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A Calorimetric Determination of the Mean Energy of the β-Spectra of P^{32}, S^{35}, Cu^{64}, W^{185} and Au^{198}

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The mean energy $\bar{E}_\beta$ of the β-spectra of P^{32}, S^{35}, Cu^{64}, W^{185} and Au^{198} were determined by the calorimetric method. The following values of $\bar{E}_\beta$ were obtained for the above isotopes,respectively: 693 ± 22; 52 ± 2; 213 ± 12 ; 144 ± 7 and 317 ± 15 kev.

1. THE electrons and positrons emitted during β-decay have a continuous energy spectrum. The mean energy of the β-particles

$$\bar{E}_\beta = \int_0^{E_{max}} En(E)\,dn \Big/ \int_0^{E_{max}} n(E)\,dn \qquad (1)$$

is always less than the maximum value E_{max} and for most β-active isotopes equals 0.3–0.4 E_{max}. The exact values of $\bar{E}_\beta$ are usually found from the spectral distribution of β-electrons, measured with the help of a magnetic or any other β-spectrograph. It should be borne in mind, however, that the experimental investigation of the shape of the whole β-spectrum is difficult, and the spectral distribution obtained can be quite incorrect. The finite thickness of the source and of the counter window, the scattering of electrons from the source mount and from the walls and baffles of the spectrograph, the diffusion of radioactive atoms into the source mount, the electrical charging of the latter, and other causes can markedly alter the shape of the β-spectrum, especially in the low-energy region. The errors of the values of $\bar{E}_\beta$ obtained by this method are in most cases not less than 3–5%

The methods of determination of $\bar{E}_\beta$ with the help of an extrapolation chamber[1] and absorption measurements[2] are as yet unsufficiently developed.

The idea of the calorimetric determination of the mean energy of the β-spectrum lies in the simultaneous measurement of the calorimetric effect Q of the β-radiation and of the number of disintegrations A of the sample. The mean energy $\bar{E}_\beta$ follows from the self-evident relation

$$\bar{E}_\beta = Q/A. \qquad (2)$$

The calorimetric method, notwithstanding its numerous advantages and relative simplicity, has almost not been used. Since the well-known experiments of Ellis and Wooster[3] who measured the mean energy of the β-electrons of RaE*, the mean energy $\bar{E}_\beta$ has been determined by the calorimetric method in the last 25 years for two cases of β-emitters only, namely, for H^3 [6] and P^{32} [7].

We determined the mean energy of the β-spectra of five β-active isotopes: P^{32}, S^{35}, Cu^{64}, W^{185} and Au^{198} using double static calorimeters having a sensitivity of 5×10^{-6} W/mm.[8] The method used is described below in short and the results are

*These classical experiments which played an important role in the formation of the modern theory of the β-decay and the neutrino hypothesis were repeated by Meitner and Ortmann[4], and also by Zlotowski[5]

Results of the calorimetric determination of the mean energy of the β-spectra of P^{32}, S^{35}, Cu^{64}, W^{185} and Au^{198}

Radio-isotope	Decay scheme	E_{max}, kev	Half-life	Original compound	Weight p, grams	Spec. activity $\beta \times 10^{-8}$ $\frac{\beta\text{-particles}}{\text{sec} \cdot \text{g}}$	Cal. effect $Q \times 10^{-6}$ W	Mean energy $\bar{E}_\beta$, kev: Calori-metric	Mean energy $\bar{E}_\beta$, kev: spectro-metric	Mean energy $\bar{E}_\beta$, kev: calc.
1	2	3	4	5	6	7	8	9	10	11
P^{32}	Fig. 3*a*	1700	14.30 days	Na_2HPO_4	3.09008	17.0	581	693±22	675 [9] 698 [10]	695
S^{35}	Fig. 3*b*	167	87.1 days	Na_2SO_4	1.03831	191	165	52±3	49,1 [11]	49.4
Cu^{64}	Fig. 3*c*	571 (β^-) 657 (β^+)	12.8 hours	$CuSO_4$	2,94220	33.2	376	213±12	187 (β^-) 272 (β^+) } 215 [12]	172 (β^-) 273 (β^+) } 206
W^{185}	Fig. 3*d*	428	73.2 days	W	2.64281	21.0	128	144±7	152 [13]	126
Au^{198}	Fig. 3*e*	960 (99%) 290 (~1%)	2.69 days	Au	0.08588	993	504 (β-calorimeter) 1010 (γ-calorimeter)	317±15; $\bar{E}_\beta + \bar{E}_\gamma = 740 \pm 40$	309 [14]	—

given for the above-mentioned isotopes.

2. A known mass of a chemical compound or element, containing radioactive atoms of the isotope in question, was placed in a thin-walled glass or brass container, and its calorimetric effect measured in a calorimeter. The absorption of the β-radiation in the source itself and in the walls of the calorimetric vessel surrounding it was accounted for, as well as the energy of the bremsstrahlung radiation not absorbed in the calorimeter in the case of hard β-rays emitters. In the case of the relatively short-lived isotopes Cu^{64} and Au^{198}, a correction was made for the heat inertia of the calorimeter used.[8] A small mass (10–30 mg) of the radioactive material was weighted carefully and dissolved in a known volume of distilled water or appropriate acid. Sources for absolute and relative β-measurements were then prepared from this solution which contained a known mass of the radioisotope per unit volume. Measurements carried out using a conventional set-up and a T–4 end window counter helped to determine the so-called mean coefficient, which was needed later for the absolute β-activities of certain sources. As a check of the radioactive purity of the sample, the half-life and the β-absorption curve in aluminum were measured using the same set-up.

The absolute β-measurements of the specific activity ρ of the sources (the number of disintegrations per mass unit of the mother radioactive material) were carried out in a special set-up with a predetermined solid angle. The value of the specific activity ρ and of the calorimetric effect Q of a given weight p being known, $\bar{E}_\beta$ could be computed with the help of the following formula:

$$\bar{E}_\beta = qQ/p\rho, \quad (3)$$

where q is a factor equal to 6.24×10^{12} where p is in grams, ρ in disintegrations per gram second, Q in watts and where $\bar{E}_\beta$ is obtained in mev. The accuracy of the measurement of $\bar{E}_\beta$ by such a calorimetric method was limited mainly by the errors of the absolute β-measurements and in our case amounted to 3–6% for different isotopes.

3. The results of the calorimetric determinations of β-spectra mean energy of the radioisotopes P^{32}, S^{35}, Cu^{64}, W^{185} and Au^{198} obtained by us are given in column 9 of the Table. The measured values of p, ρ and Q are found in respective columns.

Since the calorimetric measurements and the absolute β-activity determinations were carried out within relatively long time intervals (usually not shorter than 1–2 half-life periods), mean values of ρ and Q were used in the computations. For this purpose, linear semi-logarithmic plots, based on experimental points, were used (see Figs. 1 and 2 for the cases of P^{32} and S^{35}), the slopes of which were equal to the half-life of the respective isotope. The values of the absolute activities and of the calorimetric effects, needed for the computation of $\bar{E}_\beta$, were taken from these plots, a procedure which tended to reduce fluctuations of single measurements and somewhat enhanced the accuracy of results. The mean values of ρ and Q for a given time are listed in respective columns of the Table. For the case

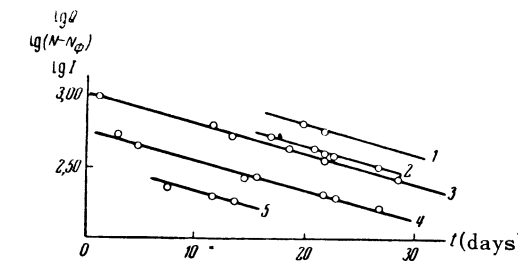

FIG. 1. Measurements of P^{32} samples: *1,2*– measurements of the absolute β-activity of the sources P^{32}II and P^{32} III used for the determination of the specific activity of the original P^{32} preparation; *3*–measurement of the half-life of the sample; *4*-calorimetric measurements; *5*–measurements of the bremsstrahlung radiation intensity with an ion chamber: $N - N_\phi$ is the number of pulses per minute (curves *1*, *2* and *3*), Q is the calorimetric effect (curve *4*), I is the ionization (curve *5*).

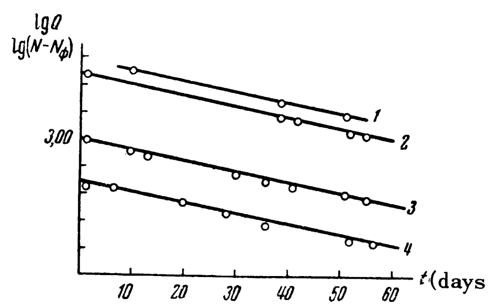

FIG. 2. Measurements of S^{35}: *1,2*–measurements of the absolute β-activity of the sources S^{35} I and S^{35} II used for the determination of the specific activity of the original S^{35} sample; *3* – measurements of the half-life of the S^{35} sample; *4* – calorimetric measurements.

of Au^{198}, the measurements were carried out not only in the thin-walled β-calorimeter, but also in a γ-calorimeter[8], in which the thickness of the walls of the inner cylinders ensured the total absorption of γ-rays up to energies of 700 kev. These measurements made it possible not only to determine the mean energy of the β-spectrum of Au^{198}, but also the total "heat energy" of the decay, equal to $\bar{E}_\beta + \Sigma\, n\gamma\, E\gamma$. This value is also given in the table. The calorimetric measurements in the β-calorimeter as well as the absolute β-measurements of Au^{198} sources with the help of a β-counter were corrected for the 410 kev γ-conversion line, and in the case of Cu^{64} samples K-capture x-rays were accounted for. For comparison, values of mean energies computed by us from the best spectrometric values are given in column 10, and values obtained from the Fermi formula under the assumption of resolved β-spectrum in column 11.

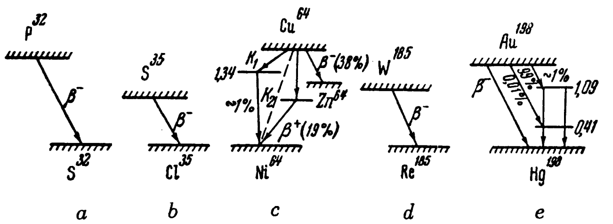

FIG. 3. Decay schemes: a–P^{32}, b–S^{35}, c–Cu^{64}, d–W^{185} and e–Au^{198}

The comparison of these values with our results of the calorimetric determination of $\bar{E}_\beta$ is generally satisfactory. It should be noted that the isotopes worked with were mainly those, the spectrum of which is well known and which corresponded to the case of the resolved β-spectrum.

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