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The Beta Rays of Thallium 204

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Abstract. The β-spectrum of ^{204}Tl has been measured using thin evaporated sources in a spheroidal field β-spectrometer. The end-point was found to be at 766 ± 2 kev. Small deviations were found from the unique shape of spectrum predicted for a first-forbidden transition with a spin change of two units. The deviations extend up to about 400 kev.

The possibility that the decay is second forbidden and that the ground state of ^{204}Tl has even parity is noted.

§ 1. Introduction

The β-decay of ^{204}Tl resembles that of radium E in that no γ-transition seems to be present. There is a weak decay by electron capture to ^{204}Hg, which has been estimated by der Mateosian and Smith (1952) to occur in $1{\cdot}5 \pm 0{\cdot}5$ per 100 disintegrations. The β-ray end-point has been found by Lidofsky, Macklin and Wu (1952), using a magnetic spectrometer, to be at 765 ± 10 kev, in agreement with the 766 ± 2 kev found in the present work. They concluded that the spectrum shape agreed with the theoretical shape for a first-forbidden transition with a spin change of 2 units and a parity change. There was, however, an excess of β-rays below 150 kev which is not explained because the theoretical shape is definite and cannot be adjusted. The present measurements do not extend to low energies but they show a small excess of slow β-rays which can be traced to energies as high as 400 kev.

Smith (1952) has shown that this shape of spectrum can be explained as a second-forbidden transition with a spin change of two units and no parity change, because contributions from several matrix elements can be adjusted to fit a variety of shapes. Both these degrees of forbiddenness give the ground state of ^{204}Tl a spin $I = 2$. A state of odd parity can easily be explained on the shell model by, for example, assigning the odd proton and odd neutron to $s_{1/2}$ and $f_{5/2}$ states, respectively. The difficulties of explaining a state of even parity are considerably greater.

§ 2. Preparation of Sources

The spectra were obtained from disc sources of 2 mm diameter made by condensation *in vacuo* of thallium on to 40 μg cm^{-2} nylon films which had been painted with an almost invisible layer of colloidal graphite to prevent source charging. The condensed deposits were transparent and had a metallic lustre, and their uniformity was verified by traversing a small aperture across each source and counting the collimated β-rays which passed through. The deposits were protected by thin covering films of formvar about 10 μg cm^{-2} in thickness. The metal was prepared by electrolysing a sulphate solution made from 100 mg of active Tl_2O_3 supplied by Atomic Energy of Canada Ltd.

The source thicknesses were estimated roughly on the assumption that the specific activity of 100 mc g^{-1} quoted by the suppliers was correct. One estimate was made by counting the total β-activity of the source over a known solid angle, and this value was checked by comparing the area of the β-spectrum found in the spectrometer with the area found for the F-line of thorium B from a source of the same diameter. The absolute intensity of the thorium (B + C) source was found by counting the α-rays with a thin-window proportional counter.

The thicknesses found for the sources A and B were 0·11 and 0·028 mg cm^{-2}. These figures should be multiplied by a path factor of sec 74° (3·63) to allow for the increased path in the source due to the small glancing angle between its surface and the focused sheaf of β-rays.

§ 3. The Spectrometer

A spheroidal field spectrometer was used with the baffles placed in the positions illustrated elsewhere (Richardson 1952, figure 1 B). The selected sheaf of rays was emitted at a mean angle of 74° to the axis of the spheroid. The ring-slit of 9 cm radius was 1·7 mm wide, giving a resolution of 3 %.

The ring window round the Geiger tube was covered with nylon of 0·3 mg cm^{-2} and the filling mixture was alcohol vapour (at about 1·5 cm pressure) and argon (added to a total of 11 cm). The magnetic field was measured by a spinning coil mechanism similar to that of Hedgran, Siegbahn and Svartholm (1950) using the centroids of the A, F and M lines of Th (B + C + C″) for calibration.

§ 4. The Spectra

The values of $y_1 = k_1(N/f)^{1/2}$ and $y_2 = k_2(N/fC_{1T})^{1/2}$ are plotted in curves 1 and 2 of the figure against ϵ, the electron energy (including rest energy) in units of $mc^2 = 510{\cdot}96$ kev. N is the number of β-particles found per second in a momentum interval of fixed width and k_1 and k_2 are convenient normalizing constants. Values of f were taken from the U.S. National Bureau of Standards Tables (1952). C_{1T} is the correction factor of Konopinski and Uhlenbeck (1941) for a first-forbidden transition with $\Delta I = \pm 2$, in which only the matrix element $\Sigma_{ij} B_{ij}$ can contribute.

$$C_{1T} = \sum_{ij} |B_{ij}|^2 \left(\tfrac{1}{12} L_0(\epsilon_0 - \epsilon)^2 + \tfrac{3}{4} L_1\right)$$

$$L_0 = \frac{g_0{}^2 + f_{-2}{}^2}{2p^2F} \; ; \qquad L_1 = \frac{g_1{}^2 + f_{-3}{}^2}{2p^2F\rho^2} .$$

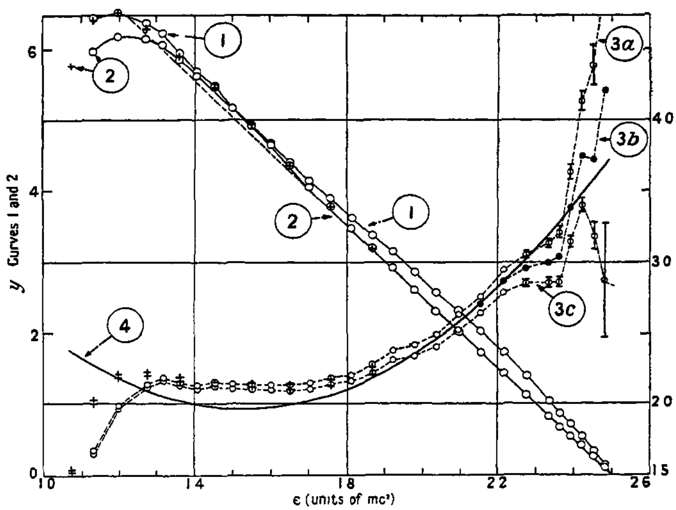
Values of L_0 and L_1 were obtained from the tables of Rose, Perry and Dismuke (1953). L_0 varies slowly with ϵ and differs slightly from the approximation $(1 + S)/2$ used in the explicit formula of Konopinski and Uhlenbeck for C_{1T}.

By fitting a straight line to y_2 by the method of least squares, using the points above 450 kev weighted inversely as their squared statistical errors, the end-point is found at $\epsilon_0 = 2{\cdot}4992 \pm 0{\cdot}002$ ($W_0 = 766 \pm 1$ kev). The probable errors are computed from the deviations from the straight line, assuming the momentum calibration to be exact. Errors in the calibration would perhaps increase the probable error to ± 2 kev.

In curves 3 and 4 of the figure the deviation from the C_{1T} type of spectrum is shown by the more sensitive method of plotting against ϵ.

$$y_3 = k_3 N/f(\epsilon_0 - \epsilon)^2 \qquad \text{and} \qquad y_4 = k_4 C_{1T}.$$

y_3 depends on the choice of ϵ_0 and is plotted for the three values 2·505, 2·501 and 2·4972. In y_4 the value chosen for ϵ_0 is 2·500.



Energy spectra : curve 1, $y = k_1(N/f)^{1/2}$; curve 2, $y = k_2(N/fC_{1T})^{1/2}$. Correction factors : (*a*) unique first-forbidden factor, curve 4, with $\epsilon_0 = 2{\cdot}50$, $y = k_4 C_{1T}$; (*b*) experimentally observed factors, curves 3*a*, 3*b* and 3*c*, $y = k_3 N/f(\epsilon_0 - \epsilon)^2$ with $\epsilon_0 = 2{\cdot}4972$, 2·501 and 2·505 respectively. Circles : source A, 0·11 mg cm^{-2}. Crosses : source B, 0·028 mg cm^{-2}.

§ 5. Discussion

The experiments show more β-rays between 400 kev and 100 kev than are predicted by the C_{1T} spectrum. The fall in the curve below 100 kev is due partly to window absorption and partly to source absorption. The latter must be present because the fall is greater than that found by Saxon (1951) for window absorption in nylon.

It seems unlikely that the small surplus of β-rays above 200 kev can be due to back-scattering or source thickness distortion because the sources A and B gave similar spectra above 250 kev. However, there is a little uncertainty due to the presence of the covering film and to the unusually low glancing angle of emission. The surplus of β-rays never exceeds 5%, so that its reality, which would indicate second forbiddenness, is not established beyond final question.

Second forbiddenness would require the ground state of ^{204}Tl to have even parity, which would be unusual for a heavy odd–odd nucleus in which the odd neutron and odd proton normally belong to configurations of opposite parity.

Another puzzling feature of the ^{204}Tl β-decay is the apparent absence of β-excitation of the 374 kev 2+ level of the daughter nucleus ^{204}Pb. This has been discussed by de Shalit and Goldhaber (1953). These authors and Bohr and Mottelson (1953) note that the long γ-ray lifetime of the 2+ state of ^{204}Pb suggests that it is a nearly pure neutron state in which the protons bound in the stable 82 shell are not excited. A β-decay to such a state would be very weak. Support for this view of the 2+ state has been obtained by Frauenfelder, Lawson and Jentschke (1954), who find its magnetic moment to be very small.

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