Measurement of the Radioactive Decay Constant of ThC′ Using a Coincidence Method*

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The radioactive half-life of ThC′ has been measured using a delayed coincidence circuit of high resolution. A theory of the effect on the coincidence rate of variations in pulse formation in counters has been developed and compared with experiment. The radioactive decay constants of ThC′ have been found to be:

$$T=(2.2\pm0.1)\times10^{-7}\text{ sec.},$$
$$\lambda=(3.15\pm0.14)\times10^{6}/\text{sec.}$$

INTRODUCTION

WARTIME research applied to coincidence circuits has improved the resolution possibility considerably. A circuit built at this Laboratory by Schultz and Beringer[1] has a resolving time of the order of 10^{-8} sec. Since the half-life of ThC′ is approximately 2.5×10^{-7} sec., it should be possible to use this circuit to measure directly the radioactive constant of ThC′, and at the same time investigate the capabilities of the circuit.

The first direct measurement of the half-life of ThC′ was made by Dunworth[2] in 1939. He measured the number of coincidences between electrons from ThC and subsequent alphas from ThC′ as a function of the resolving time of the coincidence circuit. From the data he inferred a value of $(3\pm1)\times10^{-7}$ sec. for the half-life of ThC′. In 1943 Bradt and Scherrer[3,4] used the same integral method, but included theoretical consideration of the effect of variations in time of formation of pulses in gas-filled counters on the coincidence rate. They found the value $(2.6\pm0.4)\times10^{-7}$ sec. for the half-life of ThC′.

EXPERIMENTAL PROCEDURE

In the present experiment the counters were placed front-to-front with the source in between. Electrons from ThC enter one channel, to be called channel No. 1, which counts only electrons. The corresponding voltage pulses are then passed down a delay line consisting of a helical coil forty-five centimeters long. An electromagnetic pick-up coil receives the pulses at adjustable time delays up to the total delay of the line. The delay line was calibrated and found to be uniform, with a delay of one microsecond for 26.3 cm of line. Alphas from ThC′ enter the second channel, to be called channel No. 2, which counts only alphas, and the corresponding voltage pulses are delayed a small, fixed amount. The pulses from the two channels, after these time delays, then arrive at the discriminator, which will register a count if the two pulses arrive with a time difference less than approximately 10^{-8} sec. The problem is to determine the half-life of ThC′ from the observed coincidence rate *versus* relative delay curve, including in the theory the effect of variations in pulse formation in the counters.

Two preliminary experiments were also performed, similar to those described by Schultz and Beringer. The resolving time of the electronic circuit, independent of the characteristics of the counters, was measured by stimulating both channels simultaneously with a pulse from a single counter and measuring the coincidence rate as a function of relative delay. The resolving time used was found to be 1.3×10^{-8} sec. The effect of pulse variations was determined by placing the counters in line and close together,

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[1] H. L. Schultz and E. R. Beringer, Rev. Sci. Inst. **19**, 424 (1948).
[2] J. V. Dunworth, Nature **144**, 152 (1939).
[3] H. Bradt and P. Scherrer, Helv. Phys. Acta **16**, 251 (1943).
[4] H. Bradt and P. Scherrer, Helv. Phys. Acta **16**, 259 (1943).

so that a single particle could traverse both axially, and again measuring the coincidence rate *versus* delay curve.

The source used was the active deposit of thorium on an aluminum foil one-half inch in diameter. The counters were conventional cylindrical counters filled with 20 cm pressure of argon and operated in the proportional region. The capacity-neutralized preamplifiers were similar to those described by Schultz and Beringer, and the main amplifier, delay circuits, and discriminator are the same as in their article. The recording circuit, power supplies, and auxiliary equipment were conventional in design.

THEORETICAL CONSIDERATIONS OF COINCIDENCE RATE

Any theory of coincidence rates in this type of experiment must begin by measuring or assuming a distribution of the individual times of pulse formation about their mean value. Bradt and Scherrer assumed this distribution to be Gaussian. For mathematical simplicity, the author has assumed a triangular distribution about the mean. In this connection, Madansky and Pidd[5] have measured the time delay distribution of a cylindrical counter, with a result which is roughly triangular. However, the test of the assumed distribution will be the agreement of the results of the theory with experiment.

Consider first the preliminary experiment in which the counters are placed close together and in line, both being sensitive to alphas. Let an alpha pass through both counters at time zero, and let D be the delay in channel No. 1 relative to channel No. 2. Then the probability that the pulse from counter No. 1 will arrive at the discriminator between t and $t+dt$ is assumed to be given by the triangular distribution:

$$d\alpha_1=[A-|t-D|]dt/A^2. \tag{1}$$

In the above expression, A is the half-width of the distribution, measured in centimeters, length of delay line employed. Similarly, the probability that the pulse from counter No. 2 will arrive at the discriminator between t and $t+dt$ is given by:

$$d\alpha_2=[A-|t|]dt/A^2. \tag{2}$$

[5] L. Madansky and R. W. Pidd, Phys. Rev. **73**, 1215 (1948).

Since the electronic resolving time, R, is known to be small compared to the half-width of the counter pulse distribution, A, the probability of a coincidence is given by:

$$C=2R\int d\alpha_1 d\alpha_2. \tag{3}$$

Performing the integration and letting $x=|D/A|$:

$$C=\frac{2R}{A}\left[\frac{1}{2}-x^3-x^2+\frac{2}{3}\right] \quad 0\leqslant x\leqslant 1, \tag{4a}$$

$$C=\frac{2R}{A}\left[\frac{1}{6}-x^3+x^2-2x+\frac{4}{3}\right] \quad 1\leqslant x\leqslant 2. \tag{4b}$$

Figure 1 shows a set of experimental data fitted to the above theory for the case of a single alpha-particle traversing both counters placed close together. The value of A was chosen to be 2.9 cm of delay line, corresponding to 1.10×10^{-7} sec. The fit is well within the statistical counting error of 5 percent for all points, and thus from these preliminary data the assumed distribution seems to be satisfactory. Unfortunately, counter No. 2 would not count electrons satisfactorily, so the companion experiment could not be performed for the case of an electron passing through both counters simultaneously.

Now let channel No. 1 count only electrons from ThC and channel No. 2 count only alphas from ThC′. Consider an electron emitted by ThC

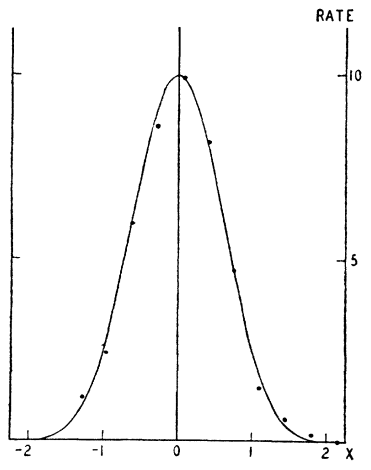

FIG. 1. Coincidence rate *versus* delay curve for the case of a single alpha traversing both counters placed close together.

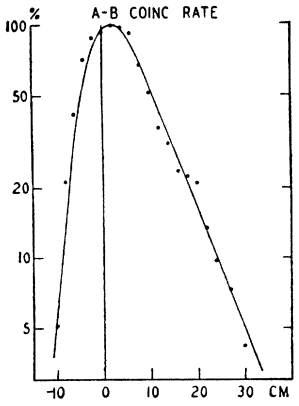

FIG. 2. Coincidence rate *versus* delay curve for the case of electron pulses from ThC delayed relative to alpha-pulses from ThC'.

at radioactive time, t', equal to zero. Then the probability of emission of the following alpha between t' and $t'+dt'$ is

$$d\alpha=\lambda e^{-\lambda t'}dt'. \tag{5}$$

The probability of the pulse arriving at the discriminator from channel No. 2 between t and $t+dt$ as a result of an alpha emitted between t' and $t'+dt'$ is found by combining Eqs. (1) and (5) (applied to channel No. 2), as follows:

$$d^2\alpha=\lambda e^{-\lambda t'}dt'[A-|t-t'|]\frac{dt}{A^2}. \tag{6}$$

However, the alpha could have been emitted at some other time satisfying $(t-A)\leqslant t'\leqslant(t+A)$ and still have its pulse arrive at the discriminator at time t. Thus, the probability of receiving a pulse at the discriminator from channel No. 2 between t and $t+dt$ is given by

$$d\alpha=\int_{t-A}^{t+A}d^2\alpha. \tag{7}$$

We now assume a triangular distribution of half-width B for the electron pulse variations in counter No. 1 given by

$$d\beta=[B-|t-D|]dt/B^2. \tag{8}$$

Since the electronic resolving time, R, is small compared to A and B, the probability of a coincidence with a relative delay setting, D, is given by

$$C=2R\int d\alpha d\beta. \tag{9}$$

The limits are determined by the fact that the electron pulse in channel No. 1 certainly arrives at the discriminator between $D-B$ and $D+B$. However, in setting up the limits it must also be remembered that the alpha is never emitted before the electron. Thus, the limits must be determined for various ranges of D and the corresponding integral found.

For large values of D, such that $D\geqslant(A+B)$, we find, on integration of Eq. (9), that the coincidence rate is:

$$C=\frac{8Re^{-\lambda D}}{\lambda^3A^2B^2}(\cosh\lambda A-1)(\cosh\lambda B-1). \tag{10}$$

Equation (10) shows that the coincidence rate decreases exponentially with delay for large values of delay. This is the important result of the theory, since it permits a direct measurement of the half-life of ThC' from data for large delays. For smaller delays the calculation of C is straightforward, but tedious, and will not be given here.

The shape of the curve is determined by A, B, and λ, where $\lambda=0.693/T$. A has already been determined to be 2.9 cm of delay (1.10×10^{-7} sec.) from Fig. 1. Plotting data for large values of D gives a value of 0.1195/cm (3.15×10^6/sec.) for λ. Since B could not be determined, a value of 10.0 cm (3.80×10^{-7} sec.) was chosen for B. From other work at this Laboratory, this value seems reasonable, and in any event the shape of the curve is not strongly affected by small errors in B.

Using these values of the constants, Fig. 2 was plotted and compared with experimental data. The fit is seen to be fairly good. The half-life of ThC' is found from the straight-line portion of the curve, covering four half-lives, to be 5.8 cm (2.21×10^{-7} sec.). The writer feels that the slope can be determined to within 1 cm over four half-lives, giving a probable error in the half-life of 0.25 cm.

CONCLUSION

The radioactive decay constants of ThC' thus determined using a delayed coincidence technique are found to be:

$$T=(2.2\pm0.1)\times10^{-7}\text{ sec.}$$
$$\lambda=(3.15\pm0.14)\times10^6/\text{sec.}$$

These results agree with earlier measurements but are thought to be more accurate.

From the theory developed above it is seen that the present circuit cannot be used to measure nuclear time intervals much less than 10^{-7} sec., because of the then relatively large effect of variations in pulse formation.

In conclusion the author wishes to express his thanks to Professor H. L. Schultz and Professor E. R. Beringer for suggesting this problem and allowing the author the use of their equipment. It is also a pleasure to acknowledge a fellowship grant from the Swarthmore College Chapter of Sigma Xi during part of this work.

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Observation of the Ferro-Electric Barkhausen Effect in Barium Titanate

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Conductivity pulses were observed immediately after a single crystal of barium titanate was placed in an electric field, but died out in a few seconds. Several experiments were designed to test the hypothesis that these pulses were caused by the Barkhausen effect. From the experiments, the volume of a Barkhausen region and the apparent velocity of a domain wall could be estimated.

WHEN a single crystal of barium titanate grown by B. Matthias[1] was placed between electrodes and inserted in the equipment used by Wooldridge, Ahearn, and Burton[2] for the observation of alpha-conductivity in diamond, it was found that conductivity pulses appeared immediately upon application of an electric field, even when no alpha-radiation was present. These pulses were quite large, and did not die out for some seconds after application of the field. They were almost all in the same direction; this direction reversed when the direction of the applied field was reversed. Perhaps one pulse in a thousand was in the wrong direction.

In order to observe this effect, it is necessary that the crystal be in a vacuum (about 10^{-2} mm). At atmospheric pressure, application of the required field gives rise to a large amount of noise, which drowns out the effect described above. This noise is readily distinguishable experimentally from the effect in question, since the former does not die out with time.

Polarizing microscope studies[3] had shown that the barium titanate crystal used had domain structure, and that, upon application of an electric field, favorably oriented domains grew at the expense of less favorably oriented ones. It therefore seemed reasonable to assume that the pulses observed were a manifestation of the ferro-electric analog to the well-known Barkhausen effect.[4] This analog has been observed for rochelle salt by Mueller,[5] and has been postulated to account for discontinuities in hysteresis loops[6] of potassium dihydrogen phosphate and barium titanate.

In order to identify the effect conclusively, we undertook the following series of essentially qualitative experiments: (a) a measure of the largest conductivity pulses, (b) a measure of the total charge transferred by all the pulses following an application of field, (c) a measure of the duration of the individual pulses, that is, the length of time during which charge is moving, and (d) a search for a Curie point (suggested to the authors by G. C. Danielson), that is, a

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