greater distance than, e.g., 10 meters so that the particles constituting the showers are unaffected by the additional layer of 10 cm of lead.

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On the Beta-Particle Spectrum from the Decay of Tritium

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In an earlier letter we presented[1] unreduced data relative to the beta-particle spectrum from the decay of tritium; these data, taken from tracks of the beta-particles in a cloud chamber, were in the form of a differential distribution of plane-projected track lengths. A reduction of these data has now been completed, with the following interesting results.

By numerical solution of the rather complicated relevant integral equation, a differential distribution of true track lengths was obtained; this, after consideration of the small effects of straggling, was converted to a differential energy-distribution; finally, this last distribution was compared in the standard way with the theory of Fermi.[2] Extrapolation of the linear portion of the Fermi plot indicated an end-point energy which is 1.222 times that shown by the initial distribution of projections; this extrapolation was based upon the statistically satisfactory portions of the data, so the extrapolated end-point can be determined by the energy-range relation of von Droste.[3] Thus the cloud-chamber data now lead to an extrapolated end-point energy of $14.0\times1.222=17.0$ kev, which is in extremely good agreement with the 16.9 kev recently obtained[4] by Curran, Angus, and Cockcroft.

Figure 1 shows the distribution of energy in the decay of tritium, as determined by both experiments, on the assumption that both experiments indicate the same end-point energy. Although there are statistical limitations to the precision of the cloud-chamber data at energies near the end point, and observational limitations at very short ranges (both of which could be considerably reduced by obvious means), the agreement between the results of the two experiments, at energies between 6 and 13½ kev, is remarkably good. This agreement, incidentally, has a significant bearing upon the results reported recently[5] on the low energy portion of the beta-particle spectrum from the decay of RaE, for the RaE data were obtained with the same apparatus and the same detailed techniques, except that $Bi^{210*}(CH_3)_3$ was the molecule instead of tritiated water.

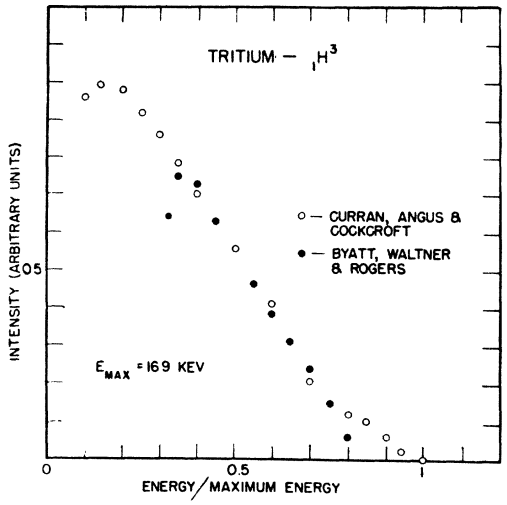

Fig. 1. Distribution of energies in the beta-decay of tritium.

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The Gamma-Rays Following Au^{198} β-Decay

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The question whether the decay of Au^{198} is simple or complex has been pointed up by much recent work in the literature. Levy and Greuling,[1] from spectrometer measurements, have proposed a complex decay scheme wherein ~15 percent of the transitions emit a β of 0.605 Mev, and γ's of 0.157 and 0.208 Mev. DuMond, Lind, and Watson,[2] by absorption in Sn, found low energy γ's in ~15 percent ratio to the precisely measured 0.4112-Mev γ-ray. These low energy γ's could explain the γ-γ coincidences of many recent measurements.[3,4]

In a spectrometer measurement of the β-shape Saxon[5] found the spectrum allowed down to 0.2 Mev, but no systematic search for the low energy γ's was made. Wilkinson and Peacock[6] also report a simple spectrum, while Jurney and Keck[7] found no γ-γ coincidences.

In view of the above conflicting measurements, it was decided to rerun the Au spectrum, with particular care in looking for low energy internal conversion lines from the 0.157- and 0.208-Mev γ's. The same source material used previously[5] was reactivated in the Argonne heavy water

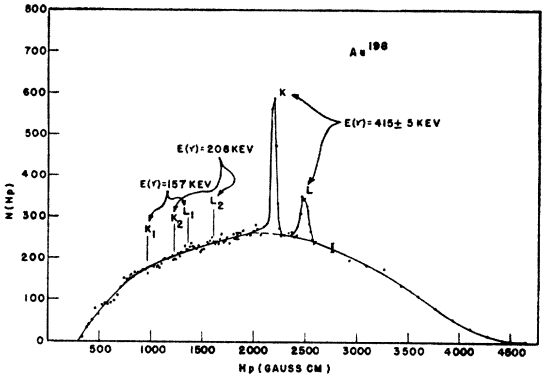

FIG. 1. The β-ray spectrum of Au^{198}.

pile. The final source was ~3 mg/cm², mounted on 0.5-mg/cm² Nylon. The counter window, as before, was 0.3-mg/cm² Nylon, while the resolution $\Delta H\rho/H\rho$ was 2 percent.

The momentum plot of the resulting spectrum is given in Fig. 1. The K and L lines of the high energy γ give 415±5 kev, close to the precision value of DuMond *et al.*[2] From the areas under the peaks and curve we get the following conversion coefficients, correction having been made for the window absorption at low energies:

$$\frac{E(\gamma)}{415\text{ kev}}\ \frac{K}{3.50\%}\ \frac{L+M}{1.30\%}\ \frac{K+L+M}{4.80\%}\ \frac{K/(L+M)}{2.69}.$$

The spin change of the γ can be estimated from the K/L ratio, assuming the M contribution to be a small part of the L peak. Extrapolating the theoretical curves of Hebb and Nelson[8] to high Z, for electric multipole radiation, the spin change is found to be $\Delta l=3$. The value of 4.80 percent for the total conversion coefficient agrees well with that of 4.70±0.24 percent determined by Wiedenbeck and Chu[3] using an entirely different method. As to the 0.157- and 0.208-Mev γ-rays, there is no sign of a conversion line at either the K or L positions. From the statistical errors in this region of the spectrum, it is possible to estimate an upper limit for the presence of the low energy γ's, after making some reasonable assumptions as to their conversion properties. If both γ's were electric dipole, then conversion coefficients of ~5 percent would be expected from Hulme's[9] theoretical data. This leads to an upper limit of ~4 percent for the presence of the γ-rays. Similarly, for electric quadrapole radiation, using the theoretical curve of Taylor and Mott,[10] this upper limit is decreased to ~1 percent. It is clear that γ's present in 15 percent ratio to the β's, would be easily detected even with conversion coefficients as low as 1 percent.

The only reasonable conclusion seems to be that the low energy γ's are associated with an impurity. Mitchell, in a communication to DuMond,[2] has suggested that this impurity is mercury. An analysis of our samples by F. Tompkins' group shows <0.01 percent Hg and Pt.

Jnanananda[11] found a conversion line at 58.4 kev, $H\rho=837$ gauss cm, which was interpreted as an Auger electron due to the 70.3 kev Hg Kα x-ray converting in the L_{III} shell of Au^{198}. We do not find this line in our curve, even though the window is thin enough to let most of the continuous β's through at the line energy. If we use our value of 3.50 percent for the K conversion coefficient of the 411-kev γ-rays, and assume a value of ~0.9 for the fluorescence yield of the Hg K level, the expected yield of the Auger line is ~0.35 percent of the continuous β-spectrum. This value is about the limit of our sensitivity, indicating why the line was not found.

The previous value for the Au^{198} half-life,[5] 2.66±0.01 days, has been raised slightly, after recalculating some of the background corrections. Our final value is 2.69±0.02.

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Coherent Scattering of Radiation and Negative Energy States

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FOLLOWING Dirac,[1] it has been generally[2] accepted that in the absence of real pairs, the theoretical expressions for the scattering cross section are identical, whether negative energy states are assumed to be free or occupied. On the basis of this reasoning Waller[2] calculates the scattering cross section of neutral atoms assuming the negative energy states to be unoccupied, and then claims that his results apply equally to the case of occupied negative energy states (hole theory proper). Heitler[2] reports in detail the proof originally given by Dirac that the matrix elements in both versions of the theory are identical; for every matrix element of a transition leading from a state of positive energy through an intermediate occupied state of negative energy to a final state of positive energy, there exists an *identical* matrix element of a transition starting from the (previously intermediate) occupied state of negative energy and leading to the final state of positive energy, while the second part of the transition leads from the initial state of positive energy to the vacated state of negative energy.

This theorem is obviously true for phenomena like the Comptom effect, where the final state differs from the initial state of positive energy. But it is equally obvious, though so far overlooked, that the theorem cannot apply, e.g. to coherent scattering processes in which the initial and final state are the same. In this latter case, the transition from the negative energy state to the final state is as impossible as the transition from the initial state of posi-