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HALF-LIFE OF ^{208}Tl (ThC')

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Synopsis

The half life of ThC'' was measured to be 3.055 ± 0.006 min. or 183.3 ± 0.4 sec., which is 1.5 per cent smaller than the best hitherto known value.

1. Introduction

The half life of ThC'' was determined in 1909 by HAHN and MEITNER¹⁾, who found the value 3.1 min. Later measurements gave the following results: VON LERCH and VON WARTBURG²⁾ (1909) 3.0 min., WOOD³⁾ (1914) 3.1 min., and ALBRECHT⁴⁾ (1919) 3.20 min. More recently, BAULCH, DAVID and DUNCAN⁵⁾ (1957) found the half life to be 3.10 ± 0.015 min. Using a Geiger counter and starting with initial counting speeds of about 10–1000 cpm, they followed the decay of 268 sources which were prepared from ThB + C by a recoil method. The ThC'' nuclei recoiling after the decay of ThC were collected, whereas, by means of an electric field, recoils after β -decay were prevented from reaching the collector.

In a recent paper by MIDDELBOE⁶⁾ on accurate half-life determinations, the importance of having a source free from radioactive impurities was stressed. This gave us the impulse for the present work.

2. Experimental method

A ThC'' source was placed close to a 3×3 inch NaJ-crystal; the amplified pulses from the photo-multiplier fed two scalers. One scaler and a stopwatch were started simultaneously ($t = 0$) by the experimenter; the second scaler was started at $t = T = 600.0$ sec., and both scalers were stopped at $t = 2T = 1200.0$ sec. Hereby the numbers M_1 and M_2 of counts in the time intervals 0–600 and 600–1200 sec., respectively, were obtained. After proper corrections, the numbers of counts N_1 and N_2 corresponding to the decay period of ThC'' yielded the fall-off factor $F = N_1/N_2$. Then, the half life is

$$T_{1/2} = T \log 2 / \log F. \quad (1)$$

By following the decay of the source for a few hours we determined the amount of ThB and ThC impurities in the source; no other radioactive impurities were present.

Originally it was intended to discriminate against energies below 1.3 MeV and to look at the high energy photons from ThC". However, observations of the γ -spectrum from a Cs¹³⁷ standard by means of an RCL 512-channel pulse height analyzer showed that the gain of the photomultiplier tube depended on the counting rate and also on the prehistory of the counter. Counting 45 minutes with a rate of 23000 counts per sec. produced a decrease in gain of about 10 per cent; when the source was removed, a rapid increase of some 4 per cent was observed, followed by a slow exponential increase, so that normal amplification was reached in about a day. Such phenomena are not unknown⁷⁾. Although shorter exposures seemed less fatal, we decided in the half-life measurements to use the whole spectrum. Consequently, the cut-off was put at a value corresponding to a γ -energy of about 0.030 MeV and tests now showed unchanged counting rates before and after exposure to a strong source.

3. Source preparation

Corresponding to three different ways of source production we denote the experiments by the letters A, B, and C.

A.

Active deposit from an emanating source of RdTh was collected on a platinum sphere of about 1 mm in diameter. Sources of ThB and its daughters of about 10–100 μ Curie were used; except for the first few hours, the sources were found to decay with a half life of 10.8 hours (the adopted value for ThB is 10.6 hours) until the counting rate was lower than one count per sec. with the source close to the crystal. Thus, no significant longer lived radioactive impurity was present.

We have no reason to suspect that the RdTh should contain any radio impurities. However, if impurities belonging to the other radioactive series were present, RaB and AcB would be collected together with ThB. Therefore, an α -spectrum of the ThB source was measured by means of a solid-state silicon detector and a 512-channel analyzer; the main α -groups and the less abundant groups with energies 5.60 and 5.76 MeV were seen, but no traces of α -particles with energies 6.28, 7.69, and 8.34 MeV, corresponding to AcC' and Po²¹³, respectively, were found. An upper limit could be set for these impurities; they could at most cause an error in the measured half life of ThC" less than 0.01 per cent.

After removal from the activation chamber, the ThB source was stored for about 20 min. so that possible adhering Tn and ThA decayed. Later, the source was placed in an evacuated tube of 2 cm diameter, the inside wall of which was covered by a thin aluminum foil, and the source was

held at a potential of -300 V with respect to the surrounding aluminum foil. For about 3–10 min., the recoiling ThC''-atoms created in the α -decay of ThC were collected on the aluminum foil. The purpose of the potential difference was to prevent recoils from β -decay of ThB to be collected; however, complete separation was never obtained; the ThC'' sources always contained small amounts of both ThB and ThC, but no longer living activities.

B.

In another attempt at producing pure ThC'' sources, the starting material was 120 μ Curie RdTh dissolved in HNO_3 . By means of a Dowex 1 ion-exchange column, a source of about 5 μ Curie of ThX + descendants was prepared. This source, after drying, was dissolved in 0.1 n HCl and put on a Dowex 50 column, from which a ThB + C source was obtained by eluting with 1 n HCl.

Tl was then oxidized to stage III by means of chlorine and the solution was made 6 n with respect to HCl. By shaking the solution with an equal volume of ethylether for 30 sec., we transferred the ^{208}Tl to the ether phase, thereby separating it from Pb and Bi (ThB and ThC).

However, also this source was found to contain small amounts of ThB and ThC, and in addition it would sometimes contain ThX. It was thought to be too risky to correct for ThX and all its successors, especially because one of them is a gas and because it has a half life comparable to the half life of ThC''. The results were therefore only used when a very low limit for possible ThX contamination of the source could be set.

C.

A ThB + C source was prepared in the way described under A. This source was placed in a vacuum box approximately one mm from a glass plate covered by a thin polyesterene film prepared in a way similar to that described by BJØRNHOLM⁹⁾. The thickness of the film was $3-5$ $\mu\text{g}/\text{cm}^2$ so that some recoil atoms from α -decay would penetrate to the glass plate, whereas ThB and ThC atoms were supposed to be caught in the film. After exposure for some 3–5 min., the polyesterene film was removed by washing the glass plate in an acetone bath.

4. Measurement of ThB and ThC impurities

Fig. 1 shows the well-known decay scheme for ThB. Let A , B , and C denote the number of atoms of ThB, ThC and ThC'' respectively, λ_A , λ_B , and λ_C the corresponding total decay constants, and λ_{B1} the partial decay constant for $\text{ThC} \rightarrow \text{ThC}''$. Then,

$$A = A_0 e^{-\lambda_A t} \quad (2a)$$

$$B = \frac{A_0 \lambda_A}{\lambda_B - \lambda_A} e^{-\lambda_A t} + \left(B_0 - \frac{A_0 \lambda_A}{\lambda_B - \lambda_A} \right) e^{-\lambda_B t} \quad (2b)$$

$$C = \left. \begin{aligned} & \frac{A_0 \lambda_A \lambda_{B1}}{(\lambda_C - \lambda_A)(\lambda_B - \lambda_A)} e^{-\lambda_A t} + \left[\frac{B_0 \lambda_{B1}}{\lambda_C - \lambda_B} - \frac{A_0 \lambda_A \lambda_{B1}}{(\lambda_C - \lambda_B)(\lambda_B - \lambda_A)} \right] e^{-\lambda_B t} \\ & + \left[C_0 - \frac{B_0 \lambda_{B1}}{\lambda_C - \lambda_B} + \frac{A_0 \lambda_A \lambda_{B1}}{(\lambda_C - \lambda_B)(\lambda_C - \lambda_A)} \right] e^{-\lambda_C t}. \end{aligned} \right\} \quad (2c)$$

The activity at the time t is $A\lambda_A + B\lambda_B + C\lambda_C$, and the counting rate is $A\lambda_A \varepsilon_A + B\lambda_B \varepsilon_B + C\lambda_C \varepsilon_C$, where for example ε_A is the probability that a transformation from ThB to the ground state of ThC is registered by the counter, and where ε_B includes the decay $\text{ThC} \rightarrow \text{ThC}''$ as well as the decay $\text{ThC} \rightarrow \text{ThC}'$ ($\rightarrow {}^{208}\text{Pb}$).

If no counts are lost due to random coincidences, the counting rate may be written

$$R_s(t) = \beta_1 e^{-\lambda_A t} + \beta_2 e^{-\lambda_B t} + \beta_3 e^{-\lambda_C t} + D, \quad (3)$$

where D is the natural background and β_1 , β_2 , and β_3 are constants depending on the initial amounts of ThB, ThC, and ThC''.

For $t > 5000$ s, $e^{-\lambda_C t} = 0$. β_1 and β_2 were determined such as to give the best fit to six values of $R_s(t) - D$ in the interval $5000 < t < 10000$.

If we had wanted to correct M_1 and M_2 for the influence of the impurities of ThB and ThC, the corrections would have been

$$-G_1 = -\int_0^T (\beta_1 e^{-\lambda_A t} + \beta_2 e^{-\lambda_B t} + D) dt - \int_0^T (\beta_3 - \varepsilon_C C_0 \lambda_C) e^{-\lambda_C t} dt = -G'_1 - G''_1. \quad (4a)$$

$$-G_2 = -\int_T^{2T} (\beta_1 e^{-\lambda_A t} + \beta_2 e^{-\lambda_B t} + D) dt - \int_T^{2T} (\beta_3 - \varepsilon_C C_0 \lambda_C) e^{-\lambda_C t} dt = -G'_2 - G''_2. \quad (4b)$$

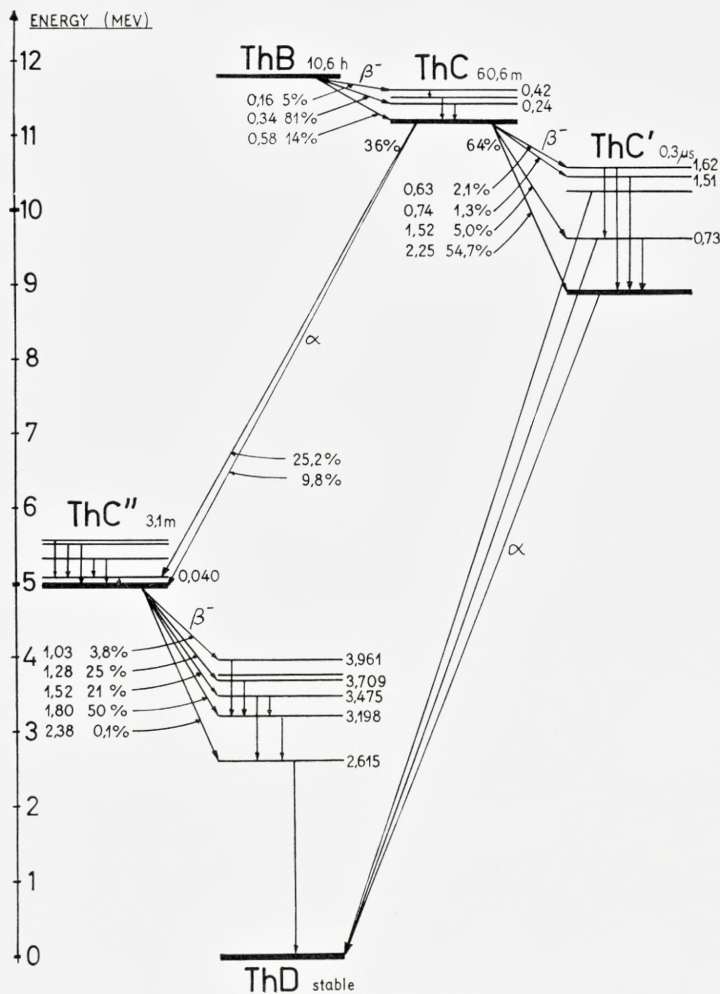


Fig. 1. Decay scheme for ThB.

However, since $G_2''/G_1'' = e^{-\lambda_1 t} = N_2/N_1$, we need only apply the corrections $-G_1'$ and $-G_2'$. To determine the half life $T_{1/2}$, M_1 and M_2 need only be corrected with the integrals of that part of the count rate which does not decay with the period $T_{1/2}$.

It should be noticed that, to determine β_1 and β_2 , we must know λ_A and λ_B , but no knowledge of the efficiencies is required.

It is unnecessary to find the actual amounts of impurities; however, if we do want them, we have to know the efficiencies. Replacing the source with a ^{32}P source an efficiency of 0.07 was found. We estimate the probability to observe a β -particle from a decay to be 0.00, 0.07 and 0.07 for ThB, ThC, and ThC", respectively. For ThC", for example, we find $\varepsilon_c = 0.07 + 0.93 \cdot \varepsilon_{\gamma c}$, where $\varepsilon_{\gamma c}$ is the probability that the decay is registered through any of the photons. Using known curves¹⁰⁾ for counter efficiency as a function of distance and energy, and taking into account the decay scheme and the known conversion coefficients¹¹⁾, we find the total efficiencies to be

$$\varepsilon_A \sim 0.18, \quad \varepsilon_B \sim 0.09, \quad \text{and} \quad \varepsilon_C \sim 0.44.$$

β_1 and β_2 may be expressed in terms of λ_A , λ_B , λ_{B1} , ε_A , ε_B , A_0 , and B_0 . From these expressions we find, with the above mentioned efficiencies,

$$\varepsilon_A A_0 \lambda_A \sim 2.5 \beta_{12}; \quad \varepsilon_B B_0 \lambda_B \sim 0.3 \beta_2 + 0.2 \beta_1,$$

which may be used to calculate the amount of impurity atoms from the values for β_1 and β_2 given in Table 2 (p. 10).

5. Corrections for deadtime losses and impurities

When determining β_1 and β_2 from the counting rate for large t -values we may safely neglect losses due to random coincidences. With the high initial counting rates, however, appreciable deadtime corrections must be applied to M_1 and M_2 . Deadtime and impurity corrections are coupled, and both have been taken care of by the following procedure. If we assume the deadtime τ of the counter arrangement to be a constant, we have

$$R_m = \frac{R_s}{1 + \tau R_s}, \quad (5)$$

where R_m and R_s are the measured and the "true" counting rates. For $0 < t < T$ we put $e^{-\lambda_A t} = 1$ and $e^{-\lambda_B t} = e^{-\lambda_B T/2} = 0.95$. Then, from (3),

$$R_s(t) = E_1 + \beta_3 e^{-\lambda_c t} = \beta_1 + 0.95 \beta_2 + D + \beta_3 e^{-\lambda_c t} \quad (6a)$$

which, introduced in (5), gives

$$M_1 = \int_0^T R_m dt = \int_0^T \frac{E_1 + \beta_3 e^{-\lambda_c t}}{1 + \tau E_1 + \tau \beta_3 e^{-\lambda_c t}} dt. \quad (7a)$$

Integrating and rearranging, one finds

$$\beta_3 = \frac{(1 - e^{-U_1})(1 + \tau E_1)}{\tau(e^{-U_1} - e^{-\lambda_c T})} = \frac{(U_1 - \frac{1}{2}U_1^2 + \frac{1}{6}U_1^3)(1 + \tau E_1)}{\tau(1 - U_1 + \frac{1}{2}U_1^2 - \frac{1}{6}U_1^3 - 0.10346)}, \quad (8a)$$

where

$$U_1 = [M_1(1 + \tau E_1) - E_1 T] \tau \lambda_c. \quad (9a)$$

Similarly,

$$M_2 = \int_0^{2T} \frac{E_2 + \beta_3 e^{-\lambda_c t}}{1 + \tau E_2 + \tau \beta_3 e^{-\lambda_c t}} dt = \int_0^T \frac{E_2 + \beta_3 e^{-\lambda_c T} e^{-\lambda_c t'}}{1 + \tau E_2 + \tau \beta_3 e^{-\lambda_c T} e^{-\lambda_c t'}} dt', \quad (7b)$$

where

$$E_2 = 0.99 \beta_1 + 0.846 \beta_2 + D. \quad (6b)$$

Now, $\beta_3' = \beta_3 e^{-\lambda_c T}$ may be found from expressions similar to (8a) and (9a). Finally, introducing $F = \beta_3/\beta_3'$ in (1), we obtain the half life $T_{1/2}$ corrected for deadtime losses and impurities.

Since $\tau \sim 6 \cdot 10^{-6} s$, one has $\tau E_1 \ll \ll 1$. Also $E_1 T \ll \ll M_1$. Hence, $U_1 \ll 1$ for $M_1 \ll (\tau \lambda_c)^{-1} \sim 40 \cdot 10^6$. This justifies the use of the series expansion in (8), and furthermore shows that no very accurate value for λ_c need be used in (9a) since, to first order in U_1 , the factor λ_c nearly cancels out in the ratio β_3/β_3' . Actually, iteration is used.

6. Determination of deadtime τ

Shortly before or shortly after each half life measurement the dead-time was measured. Two standard sources, ^{22}Na and ^{60}Co , were used. The counting rates m_1 , m_2 , m_{12} , and m_b , corresponding to one source in a standard position, the other source in another standard position, both sources in their respective positions, and no sources, respectively, were measured. Then⁸⁾,

$$\tau = \tau_1 \left[1 + \frac{\tau_1}{2} (m_{12} - 3m_b) \right]$$

with

$$\tau = \frac{m_1 + m_2 - m_{12} - m_b}{2(m_1 - m_b)(m_2 - m_b)}.$$

When counting one source, the other source was removed, but a "dummy" was used to secure identical conditions in the various measurements. The counting times were so as to give a statistical error in τ of about 0.3%. The half life determinations were carried out in two periods, separated by several months. τ was found to be constant within each period, but slightly different for the two periods (5.60 and 5.70 μs , respectively). Table 1 gives the results for the first period.

TABLE 1.

	m_1	m_{12}	m_2	m_b	τ
A1.....	9 988	28 494	20 675	16.2	5.62
A2.....	18 333	33 799	19 066	15.0	5.58
A3.....	17 836	33 434	19 117	15.0	5.59
A4.....	17 858	33 384	19 055	14.8	5.62
A5.....	13 687	26 751	15 259	11.9	5.60
A6.....	15 732	29 465	16 422	12.9	5.58
A7.....	18 471	32 865	17 805	21.0	5.60

7. Results

Disregarding two B-measurements, because the source contained ThX, the first 12 measurements are summarized below.

In Table 2, M_1 and M_2 are the actually registered numbers of counts in the first two 10 min.-periods. The fourth column gives approximate values for β_3 (approximately the initial count rate). The background was always found to be between 7.2 and 7.5 c/s. For example, for A1: $D = 7.38 \pm 0.05$ c/s. The deadtime τ is given in § 6.

The mean value of the twelve measurements is $T_{1/2} = (3.055 \pm 0.002)$ min., where the stated error covers only statistical errors.

TABLE 2.

	M_1 counts 0-600s	M_2 counts 600s-1200s	β_3 c/s	β_1 c/s	β_2 c/s	$\frac{(\beta_1 + \beta_2)}{\beta_3}$ ‰	$T_{1/2}$ min	$\Delta T_{1/2}$ stat. error ‰
A1....	2 679 523	293 064	11 600	1.0	3.4	0.38	3.060	1
A2....	2 447 774	267 815	10 600	1.8	5.0	0.64	3.056	1
A3....	2 877 098	313 071	12 500	0.6	4.4	0.40	3.051	1
A4....	1 139 344	134 599	4 800	1.6	24	5.3	3.049	4
A5....	2 001 459	222 650	8 600	2.1	9.5	1.35	3.064	1.5
A6....	1 684 836	185 540	7 200	0.4	9.2	1.35	3.051	1.5
A7....	1 296 647	145 292	5 500	1.3	11.6	2.4	3.048	2
B1....	396 506	45 704	1 650	1.3	-0.4	0.55	3.060	3
C1....	706 550	80 186	2 900	1.8	3.9	2.0	3.055	2.5
C2....	981 243	107 501	4 100	0.5	1.4	0.45	3.056	2
C3....	1 059 091	115 065	4 500	0.05	1.2	0.38	3.051	2
C4....	429 359	48 762	1 800	-0.02	0.34	0.18	3.059	2.5

8. Discussion

The fluctuation of the twelve values for the half life, defined by $\sigma^2 = \langle (T - \langle T \rangle)^2 \rangle$, is found to be $\sigma = 0.005$ min., in agreement with the statistical uncertainty of a single measurement.

By plotting the values of $T_{1/2}$ against M_1 no correlation is found. Plotting $T_{1/2}$ against the fractional amount of impurities may possibly show a slight tendency towards lower $T_{1/2}$ values for high impurities, but the variation is not outside the limits of error.

First, when discussing a possible error due to an error in τ , we may disregard the impurities and the background. Then, according to (5) and (6a),

$$\begin{aligned}
 N_1 &= \int_0^T R_s dt = (\beta_3/\lambda_c) (1 - e^{-\lambda_c T}) \\
 M_1 &= \int_0^T \frac{R_s dt}{1 + \tau R_s} \approx \int_0^T R_s dt - \tau \int_0^T R_s^2 dt. \\
 \Delta M_1 &= N_1 - M_1 \approx \tau \int_0^T R_s^2 dt = \tau \int_0^T \beta_3^2 e^{-2\lambda_c t} dt \\
 &= \frac{1}{2} \tau \lambda_c \frac{1 - e^{-2\lambda_c T}}{(1 - e^{-\lambda_c T})^2} \left[\frac{\beta_3}{\lambda_c} (1 - e^{-\lambda_c T}) \right]^2. \\
 \Delta M_1 &\approx 2.4 \cdot 10^{-3} N_1^2 \tau.
 \end{aligned}$$

An error $\delta\tau$ causes an error in N_1 ($\delta N_1 = \delta(\Delta M_1)$), which is

$$\delta N_1 / N_1 \sim 2.4 \cdot 10^{-3} M_1 \tau (\delta\tau / \tau)$$

and, since $F \sim 10$ and since the relative error in N_2 (due to $\delta\tau$) may be disregarded,

$$\delta T_{1/2} / T_{1/2} \sim -(1/2) \delta F / F \sim -(1/2) \delta N_1 / N_1 \sim -1.2 \cdot 10^{-3} M_1 \tau (\delta\tau / \tau).$$

Introducing $\tau \sim 6 \cdot 10^{-6}$ s we find

$$\text{for } M_1 \sim 2 \cdot 10^6 \qquad \delta T_{1/2} / T_{1/2} \sim -0.015 \delta\tau / \tau$$

$$\text{for } M_1 \sim 7 \cdot 10^5 \qquad \delta T_{1/2} / T_{1/2} \sim -0.005 \delta\tau / \tau.$$

The statistical uncertainty in τ is insignificant. But the value used for τ might be erroneous, because τ may depend on the energy spectrum. However, the mean values of $T_{1/2}$ for A1-2-3-5-6 and for B1-C1-2-3-4, are 3.057 and 3.056 min., respectively, with a statistical uncertainty of about 0.002 min. and these two groups of measurements happen to correspond roughly to the above mentioned values of M_1 . If the error in τ were as much as 20 per cent, the two mean values should differ by 0.006 min. – which they

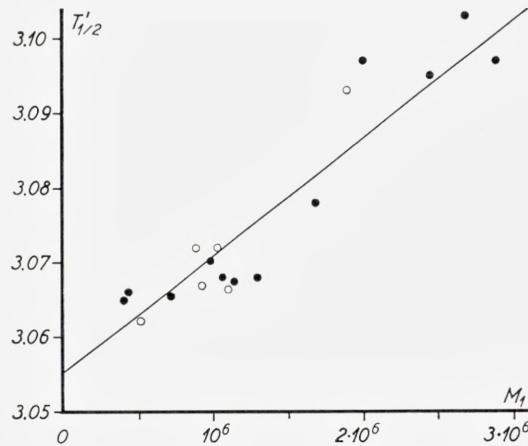


Fig. 2. $T'_{1/2}$ is the measured half life of ThC'', corrected for ThB and ThC impurities, but not for deadtime losses. M_1 is the number of counts in the first 10 min.-period. The closed circles refer to the measurements summarized in Table 2, and the straight line represents a least square fit to these points. The open circles refer to the measurements of Table 3.

do not – and in this case the error in the last mean value would be 0.003 min. It seems safe to conclude that $\delta T_{1/2} < 0.006$ min.

The experimental data may be treated in a different way. When F is replaced by $F' = (M_1 - E_1 T)/(M_2 - E_2 T)$, formula (1) gives values $T'_{1/2}$ for the uncorrected half life. Plotting $T'_{1/2}$ against M_1 should be expected to give a straight line with a slope determined by τ and intersecting the Y-axis at $T_{1/2}$. Such a plot is shown in Figure 2, where the straight line is drawn by means of the method of least square deviations. Again we find $T_{1/2} = 3.055$ min. and the slope of the line corresponds to a value of the deadtime $\tau \sim 5.6 \mu\text{s}$.

Next, when discussing errors due to erroneous impurity corrections, we may disregard deadtime losses and background. Statistical errors of the impurity corrections have already been included in $\Delta T_{1/2}$ given in Table 2.

Assuming, for the sake of simplicity, only two $R_s(t)$ values used for the determination of β_1 and β_2 , we have

$$\begin{aligned} R_1 &= \beta_1 e^{-\lambda_A t_1} + \beta_2 e^{-\lambda_B t_1} \\ R_2 &= \beta_1 e^{-\lambda_A t_2} + \beta_2 e^{-\lambda_B t_2}. \end{aligned}$$

Solving for β_1 and β_2 and differentiating, we obtain $\delta\beta_1/\delta\lambda_A$, etc. Further,

$$G'_2 = \beta_1 e^{-\lambda_A T} \frac{1 - e^{-\lambda_A T}}{\lambda_A} + \beta_2 e^{-\lambda_B T} \frac{1 - e^{-\lambda_B T}}{\lambda_B}.$$

By differentiation, $\frac{\delta G'_2}{\delta \lambda_A} = \frac{\delta N_2}{\delta \lambda_A}$, etc., are obtained. For example, $\delta N_2 \sim 2.5 \cdot 10^6 \beta_2 \delta \lambda_B$, which shows that an error of 5 per cent in λ_B will only for A4 produce an error in the half life of more than about 0.5%.

Now, let us consider errors due to time measurement. Repeated checks showed the stopwatch time to be in error by less than 0.1%.

The half life is found from the expression $T_{1/2} = 600 \log 2 / \log F$ and, therefore,

$$\delta T_{1/2} = -T_{1/2} \delta(\log F) / \log F \sim -(1/2) T_{1/2} \delta F / F.$$

One scaler worked in T_2' seconds, the other scaler in $(T_2'' - T_1)$ seconds, where $T_1 \sim 600$, $T_2' \sim T_2'' \sim 1200$. Then,

$$\begin{aligned} N_1 &= \frac{\beta_3}{\lambda_c} [1 - e^{-\lambda_c T_2'} - (e^{-\lambda_c T_1} - e^{-\lambda_c T_2''})] \\ N_2 &= \frac{\beta_3}{\lambda_c} (e^{-\lambda_c T_1} - e^{-\lambda_c T_2''}). \end{aligned}$$

Differentiating, putting the numerical values $\delta T_1 \sim \delta T_2' \sim \delta T_2''$, and assuming the worst possible signs, one gets $\delta T_{1/2} \sim \delta T_1$. T_1 is the important time interval, i.e., the interval from the start of the first to the start of the second scaler. δT_1 is supposed to be smaller than 0.2 sec. ~ 0.003 min. for the mean value.

The stability of the counter arrangement was checked occasionally. The power supply was stabilized, and a change of 10 volts of the main 220 Volt A.C. supply would produce a change of only 3% in counting rate. Supervising the main supply for long periods never revealed so large

changes, and the possibility that the average half life should be significantly in error due to spurious changes is vanishingly small.

We consider it safe to state that $T_{1/2} = 3.055 \pm 0.006$ min.

To account for the disagreement with the result of BAULCH, DAVID and DUNCAN⁵⁾, we are inclined to believe that their sources may have contained ThB+C impurities. This would have been difficult to observe due to the small counting rates involved in their experiments; furthermore, in spite of various efforts using different retarding potentials, we were never able to produce a pure source by means of method A, which is similar to their source preparation techniques.

9. Supplementary measurements

As a further check, six measurements of the half life of ThC'' were performed by another experimenter. These measurements are summarized in Table 3.

TABLE 3.

	M_1	M_2	β_3	β_1	β_2	$\frac{\beta_1 + \beta_2}{\beta_3}$	$T_{1/2}$		$\Delta T_{1/2}$
	c/600s	c/600s	c/s	c/s	e/s	‰	uncorr.**	corr.	stat. error
							min	min	‰
C5 ...	508 738	57 007	2 150			0.15 ± 0.15	3.057	3.053	3
C6 ...	881 877	96 945	3 750	0.45	1.0	0.40	3.067	3.057	2
C7 ...	1 102 386	120 661	4 700	0.03	3.5	0.75	3.068	3.047	2
C8 ...	923 117*	85 310*	3 800	1.4	6.2	2.0	3.117	3.053	2
C9 ...	1 942 335	251 181	8 200	49	33	10	3.325	3.061	4
C10 ..	1 032 474	114 223	4 400	0.80	3.2	0.9	3.079	3.055	2

* Counts in 660 s.

** These values are corrected for deadtime losses, but not for impurities of ThB+C.

Here, $\tau = 5.90 \cdot 10^{-6}$ s. $D \sim 7.5$ c/s as before. The mean value of the six measurements is again 3.055 min.

When preparing the source for C7, the polysterene film was removed from the glass plate in a bath of acetone to which had been added carriers of Pb and Bi. As seen, the purity of the source was not improved. In C8, no polysterene film was used; the idea was to investigate whether the im-

purity correction would work for high impurities. The same applies to C9, in which experiment the bare glass plate was exposed to the ThB + C source for two hours with the aim to increase the amounts of both ThB and ThC in the ThC" source. Also in C10 no polystyrene film was used. Furthermore, in this experiment the counter arrangement was changed; the β -particles from the source were stopped in a second inactive glass plate and the bremsstrahlung photons were filtered away with one mm of lead; thus the efficiencies were radically changed.

Auxiliary deadtime measurements, using sources of ^{60}Co and ^{22}Na , gave the same value for τ with counting rates m_{12} of 30 000 and 15 000 c/s, and within the statistical error also for $m_{12} = 2\,500$ c/s. The deadtime was about 2 per cent higher for $^{60}\text{Co} + ^{137}\text{Cs}$ sources or for $^{22}\text{Na} + ^{137}\text{Cs}$ sources, and some 5 per cent higher when two ^{137}Cs sources were used. Using sources of ^{60}Co and ^{241}Am , τ was found to be $11.5\ \mu\text{s}$, but the radiation from ^{241}Am is very soft (~ 60 keV).

10. Half life of $^{137}\text{Ba}^m$

As a further check of our procedure we measured the half life of $^{137}\text{Ba}^m$, previously determined by MIDDELBOE⁶⁾. Ba was separated from the parent ^{137}Cs by means of a KCFC-ion exchange column¹²⁾ with particle sizes 35–60 standard mesh size; the background count rate due to radioimpurities was about 10^{-5} times the initial count rates of $^{137}\text{Ba}^m$. Using count rates of 3 000–30 000 c/s at the start of the measurements, our mean value from ten determinations was 2.559 ± 0.006 min., in good agreement with the value 2.5577 ± 0.0032 min. given by MIDDELBOE.

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