YIELD OF ELECTRONS FROM GAMMA-RAY BOMBARDMENT

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The absolute yield of electrons produced by 2.62 Mev γ-quanta in an aluminum target of effective thickness is determined experimentally and computed theoretically.

INTRODUCTION

VARIOUS experimenters have studied the relative yield of electrons emitted in bombardment with γ-rays of different energies of targets of various materials[1-8] having an effective thickness.* At the same time, there are actually no data in the literature on absolute values of these yields. Papers on the determination of the efficiency of cylindrical γ-counters, for example that of Bradt et al.,[9] do not give such data directly† since the broad divergent beams used in these experiments lead to a multiplicity of angles of incidence of γ-rays on the walls of the counter (from 0° to 90°). As is well known, this gives a comparatively complicated relation between the value of the counter efficiency obtained and the yield of electrons from a flat target of the same material which is, instead, irradiated by a beam along the normal.[10]

Since data on relative yields are available, it is sufficient to determine the absolute yield for any one material at one γ-ray energy, in order to convert to absolute values for other materials and energies. The present paper is devoted to this problem.

Aluminum was chosen as the target material and the yield of electrons was determined for the hard component of the radiation from ThC″ (2.62 Mev). The quantity to be determined was found by experimental and computational methods.

COMPUTATION

Let us consider an aluminum target of infinite thickness (cf. Figure 1), where A-B is the front face at which the γ-rays enter, and a-b is a plane parallel to this face at a distance r from A-B. The general expression for the flux through

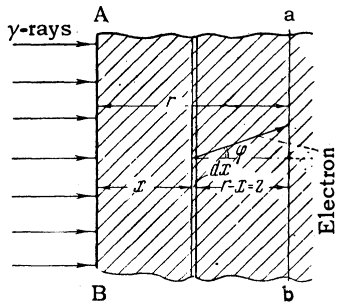

FIG. 1.

the plane a-b of electrons with initial energy in the interval from E to E + dE, which are produced in the elementary layer dx at distance x from the front face of the target is

$$dN = \sigma e^{-\sigma x} D(E)_\alpha f\left\{E, \frac{r-x}{\cos\varphi(E)}\right\} dx\, dE, \qquad (1)$$

where σ is the linear Compton scattering coefficient, $D(E)_\alpha$ is the energy distribution function for the Compton electrons for a given value of $\alpha = E_\gamma/mc^2$, and is given by the Klein-Nishina formula; $f\{E, (r-x)/\cos\varphi(E)\}$ is the function which gives the probability that a Compton electron emerging at an angle φ (relative to the initial direction of the quantum) will penetrate to depth $r-x$ in the target. For this function we took the experimental curves for absorption of monochromatic electrons of various energies in aluminum,

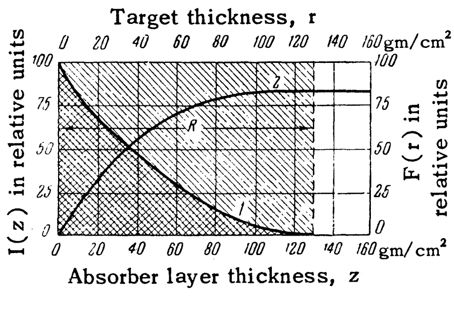

FIG. 2. Results of integration of expression (1). 1 – I(z) (ordinate scale on the left); 2 – F(r) (ordinate scale on the right).

*I.e. a target thickness of the order of the range of the secondary electrons of maximum energy.

†This is the case even when one takes into account the yield of electrons from the back wall, using for example the data of Hine.[7]

which were obtained by Sinel'nikov, Val'ter et al.[11]

To find the total flux of electrons passing through the plane a-b, expression (1) was integrated over the whole range of energies and then over x. The integration was done numerically. The result is shown on an arbitrary scale in Fig. 2. The first integration gives the curve I(z), where $z = r - x$ (cf. Figure 1). This is just the absorption curve of the electrons produced in the layer dx. The second integration gives the curve F(r),* which shows the dependence of the flux of electrons through a-b on the distance from the front face, or in other words, the dependence of electron yield on target thickness.

It is not hard to see that the ratio of the area under the curve I(z) to the total area of the shaded rectangle gives the ratio of the electrons emitted from the back face of a target of effective thickness to the total number of Compton electrons formed in the body of the target. Denoting this ratio by ξ, we determine η — the number of electrons per quantum incident on the target, from the simple relation

$$\eta = \xi\sigma R,$$

where R is the effective thickness of the target. Taking $R = 0.048$ cm (cf. Figure 2), $\sigma = 0.098$,[12] and substituting the value of $\xi = 0.33$ found from the graph, we get finally

$$\eta = 1.6 \cdot 10^{-2} \text{ electrons}/\gamma\text{-quantum}.$$

EXPERIMENTAL DETERMINATION OF η

For the experimental determination of η, a special aluminum counter tube was prepared. Its construction is shown in Figure 3. In the middle of the body of the counter, on the outer wall, there is a cylindrical projection 13 mm in diameter. The wall thickness of the tube at the position of the projection is 6 mm, i.e., a little greater than the effective thickness. There is a fine channel 1 mm in diameter at the center of the projection, and its outer end is covered by a thin (30 μ) cellophane window. In the diametrically opposite wall of the tube there is a circular opening 15 mm in diameter, also covered with cellophane. A constant pressure of 40 — 60 mm Hg was maintained in the tube, and the operating voltage was 2000 V. The tube plateau was 40 — 50 V, which is entirely adequate.

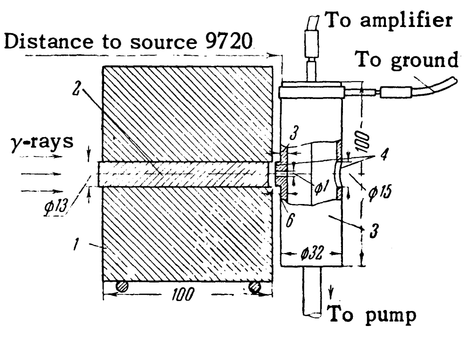

FIG. 3. Counter tube with lead collimator-shield. 1) Shield, 2) collimator channel, closed by lead plug, 3) counter tube, 4) cellophane windows. All dimensions given in mm.

*The factor $\exp\{-\sigma(r - x)\}$, which is unimportant for the thicknesses used, was set equal to unity.

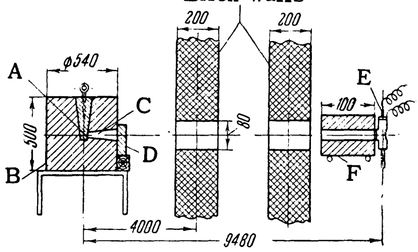

FIG. 4. Arrangement of apparatus (dimensions in mm).

The overall geometry of the experiment is shown in Figure 4. The source A (RdTh with an intensity of 896 ± 20 mC) was placed in the lead container B at a distance of 948 cm from the center of the tube. The preliminary collimation of the γ-rays was done by the channel C in the container and a pair of brick walls with 80 mm diameter holes. The radiation was filtered by a 5 cm lead filter D at the exit of the channel C. In front of the counter tube E we placed the main collimator F, consisting of a lead shield 100 mm thick, with a cylindrical channel whose cross section precisely matched that of the projection on the tube (13 mm diameter). The channel could be closed throughout its length by means of a tight-fitting lead plug (cf. Figure 3).

The experiment was carried out as follows. A small lamp was placed at the position of the source, and its light was used to align the whole apparatus visually, so that the source, the axis of the channel in the shield, the projection on the tube and the cellophane window opposite it were in a straight line. With the shield channel closed by the lead plug, we measured the tube background and the effect of scattered radiation from the source. Then the plug was removed, and the collimated beam of γ-rays passed through the projection into the counter tube and emerged from it through the cellophane window. The excess count thus obtained above the effect of background and scattered radiation was attributed to electrons produced in the tube by the γ-rays. The effect of the action of the γ-rays on the rear cellophane window was assumed to be equal to zero.

Three series of measurements were made, with repeated counting of background and effect. Between series of measurements the apparatus was readjusted to eliminate possible systematic errors resulting from inexact alignment. The measurements gave the value

$$\eta = 1.3 \pm 0.2 \cdot 10^{-2} \text{ electrons/quantum}.$$

Here it is assumed that only quanta with energy 2.62 Mev are effective.* This result is in satisfactory agreement with the computed value.

From this value and the data of Hine[8] we can compute, for example, the absolute values of the yields of electrons per 2.62 Mev quantum for other materials (cf. the table).

Yield of electrons per quantum of energy 2.62 Mev for various materials

Element	Atomic number of element	Relative yield according to Hine	Absolute yield (electrons/quantum) × 10^2
C	6	2.1	1.6
Al	13	1.7	1.3±0.2
Cu	29	1.2	0.9
Sn	50	0.92	0.7
Pb	82	1	0.8

Comparing these data with the values found in Bradt's experiments for the efficiency of copper and lead counters for γ-rays of the same energy (1.45 electrons/quantum for copper, and 1.94 ± 0.07 for lead), we see that, as was to be expected, Bradt's data are higher than the values in our table, by factors of 1.6 and 2.4, respectively. This excess is completely reasonable, since in the geometry of Bradt's experiment, there should be an appreciable effect of small angles of incidence in the irradiation of the cylindrical surfaces of the counters, while for the lead counter there is in addition the yield of electrons from the back wall, which is known to amount for lead to about $\frac{1}{3}$ of the yield of electrons from the front wall.[7]

*For the fraction of quanta with energy 2.62 Mev in the spectrum of the radiation, cf., for example, Reference 13.

CONCLUSION

We have made an experimental determination of the yield of electrons from an aluminum target bombarded by 2.62 Mev γ-rays. The value 1.3 ± 0.2 electrons/quantum which was found is in satisfactory agreement with the value 1.6 electrons/quantum which was computed using data from the literature on absorption of monochromatic electrons.

On the basis of these data and values in the literature for relative yields of electrons from various materials at various energies, one can find absolute values of these quantities.

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