# Temperature dependence of gas gain for MWPC readout

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## 1 Introduction

This note is to consider the gas gain dependence on temperature for proportional counters. Under constant pressure, the increase of temperature reduces the gas number density. The mean-free-path of the electron in the gas then becomes larger. The electron will gain more kinetic energy under the acceleration of the electric field. Eventually it leads to the gas gain increase which has been observed experimentally. In the following, expressions will be derived based upon the Reference 1 in order to understand the effect quantitatively.

## 2 The gas gain

The gas gain in the proportional counter is provided by the electron avalanche process when an electron enters the high electric field region around the anode wire. Neglecting effects such as photo-ionization, electron attachment by molecules, electron-ion recombination and space charge accumulation, the gas gain G can be expressed by

$$G = \exp\left(\int_{r_a}^{r_s} \alpha \, dr\right), \tag{1}$$

where $\mathbf{r_a}$ is the anode radius and $\mathbf{r_s}$ is the distance from the axis to the point where the gas avalanche starts. It is directly related to the anode voltage[2]. Assuming a threshold voltage, $V_t$ , at which the avalanche occurs right on the surface of the anode wire, Rose [2] argued that $r_s = r_a V/V_t$. $V_t$ is usually obtained by fitting to the data. The Townsend ionization coefficient a is given by [1]

$$\alpha = PA(\varepsilon - I) \tag{2}$$

where $\varepsilon$(eV) is the electron energy, I (eV) the ionization potential and P (Torr) the filling gas pressure. The constants *A, I* are given in the Reference 1 as fitted parameters for typical filling gases.

## 3 The temperature dependence

For an ideal gas, P = *nkT* where *k* is the Boltzmann constant. At a fixed pressure P, we obtain

$$\frac{\Delta n}{n} = -\frac{\Delta T}{T} \tag{3}$$

The electron mean-free-path is defined as $\lambda = 1/n\sigma^{ion}$ where $\sigma^{ion}$ is the electron ionization cross section in $cm^{-2}$. Using Equation 3, the mean-free-path will change as follows:

$$\frac{\Delta\lambda}{\Delta T} = \frac{\lambda}{T} \tag{4}$$

The extra electron energy gained by the electric field acceleration is

$$\Delta\varepsilon = eE \times \Delta\lambda \tag{5}$$

Using Equations 2,3,4,5, the temperature dependence of a becomes

$$\left(\frac{\Delta\alpha}{\Delta T}\right)_P = \left(\frac{keA}{\sigma^{ion}}\right) E, \tag{6}$$

The gain varies with the temperature as follows:

$$\left(\frac{\Delta G}{\Delta T}\right)_P = G\cdot\int_{r_a}^{r_s}\left(\frac{\Delta\alpha}{\Delta T}\right)_P dr = G\cdot\left(\frac{keA}{\sigma^{ion}}\right)\cdot\int_{r_a}^{r_s} Edr, \tag{7}$$

In a cylindrical proportional counter, the electric field $E$ is given by

$$E = \frac{V}{r\cdot\ln(r_c/r_a)}, \tag{8}$$

where V is the anode voltage and $r_c$ the inner radius of the cathode. For simplicity, we assume this electric field for Equation 7 and obtain the coefficient of gain variation with respect to temperature after the integration.

$$\left(\frac{\Delta G}{\Delta T}\right)_P = G\cdot\left(\frac{keA}{\sigma^{ion}}\right)\left\{\frac{V\ln(V/V_t)}{\ln(r_c/r_a)}\right\}. \tag{9}$$

Further integration gives an explicit expression for the gas gain

$$G(V,T|P) = \exp\left\{CTV\ln\left(\frac{V}{V_t}\right)\right\}. \tag{10}$$

where $C = ke\,A/(\sigma^{ion}\ln(r_c/r_a))$ is a constant

## 4 Comparison with the data

Figure 1 shows a typical measurement of gas gain at different temperatures for an anode voltage of 1350V. The rate of gain increase per degree is about 2.2%. Measurements taken at different anode voltage show variations of 1.7-2.5%.

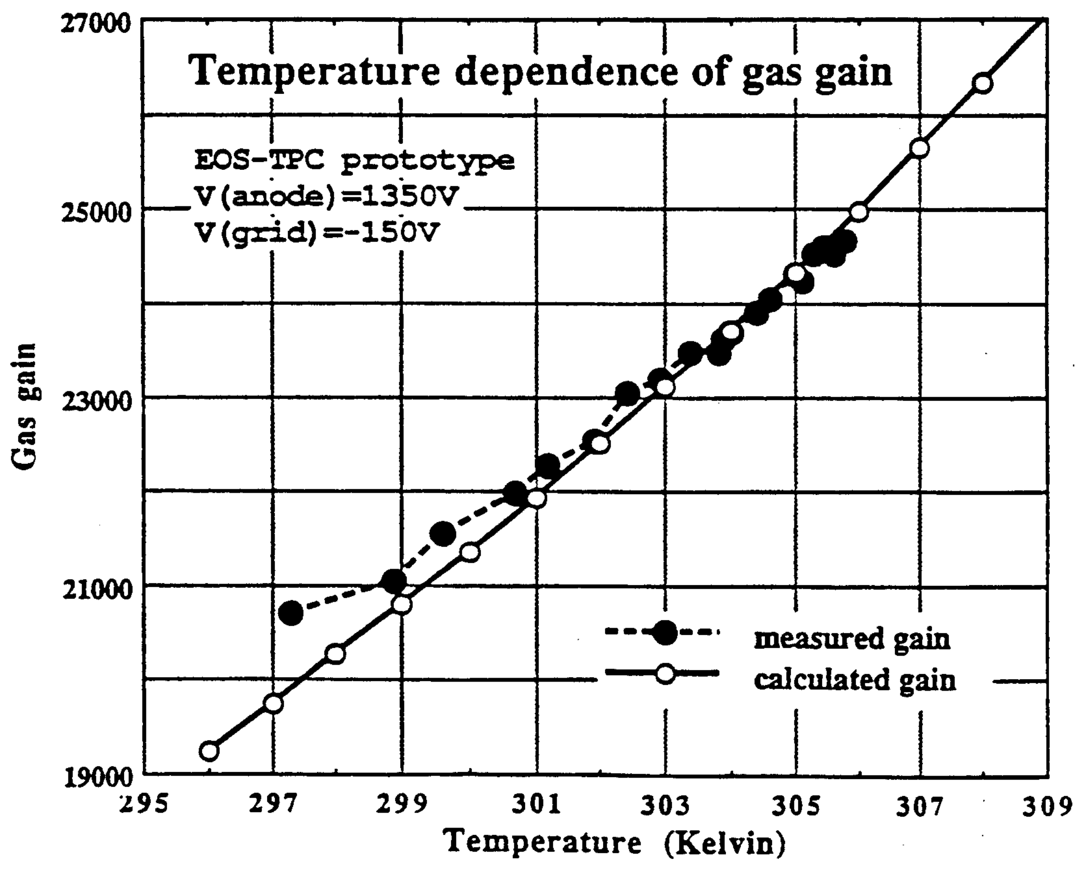

Table 1: Change of the gas gain over 1 degree temperature increase at various anode voltage.

| V*anode* | 1200V | 1250V | 1300V | 1350V | 1400V |
|---|---|---|---|---|---|
| G'/G (T= 1K) | 1.0206 | 1.02225 | 1.0245 | 1.0265 | 1.0285 |

It was known empirically that $V_t = 514V$, $V = 1260V$, $T = 300K$, and the gain increase by a factor of 2 when the voltage is increased by 60 Volt which gives

$$C = \frac{(\ln 2)/300}{(1260+60)\ \ln\left(\frac{1260+60}{V_t}\right) - 1260\ \ln\left(\frac{1260}{V_t}\right)} \approx 2 \times 10^{-5} \tag{11}$$

The open circles in Fig. 1 shows the calculated gain as a function of temperature. The calculations were multiplied by a factor of 8.4 to match the absolute gas gain and that factor may be attributed to the presence of field wire in our chamber. There seems to be good agreements between the measurements and calculations.

# 5 Conclusion

Good agreement between the prediction and the measured effect appears to confirm our simple picture for gas gain dependence on temperature. We find that temperature variation in the MWPC readout region has to be controlled within 1°C in order to achieve less than 3% gain variation. Therefore, it is important to control and monitor the temperature field on the sectors during TPC operation.

# 6 References


1. Y. Uozumi, T. Sakae, M. Matoba, H. Ijiri, N. Koori, "Semi-microscopic formula for gas gain of proportional counters", Nucl. Instru. and Methods **A324** (1993) 558-564

2. M. E. Rose and S. A. Korff, "An investigation of the properties of proportional counters. I" Phys. Rev. 59 (1941) 850