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ENERGY RESOLUTION OF THE PROPORTIONAL COUNTER

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Resolution values 11.6% and 12.2% for 5.9 keV have been obtained experimentally for proportional counters with gas fillings Ne+0.5% Ar or Ar+0.5% C_2H_2. This is appreciably better than earlier measurements which exceed 14%. Theoretical computation indicates that even better resolutions can be obtained.

1. Introduction

The fluctuation of the pulse amplitude in the proportional counter is known, e.g. refs. 1–3, to depend on the variance of primary ionization and gas amplification in the following way:

$$\left(\frac{\delta_P}{\bar{P}}\right)^2 = \left(\frac{\delta_N}{\bar{N}}\right)^2 + \frac{1}{\bar{N}}\left(\frac{\delta_A}{\bar{A}}\right)^2; \tag{1}$$

$\bar{N}$ is the mean number of the primary ion pairs,
$\bar{A}$ is the mean amplification factor,
$\bar{P} = \bar{N}\cdot\bar{A}$ and
$\delta_N, \delta_A, \delta_P$ are the standard deviations of the previous quantities.

The variance of the number of primary ion pairs follows the dependence $(\delta_N/\bar{N})^2 = F/\bar{N}$, where F is a constant characteristic to gases, the so-called Fano-factor[4]). The number of primary ion pairs is determined by another constant specific for the gas, the mean ionization energy $W = E/\bar{N}$, where E is the energy of the quantum that is to be measured. If we write the variance of gas amplification for one electron $f = (\delta_A/\bar{A})^2$, we obtain from expression (1) the well-known fact that the relative deviation of pulses is dependent on the square root of the energy to be measured

$$\frac{\delta_P}{\bar{P}} = \sqrt{\left[\frac{(F+f)\,W}{E}\right]}. \tag{2}$$

The peak width expressed in percentage of maximum is the so-called resolution and in case of a Gaussian distribution it is $236\delta_P/\bar{P}$%. In order to optimize the resolution we naturally have to try to minimize the quantity $(F+f)\,W$.

2. Optimization of resolution

A rather profound analysis of the Fano-factor has been done by Alkhazov et al.[5]). Table 1 lists the Fano-factors and mean ionization energies[5–9]) of the gases which concern this work. Certain gas mixtures, e.g. Ne+0.5% Ar or Ar+0.5% C_2H_2, are especially interesting. In them the excited atoms of the main gas that are born in the absorption of the quantum are able to ionize the atoms of the minor gas. This is the reason for the strongly decreased mean ionization energy and Fano-factor.

TABLE 1

Several gas constants.

Gas	W	F [calc.[5])]	F (exp.)	WF
Ne	36.2 [9])	0.17		6.15
Ar	26.2 [9])	0.17		4.45
Xe	21.5 [7])		≤0.17 [6])	3.66
Ne+0.5% Ar	25.3 [5])	0.05		1.27
Ar+0.5% C_2H_2	20.3 [8])	0.075	≤0.09 [5])	1.52
Ar+0.8% CH_4	26.0 [5])	0.17	≤0.19 [5])	4.42

The statistics of gas amplification have been largely investigated both experimentally[10–13]) and theoretically[14–17]). However, the results are surprisingly meager from the point of view of the planner of the detector. According to Byrne[14]) the minimum of the variance of gas amplification is 0.61. Charles and Cook have drawn the conclusion, based on experimental resolution measuring, that Byrne's limit value is correct within the limits ±3%.

Only Alkhazov[1,17]) has developed a quantitative model for the calculation of the variance of gas amplification as a function of the parameters of the detector. The following conclusions can be drawn from his results:

1) The smaller the gas amplification the smaller its variance. Unfortunately the variance does not decrease to a great extent until the gas amplification is ≲ 10.

TABLE 2
Calculated and measured results.

Gas	f	Resolution calculated for 5.9 keV (%)	Resolution measured for 5.9 keV (%)
Ne	0.45	14.5	
Ne+0.5% Ar	0.38[a]	10.1	11.6
Ar	0.50	12.9	
Ar+10% CH_4	0.50	12.8	13.2
Ar+0.5% C_2H_2	0.43[a]	9.86	12.2

[a] According to Alkhazov the decrease of the variance of gas amplification is estimated at 15%.

2) The product of the gas pressure of the detector and the radius of the anode wire pr_a has to be as low as possible in practical situations.
3) Certain gas compositions increase ionization and decrease the variance of gas amplification from 10 to 20%.

3. The calculated and measured results

In this work the variance of gas amplification is calculated by Alkhazov's[17]) formulas and the results are presented in table 2. The detector parameters used in the calculations are $pr_a = 0.5$ torr·cm and gas amplification $A = 100$.

A number of detectors has been constructed and measured. The measurements have been performed using approximately the same parameter values as in theoretical calculations. The resolution measurements are shown as such without any corrections due to the background or the electronic noise.

4. Discussion

The results show that the extreme resolution of the proportional counter has not been reached, although earlier experimental [2,3,13]) and theoretical[14]) research gives that impression. The better resolution obtained in this work is mainly due to the low-noise, charge-sensitive preamplifiers. They enable the use of gas amplification $\lesssim 100$. Because of the small gas amplification it is possible to use noble gases and mixtures of them without quenching gas. As an additional advantage the longer lifetime of the detector may be mentioned.

The purity of the detector and the filling gases proved to be the most critical technical problem in this work. Ne–Ar and Ar–C_2H_2 compositions are very sensitive to impurities. There is little doubt that sufficient stability of the gas compositions is achieved, if the best modern production techniques are used. The resolutions obtained in this work can still be improved by careful control of the gas impurities and by further decrease of gas amplification.

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