

GAS AMPLIFICATION FACTOR IN NEON–NITROGEN FILLED PROPORTIONAL COUNTERS

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The gas amplification factor in a cylindrical proportional counter filled with Ne–N₂ Penning mixtures has been measured (over the range $1 < A < 6.4 \times 10^3$) to verify the validity of the gas gain formulae of Rose and Korff, Khristov, Williams and Sara, Diethorn and Zastawny. This factor has been found to obey Zastawny's formula over the range of variables studied. The formula of Diethorn can be fitted only for small nitrogen concentrations (below 5×10^{-4}).

Constants appropriate to the Zastawny and Diethorn formulae have been determined over a wide range of N₂ concentrations from spectroscopically pure Ne up to 11.1% N₂.

1. Introduction

The mechanism of gas amplification in proportional counters has been studied theoretically by several authors [1–10]. Zastawny [6] has estimated that there are five distinct regions in each of which Townsend's first ionization coefficient α/p has a different dependence on S (where $S = E/p$, p is the gas pressure, E is the electric field strength and α is the number of ion pairs formed by one electron per cm of the path). Various gas amplification formulae have been derived depending on the form of α/p as a function of S .

Experimental verification of these formulae is usually made at large values of the gas amplification factor A (10^2 to 10^5) and over a small range of the parameter $S = E/p$, either for argon based mixtures: Ar + ether [1], Ar + methane [7,9,13], Ar + ethanol [12], or for pure gases such as Ar [11,14], CO₂ [6], N₂ [14] or CH₄ [5,12]. Krypton + iso-pentane mixtures have been studied by Kowalski [15].

In some applications, such as the detection of low energy X-rays ($E < 10$ keV), Ne-based Penning mixtures are useful because of their small count rate effects [16,17].

In this work electron avalanche multiplication in Ne–N₂ filled proportional counters with N₂ as a quench gas was systematically studied in order to know the correct analytical formula which describes the gas amplification factor in these mixtures.

2. Gas gain formulae

Since Townsend's first ionization coefficient α/p is an explicit function of S , it is advantageous to take S as

the fundamental parameter in the formulae describing the gas amplification in proportional counters.

The electric field strength $E(r)$ per unit pressure at a distance r from the axis of a cylindrical counter is given by the relation

$$S(r) = \frac{E(r)}{p} = \frac{V}{pr \ln(r_c/r_a)}, \quad (1)$$

where V is the applied voltage between the anode and the cathode of the counter, r_a , r_c are the anode and cathode radii respectively.

The mean amplification factor A is given by

$$\ln A = \int_{r_a}^{r_0} \alpha \, dr, \quad (2)$$

where $A = N/N_0$ (N is the number of electrons (ions) reaching the anode (cathode), N_0 is the number of electrons (ions) in the primary ionization) and r_0 is a certain critical distance from the anode at which electron multiplication starts.

From eqs. (1) and (2) the mean amplification factor A as a function of S is given by the relation

$$\frac{\ln A}{pr_a S_a} = \int_{S_0}^{S_a} \frac{\alpha(S)}{p} \frac{dS}{S^2}, \quad (3)$$

where S_0 and S_a are the values of the electric field strength at r_0 and r_a respectively.

Making proper assumptions about the electron energy distribution and the electron energy losses in collisions with the gas molecules, and neglecting secondary effects accompanying the multiplication process, one can obtain an expression for α/p and a formula for gas amplification given as $\ln A/(pr_a S_a)$ after integration of eq. (3).

Rose and Korff [1], Khristov [2] and Diethorn [5] assumed that α/p takes the values $\frac{1}{2}C_1\sqrt{S}$, C_2 and C_3S respectively. Thus we have the following: Rose and Korff formula:

$$\frac{\ln A}{pr_a S_a} = C_4 - C_1/\sqrt{S_a}; \tag{4}$$

Khristov formula:

$$\frac{\ln A}{pr_a S_a} = C_5 - C_2/S_a; \tag{5}$$

and the Diethorn formula takes the form:

$$\frac{\ln A}{pr_a S_a} = C_3 \ln S_a - C_6. \tag{6}$$

Zastawny [6] assumed α/p to be a linear function of S as follows:

$$\alpha/p = C_7(S - S_0), \tag{7}$$

and found the following amplification formula

$$\frac{\ln A}{pr_a S_a} = C_8 + C_7 \left(\ln \frac{S_a}{S_0} + \frac{S_0}{S_a} - 1 \right). \tag{8}$$

Williams and Sara [7] used Townsend's semiempirical formula [8]:

$$\alpha/p = C_9 \exp^{-C_{10}/S}, \tag{9}$$

and express the amplification formula as

$$\frac{\ln A}{pr_a S_a} = \frac{C_9}{C_{10}} \exp\left(\frac{-C_{10}}{S_a}\right). \tag{10}$$

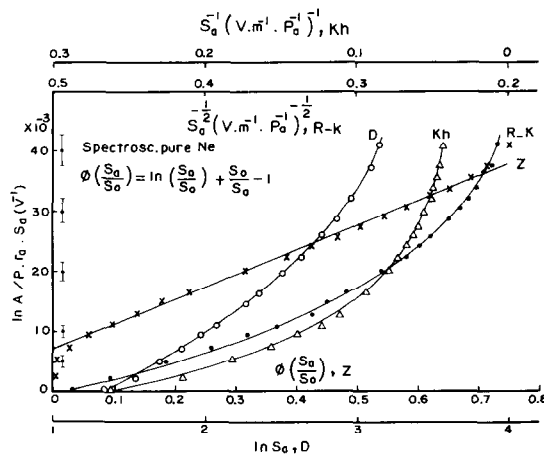


Fig. 1. Gas amplification factors, A , (given as $\ln A/(pr_a S_a)$) measured for spectroscopically pure Ne and plotted according to different gas amplification formulae; $S_a^{-1/2}$ (Rose-Korff: curve R-K, dots), S_a^{-1} (Khristov: curve Kh, triangles), $\ln S_a$ (Diethorn: curve D, circles) and $\phi(S_a/S_0) = \ln S_a/S_0 + S_0/S_a - 1$ (Zastawny: curve Z, crosses).

Charles [9], using Ward's formula [10], found that

$$\alpha/p = C_{11} \exp\left(\frac{-C_{12}}{\sqrt{S}}\right), \tag{11}$$

and arrives at:

$$\frac{\ln A}{pr_a S_a} = C_{13} + \frac{2C_{11}}{C_{12}^2} \left(\frac{C_{12}}{\sqrt{S_a}} + 1 \right) \exp\left(\frac{-C_{12}}{\sqrt{S_a}}\right), \tag{12}$$

where the constants C_1, C_2, \dots, C_{13} and S_0 are specific

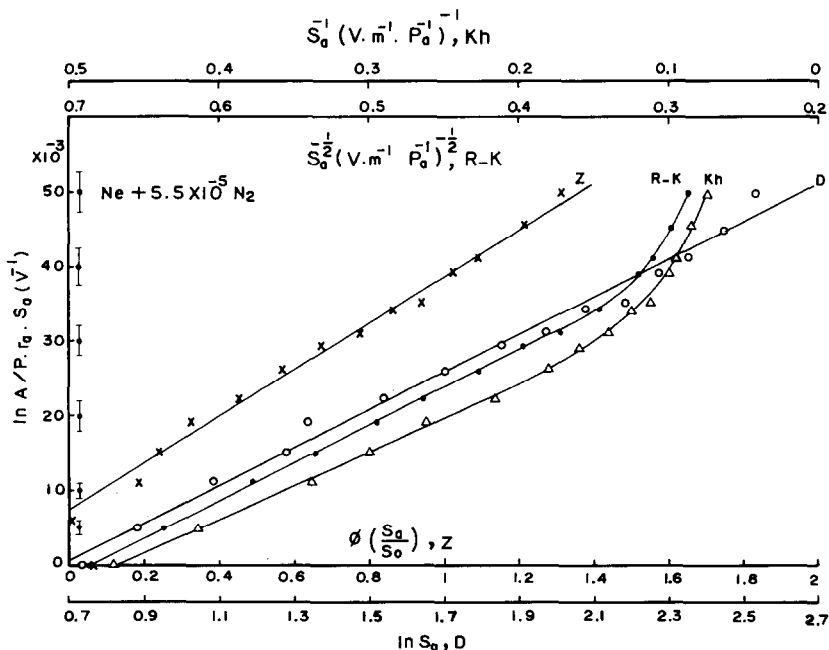


Fig. 2. Gas amplification factors, A , measured for $Ne + 5.5 \times 10^{-5} N_2$ and plotted according to different gas amplification formulae; for notation, see fig. 1.

constants for a given gas or mixture and can be determined from the measured gas amplification data.

3. Experimental

The gas amplification factor over the range 1 to 6.4 × 10³ was measured for Ne + N₂ Penning mixtures ranging from spectroscopically pure Ne up to Ne + 11.1% N₂ as a function of the applied voltage between anode and cathode at 746.6 hPa (total pressure). The parameter S_a varies from 1.3 to 75 V m⁻¹ Pa⁻¹.

A cylindrical proportional counter provided with a special grid of guard rings was used for these measurements in order to minimize dark current [18]. The brass counter cathode diameter is 32 mm with an axially mounted Ni-Cr anode wire of 100 μm diameter. This counter was connected to a vacuum system enabling rapid change of the filling mixture.

The gas amplification factor A was measured by the current method [15,18], using monoenergetic X-rays (Mn K_α from a ⁵⁵Fe source) of 5.9 keV.

The accuracy of measuring A is limited by:

- (1) the error in measurement of the current I₀ in the ionization chamber regime and that in measuring

the current I for different voltages in the proportional regime (ΔI₀/I₀ ≈ 2.5%, ΔI/I ≈ 2%);

- (2) the error in gas mixture preparation (less than 3%);
- (3) leaks and impurities remaining in the vacuum system and impurities in the used gases and vapors. (In this work spectroscopically pure Ne was available from Norsk-Hydro, Oslo, Norway and spectroscopically pure N₂ was available from VEB Technische Gase, Leipzig Betrieb, Berlin, DDR.)

The overall errors in the measurement of both ln A/(pr_aS_a) and S_a are estimated to be less than 10% and 5% respectively.

4. Results

The experimental results were analyzed using the gas amplification formulae (4), (5), (6), (8) and (10). We did not verify Charles' formula, eq. (12). Plots of ln A/(pr_aS_a) as a function of S_a according to the different formulae are given for Ne-N₂ Penning mixtures from spectroscopically pure Ne up to 11.1% N₂ (figs. 1-6). Fig. 7 shows ln[ln A/(pr_aS_a)] as a function of S_a⁻¹ for these mixtures according to the Williams and Sara

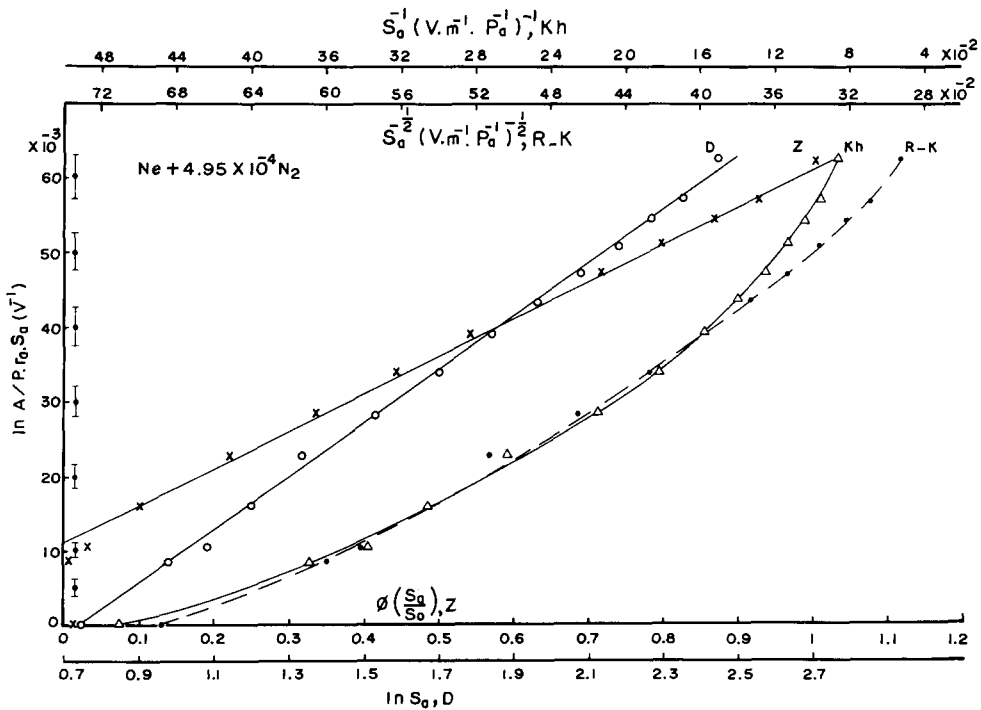


Fig. 3. Gas amplification factors, A, measured for Ne + 4.95 × 10⁻⁴ N₂ and plotted according to different gas amplification formulae; for notation, see fig. 1.

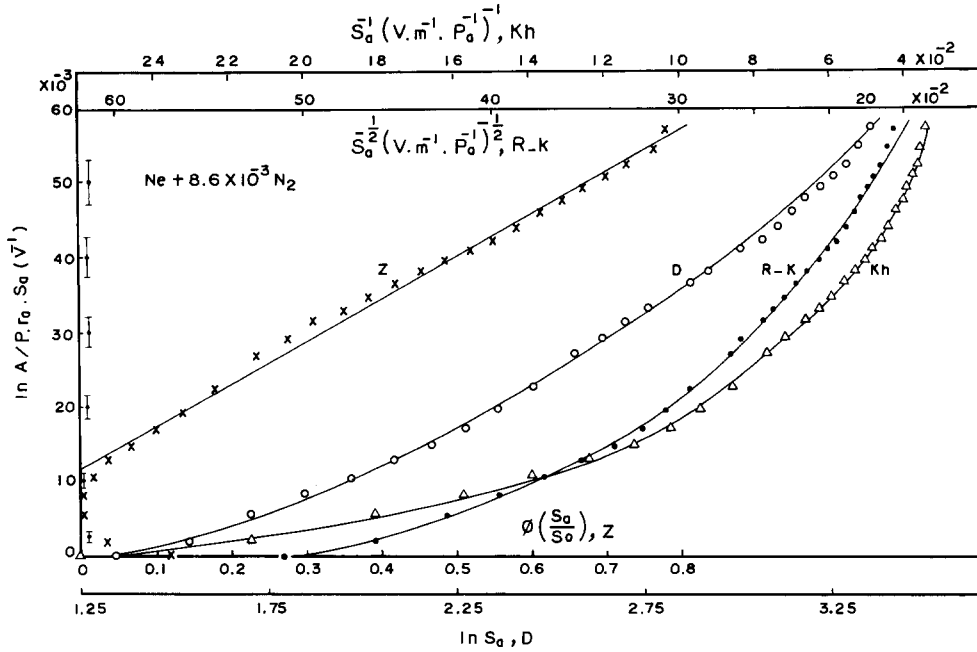


Fig. 4. Gas amplification factors, A , measured for $\text{Ne} + 8.6 \times 10^{-3} \text{N}_2$ and plotted according to different gas amplification formulae; for notation, see fig. 1.

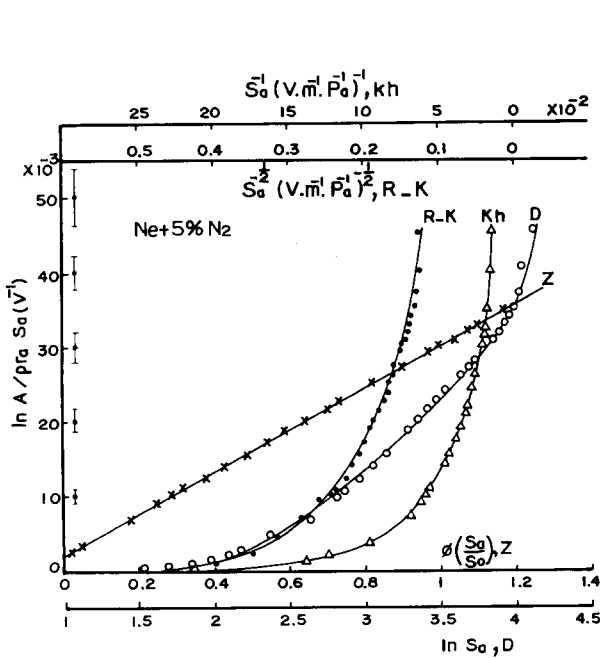


Fig. 5. Gas amplification factors, A , measured for $\text{Ne} + 5\% \text{N}_2$ and plotted according to different gas amplification formulae; for notation, see fig. 1.

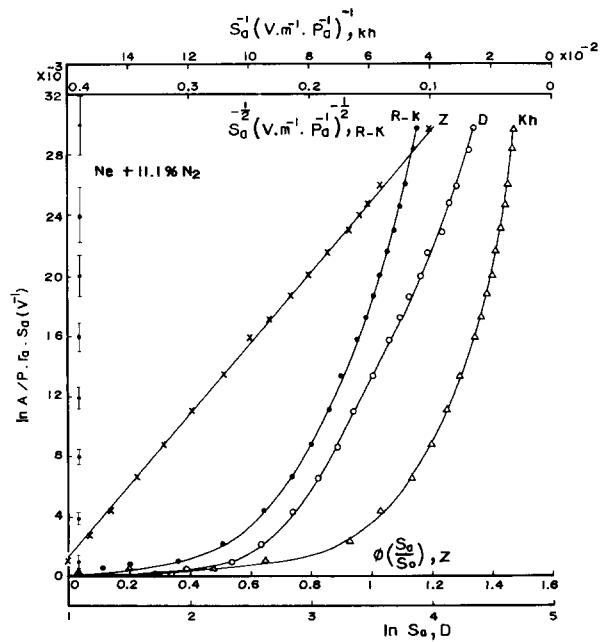


Fig. 6. Gas amplification factors, A , measured for $\text{Ne} + 11.1\% \text{N}_2$ and plotted according to different gas amplification formulae; for notation, see fig. 1.

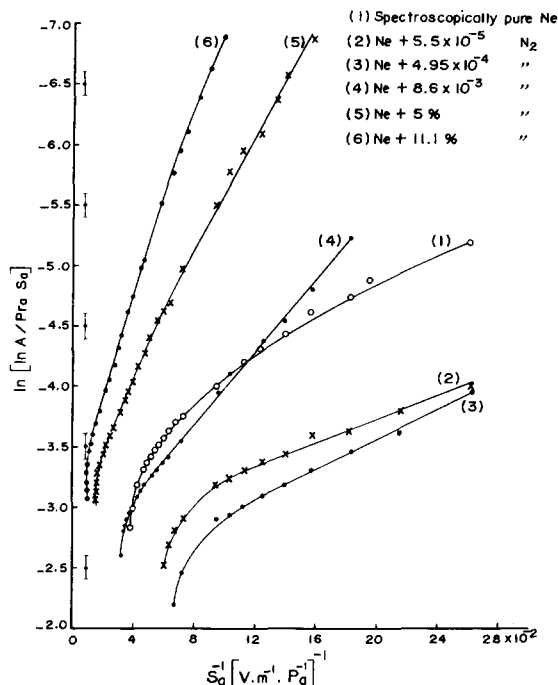


Fig. 7. Gas amplification factors, A , measured for different Ne+N₂ mixtures and plotted vs S_a^{-1} according to the Williams and Sara formula.

formula [7]. The choice of coordinates is such that the experimental points should lie on straight lines. Thus the range of linearity indicates the extent of applicability of these formulae.

5. Discussion

The various gas amplification formulae have varying success with different authors. Kocharov and Korolev [11] report good results with the Diethorn, Curran and Craggs and Khristov formulae, whereas Zastawny [6] finds the first and the last of the previously mentioned formulae as well as the Rose and Korff formula to be

unsuccessful. Kiser [12] does not find the Diethorn formula to be successful for all gas fillings. The Williams and Sara formula [7] is generally found to be unsuccessful, while the Zastawny formula has been reported a great success. Our results for Ne-N₂ mixtures generally support the validity of Zastawny's formula for these mixtures.

From the experimental data presented in figs. 1-7 we find:

- (1) For all the mixtures studied, the coordinate $\ln A / (pr_a S_a)$ is a monotonic function of the concentration of the admixture.
- (2) The gathered data are well described by Zastawny's formula after proper choice of the constant S_0 . These data are in good agreement with the Zastawny's linear formula, eq. (8), as is seen from figs. 1-6.

A least-squares fit yielded the constants of the Zastawny and Diethorn formulae for the studied mixtures (see table 1).

6. Conclusions

Analysis of the gas amplification factor measured for Ne + N₂ Penning mixtures indicates that the Zastawny formula satisfactorily describes the data over the range of variables studied. The Diethorn formula can be applicable only for small nitrogen concentrations ($< 5 \times 10^{-4}$).

Using the constants given in table 1, one can accurately predict the performance of proportional counters containing these mixtures.

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Table 1

The constants of the Zastawny and Diethorn formulae determined from the experiments for Ne-N₂ mixtures

Filling gas	Zastawny constants			Diethorn constants	
	S_0 [V m ⁻¹ Pa ⁻¹]	C_7 [10 ³ V] ⁻¹	C_8 [10 ³ V] ⁻¹	C_3 [10 ³ V] ⁻¹	C_6 [10 ³ V] ⁻¹
(1) Pure Ne	5	41	6.9		
(2) Ne + 5.5 × 10 ⁻⁵ N ₂	1.5	30.7	7.7	24.6	17.2
(3) Ne + 4.95 × 10 ⁻⁴ N ₂	1.8	49.3	11	36	26.9
(4) Ne + 8.6 × 10 ⁻³ N ₂	6	56.3	11.8		
(5) Ne + 5% N ₂	7.2	27	2.6		
(6) Ne + 11.1% N ₂	10	23.7	1.4		

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