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A STUDY OF THE TEMPERATURE DEPENDANCE OF GAS GAIN

by

Victor Silalahi

**A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfilment of the
requirements for the degree of
Master of Science**

**DEPARTMENT OF PHYSICS
CARLETON UNIVERSITY
OTTAWA, ONTARIO**

March 7, 1992

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submitted by Victor Silalahi, BSc, drs.

in partial fulfilment of the requirements for the degree of Master of Science.

Thesis Supervisor

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ABSTRACT

This thesis presents data collected during a study of the temperature dependence of gas gain (G). Five gas mixtures were measured and values for the change in gain divided by the corresponding change in temperature $\{(\Delta G/G)/(\Delta T/T)\}$ were found to be in the region of 5 to 7. This study has implications for detectors designed to operate in the regions with high backgrounds for example at the SSC (Superconducting Super Collider).

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This thesis is dedicated to my wife Chatrin, my daughters Eva, Ida, and Maria, and my son Michael.

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Chapter I

INTRODUCTION

The basic concept in the detection of energetic particles is that they must interact with the detector. The interaction should be the minimum required to detect the particle without disturbing its trajectory too much. A smaller loss of energy can be obtained with gas filled detectors, than with liquid or solid (scintillators) detectors. While travelling in the gas volume, energetic particles will "hit" gas molecules, interacting with them via electromagnetic interaction, thus transferring a fraction of their energy to these molecules. If the energy being transferred to the gas molecules is high enough, they may liberate a bound electron from one of the energy levels of the gas atoms (e.g. from the K-shell of argon, one of the common gases used). Through the liberation of the electrons, the gas molecules become positive ions. This process is called ionization.

Electrons which are liberated usually have enough energy to cause further ionizations, a process that ultimately creates localized clusters. Very energetic electrons that travel a few millimeters are called δ rays. Charged particle tracks in a gaseous detector are thus characterized by a trail of positive ions and electrons distributed non-uniformly along the track in clusters of typical size two to three ion pairs. If a small external electric field is applied, the electrons will drift towards the anodes, the positive ions to the cathodes.

In a proportional counter the anode is usually made from a fine wire, typically 20 to 50 microns in diameter. Near the anode, the electrons come under the influence of a strong electric field and gain energy, and above a certain value of the field they gain enough energy between collisions to ionize the gas atoms. This is the process of "gas gain". A signal is produced at the anode due to the collection of the electrons and also due to the movement of the positive ions away from the anode. The pulses recorded on the anode wire can be used for detecting the incoming particles.

From the above we see that gas multiplication is dependent on the electric field. In addition many other parameters can affect the gas multiplication factor, including pressure, temperature, ion mobility, etc, but in this experiment only the dependancy on temperature at constant pressure is studied.

This study is motivated by the new accelerator being built in Texas. This accelerator, called SSC (Superconducting Super Collider), will be the highest energy accelerator in the world, and there is no other machine at which a direct comparison can be made for detector design at this time. Design studies using a computer simulation are continuing as well as indirect comparison by extrapolating from experience at lower energy accelerators.

The SSC will produce high luminosity interactions ($10^{33} \text{ cm}^2 \text{ sec}^{-1}$ at 40 TeV), and with this high luminosity and high energy, the particle rates are anticipated to be large enough to cause a continuous current in the detectors, which produces a heating effect and could raise the temperature in a proportional chamber by several degrees Centigrade [ref 1].

The relationship between the gas gain and the temperature will therefore be important at the SSC. It will place more restriction on the design of detectors than at previous particle accelerators, such as Fermilab, and SPS. In these experiments the beam luminosity is 10^{30} to 10^{31} and the energy is considerably lower than at the SSC. Thus the temperature effect on the gas gain has not been experienced before. The relationship under study can be used to predict the gas flow needed in a "straw tube" (a thin proportional tube) at the SSC in order to maintain the gas within certain limits of temperature and hence gain.

The experiment was also motivated by calculations done by Kadyk et.al [ref 2] at an SSC workshop which first indicated that extremely high flow rates of gas may be required to cool proportional (straw) tubes at the SSC, as well as Straw Tube Prototype Study by Lu et.al [ref 3].

It was decided to place a single wire proportional counter into an oven, which can be operated at various temperatures. By taking gas gain data at various temperatures and analyzing them, it is possible to determine the required relation without the use of high rate radioactive sources or intense accelerator beams.

More detailed information on the measurement of gas gain change and temperature change, as well as gas flow predictions, will be discussed in chapter V and VI. In this experiment the temperature dependence of gas gain for four kinds of gas mixtures: Ar/CH₄ (90/10), Ar/C₂H₆ (50/50), Ar/CO₂ (50/50), and Ar/CF₄ (80/20) were measured. The latter has been identified as a gas which is most appropriate for SSC operation due to its high drift velocity [ref 2].

I.1. Charged Particle Detection in Gaseous Detectors

A charged particle is "observed" by detecting its energy loss during travel through a dense medium. Bethe and Bloch treated the energy loss in the framework of relativistic quantum mechanics [ref 4,8,9]. Bethe's theory classifies atomic collisions according to the amount of momentum and energy transferred to the bound electron. A fast charged particle traversing a gaseous medium can interact with that medium in many ways. Generally, only electromagnetic interactions are considered for the purpose of ionization. One can associate a small momentum transfer with a large impact parameter or with a distant collision, and a large momentum transfer with a small impact parameter or with a close collision. In a distant collision the incident particle will interact with the atom as a whole.

In this process there will be a certain probability that the energy loss of the incident particle will cause the excitation of the electron to a higher energy level or may cause ionization. Bethe calculated the probabilities for these transitions using first-order perturbation theory [ref 4, 8, 9]. In a close collision, the interaction of a particle with an atom of a dense medium can be considered to be the interaction with a free electron. The equation for the total energy loss per unit thickness of material traversed with contributions from both close and the distant collisions is [ref 4, 8, 9]:

$$\frac{dE}{dx} = \frac{4\pi n_e Z_1^2 e^4}{mv_1^2} \left[\ln \frac{2mv_1^2 \gamma^2}{I} - \beta^2 \right] \quad 1.1$$

where n_e is electron density factor, Z_1 is atomic number of the target molecules (detector), v_1 is the velocity of an incident electron, e and m is electron charge and mass respectively, I is the ionization potential of the gas, β is a relativistic velocity and γ is related to β as :

$$\beta = \frac{v_1}{c} \quad ; \quad \gamma = \frac{1}{\sqrt{1-\beta^2}} \quad 1.2$$

Light charged particles such as electrons and positrons lose most of their energy by bremsstrahlung, which can happen to other heavy charged particles at extremely high energies. For heavy particles the bremsstrahlung effect is much less as it depends inversely on the fourth power of the particle's mass.

The detection process discussed in this paper is by the deposition of ionization in a gaseous detector using various gas mixtures as the detecting medium. This kind of detector is usually placed close to the interaction point in order to link the tracks with a precision vertex detector like a silicon strip device. In this position the high luminosity and large secondary flux at the accelerator will produce a high current in the detector and consequent rise in the temperature.

I.2. Proportional Counter Characteristics

The general characteristics of the proportional counter are shown in fig (1.1) [ref 7]. The vertical axis represents the gas gain, and the horizontal axis represents the electric field strength. This characteristic is found by incrementing the field strength (x-axis), and measuring the gas gain (y-axis) at each step.

From the proportional counter characteristics in fig (1.1), we can see that increasing the field strength increases the gas gain. Four different regions are important to discuss in this operational characteristics (simple set up as fig 1.2 was used in finding the prop tube characteristics).

Figure (1.1). Operating Characteristics of a Proportional Counter

Figure (1.2). The Prop Tube Set Up
(for finding the operational
characteristics of the prop tube)

At very low electric fields, the counter works as an ionization chamber, which means the ionization is collected without amplification. By increasing the electric field slowly, we will find a threshold point, at which gas amplification occurs. After the threshold point, we enter the second region, called the proportional region. In this region, the charge collected at the anode wire is proportional to the charge deposited to the gas volume. The gas gain increases linearly (on the log plot) at this region. At the end of this region we enter the region of limited proportionality, in which the proportional counter can still work proportionally but the output signal becomes less sensitive to the initial charge. This area has become interesting due to the wide use of Multi Wire Proportional Chambers and Drift Chambers in this region.

After this region, the charge collected at the anode wire is no longer dependant on the charge deposited in the gas volume. This region is called the Geiger Muller counter area. In this area, the growth of a positive ion sheath around the wire during the avalanche process consequently causes a local reduction of the electric field. For several hundred micro seconds afterwards no further detection is possible until the ionization has drifted to the cathode and been neutralized. Continued increase in the electric field above this region leads to a continuous discharge. The gas gain is not well defined in this region.

I.3. A Prediction of The Event Rate at SSC Accelerator

The SSC (Superconducting Super Collider) particle accelerator, built in Texas, was based on a design study carried out at LBL (Lawrence Berkeley Laboratory) [ref 1. and ref 6]. This accelerator will be a proton-proton collider with a C.of.M energy of 40 TeV, and luminosity, $\mathcal{L}$ of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. The inelastic cross section, σ at the energy of 40 TeV is expected to be about 100 mb. At the design luminosity, the rate of inelastic interactions is 10^8 interactions/sec. This is a very high rate of interaction and is required to hunt for rare processes.

At a given C.of.M. energy, the particles produced are found to be uniformly distributed in terms of a kinematic variable called rapidity, up to the maximum value of rapidity allowed at that energy. Rapidity (y) is dependant on the polar angle of the track and is defined by : [$c=1$ for E and p are quoted in MeV]

$$y = \frac{1}{2} \ln \left(\frac{E+p_z}{E-p_z} \right) \quad 1.3$$

where p_z is the momentum of the particle along the direction of the beam and E is its total energy. At high energies the rapidity can be approximated to

$$y \sim \tanh^{-1} \left(\frac{p_z}{p} \right) \sim - \ln (\tan \theta/2) \quad 1.4$$

where θ is the polar angle of the track [ref 5].

This variable can be used to scale up interaction rates from lower energies to the SSC energy.

The number of charged particles produced at the SSC is the number of interactions ($\sigma\mathcal{L}$) times the average charged particle multiplicity per unit rapidity (n_c). For a counter element of length L and width w and depth h , the number of electrons collected at the anode is the primary ionization at the detector (αh) times the gas gain (G). If the number of charged particles produced is multiplied by the number of electrons and the fraction of the solid angle ($Lw/2\pi r^2$) then we can predict the anode current as :

$$I = (n_c \sigma \mathcal{L})(\alpha h G)(e) \left(\frac{Lw}{2\pi r^2} \right) \quad 1.5$$

For the SSC the value of each parameter based on computer simulation [ref 16] are : n_c is the average charged particle multiplicity per unit of rapidity (7.5), w and h are the width and the height of the cell respectively (4mm and 4mm), σ is the inelastic cross sections, $\mathcal{L}$ is luminosity, G is gas gain (2×10^4), e is electron charge, α is the ionization rate (100 electrons/cm), L is the length of the detector (213 cm), and r is the radius of the detector layer position (50 cm).

The calculation gives us a prediction of an anode current of 0.52 μA , which is quite high. The acceptable limit of the anode current before breakdown is about 1 μA . Typical current in these detectors are usually of the order of 1 nA.

Chapter II

TEMPERATURE CHANGE AND ITS EFFECT ON THE GAS GAIN

In this chapter the relation of the gas gain to the change in the temperature is discussed. As the temperature of a gas increases at constant pressure, the number of molecules per unit volume decreases and the mean free path (l) between collisions will increase. This basic physics phenomenon is the main focus of this chapter. The mean free path determines the value of the Townsend coefficient which in turn, determines the gas gain. As the Gas Gain process is not easy to calculate theoretically, the quantitative relation of the gas gain to the temperature change is measured experimentally.

II.1. Gas Gain and Townsend Coefficient

The Townsend Coefficient for the proportional counter is defined as the number of ionizing events induced by an electron per unit of length (/cm) in the direction of the electric field. The original proposal of J.S. Townsend for electron multiplication in a

uniform field is :

$$dN = \alpha N dr \quad 2.1$$

where dN is the extra number of electrons produced after traversing a distance dr , α is the Townsend Coefficient, and N is the number of electrons. For an uniform electric field, the equation above has a simple solution :

$$N = N_0 \exp(\alpha r) \quad 2.2$$

Then the gas gain can be defined as

$$G = \frac{N}{N_0} = \exp(\alpha r), \quad 2.3$$

or,

$$\ln G = \alpha r \quad 2.4$$

For the cylindrical proportional counter, the relation of the Townsend Coefficient and the gas gain can be expressed by

$$\ln G = \int_{r_0}^r \alpha(E) dr \quad 2.5$$

where G is the gas gain, α is the Townsend ionization coefficient, r is the critical distance where gas multiplication begins to occur, and r_0 is the anode radius. Because α depends on the electric field and in the cylindrical prop tube the electric field is a function of the radius, then $\ln G$ depends on the integral of α from r_{critical} to r_{anode} .

The electric field in the cylindrical proportional counter can be expressed by

$$E(r) = \frac{V}{r \ln (r_c/r_a)} \quad 2.6$$

where V is the voltage applied to the proportional tube (the voltage difference between cathode and anode), r_c is the cathode radius, and r_a is an anode radius.

If we define a constant K as

$$K = \frac{V}{\ln (r_c/r_a)} \quad 2.7$$

then the field strength in the cylindrical proportional counter can be rewritten as

$$E = K (1/r) \quad \text{or,} \quad E \propto \frac{1}{r} \quad 2.8$$

This equation shows that the electric field strength is inversely proportional to the distance away from the anode wire. The closer to the anode wire, the higher the electric field strength. As Townsend's coefficient is a function of the field strength then the gas gain in a cylindrical proportional counter becomes proportional to the exponential of $\int \alpha(E) dr$. This implies that the gas multiplication is very high in the region of the anode surface.

$$G = \exp \int_{r_a}^r \alpha(E) dr \quad 2.9$$

Various parametrizations are available to determine α from E . See for example Kowalski [ref 16]. A common parametrization is that due to Rose & Korff [ref 19]

$$\alpha = AP \exp \left(-\frac{B P}{E} \right) \quad 2.10$$

where A and B are constants.

II.2. Time Dependence of the Prop Counter Pulse

The pulses caused by the electron movement into the anode wire are so fast (of the order of a nS) that it is very difficult to measure. Positive ions produced in the electron avalanche move in the opposite direction. They do so more slowly than the electrons and they induce a signal on the anode. Simple electrostatic considerations show that if a charge Q is moved by dr , in a system of total capacitance $1C$ (l is the length of the counter) the induced signal is :

$$dv = \frac{Q}{1CV_0} \frac{dV}{dr} dr \quad 2.11$$

where V_0 is the potential between anode and cathode.

Electron avalanches are produced very close to the anode (half of them in the last mean free path) therefore their contribution to the total signal will be very small. Thus most of the signal is generated by the movement of the positive ions.

The electric charge collected on the anode wire is measured from the induced pulse. This induced pulse lasts until the positive ions are neutralized at the cathode. Based on the result shown by Beingessner on his PhD thesis [ref 10] that with a separation of anode and cathode of 3 cm, the positive ions reach the cathode in the time from 1 to 10 mS. For the smaller radii cylindrical proportional tube used in this experiment, the positive ions will reach the cathode wall in about 0.1 mS.

The amplifier that was used had a time constant of 2 μ S. Thus not all of the signal produced is sampled.

The signal induced on the anode can be expressed by integration of equation (2.11) :

$$v(t) = -\int_{r_a}^t dv = -\frac{Q}{2\pi\epsilon_0 l} \ln \frac{r(t)}{r_a} \quad 2.12$$

where Q is the electric charge, ϵ_0 is the permeability constant of the gas, l is the length of the counter, r_a is the anode radius and $r(t)$ is the radius of the positive ions from the anode at a time (t) .

To define $r(t)$ in the equation above we use the definition of the positive ions mobility :

$$\mu^+ = \frac{w^+}{E/P} \quad 2.13$$

the drift velocity of the positive ions :

$$w' = dr/dt = \mu' E/P = \frac{\mu' K}{r P} \quad 2.14$$

where : E is the electric field strength, and P is pressure.

The reduced electric strength K can be defined as :

$$K = \frac{V}{\ln(r_c/r_a)} \quad 2.15$$

The integration of equation (2.14) [ref 7] gives :

$$r(t) = (r_a^2 + 2 \mu' K t / P)^{0.5} \quad 2.16$$

or :

$$\frac{r(t)}{r_a} = (1 + t/t_0)^{0.5} \quad 2.17$$

In this t_0 is defined as :

$$t_0 = \frac{r_a^2 P}{2 \mu' K} \quad 2.18$$

The charge induced at the cathode which is released from the anode is

$$Q(t) = 0.5 Q_0 [\ln(1 + t/t_0) / \ln(r_c/r_a)] \quad 2.19$$

If we define the new constant C_e as :

$$C_e = \frac{1}{2 \ln(r_c/r_a)} \quad 2.20$$

Then the equation (2.19) can be simplified as :

$$Q(t) = Q_0 C_e [\ln(1 + t/t_0)]$$

2.21

Thus, the charge accumulated during a time (t) can be related to the total charge Q_0 . It is dependant on the positive ion drift and therefore requires a knowledge of the positive ion mobility in gas mixture. The study of the time constant correction was already discussed by Beingessner on his PhD thesis [ref 10].

II.3. Positive Ion Mobility in Gas Mixtures

Positive ions move in a gas volume with velocities that are directly proportional to the external electric field. Therefore it is usual to express them as the velocity divided by the electric field i.e. as a mobility. Positive ion mobility values are also dependent on the gas medium and the type of ions.

As the electric field is applied in the gas volume, positive ions drift toward the cathode, with the drift velocity w^+ . The drift velocity can be defined as

$$w^+ = \mu^+ \cdot \left(\frac{E}{P}\right)$$

2.22

where w^* is the ion drift velocity, μ^* is ion mobility, E is the electric field applied, and P is the pressure.

The main difficulty in the study of ion mobility in mixtures of gases is the identification of the migrating ion. The only way to be sure of the nature of the migrating ion is by appealing to a mass spectroscopic identifications [ref 12, 28].

Experimental results on ion mobility have been reported for various gas mixtures and for different proportions of gases in the mixture at room temperature and atmospheric pressure. The mobility of the positive ions in a gas mixture can be expressed by Blanc's law [ref 28] as :

$$\frac{1}{\mu(I^*, AB, \dots, N)} = \sum \frac{f(k)}{\mu(I^*, k)} \quad 2.23$$

where $\mu(I^*, AB, \dots, N)$ is the mobility of ion I^+ in a mixture of gases $AB, \dots, N$ (including I), $\mu(I^*, k)$ is the mobility of ion I^+ in a gas k , and $f(k)$ is the concentration of gas k in the mixture.

By using equations (2.22) and (2.23), one can calculate the positive ion mobility for several gas mixtures. The positive ion mobility for four gas mixtures used in the experiment is shown in table (3.1). These values will be used later for calculating the positive ions displacement per second as well as for calculating the time constant correction.

Type of gas mixtures	Positive ion mobility (cm ² .torr/volts.sec)
Ar/CH ₄ (90/10)	1446
Ar/C ₂ H ₆ (50/50)	878*
Ar/CO ₂ (50/50)	1014
Ar/CF ₄ (80/20)	1250*

*) means that the values are found by extrapolation.

Table (3.1). The positive ion mobility used for the calculations of the gas gain [12]

As the temperature increases the mobility of the positive ions will also increase [ref 30] as

$$\mu = \frac{760}{p} \frac{T}{273.16} \mu_0$$

where the pressure is in torr and temperature is in degrees Kelvin.

A change in temperature of 20°K (from 273+25 to 273+45°K) at constant pressure will change the mobility by 7%. As the relation of the gas gain and the mobility is a logarithmic function (see eqs 2.21), a change of 7% in the mobility causes a change of 0.5% in the correction factor. This is much less than the systematic errors (10%) in the experiment and is neglected.

The initial number of electrons before amplification was calculated by considering the concept of the mean energy (W_i) required to produce an ion pair.

The total number of ion pairs can be conveniently expressed by

$$n_T = \frac{\Delta E}{W_i} \quad 2.24$$

where ΔE is the total energy deposited in the gas volume by the original particle, W_i is the effective average energy to produce one ion pair. In this experiment we used four kinds of gas mixtures. Table (3.2) gives the value of the primary ionization caused by the Fe-55 gamma source.

Gas mixtures	Average energy loss (W_i) eV	Primary Ionization for Fe-55 No of ion pairs	Electronic Charge (Qo) $\times 10^{-19}$ Coulombs
Ar/CH ₄ (90/10)	26.8	220	352.0
Ar/C ₂ H ₆ (50/50)	26.5	223	356.8
Ar/CO ₂ (50/50)	30.8	192	307.2
Ar/CF ₄ (80/20)	28.9	204*	326.4

*) means that the value is found by $n_T = (\Delta E/W_i) \times 1.6 \times 10^{-19}$ Coulombs

Table (3.2). The primary ionization and the average energy loss for the gas mixtures used in the experiment [ref 7].

II.4. The Mean Free Path

The average distance travelled by a group of molecules before they make their first collision is called the mean free path. The general equation for mean free path is

$$l = \frac{1}{n_v \sigma} \quad 2.25$$

where σ is the total cross section for collision of an electron with the gas and n_v is the number of molecules per unit volume.

For an ideal gas, pressure and volume are related to the gas constant and temperature as :

$$P V = n R T \quad , \text{or} \quad n = (V/R) (P/T)$$

where n is the number of molecules.

From this equation we can see that for constant pressure, the number of molecules decreases if the temperature increases. The number of molecules per unit volume can be defined as

$$n_v = \left(\frac{n}{V}\right) = \frac{P}{RT} \quad 2.26$$

As the gas molecules are always moving and our gas mixtures have molecules with different diameters and different velocities, the actual expression for the mean free path is more complicated than equation (2.25) [ref 5] :

$$l = \frac{1}{n_v \pi (d_1 + d_2)^2 \sqrt{1 + (V_1/V_2)^2}} \quad 2.27$$

where V_1 is the mean velocity of the gas with the diameter d_1 , and V_2 is the mean velocity of the gas with the diameter d_2 . V_1 and V_2 can be calculated by the equipartition of energy :

$$\frac{1}{2} m_1 V_1^2 = 3/2 kT \quad 2.28$$

Then the velocity of molecule 1 is

$$V_1 = \sqrt{\frac{3 kT}{m_1}} \quad 2.29$$

In the same way we can also find the velocity of molecule 2.

By substituting we find

$$l = \frac{T}{\pi (d_1 + d_2)^2 \sqrt{(1 + m_2/m_1)}} \left(\frac{R}{P}\right) \quad 2.30$$

From the equation (2.30) we see that for constant pressure, an increase in temperature will increase the mean free path.

II.5. The Temperature Effect on the Gas Gain

Rose and Korff [ref 19] express the Townsend Coefficient by parametrization as

$$\alpha = AP \exp \left(-\frac{B P}{E} \right) \quad 2.31$$

where A and B are constants depending on the gas composition, P is pressure, and E is electric field.

The exponential factor measures the probability of ionization taking place and is derived from the Maxwell distribution of electron velocities. It is the probability that an electron will gain enough energy to ionize the gas molecule. The product, AP is inversely proportional to the mean free path (it has the same unit as α of cm^{-1}).

Both the product AP, and the exponential factor are dependant on the pressure. It is known that as the pressure increases the gas gain, and hence α , decrease, which implies that the exponential factor dominates.

A temperature increase, will decrease the number of molecules per unit volume hence increasing the mean free path. Its effect is the opposite of a pressure increase. The electrons gain more energy between collisions, and the probability of ionization increases. Overall there is a resulting increase in α and in the Gas Gain.

Chapter III

THE GAS GAIN IN THE PROPORTIONAL COUNTER

The gas gain in the proportional counter can be found by measuring the pulse height at the anode wire. Principally the gas gain in proportional tube is the number of electrons after multiplication divided by the number of electrons before multiplication, or the division of the charge collected in the anode wire (Q) by the charge deposited in the gas volume (Q_0) from the Fe-55 source (see table 3.2) :

3.1

$$G = \frac{Q}{Q_0}$$

The calibration of the ADC and amplifiers is carried out with a fast rise time pulse. We have to correct the calibration for the integrating and differentiating time of the electronics which will give a different pulse height for a slow rise time pulse even though it contains the same charge as the fast rise time pulse. The Calibration and Time Constant Correction is discussed in the following section.

III.1. Calibration Data

The calibration data uses the square pulses from a pulse generator connected to a capacitor (this capacitor is part of the pre-amp) of (1.0 ± 0.1) pF. The output of this capacitor is fed into the input of the pre-amplifier. Knowing the capacitance of the pre-amp capacitor and the voltage, the charge of the calibration pulse is easy to calculate.

By using a variable voltage as input and calculating the charge for each pulse, we can plot the charge per channel of the system. The graph shows a linear relation between the charge and channel number (fig 3.1). There is an overall systematic error of up to 10% due to the accuracy of the calibration capacitor. This charge per channel will be used for gas gain calculation. The calibration pulse is a very sharp pulse compared to the real pulse which is poor in resolution (see fig 5.4). The poor resolution which is typical for a gas detector can be analysed using peak finding software. The MAESTRO II EG&G ORTEC software package is good for this purpose. The difference between the rise time of the data and the rise time of the calibration pulse is the main reason for doing the time constant correction to the data. The calibration pulse has a rise time of 2 nS, whereas the real data has a rise time of 50 nS.

Figure (3.1). The Calibration Graph

Chapter IV

HEAT GENERATION AND REMOVAL IN THE PROPORTIONAL TUBE

In a steady state condition the heat produced by the current between anode and cathode is equal to the heat removed by the gas flow plus the heat transferred to the detector wall by convection, by radiation, and by diffusion.

If we give the power input, or the heat source, the symbol, P_1 ; the heat taken by the gas flow, P_2 ; the heat transfer to the wall by convection, P_3 ; and the heat transfer to the wall by radiation from the anode surface to the cathode surface, P_4 ; and the heat transferred by diffusion, P_5 , then the heat transfer in the system can be written as,

$$P_1 = P_2 + P_3 + P_4 + P_5 \quad 4.1$$

- Heat Input, P_1 :

This is due to the high rate of particles incident on the prop tube which produces an almost continuous current I (defined earlier in equation 1.8), so the power that is dissipated is given by :

$$P_1 = I V_o \quad 4.2$$

where : V_o is the potential between anode and cathode.

For the SSC design [ref 1] the heat input will be of the order of 10^{-3} Joule/sec

- Heat taken by gas flow, P_2 :

This is like forced "air" cooling. Heat is transferred to the gas molecules which are then flushed out of the tube. Assuming the main body of the gas remains at room temperature, whereas the anode wire becomes heated to a temperature ΔT above room temperature then the amount of heat conducted to the gas is,

$$P_2 = (\text{moles/sec}) C_p \Delta T \quad 4.3$$

where : C_p is molar heat capacity.

The number of mole per second can defined as :

$$\frac{dn}{dt} = \frac{1}{N_A} \frac{dN}{dt} = \left(\frac{P}{RT} \right) \frac{d}{dt} (V) = \left(\frac{P}{RT} \right) A \frac{d}{dt} x = \left(\frac{P}{RT} \right) A v \quad 4.4$$

where N_A is Avogadro Number, N is the number of gas molecules, P is pressure, R is gas constant (table 6.1), T is temperature, V is gas volume (prop tube volume = Ax), x is the distance the gas flows in the detector (213 cm), v is the velocity of gas flow, and A is the prop tube or the straw tube cross section ($A_{\text{straw tube}}$ is $1.256 \times 10^{-5} \text{ m}^2$).

-Convection, P_3 :

The heat removed by the convection perpendicular to the flow can be calculated by

$$P_3 = h_c A [T_{gas} - T_{wall}] \quad 4.5$$

where : h_c is the convective conductance of the gas mixture, A is the area where the convection taking place, T_{wall} and T_{gas} are the wall and the gas temperature respectively. Using this method the heat removed by convection is of the order of 10^{-4} Joule/sec (for the temperature difference of 2°C , $h_c=11.34 \text{ W/m}^2\text{K}$, anode wire area : $A=1.33 \times 10^{-4} \text{ m}^2$).

-Radiation, P_4 :

The heat removed by radiation from the anode to the cathode can be calculated by

$$P_4 = A_1 F_{1-2} (\epsilon \cdot \sigma) (T_2^4 - T_1^4) \quad 4.6$$

where A_1 is the anode surface, σ is the Stefan-Boltzman constant, ϵ is the emissivity of the anode surface. T_2 and T_1 are the temperature of the anode wire and the cathode wall respectively.

F_{1-2} is the shape factor and is calculated by,

$$F_{1-2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos\theta_1 \cos\theta_2 dA_1 dA_2}{\pi r_{(c-a)}^2} \quad 4.7$$

(for the cylindrical straw tube $F_{1-2} = 1$)

If we calculate the heat removed by convection and radiation by the equation 4.6, 4.7 we find that the heat removed by radiation from the anode to the cathode is so small that it can be neglected (of the order of 10^{-7} Joule/sec for the temperature different of 2°C , A_1 is $1.33 \times 10^{-4} \text{ m}^2$, and σ is $5.67 \times 10^{-8} \text{ watts/m}^2$).

Diffusion, P_3 :

The diffusion of the positive ions & molecules to the cathode wall will also transport heat to the detector wall. This form of heat transfer and removal by the wall is only effective if the detector wall is cooled. This will be considered later and is really the conduction of heat through the gas in a direction perpendicular to the gas flow.

Gas Flow Prediction for equilibrium :

Based on the equations above, the gas flow prediction for equilibrium at a certain temperature is

$$IV_o = \left(\frac{P}{RT}\right) A v C_p \Delta T + P_3 + P_4 + P_5 \quad 4.8$$

$$v = (IV_o - P_3 - P_4 - P_5) \left(\frac{1}{PA}\right) \left(\frac{T}{\Delta T}\right) \left(\frac{R}{C_p}\right) \quad 4.9$$

Knowing that P_3 , P_4 , and P_5 can be neglected (for now) then the equation for equilibrium can be simplified as :

$$v = \left(\frac{IV_o}{PA}\right) \left(\frac{T}{\Delta T}\right) \left(\frac{R}{C_p}\right) \quad 4.10$$

This simplified equation will be used to predict the velocity of the gas flow needed through proportional tube to keep the value of the gas gain to within 5% of its zero current value. If the gain changes by more than 5%, it could lead to an increase in rate (due to the use of a fixed discriminator threshold) and at SSC, where the rates are already very high, this could have a big effect on the efficiency of the counter.

Figure (4.1). Proportional Tube Schematic Diagram

Chapter V

EXPERIMENT

The aim of the experiment is to measure the effect of the temperature change on the gas gain. To do this the proportional tube was placed in an oven and was operated over a range of temperatures between 20°C and 50°C. Graphs were obtained of gas gains versus temperature.

There are two differences between this experiment and the situation we are trying to model. For a detector operating at the SSC, heat is generated by the current between anode and cathode. In this experiment the heat is generated by the oven. This is done in order to simulate the SSC situation without having to use high rate accelerators or highly radioactive sources. Problems of pulse pile-up are avoided.

Secondly. In the real detector the primary ionization is caused by the particles created in a collider event, while in this experiment the primary ionization is caused by the iron-55 source. This deposits a well known amount of ionization, suitable for calibration purposes and is not subject to Landau fluctuation. This method is able to give the required relation between gas gain and temperature. This data will be used to predict the velocity of the gas flow required in the proportional tube in order to maintain constant temperature and therefore constant gain in the detector.

Figure (5.1). Layout of the Proportional Counter

V.1. Description of The Apparatus

A single wire proportional counter with an anode wire diameter of 20 microns and a cathode tube diameter of 9 mm was used in this experiment. The proportional tube is shown in fig 5.1. The cathode was made from aluminum tube. Both end caps were made of Teflon material. To permit the gas flow through the proportional tube, both end caps have a hole of diameter of 0.5 mm (for inlet and outlet of the gases). In the centre of the proportional tube was stretched an anode wire with the diameter of 20 microns. The anode wire is made of gold plated tungsten. An iron-55 source was located in the cathode wall of the proportional tube. The proportional tube was built at Carleton University workshop.

In this experiment the temperature was varied between 293 and 323 K. The oven was able to maintain the temperature roughly uniform for a limited time. The limitation was due to heat losses through the oven walls. The temperature was measured using several thermocouples placed around the oven, and at the inlet and the outlet of the proportional tube.

As the inlet gas is cooler than the detector we need to heat the gas up to the oven temperature before entering the detector. The techniques used were:

1. The gases were passed through a copper coil (about 8 meters long) placed in the oven (between the oven gas inlet and the proportional counter gas inlet).
2. A slow gas flow was used to allow the heat to flow from the oven environment to the gas.

By using both of these techniques, we were assured that the temperature in the oven is equal to the gas temperature. The uniformity of the detector temperature was also checked by an other thermocouple in the oven. This was particularly important after changing the temperature.

V.1.1. Iron-55 Gamma Source

The choice of Fe-55 as X-ray source is due to its mono energetic 5.9 keV photon which is very close to the mean energy deposited by a ionizing particle traversing 1.0 cm of gas. The photon energy is absorbed in a multi-step process. The 5.9 keV photon can ionize the electron in K-shell of argon with an ionization energy of 3.20 keV producing a photoelectron of energy 2.7 keV.

The excited atom can then return to its ground state through two kinds of effects. First through internal re-arrangement of the atomic orbital involving electrons from the lower energy shells (Auger effect). In this process two electrons of energy very close to the K-shell energy is emitted, contributing to the events in the photo peak. The second process is fluorescence. In this process the excited atom will emit photons of energy 2.954 keV or 2.956 keV [ref 10], and these photons can deposit their energy in the gas ionizing more molecules and contributing to the events in the photo peak.

If they escape from the detector (they have a lower cross section being below the K shell edge) they take away energy from the photo peak creating a second peak called the 'escape' peak.

The escape peak can be used to predict the zero position of the pulse or the pedestal position we get from the experiment. The photo peak position (channel number) will be about twice that of the escape peak. So that by measuring the distance of this two peak then the zero point can be predicted.

Fig 5.2 shows the Fe-55 spectrum taken in the proportional counter used in this experiment. The photo peak is the highest peak, and the escape peak is the lower.

TYPE = -1 MCA # 1 SEGMENT # 1
REALTIME = 87.86 SECONDS, LIVETIME = 12.52 SECONDS
DATA COLLECTED AT 12:48:00 ON 08-OCT-91

Figure (5.2). The pulse shape of Fe-55
in argon gas base mixture

V.1.2. Electronics

To create a potential difference between the cathode and the anode, a positive high voltage was applied to the anode, while the cathode remains grounded. The high voltage required depends on the gas mixture. Different gases have different ionization potentials which change the gas gain. In this experiment, four different gas mixtures were used with high voltages ranging between 1 to 1.5 kV. To detect the pulses from the anode, the electronics shown in the block diagram in figure (3.2) was used. The anode wire of the proportional counter was connected via a high voltage capacitor to a pre-amplifier (ORTEC type 142 PC) then to the main amplifier (ORTEC type 572). This ORTEC type 572 has a gain range of 1 to 1500. The pulse shape is Gaussian on all ranges. It has a 2 micro second shaping time. The typical noise is less than 5 micro volts for unipolar output. A ten turn precision potentiometer with graduated dial produces a continuously variable gain factor of 0.5 to 1.5 for fine gain selection, while a six position switch selects feedback resistors for coarse gain factors of 20, 50, 100, 200, 500, and 1k. A six position switch also selects time constants for active pulse shaping filter network from 0.5, 1, 2, 3, 6, and 10 micro seconds. In our experiment a 2 micro seconds time constant for the pulse shaping filter was chosen. The delay time is 1 micro second.

After the amplification the pulses are digitized by a Multichannel Analyzer (EG&G model 915A MCB). This Multichannel Analyzer Board (MCB) sits in an IBM PC and has a matched memory of 8 million counts/channel (23-bit data values). The dual ported memory allows the entire spectrum to be transferred from the card memory into the PC memory in the order of milliseconds. The MAESTRO II software package (Model A63-B) was used to analyze the anode pulses.

V.2. The Experimental Set Up

Before doing the experiment the gas has to be flushed for about 5 minutes to purge the air from the prop tube, after that the gas is flowed slowly to permit temperature equalization to take place. At first the pulses are checked by using the simple circuit as shown in fig (1.1). This circuit is only used to find the voltage needed to operate the counter in the proportional region.

The second step is to connect ADC as shown in figure (5.3). The anode wire is connected to the positive high voltage and the cathode wire remains at ground voltage. This creates a cylindrical electric field in the proportional tube. The field strength can be calculated and is a function of the radius.

Figure (5.3). Experimental Set Up

The third step is to heat the gas to the highest temperature needed then switch off the heater and take the data as the temperature decreases. With this method we check the highest gain first. This allows the calibration to be done over the full range of channels occupied by the data.

The fourth step is to connect the calibration pulser. The pulses have to be able to cover all the data sample from the lowest to the highest. As it is already known that the highest temperature will give the highest gas gain. We wish to operate the prop tube in proportional region so by calculating the gas gain at this setting and checking that it is below 10^4 will ensure that all of the data is kept out of the limited proportional region. This procedure also enables the high voltage to be kept constant as the temperature decreases.

The final step is to select a suitable voltage for each gas mixture. After that data taking can proceed. As we are interested to begin the measurement at 50°C the gas was heated up to about 70°C and the heater switched off. The gas temperature decreased and all thermocouples become uniform at about 50°C.

V.3. The Experimental Method

Working from the raw data with pulses of varying heights, we accumulate a histogram and measure the peak position. Initially this peak position is measured in "channel numbers" and has to be converted to charge using the calibration procedure described earlier. The histogram has a shape shown in figure (5.4).

The gas gain is equal to the division of the charge collected in the anode wire (Q) by the charge deposited in the gas volume (Q_g) from the Fe-55 source (see table 3.2) :

$$G = \frac{Q}{Q_g} \quad 5.1$$

The value of Q_g for each gas mixtures were taken from table (3.2) in page 21, and Q was measured in the experiment. The calibration of the ADC and amplifiers is carried out with a fast rise time pulse. We have to correct the calibration for the integrating and differentiating time of the electronics which will give a different pulse height for a slow rise time pulse even though it contains the same charge at the fast rise time pulse.

The temperature range we are interested in is between 20 °C and 50 °C. Each data point was collected over a period of about 11 to 20 seconds which is small compared to the time required to change the temperature of the prop tube. The peak channel of the pulse height is then found.

This gives the charge collected on the anode wire, Q in channel numbers. To convert Q to femto coulombs we need to use the calibration data. The calibration data will give us the charge per channel, A and the intercept, B . Under the assumption that the amplifier system is linear, we can calculate Q by :

$$Q = (\text{peak} \times A + B) \quad 5.2$$

The calculation of the gas gain needs to be corrected for the time constant correction which has already been discussed in section (II.2 and III.1). The correction to the charge collected in the anode wire is :

$$Q(t) = Q_0 [C_e(1+t/t_0)] \quad 5.3$$

where Q_0 is the charge calculated by equation (5.2) and $Q(t)$ is the charge after correction.

By equating t to the amplifier time constant and obtaining t_0 from equation (2.18) the correction to the gas gain can be calculated.

TYPE = -1 MCA # 1 SEGMENT # 1
REALTIME = 144.94 SECONDS, LIVETIME = 20.74 SECONDS
DATA COLLECTED AT 12:43:00 ON 08-OCT-91

Figure (5.4). A Sample of Raw Experiment Data

Figure (5.5). The Channel Number Vs Temp of Ar/C₂H₆ (50/50)

Figure (5.6) The Comparison of the Gas Gain from the Result to a Published Result. In this case we compare with the Parametrization Result by Armitage et.al. [ref 14]

V.4. Analysis of The Gas Gain

First, the peak of each histogram is found, using the MAESTRO II software package. By selecting the "range of interest" around the peak of Fe-55, the software is able to determine the peak position very well. However if the peak is too wide the software will reject the peak. The channel numbers were recorded together with the temperature and a graph of channel numbers versus temperature is constructed. The second job is to apply the calibration. Then the numbers are put into a program that calculates the gas gain based on the method out-lined in section V.3 and the correction factor in section (II.2). The method we applied on the gas gain calculation were compared with the parametrization result by Armitage et.al. An agreement was found as shown in figure 5.6.

The change of gas gain with temperature can be calculated without calculating the absolute gas gain. Fig 5.5 is the graph of the channel number change as a function of the temperature. The channel numbers on the Y-axis are proportional to an increase in gas gain.

Figure (5.7). The Experiment Result for Gas Gain at various Temperature of Ar/CH₄ (90/10)

Figure (5.8). The Experiment Result for Gas Gain at various Temperature of Ar/CO₂ (50/50)

Figure (5.9). The Experiment Result for Gas Gain at various Temperature of Ar/C₂H₆ (50/50)

Figure (5.10). The Experiment Result for Gas Gain at various Temperature of Ar/CF₄ (80/20)

$$\frac{\Delta G}{G} = \frac{\Delta N}{N}$$

where G and N representing gas gain and channel number respectively.

The calculation of the absolute gas gain allows us to compare our results with the published data. The graphs shown in figures 5.7, 5.8, 5.9 & 5.10 indicate that the relation between the gas gain and the temperature is linear at least over this restricted temperature range.

The data were fitted to a linear function. Four gas mixtures were used in this experiment, and four linear functions (see Fig 5.7) to (Fig 5.10) were determined. The slopes are given in table (5.1) and are labelled GTT or $(\Delta G/G)/(\Delta T/T)$. This ratio is convenient for comparing the properties of different gases.

Gas mixture	V_0 (kV)	GTT
Ar/CH ₄ (90/10)	1.026	4.81 ± 0.09
Ar/CO ₂ (50/50)	1.426	6.19 ± 0.13
Ar/C ₂ H ₆ (50/50)	1.260	6.26 ± 0.12
Ar/CF ₄ (80/20)	1.402	7.04 ± 0.15

Table (5.1). The result of the gas gain change to the temperature change for four kind of gas mixtures base on the experimental measurement.

The statistical error of GTT comes from the error of gas gain measurement shown in graph in page 50 to 53. There are two main errors appear in the gas gain calculation. one is from uncertainty in the peak position and is estimated by mean standard deviation and error from the MAESTRO II fitting routine. The other error comes from the fitting. The calculation of errors in the fitting were obtained with the standard formula for estimating errors in the parameters of a least squares fit. In addition there are systematic errors, not shown, which are of the order of 10 %.

The results shown in table (5.1) are comparable to the "Prototype Study of The Straw Tube Proportional Chamber" result by Lu et.al [ref 3]. They measure $(\Delta G/G)/(\Delta T/T)$ to be 4.9, 6.6, 6.8, 9.2 for four gas mixtures Ar/CH₄ (90/10), Ar/C₂H₆ (50/50), Ar/CO₂ (50/50), and Ar/CO₂ (20/80) tested with the Straw Tube Prototype using five different anode wire diameters of : 0.0203, 0.0254, 0.051, 0.076, and 0.127 mm. The data were fitted using Aoyama's parameterization [ref 3].

Chapter VI

THE GAS FLOW PREDICTIONS

It is required that the velocity of the gas flowing in the proportional counter (straw tube) be such that the gas has a constant temperature.

To keep the temperature of the detector constant we need an equilibrium to be established between heat generated and heat removed (Chapter IV), and first we calculate the removal of heat by gas flow. The amount of heat removed by radiation and convection is small and can be neglected. The heat removed by diffusion effect considered later.

By using equation (4.10) and the table of parameters corresponding to the gas mixtures, we can calculate the velocity of the gases needed to limit the change of gas gain to less than 5% at a detector situated at SSC. The results of the calculation and the parameters used are shown in table 6.1.

Gas mixture	ΔT (K)	C_p (J/K)	C_p/R	Gas velocity (cm/sec)
Ar/CH ₄ (90/10)	3.12 ± 0.03	27.08	2.68	2.85 ± 0.03
Ar/CO ₂ (50/50)	2.43 ± 0.04	28.95	3.50	2.81 ± 0.04
Ar/C ₂ H ₆ (50/50)	2.40 ± 0.04	36.70	4.40	2.27 ± 0.04
Ar/CF ₄ (80/20)	2.14 ± 0.04	27.08	3.26	3.42 ± 0.04

Table 6.1. The gas velocity predictions for the straw tube used at SSC.

From the results in table 6.1, the velocities of the gas for the four gas mixtures used are in between 2 to 3 cm/sec. We compare to previous non SSC detector gas velocities calculated under the assumption that the gas in a typical detector has to be changed every 2 hours. Assuming a detector length of about 2 meters then the flow rate can be predicted as,

$$v = \frac{2 \text{ meters}}{2 \text{ hours}} = 0.0278 \text{ cm/sec}$$

The gas flows predicted in Table (6.1) in between 2 to 3 cm/sec are higher by a factor of 100. (This will result large volumes of gases being used and which may need cooling and recirculation to reduce costs) It is noted that one of the preferred SSC gases ; CF_4 , is the one has the highest values of $(\Delta G/G)/(\Delta T/T)$ and one of highest flow rates (see table 5.1 and 6.1). The more complex the molecule the higher is the value of C_p/R , the smaller the velocity required.

The gas velocities shown in table (6.1) is higher than the prediction shown by Kadyk et.al [ref 2], which says that the velocity of the gas flows in the straw tube to keep the gas gain within 5% nominal is 2 cm/second. This values is based on the gas mixtures being tested. For the gas mixture of $\text{Ar}/\text{C}_2\text{H}_6$ (50/50) the result shows agreement.

VI.1. Alternative Means of Heat Removal

The heat removal can be increased and the velocity of the gas flow reduced, by finding a new path for heat to escape. As discussed before, convection, radiation, and gas flows are fairly ineffective. The heat removal by diffusion may help to reduce the gas flow if the detector wall is cooled. If there is a way to cool the detector wall then this effect can remove more heat.

VI.1.1. Diffusion of Positive Ions and Neutral Molecules

Ions migrating in a time t over a length x will diffuse with the probability of Gaussian distribution:

$$\frac{dN}{N} = \frac{1}{\sqrt{4\pi Dt}} \exp\left(-\frac{x^2}{4Dt}\right) dx \quad 6.1$$

where dN/N is the fraction of the charge found in the element dx at a distance x from the origin, and after time t . D is the diffusion coefficient. The root mean square width of the distribution is given by

$$r_x = \sqrt{2Dt} \quad 6.2$$

The diffusion coefficient can simply estimated from the Einstein relation. Let T be the electron temperature in a gas, k is the gas constant, and μ^* is the ion mobility then the Einstein relation to the Diffusion coefficient D is :

$$\frac{D^*}{\mu^*} = \frac{kT}{e} \quad 6.3$$

Positive ions are in fact a small minority of the total number of molecules. The number of neutral molecules is about $10^{23}/\text{cc}$. So we are considering the diffusion of neutral molecules and assume that their mobility and diffusion will be similar to the diffusion of the charged molecules (ions of the same species). So we use :

$$r_x = \sqrt{2\mu \cdot \left(\frac{kT}{e}\right)t} \quad 6.4$$

where $(kT/e)=0.025$ eV, and :

$$t = \frac{x}{V} \quad 6.5$$

where x is the length of the detector, and V is the velocity of gas molecules caused by the flow of gas.

VI.1.2. Time needed for the ions and molecules to reach the wall

We can predict how far the ions will move per second and hence estimate how far the neutral molecules will migrate. The deflection per second is perpendicular to the direction of the gas flow and allows us to check the feasibility of heat transfer by diffusion to the detector wall. A simple prediction for the time needed to reach the (stew tube wall) detector wall can be made by the equations (6.2),(6.3) and (6.5). The result shows us that the molecules need about 0.5 second to reach the wall. The results for the four gas mixtures used in the experiment are shown in table (6.2).

Gas mixtures	Diffusion Coefficient (cm ² /sec)	Time needed to reach the straw tube wall(sec)
Ar/CH ₄ (90/10)	0.0495	0.4040
Ar/C ₂ H ₆ (50/50)	0.0300	0.6666
Ar/CO ₂ (50/50)	0.0347	0.5764
Ar/CF ₄ (80/20)	0.0428	0.4673

Table (6.2). The Diffusion Coefficient and time needed to reach the cathode.

As we know that in the previous detector the gas will be in the detector in about 2 hours then the gas molecules can travel from the anode to cathode back and forward in about 7200 times before flowing out of the detector. This process may be used to transport the heat if there is a cooling system applied to the cathode wall.

This Section shows that detector wall cooling may be necessary in the new detector design used at SSC.

Chapter VII

CONCLUSIONS

The goal of this study is to find the relation of the gas gain change to the temperature change. From the result of the experiment we can conclude that the gas gain will increase with the temperature. The temperature dependencies of the gas mixtures are different (complex molecules have a higher value of C_p/R and need less flow). By using four kinds of gas mixture we see that $(\Delta G/G)/(\Delta T/T)$ are in between 5 and 7 (table 5.1).

The temperature dependence of the gas gain has been measured and used to give a prediction of the gas flow required for stable operation of detectors at the SSC. Comparing the value we get to other results ; e.g. to the results of Lu et.al and Kadyk et.al. There is general agreement with the result found for $(\Delta G/G)/(\Delta T/T)$ in the range of 5 to 7 (depending on the type of the gas mixture). Lu et.al used the Aoyama parameterization and has a result of 5 to 9 [ref 3]. Kadyk et.al predict gas flows of 2 cm/sec in 4 mm diameter straw tubes, if the gas gain is to be kept within 5% of nominal.

The implications of this study to the detector designer at the SSC is that the new detector may need gas flows increased by a factor of 100 over previous detectors.

The heat removal by the diffusion may be used to reduce the high gas flows. This technique is only useful if the cathode wall is cooled. Unfortunately there is no information about the cooling of the cathode at this time. This experiment used the gas mixture of Ar/CF₄ (80/20) [table 5.1 and 6.1]. For the concentration of CF₄ more than 20% the value C_p/R will be higher that can reduce the gas flow. And if there is the way to transfer the heat from the detector then the CF₄ gas mixture is the best choice due to its fast diffusion.

REFERENCES

- 1) G.G. HANSON, B.B. NICZYPORUK, and A.P.T. PALOUNEK, Wire Chamber Requirements and Tracking Simulation Studies For Tracking Systems at the SSC, NIM A283 (1989) p735-743.
- 2) J.A. KADYK, D.W. HESS, T. VA'VRA, and J. WISE, Symposium on Detector Research and Development for The Superconductor Super Collider, World Scientific Publishing Co.Pte.Ltd (1991) p236-240
- 3) C. LU, K.T. McDONALD and D. SECREST, Prototype Study of the Straw Tube Proportional Chamber, DOE/ER/3072-56 (1990)
- 4) H.A. BETHE, Annalen der Physik 5 (1930) p325
- 5) J. ARMITAGE, Tutorial Note, 1991
- 6) Gail G. HANSON, Maria C. GUNDY, and Andrea P.T. PALOUNEK, Tracking with Wire Chambers at the SSC, NIM A289 (1990) p365-374
- 7) F. SAULI, Principles of operation of multi wire proportional and drift chambers, CERN 77-09 (1977) p18-45
- 8) H.A. BETHE, Z. Physik 76 (1932) p293
- 9) H.A. BETHE, Handbuch der Physik 24 (1933) p518
- 10) S.P. BEINGESSNER, Ph.D Thesis (1984) p115-118
- 11) M.W. CHARLES, Gas Gain Measurement in Proportional Counters, Journal of Physics E: Scientific Instruments (1972) p95-101

- 12) G. SCHULTZ, G. CHARPAK and F. SAULI, Mobilities of Positive Ions in some gas mixtures used in Proportional and drift chamber, *Revue de Physique Appliquee* (1977) p67-70
- 13) Earl W. McDANIEL, *The Mobility and Diffusion of Ions in Gases*, John Wiley & Sons, Inc (1973) p10-24
- 14) J.C. ARMITAGE, S.P. BEINGESSNER, R.K. CARNEGIE, E.F. RITCHIE, J.WATERHOUSE, A Study of the effect of Methane and Carbon Dioxide Concentration on Gas Amplification in Argon Based Gas Mixtures, *OCIP* (1988)
- 15) Sean BEINGESSNER, R.K. CARNEGIE and C.K. HARGROVE, A Study of the effect of Methane and Carbon Dioxide Concentration on Gas Amplification in Argon Based Gas Mixtures, *NIM A260* (1987) p210-220
- 16) Tadeusz Z. KOWALSKI, Measurement and parametrization of the gas gain in proportional counters, *NIM A234* (1985) p521-526
- 17) Takahiko AOYAMA, Generalized gas gain formula for proportional counters, *NIM A234* (1985) p125-131
- 18) Frank KREITH, *Principles of Heat Transfer*, Intext Press, Inc (1973) p4-66
- 19) M.E. ROSE and S.A. KORFF, *Phys Rev* 59 (1941) p850
- 20) Otto Claus ALLKOFER, *Spark Chamber*, Verlag Karl Thiernig KG. Munchen p22-37.
- 21) Earl W. McDANIEL, *The Mobility and Diffusion of Ions in Gases*, John Wiley & Sons, Inc (1973) p118-132

- 22) R. GOTT, M.W. CHARLES, Attenuation of Proportional Counter Pulses by Equal Integrating Time Constants, NIM 72 (1969) p157-160
- 23) Tadeusz Z. KOWALSKI, Measurement and Parametrization of The Gas Gain in Proportional Counters, NIM A234 (1985) p521-526
- 24) Takahiko AOYAMA, Generalized Gas Gain Formula for Proportional Counters, NIM A234 (1985) p125-131
- 25) J. FELTESSE, Liquid Noble Gas and Warm Liquid Detectors, NIM A283 (1989) p375-386
- 26) S. KISHIMOTO, and Y. ISOZUMI, Gas Gain of Helium-Filled Proportional Counter at Low Temperatures (~ 4.2 K), NIM A286 (1990) p262-264
- 27) P. GIUBELLINO, W.A. ROWE, H.F-W. SANDROZINSKI, J.L. SKALA, Phenomena Association With Very Large Gains in Drift Chambers, NIM A252 (1986) p528-530
- 28) A. BLANC, J. Physique 7 (1908) p825
- 29) W.S. ANDERSON, J.C. ARMITAGE, P. CHEVREAU, J.G. HEINRICH, C. LU, I. McDONALD, K.T. McDONALD, B. MILLER, D. SECREST, and J. WECKEL, Investigations of Single-Electron Avalanches in a Proportional Drift Tube, Symposium on Detector Research and Development for the SSC, World Scientific Publishing Co.Pte.Ltd (1991) p222-224

- 30) Earl W. McDANIEL, Edward A. MASON, The Mobility and Diffusion of Ions in Gases, John Wiley & Sons, Inc (1973) p267
- 31) M. SAPOROSCHENKO, The Journal of Chemical Physics 49 (1968) p768-774
- 32) MAESTRO II Emultion Software and Manual, EG&G ORTEC (1989)
- 33) 916A Hardware Manual, EG&G ORTEC (1989)
- 34) 142PC Preamplifier Hardware Manual, EG&G ORTEC (1989)
- 35) Nuclear Instruments and Systems Manual, EG&G ORTEC (1989) p4.62-4.64
- 36) Dupont Tech Bulletin Freons (1964)
- 37) Handbook of Chemistry and Physics 62nd, CRC Press (1982)

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