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GAS GAIN IONIZATION CHAMBER

DUŠAN NOVKOVIĆ, ĐURA KRMPOTIĆ*, MILOJKO KOVAČEVIĆ,
RADIVOJ TASIĆ and DRAGICA PALIGORIĆ

Boris Kidrič Institute of Nuclear Sciences, 11000 Beograd, Yugoslavia

**Department of Physics, Faculty of Natural Sciences, 11000 Beograd, Yugoslavia*

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The aim of the investigation was to study the increase of sensitivity of ion chambers operated in the internal gas multiplication voltage range, to specify operating conditions and establish limitations. Amplification factors were determined for a proportional-counter-like device filled with various pure gases and gas mixtures, at different voltages and pressures. There is overall agreement with theoretical predictions for the majority of fillings, except for pure nitrogen and pure argon. The suppression of the gas gain becomes noticeable at exposure rates of about 250 nA/kg and becomes drastic at about 4 μA/kg.

1. Introduction

The gas gain ionization chamber consisting of a proportional counter-like device with the cathode voltage supply and with wire anode connected to an electrometer was studied.

It may be used for various applications. The internal gas gains for diferent gas fillings can be studied more readily and with greater precision by this chamber than by conventional counters.

Its gas gain is greater than 1, and its sensitivity is greater than the sensitivity of standard chambers of the same size. This makes it particulary suitable to low exposure rate measurements.

2. *Experiment*

The ionization chamber assembly consists of a 40 mm diameter 140 mm long cylindrical stainless steel cathode and a 100 μm diameter gold coated stainless steel wire anode protected by guard rings housed in a gas-tight aluminium alloy cylinder[1]. The anode serves as the collector electrode and is connected to a Vibron Model 33C electrometer. Three sources of activity of the order of 40 MBq were used and these were ^{226}Ra, ^{137}Cs and ^{60}Co. Helium, nitrogen, argon and methane fillings were used as well as a 10% and a 20% methan-helium mixture. The purity of used gases was 99.9% or better. The ionization chamber was evacuated to pressures below 0.5 μbar before each new filling. In order to assess the effect of wall degasing, measurements were performed after the chamber was filled by a new gas and 24 hours afterwards. The results were identical except for pure helium which produced curves exhibiting uniform shifts in time.

2.1. *Experiments with pure gases*

The gas gain is defined as

$$A = i/i_0 \tag{1}$$

where i_0 is the ionization current without gas gain and i the current with amplification under identical irradiation conditions. The i/i_0 ratio was measured as a function of the applied voltage at constant temperature. As the current measurement error was estimated at 1%, the gain was established to better than 2%. No increase in the noise current was observed to operating voltages of 3.1 kV. The obtained gain values for some fillings and pressures are presented in Fig. 1. The data were fitted to the Diethorn equation[2]

$$\frac{1}{V}\left(\ln A \ln \frac{r_c}{r_a}\right) = \frac{\ln 2}{\Delta V} \ln \left[\frac{V}{p r_a \ln \frac{r_c}{r_a}}\right] - \frac{\ln 2}{\Delta V} \ln K \tag{2}$$

where A is the gas gain, V is the operating voltage, r_a and r_c are the anode and cathode radii, respectively, p is the pressure, ΔV and K are constants characteristic for the gas used and independent of the gas pressure and the applied voltage.

This expression may be written as

$$\frac{1}{V} \ln A = a \ln \left(\frac{V}{p}\right) - b \tag{3}$$

where a and b are newly introduced constants. The relations (2) and (3) are log-log linear and thus theoretical predictions may easily be verified.

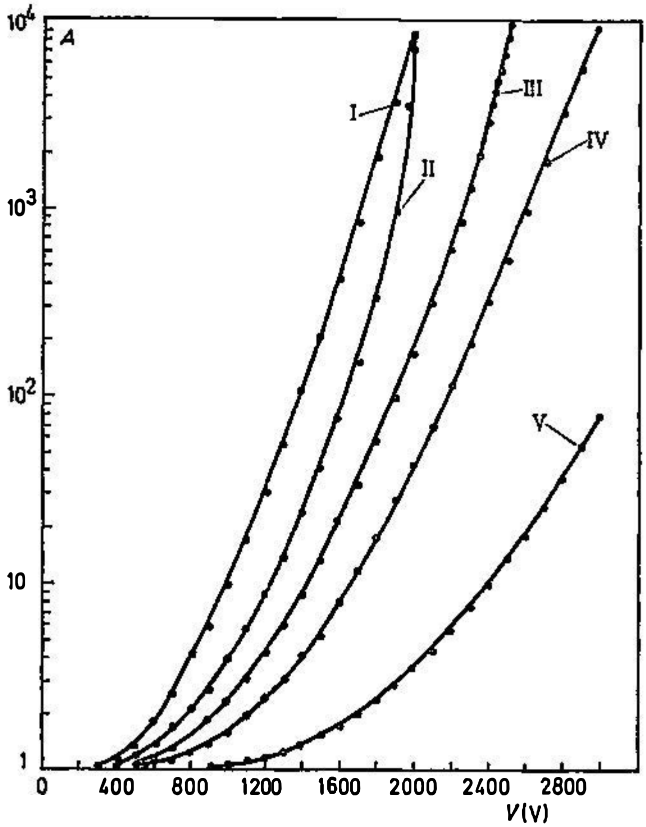

Fig. 1. The dependence of gas gain on the operating voltage for various gas fillings. I — 0.2 CH_4 + 0.8 He; p = 1013 mbar; II — Ar; p = 1013 mbar; III — N_2; p = 1013 mbar; IV — CH_4; p = 587 mbar; V — CH_4; p = 1013 mbar.

The Williams and Sara$^{3)}$ equation was also used to obtain the gas gain

$$\ln\left[\frac{1}{V}\ln A\ln\left(\frac{r_c}{r_a}\right)\right] = -\left(\frac{B_1}{D_1}\right)\varrho\left[\frac{1}{V}r_a\ln\left(\frac{r_c}{r_a}\right)\right] - \ln B_1. \tag{4}$$

Here, B_1 and D_1 are again constants and ϱ is the filling gas density.

As the gas density at constant temperature is directly proportional to the pressure, (4) yields

$$-\ln\left(\frac{1}{V}\ln A\right) = a'\frac{p}{V} + b', \tag{5}$$

where a' and b' are also constants.

In order to determine the values of the constants in (4), measurements were performed with methane at 267 mbar, 587 mbar and 1013 mbar. The obtained data are plotted in Fig. 2. A nonlinearity was observed at low gains that is more pronounced for higher filling pressures. At 267 mbar, the plot is fairly linear for

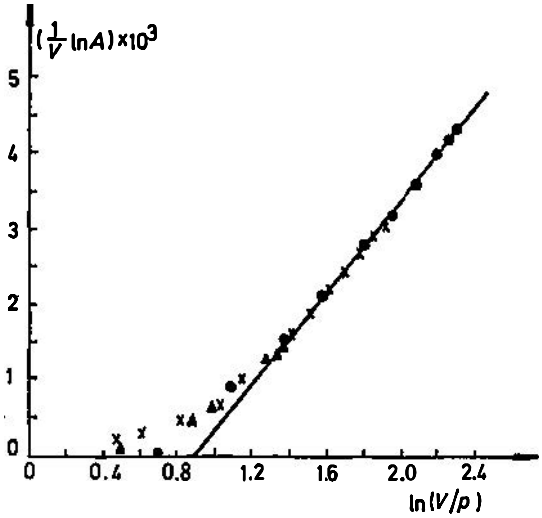

Fig. 2. Methane data compared with Diethorn's prediction — solid line.
● — p = 267 mbar; x — p = 587 mbar;
▲ — p = 1013 mbar; ΔV = 37.5 V.

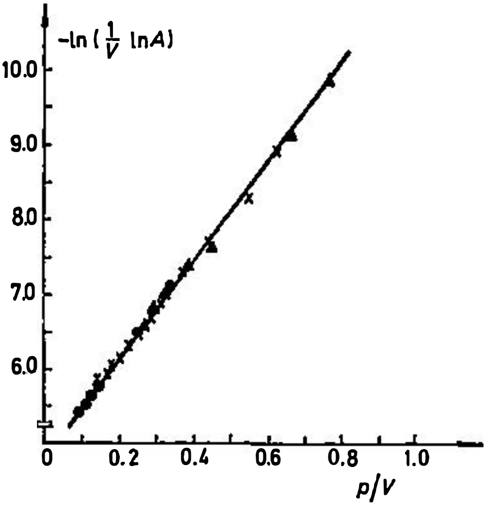

Fig. 3. Comparison of the Williams — Sara theory (solid line) with observed methane data.
● — p = 267 mbar; x — p = 587 mbar;
▲ — p = 1013 mbar.

gains greater than 3, at 587 mbar for gains larger than 8 and at the highest used presure of 1013 mbar, the lower bound of the linear portion is at a gain of 36. It may be said that the experimental data are in good agreement with Diethorn's predictions. This also applies to the value of $\Delta V = 37.5$ V and $K = 6.14$ V/(μmbar m), obtained by fitting the experimental data to the Diethorn equation. The obtained values for these constants are in agreement with the results of Buraei[4].

However, overall agreement with the Williams and Sara equation, including at lower gains, is better as evidenced in Fig. 3. In order to illustrate this, the A_c/A_{exp} ratio is plotted in Fig. 4. Here A_c are the computed gains according to Williams and Sara and A_{exp} are the measured values. No experimental points may be observed above $A = 10^4$ due to current instabilities that hinder measurements.

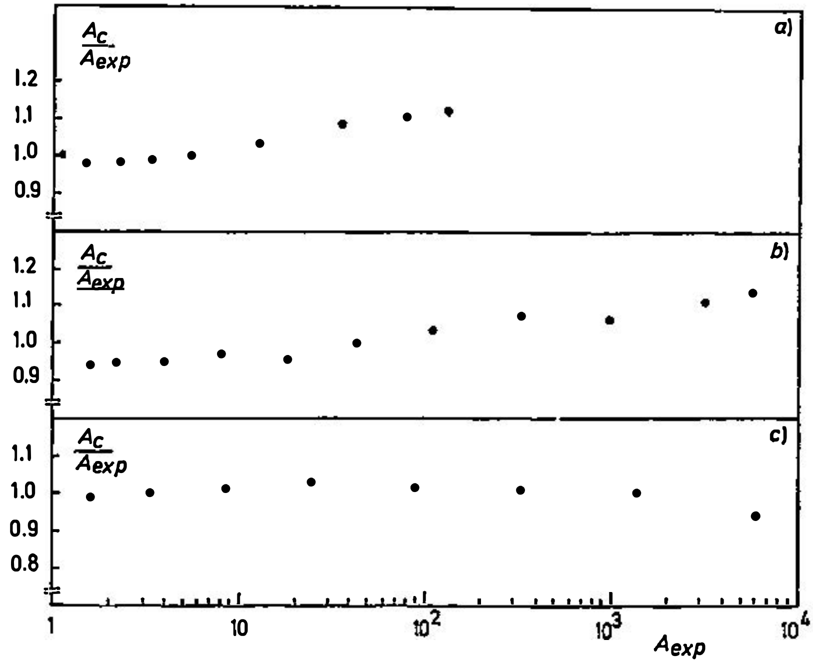

Fig. 4. The dependence of gain ratio A_c/A_{exp} on A_{exp} for different pressures in methane.
a) — $p = 1013$ mbar; b) — $p = 587$ mbar;
c) — p = 267 mbar. A_c — calculated value of the gas gain using Williams — Sara expression, A_{exp} — experimental value.

Data obtained for pure nitrogen and argon could not be fitted to both of the previously discussed equations. The time shifts of characteristics of helium filled chambers are shown in Fig. 5. This is most probably due to impurities that degass from the walls. Helium was obviously very sensitive to the presence of even the smallest amounts of impurities.

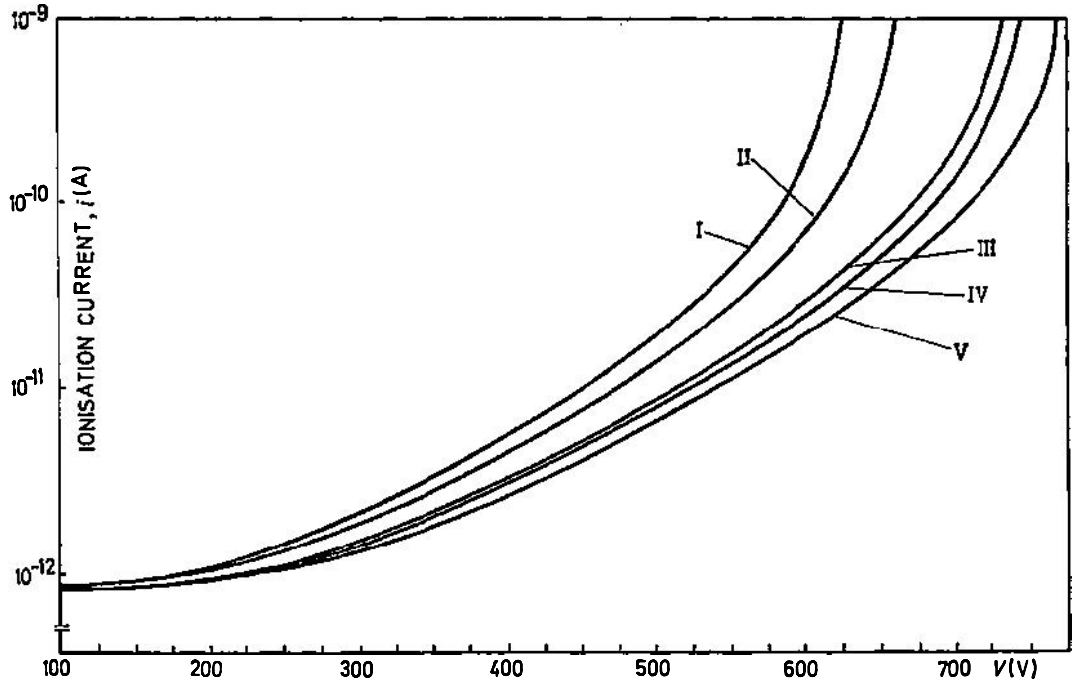

Fig. 5. Shift of the gas gain in helium after filling.
p = 1013 mbar; I — t = 0 h; II — t = 4 h; III — t = 22 h; IV — t = 27 h; V — t = 45 h.

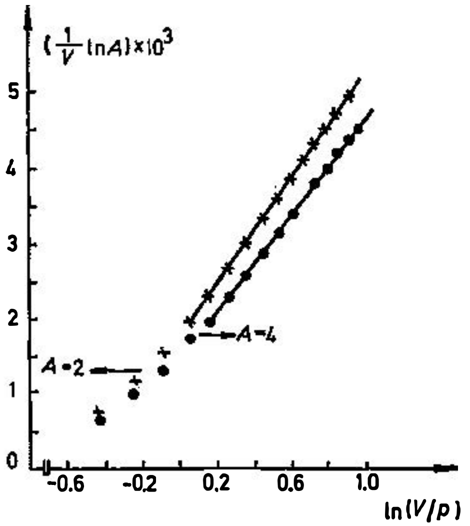

Fig. 6. Comparison of Diethorn's theory — solid lines — for two He-CH_4 mixtures.
● — 0.2 CH_4 + 0.8 He; p = 1013 mbar
x — 0.1 CH_4 + 0.9 He; p = 1013 mbar.

2.2. *Gas mixture measurements*

The two used mixtures of helium containing 10 and 20% of methane weres table. The obtained results were consistent with both Diethorn Eq. (2) and Williams and Sara Eq. (4) as can be seen in Figs. 6 and 7. The measurements were performed only at 1013 mbar. The behaviour was similar to that of pure gases. According to Diethorn, a log-linear relationship was observed for gains greater than 2 and 4 for the 10% and 20% mixtures, respectively. The ΔV constant was equal to 33.6 V for the 10% mixture and 35.2 V for the 20% mixture. The agreement with Williams and Sara was even better (Fig. 7).

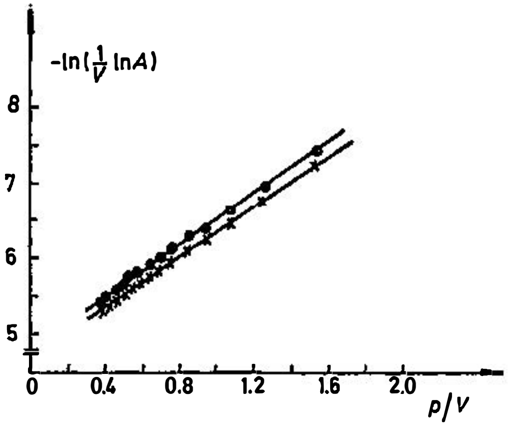

Fig. 7. Comparison of the Williams — Sara theory for two He-CH$_4$ mixtures.
● — 0.2 CH$_4$ + 0.8 He; $p = 1013$ mbar
x — 0.1 CH$_4$ + 0.9 He; $p = 1013$ mbar.

2.3. *Exposure rate dependence*

One of the objectives of the study was to test the linearity of the gas gain ionization chamber for high exposure rates, or, in other words, to evaluate the effect of the space charge density on the gain. A nitrogen filled chamber at 1013 mbar was succesively exposed to radiation fields with exposure rates of 30, 250, 1600 and 4500 nA/kg. The gas gain vs. exposure rate is given in Fig. 8. At the highest rates used, gas gain suppression becomes observable at gains of only $A = 14$ while the effect starts, at $A > 200$ for exposure rates of 250 nA/kg, under the assumption that at 30 nA/kg no suppression takes place.

The observed gain suppression due to space charge density was compared to the reduction of the effective anode voltage obtained by Campion[5] for proportional counters. According to Campion, the reduction in voltage V is related to the average ion pair density as

$$\delta V = V_0 - V = \frac{F}{V_0} \cdot \eta p^2 r_c^2 A R \ln\left(\frac{r_c}{r_a}\right) \qquad (6)$$

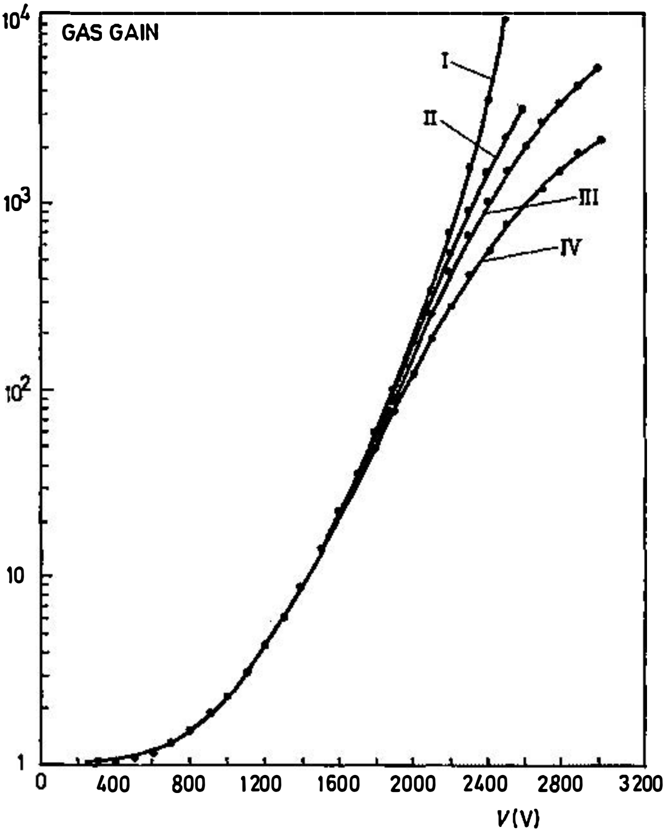

Fig. 8. Gas gain in N_2 for different exposure rates.
I — 30 nA/kg; II — 244 nA/kg;
III — 1580 nA/kg; IV — 4500 nA/kg; $p = 1013$ mbar.

where V_0 and V are the operating and reduced voltages, respectively, η is the average linear ion pair density per unit pressure (the number of ion pairs per unit lenght and unit pressure), R is the counting rate and F a constant. The reduction in voltage was determined at preselected gas gains. The curves in Fig. 8 show that there was no reduction at an exposure rate of 30 nA/kg. The A/V_0 vs. δV curves at the same exposure rates are presented in Fig. 9. The data are in fairly good agreement with the Campion expression.

3. *Conclusions*

This investigation has shown that gas gain ionization chambers have advantages over conventional ones at low exposure rates in spite of the space charge effects that occur at higher exposure rates. The latter response nonlinearities can

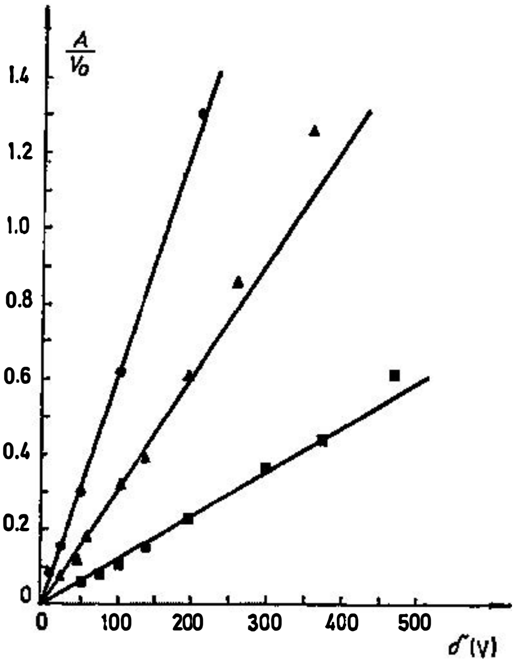

Fig. 9. Test of Campion's expression in N_2, p = 1013 mbar.
● — 244 nA/kg; ▲ — 1580 nA/kg;
■ — 4500 nA/kg.

be corrected for by proper calibration. At lower exposure rates, the size of the sensitive volume is an advantage in radiation field mapping in comparison to necessary large spatial averaging in the regions near the source measurements with conventional ionization chambers.

The applicability of gas gain ionization chambers to exposure measurements is however very affected by the temperature dependence of the gas gain, a dependence that we did not investigate either.

Our investigations have also shown that the gas gain ionization chamber is suitable for the fast and accurate measurement in the range from 1 to 10^4. The study of the effect of the space charge on gas multiplication is also a field were it may be propitiously used. At gas gains greater that 10^4 measurement showed excessive sporadic current fluctuations probably due to some high density ionisation events in the chamber.

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JONIZACIONA KOMORA SA GASNIM POJAČANJEM

DUŠAN NOVKOVIĆ, ĐURA KRMPOTIĆ*, MILOJKO KOVAČEVIĆ, RADIVOJ TASIĆ
i DRAGICA PALIGORIĆ

Institut za nuklearne nauke »Boris Kidrič«, 11000 Beograd

**Odsek za fiziku, Prirodno matematički fakultet, 11000 Beograd*

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Cilj naših istraživanja je bio da se prouči rad jonizacione komore sa gasnim pojačanjem, da se definišu radni uslovi i odrede njena ograničenja. Izmerena su gasna pojačanja za uređaj koji je sličan proporcionalnom brojaču koji je punjen različitim čistim gasovima i gasnim mešavinama sa različitim naponima i pritiscima.Dobijeno je dobro slaganje sa teorijom za većinu punjenja izuzev za čisti azot i čisti argon. Smanjenje gasnog pojačanja postaje primetno za brzine ekspozicionih doza od 250 nA/kg i postaje drastično kod 4 μA/kg.