Academician of the Academy of Sciences of the Ukrainian SSR A. P. KOMAR, S. P. KRUGLOV, I. V. LOPATIN, K. F. MUS

1964

SovietRxiv

Abstract

Full Text

Academician of the Academy of Sciences of the Ukrainian SSR A. P. KOMAR, S. P. KRUGLOV, I. V. LOPATIN, K. F. MUS

A Quantometer with Constant Sensitivity for Gamma Radiation with Energy above 15 MeV

Recently the name "quantometer" has become established for a certain type of instrument for measuring the energy in a beam of γ-quanta. It is a multiplate ionization chamber, constructed in such a way that its ionization current is proportional to the area under the transition curve*, determined by one of the approximate-integration formulas. If, in particular, the parabolas formula (Simpson' s formula) is used, then the quantometer must consist of an even number of plates of equal thickness; the odd gaps must be twice as wide as the even ones. A detailed theory and calculation of the quantometer are given in work ([1]).

Initially the quantometer was intended for operation with very hard bremsstrahlung: $E_{\gamma\,\max} > 100$ MeV ([2]). In this energy region its sensitivity remains practically constant and can be calculated theoretically with good accuracy from the formula

$$C = \frac{e}{w\bar{\rho}}\frac{\delta_g}{\delta_z}\frac{\bar{a}}{X_0}. \tag{1}$$

Here e is the electron charge; w is the work of formation of an ion pair in the gas; $\bar{\rho}$ is the ratio of the mass stopping powers of the solid substance and the gas, averaged over the electron spectrum; δ_z and δ_g are the densities of the substance and the gas; $\bar{a}$ is the mean width of the gaps; X_0 is the thickness of the plates.

At lower energies the sensitivity of the quantometer decreases somewhat. As shown in ([3]), this change amounts to 7% in the interval $E_{\gamma\,\max} = 15 \div 90$ MeV, and is due to two main factors: 1) as $E_{\gamma\,\max}$ decreases, the area under the t.c. is integrated by Simpson' s formula with an ever larger error; 2) at low energies the dependence of $\bar{\rho}$ on $E_{\gamma\,\max}$ becomes significant. It follows from this that, in order to reduce the change in sensitivity with radiation energy, one must proceed in two ways. First, the design parameters of the instrument must be chosen so that they ensure a sufficiently accurate determination of the area under the t.c. down to low energies. Second, by an appropriate choice of the filling gas, the dependence of $\bar{\rho}$ on $E_{\gamma\,\max}$ must be reduced to a minimum.

Concerning the first problem, it should be noted that the main error in determining the area is associated with inaccurate integration of the initial segment of the transition curve, characterized by the presence of a maximum; the smoothly

Fig. 1. Schematic design of the tandem quantometer: B—high-voltage electrode; C—collecting electrode

Figure 1: Fig. 1. Schematic design of the tandem quantometer: B—high-voltage electrode; C—collecting electrode

decreasing part of the curve is integrated by Simpson' s formula with $X_0 = 1$ cm quite satisfactorily. Therefore our task will be to choose such an approximate-integration formula that would give the area under the initial segment of the transition curve accurately (say, down to a depth of 3 cm). In doing this one must take into account certain requirements arising from the design features of the instrument and its physical characteristics, namely: 1) under the conditions of mechanical strength, the minimum plate thickness must be $0.4 \div 0.5$ cm; 2) to ensure good accuracy in setting the gaps, their width must be not less than 0.1 cm; 3) so that losses in ionization due to scattering of electrons to the sides are not very substantial, the largest gap must not exceed $0.3 \div 0.4$ cm.

---

* Let us recall that the transition curve (abbreviated t.c.) is the curve showing the dependence of the ionization in a small gas cavity on the position of this cavity in depth in the material; with complete absorption of the radiation beam in the substance, the area under the curve is proportional to the energy of the beam.

Taking these requirements into account, the possibilities of using various quadrature formulas for the quantometer were studied. The analysis showed that the most accurate formulas (Gauss) cannot satisfy these requirements simultaneously. Practically the most suitable proves to be the same Simpson formula, but with a smaller step. For $X_0 = 0.4$ cm

Fig. 1. Schematic design of the tandem quantometer: *B*—high-voltage electrode; *C*—collecting electrode

it integrates the initial portion of the transition curve with an accuracy better than 1%. It is of interest to apply the Gauss or Chebyshev formula in the second region so as, with the same integration accuracy, to use a smaller number of plates. Here, however, this also proves impossible; from the conditions of "joining" with the Simpson formula ($X_0 = 0.4$ cm), the gaps turn out to be inadmissibly large. The use in the second region of the Simpson formula with $X_0 = 0.8$ cm gives, for the largest gap, a value of 0.4 cm.

Thus, the quantometer should consist of two sets of plates of thickness X_0 and X'_0 (as if of two quantometers connected in series*), and the integration should be carried out by means of two Simpson formulas. In both parts of the instrument the odd gaps must be twice as wide as the even ones. From the conditions of "joining"there follows the following relation between the parameters of the quantometer:

Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

$$\frac{X_0}{\bar{a}} = \frac{X_0'}{\bar{a}'} = \frac{X_0 + X_0'}{3a_n} = \frac{X_0'}{3a_N}. \quad (2)$$

It relates the plate thicknesses in the two parts of the instrument, X_0 and X_0', and the corresponding mean gaps $\bar{a}$ and $\bar{a}'$, and also makes it possible, from these parameters, to determine the intermediate (a_n) and last (a_N) gaps. The gap calculated in this way must be increased by some amount Δ to compensate for the energy leakage due to γ-quanta and electrons escaping through the end face of the instrument.

Guided by the considerations indicated above, we developed a new model of the quantometer in which integration of the t.c. should be carried out with an accuracy of up to 1% down to energies of $5 \div 10$ MeV. The main design data of the new model are: $X_0 = 0.4$ cm; $X_0' = 0.8$ cm; total number of plates

* Therefore it may be called a tandem quantometer.

$N = 18$; the number of plates in the first part of the instrument is $n = 8$; the plate material is copper; $\bar{a} = 0.15$ cm; $a' = 0.3$ cm. The additional gap Δ was calculated from the formula $\Delta = \bar{a}/X_0\tau$ (cm, for example, (1)), where τ is the exponent of the exponential decay of the transition curve; $\Delta = 1.5$ cm. The equivalent width of the side gaps, serving to compensate for leakage of quanta through the side surface of the quantometer, is chosen to be the same. A schematic design of the instrument is shown in Fig. 1.

The dependence of the sensitivity of the tandem quantometer on the radiation energy was determined by comparison with a calorimeter; the results are presented in Fig. 2.

Fig. 2. Dependence of the sensitivity of the quantometer on $E_{\gamma\,\max}$ in the case of filling with air. 760 mm, 20°

Fig. 3. Dependence of the sensitivity of the quantometer on $E_{\gamma\,\max}$ when filled with hydrogen. 2.5 atm., 20°

The total change in sensitivity is 3.5% in the interval $E_{\gamma\,\max} = 15 \div 85$ MeV. Theoretical estimates indicate that this dependence is due mainly to a change in the value $\bar{p}$, and therefore a further reduction of it can be achieved by a corresponding choice of the filling gas.

Calculations carried out for various gases showed that hydrogen is the most satisfactory in this respect. With hydrogen filling, the change in the value $\bar{p}$ does not exceed 1% in the range $E_{\gamma\,\max} = 15 \div 85$ MeV; moreover, as the energy decreases, $\bar{p}$ at first increases slightly and then begins to fall, thereby compensating for the change in sensitivity caused by the inaccurate integration of the transition curve.

The results of an experimental determination of the sensitivity of a quantometer filled with hydrogen are given in Fig. 3; to increase the sensitivity, and also to prevent air from entering the instrument, an elevated pressure was maintained in it (2.5 atm.). It is seen that, within the limits of error, the sensitivity may be considered independent of $E_{\gamma\,\max}$ (if such a dependence exists, it does not exceed 1% in the energy interval studied).

For $E_{\gamma\,\max} > 100$ MeV the sensitivity of the tandem quantometer will practically not change up to the highest energies (1 GeV and above), since Simpson's double formula integrates the transition curve with an accuracy to fractions of a percent, and the electron spectrum (and, consequently, the value $\bar{p}$) at such high energies does not depend on the value of $E_{\gamma\,\max}$. Thus, the quantometer described has constant sensitivity for all $E_{\gamma\,\max} \geqslant 15$ MeV.

Regarding the question of the limiting values of the energy fluxes that can be measured, it should be noted that the lower limit is determined only by the accuracy of measuring the ionization current from the quantometer. The maximum permissible value of the flux is governed by saturation conditions and is $5 \cdot 10^{11}$ MeV/sec (0.08 W) and 10^{15} MeV/sec (160 W) for quantometers filled with air and hydrogen, respectively.

Ioffe Physico-Technical Institute
Academy of Sciences of the USSR

Received
23 XI 1963

CITED LITERATURE

1. A. P. Komar, S. P. Kruglov, ZhTF, **30**, 1369 (1960).
2. R. R. Wilson, Nucl. Instr., **1**, 101 (1957).
3. A. P. Komar, S. P. Kruglov, I. V. Lopatin, DAN, **145**, 309 (1962).

Note: Figure translations are in progress. See original paper for figures.