculations is strong evidence against statistically

[6] Y. Beers, *Introduction to the Theory of Error* (Addison-Wesley Publishing Company, Reading, Massachusetts, 1957), 2nd ed., p. 42, Eq. (66).

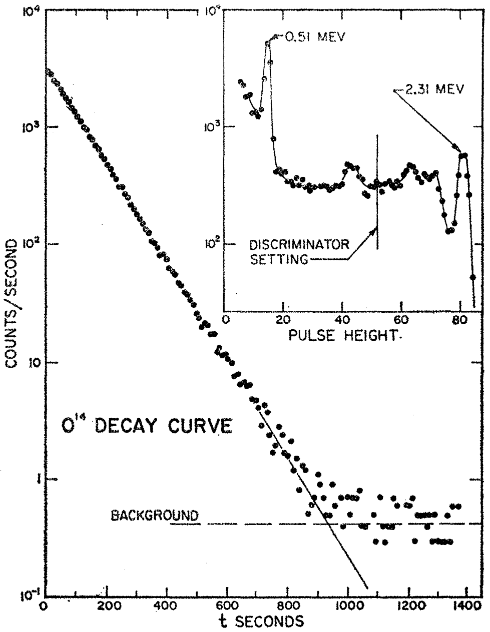

FIG. 2. One of the 40 decay curves used to determine the O^{14} half-life. The data shown have not been corrected for gain shift at the higher counting rates. The inset shows the pulse-height spectrum observed in the detector. The integral discriminator setting used in the half-life measurements is indicated.

significant, long-term variations in our apparatus during the period in which data was collected. The standard deviation of the average of all 40 determinations is 0.04 second. Thus our final value for the O^{14} half-life is (70.91 ± 0.04) seconds.

Combining this half-life with the experimentally determined[7] branching ratio for decay to the first excited state of N^{14} (0.994 ± 0.001), we obtain for the partial half-life for the $0^+\rightarrow0^+$ transition from O^{14} (71.34 ± 0.08) seconds. It should be noted that the uncertainties given here represent statistical standard deviations only, and that no allowance is made for unknown systematic errors.

III. DISCUSSION

The O^{14} half-life of (70.91 ± 0.04) seconds and the corresponding partial half-life for the $0^+\rightarrow0^+$ transition of (71.34 ± 0.08) seconds, differ significantly from the older measurements by Gerhart[1] of (72.1 ± 0.4) seconds and (72.5 ± 0.5) seconds, respectively. Several new precautions were taken in the present experiment which probably account for the difference. In particular the care taken to confine the O^{14} source to a small, well-defined volume and the study of counting rate effects were not done so well in the older measurements. Also, the old data were analyzed graphically rather than by the method of least squares, and consequently the old measurement was more open to subjective error. Finally, the present measurements used much stronger O^{14} sources which greatly reduced the relative correction for background. The recent measurement of Bardin *et al.* of (71.1 ± 0.2) seconds for the O^{14} half-life is in good agreement with our present result.

Until recently the O^{14} ft value has been computed from the half-life given in reference 1 and the $C^{12}(He^3,n)O^{14}$ threshold as measured by Bromley *et al.*[8] Bardin *et al.*[3] have redetermined the O^{14} end-point energy with great accuracy by measuring the Q values of the reactions $C^{12}(He^3,n)O^{14}$ and $C^{12}(He^3,p)N^{14*}$. Their value for the O^{14} end-point energy is (1810.6 ± 1.5) kev. From this end-point energy and our partial half-life we find for the O^{14} ft value (3061 ± 10) seconds.[9] Using this ft value and the Coulomb correction to the nuclear matrix element calculated by MacDonald,[10] we find for the coupling constant g_V in nuclear beta decay $g_V=(1.420\pm0.003)\times10^{-49}$ erg cm^3. If we include the radiative correction for the O^{14} decay calculated by Kinoshita and Sirlin,[11] then $g_V=(1.407\pm0.003)\times10^{-49}$ erg cm^3. If we use instead the radiative correction of Durand *et al.*,[12] then $g_V=(1.427\pm0.003)\times10^{-49}$ erg cm^3.

When our O^{14} ft value is combined with μ-meson mass $[(206.76\pm0.03)\,m_e]$[13] to calculate a predicted μ-meson mean life, we find $\tau_\mu=(2.235\pm0.008)\times10^{-6}$ second (with no radiative corrections included in either the O^{14} ft value or the μ-meson mean life). If the relative radiative corrections for O^{14} vs the μ meson of Kinoshita and Sirlin[11] are used, we compute $\tau_\mu=(2.282\pm0.008)\times10^{-6}$ second. With the radiative corrections of Durand *et al.*,[12] we obtain $\tau_\mu=(2.241\pm0.008)\times10^{-6}$ second. These calculated mean lives differ significantly from the observed mean life $[(2.208\pm0.004)\times10^{-6}$ second[13]; $(2.211\pm0.003)\times10^{-6}$ second[14]$]$. The difference between the calculated and observed mean lives is $(3.3\pm0.4)\%$ or 8 times the experimental standard deviation if the radiative corrections of Kinoshita and Sirlin[11] are used. If the radiative corrections of Durand *et al.*[12] are used, this difference is $(1.4\pm0.4)\%$, more than 3 times the experimental standard deviation.

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ACKNOWLEDGMENTS

The authors are indebted to Mr. C. L. Bradeen of the Seattle City Light Department and to Mr. W. E. Rawlings of the Columbia Basin Project who kindly gave us access to their records in order to verify the accuracy of our clocks. We are grateful to Professor E. M. Henley and Professor G. E. Masek for discussions of the implications of this work, and to Professor W. A. Fowler for sending us the data given in reference 3 before publication. We wish to thank Dr. J. C. Hopkins for assistance in the initial phases of this experiment and Mr. J. S. Heagney for help in taking data.

PHYSICAL REVIEW VOLUME 121, NUMBER 3 FEBRUARY 1, 1961

Three-Body Nuclear Problem with Repulsive Core Forces*†

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(Received August 3, 1960)

A variational calculation of the binding energy of the triton has been carried out using the Gartenhaus potential. The results indicate that this potential leads to an unbound ground state of the three-nucleon system; this result is attributable to the even-parity tensor potential which is relatively large in magnitude compared to the weakly attractive even-parity central potential. Since this property is also a characteristic of the Signell-Marshak potential, it too should lead to an unbound triton.

I. INTRODUCTION

DURING the past few years, a great amount of effort has been expended in obtaining repulsive-core nucleon-nucleon potentials which are consistent with a wide range of two-body data. A number of such potentials have been found which lead to good agreement with experiment.[1-4] While repulsive-core potentials may be treated in a straightforward manner in the two-body problem, they complicate considerably the three- and four-body nuclear problem; such systems have traditionally acted as critical tests for two-body potentials. Aside from calculations done with purely central hard-core forces,[5,6] only Derrick and Blatt[7] have heretofore calculated the binding energy of the trition with a realistic potential. Using Monte Carlo methods, they have found that the Gammel-Thaler potential apparently leads to a ground-state energy for the triton that is in the continuum region, $E\approx+2$ Mev.

In this paper the results of a variational calculation using the Gartenhaus potential[2] will be presented which indicate that this potential also predicts an unbound ground state for the triton. The Gartenhaus potential is known to be inadequate for all but the lowest energies[8] and it has been modified in a significant manner by Signell and Marshak[4,9,10] to obtain agreement with scattering data up to 150 Mev. These extensive modifications were not included in the present calculation for several reasons: The most important change is the addition of a strong spin-orbit term to the potential. However, the matrix elements of a spin-orbit potential acting between two S states or an S and a D state vanish; the matrix element of a spin-orbit potential between the principal S and the principal P state (these states are defined in the next section) also is zero. Since the totally symmetric S state has by far the lowest kinetic energy, it should predominate in the ground state of the triton and any term in the nuclear potential which cannot couple the other important states directly to it can have little effect on the total energy. Signell and Marshak suggest making the odd-parity central potentials less attractive by setting them equal to zero in the core regions and at the same time making the positive cores of the even-parity central potentials more repulsive. They have not defined these changes quantitatively but, as will be discussed later, decreasing the strength of the attractive central potential relative to the tensor should raise the total energy of the triton. In view of the latter point, it is felt that the results of the calculation reported here are characteristic of the Signell-Marshak potential as well as of that of Gartenhaus.

All of the calculations reported in this paper have been carried out using the more attractive singlet even-parity potential, ${}^1V_c{}^+$, of the two given by Gartenhaus.

* This work was supported in part by the U. S. Atomic Energy Commission.
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