Determination of the Branching Ratio in the Disintegration Scheme of Po^{210}

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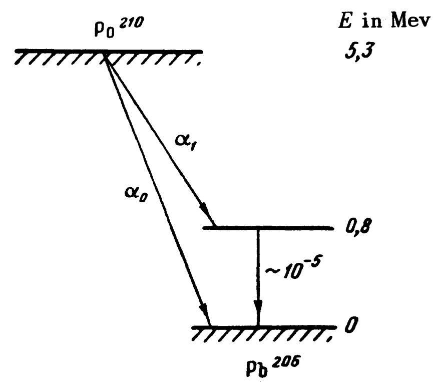
Measurements were made of the branching ratio in the disintegration scheme of Po^{210}. The probability of transition to the excited level Pb^{206} (with an energy of $E = 800$ kev) was found to be $1.2 \pm 0.2 \times 10^{-5}$.

1. FOR a long time after the discovery of Po^{210} it was considered that this radioactive isotope was a monochromatic α – radiator which did not emit any other radiation besides 5.3 mev α– particles. Only in 1930 Bothe and Becker[1], while investigating γ-radiation arising under the action of α-rays from Po^{210}, discovered that the same isotope emits a characteristic, very weak, γ-radiation. A comparison with a Ra standard enabled the authors to obtain a rough evaluation of the absolute amount of this radiation ($\sim 10^{-5}$ quanta/α-disintegration Po^{210}). During succeeding years the radiation of Po^{210} has not been the subject of study by experimental physicists. With the exception of the works of Curie and Joliot[2] and Bothe[3], whose results were not too clear nor reliable, nothing has been published in literature concerning γ–rays of Po^{210} for 15 years following the discovery of Bothe and Becker. The question of γ–radiation from Po^{210} was again raised in 1946 in connection with the publication of the work of Chang[4] who reported that there seems to exist a "thin structure" spectrum of Po^{210}. Chang found in the energy region 3.5 to 5.3 mev 12 lines of intensities from 1.3×10^{-4} to 2×10^{-5} from the basic 5.3 mev line. These results of Chang naturally aroused special interest concerning γ–radiation of Po^{210}, since they contradicted the little information on the intensity and energies of γ–rays from Po^{210} available in physics at that time. There appeared, therefore, after Chang's communication, a series of papers[5-7] on the investigation of energy and intensity of γ–radiation from Po^{210}. It was concluded in these investigations that the energy of the nuclear radiation is 700 to 800 kev and its emission does not exceed 2×10^{-5} γ– quanta/α–disintegration of Po^{210}. That the results of Chang were faulty was proven by the work of Wadey[8] and subsequent experiments of Haissinsky[9]. The appearance of short path α–particles was explained by the diffusion of the Po^{210} atoms in the metal backing.

In recent years there appeared several more papers[10-15] on the study of γ–radiation from Po^{210}, its energy, absolute intensity, conversion coefficients and their relations for different shells. Results obtained by different authors are shown in Table I.

The work of Benedetti and Minton deserves special attention. The authors were first to observe, by means of scintillation counters, short range α–particles coincident with the $\sim$803 kev γ–rays. The difference between the energy of the basic group α–particles of Po^{210} and that of the short range line corresponded, within the limits of experimental error, with the energy of the γ–rays. The shape of the angular correlation curve between the short range alpha-particles and the γ–rays ($I_\gamma \sim A \sin^2 2\alpha$) and the lifetime of the excited state of Pb^{206} ($< 10^{-9}$ sec) indicated the presence of an electric quadrupole γ–transition. Thus we can accept the disintegration scheme for Po^{210} shown in the diagram.



The intensity of γ–radiation from Po^{210} and, consequently the branching ratio in the disintegration scheme of this isotope, were not reliably determined at that time. Results obtained by different authors vary considerably. Thus the following values were obtained: in Ref. 3, 0.8 to 1×10^{-5};

TABLE I

γ– Radiation Po^{20}

Author	Year of the work	Energy E_γ (kev)	Emission n_γ $\frac{\text{quanta}}{\text{disint.}}$	Conversion coefficient	
				α_K (%)	α_K/α_L
Alburger and Friedlander[10] .	1951	800±6		<5	3.7±0.5
Grace et al.[11]	1951		1.80±0.14		
Barber and Helm[12]	1952		1.5±0.4	~12	
Pringle, Taylor et al.[13] . .	1952	804		~20—30	
Benedette and Minton[14] . . .	1952	803 (E_{α_1} = 4500)			
Rioux[15]	1952		1.6±0.2	~9	
Present work	1954		1,2±0,2		
Hayward, Hoppe and Mann[16] . .	1955		1.22±0,06		

in Ref. 11, 1.8 ±0.14 × 10^{-5}; in Ref. 12, 1.5 ±0.4 × 10^{-5}; in Ref. 15, –1.6 ±0.2 × 10^{-5}. From the data of Benedetti and Minton[14] one can obtain the value 0.5 × 10^{-6}. A more or less accurate measurement of the number of γ – quanta in the disintegration of Po^{210} would be of interest from the standpoint of clarifying the multipole nature of this transition, since at the present time no definite conclusion can be made on this question.

2. To determine the value of the branching ratio in the disintegration scheme of Po^{210} it is obviously necessary to determine, in addition to the disintegration rate of any single source of γ – quanta, also the absolute activity (number of disintegrations per second). In the case of polonium preparations of high activity (> 10 to 100 millicuries) the usually employed methods of α–measurements---ionization or impulse chamber and the luminescent counter method---can result in considerable errors not only due to diffusion and migration of active atoms but also due to the absorption of particles in the active layer itself and their reflection from the backing material, appearance of counts of not readily understood origin, etc. Besides, as we have shown, in the case of strong open sources of Po^{210}, chemical-physical processes take place which are apparently connected with the formation of surface films of noticeable thickness. This phenomenon can distort to a considerable degree the values of activity for polonium sources obtained by the above-mentioned methods. A comparison, carried out by us, of results of measuring activities of a series of strong Po^{210} sources in the calorimeter, in a luminescent arrangement and in an impulse chamber of a small solid angle, showed that α – measurements by the last two methods can give considerable errors reaching sometimes 30 to 50%. It is possible that the inaccuracy in the determination of the polonium content in the source is the cause of the diversity in the data on emission of γ – quanta from Po^{210} mentioned above.

3. The source used by us was a preparation of pure Po^{210}. Absence of any noticeable radioactive impurities was confirmed by long time (eight months duration) calorimetric measurements of its disintegration curve as well as of the absorption curve of its γ – radiation in lead. The decrease of the activity of the source also corresponded to the half life of Po^{210} (138.5 days).

The number of γ – quanta emitted by the source in unit time was determined by comparison with a source of Co^{60} of known activity (N_0 = 19.3 ±0.8 × 10^3 disint/sec). These measurements were made with a standard β – counter B-1 with an additional 2 mm aluminum filter. Sources of Po^{210} and Co^{60} were placed at an accurately determined distance from the counter, and the two sources were, in addition, surrounded by 1 mm layer of lead. This was done to remove soft radiation of Po^{210} if present. This radiation, as measurements have shown, is not stopped by the 2mm alluminum filter. The results of two series of similar measurements are shown in Table II. Determination of the absolute activity of the source was made in a double static calorimeter used in the Radium Institute, Academy of Sciences, USSR, for the measurement of absolute activities of radioactive preparations[17].

Results of these measurements are also shown in Table II. In processing the calorimetric data, the quantity of heat emitted by one Curie of Po^{210} in the calorimeter was taken as 32.01 × 10^{-3} watts, or 27.54 m cal/hr[E_{α_0} (Po^{210}) = 5.298 mev; one Curie = 3.7 × 10^{10} disint/sec]. Knowing the ratio

TABLE II

Measurement of γ-Radiation Intensity and Activity of the Po^{210} Source

Date	γ-measurements: Number of pulses per minute N_γ — Po^{210}	Co^{60} standard	$k_0 = \frac{N_\gamma P(o^{210})}{N_\gamma (Co^{60})}$	Calorimetric measurements: Quantity of heat Q, cal/hour	Activity of source N_α, mCu
11.VII				4.19	152.0
12.VII	407±6	402±6	1.013±0.035		
14.VII	427±6	418±6	1.021±0.035	4.15	150.8
2.VIII				3.73	135.3
9.VIII				3.58	130.1
1.X				2.77	100.5
2.X				2.77	100.5

$\bar{k}_0 = 1{,}017 \pm 0.035$ Value of N_α averaged 150.3 mCu for 13. VII

k_0 of the γ-ray intensity of the calibrating source to that of the measured Po^{210} preparation and their absolute activities N_0 and N_α, it was possible to find n_γ---the number of 800 kev γ-quanta emitted from Po^{210} per each α-disintegration. It was thereby necessary to introduce also correction coefficients for the difference in the sensitivity of our counter to γ-radiation from Co^{60} and Po^{210} —k_1; for the difference in absorption of these radiations in the millimeter lead foil surrounding both counters—k_2; and in the 2 mm. aluminum filter—k_3. The experimentally obtained values of these coefficients were equal respectively to: 1.56 ±0.08; 1.043 ± 0.005 and 1.014 ± 0.005, while the value obtained for n_γ was

$$N_\gamma = (2N_0/N_\alpha)\cdot k_0 \cdot k_1 \cdot k_2 \cdot k_3 = 1.16 \times 10^{-5}$$

γ-quanta / α-disint Po^{210}

with a maximum possible error ±14%. Considering the internal conversion of Po^{210} γ-radiation (E_γ = 800 kev) in the K- and L-shells (1.07% [10,18]) and rounding off the value of N_γ and its error we have finally:

$$N = 1.2 \pm 0.2 \times 10^{-5} \text{ γ-transitions/α disint } Po^{210}.$$

The values of the absolute number of γ-transitions in Po^{210}, and therefore the values of the branching ratio in the disintegration scheme of this isotope obtained by us were considerably less than those reported in Refs. 11, 12 and 15. Since the usual ionization or impulse chamber methods were used by these investigators to determine the activity of the polonium source, it was possible that some of the α-particles were not registered, as mentioned above, due to the diffusion of the active atoms into the backing material and absorption in the surface films. This could result in raising the value obtained for the absolute intensity of nuclear radiation from Po^{210}. It should be mentioned that after the completion of our measurements there appeared in print a paper by Hayward, Hoppes and Mann[16] (the results contained in this paper were entered into Table I). The authors, who used a balanced calorimeter to measure the absolute activity of the polonium preparation, obtained a value for the γ-ray emission very close to ours, namely, 1.22×10^{-5}. Measurement of the γ-ray intensity was made by a comparison with a Co^{60} standard, using a scintillation counter with a NaI(Tl) crystal.

In conclusion it should be noted that the values obtained by different authors for the branching ratio in the Po^{210} disintegration scheme do not agree with the deductions of Benedetti and Minton concerning the quadrupole nature of γ-radiation from Po^{210}. Indeed, the penetration ratio for α-particles 5.3 and 4.5 mev and $\Delta j = 2$ computed according to Gamow's theory as 3.2×10^{-5}, is considerably larger than the experimental values for this ratio. The experimental value of the ratio of conversion coeffecients in the K and L shells, $\alpha_K/\alpha_L = 3.7 \pm 0.5$, obtained by Alburger and Friedlander[10] is evidence against the quadrupole nature of the γ-transition in the disintegration scheme of Po^{210}.

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