The Drift Chambers Handbook, introductory laboratory course (based on, and adapted from, A H Walenta’s course notes)

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Abstract. This handbook was written for the Drift Chambers introductory laboratory course to be held at 11th Mexican School of Particles and Fields that will be held at the Universidad Veracruzana on the campus of the University at Xalapa, Veracruz, Mexico. This course intends to introduce drift chambers, which play an important role in particle physics experiments as tracking detectors. We start such laboratory course with a brief review of the physics theoretical background. The experimental setup consists of a single-sided, single-cell drift chamber, a plastic scintillator detector, the standard P-10 gas mixture (90\% Ar, 10\% CH\textsubscript{4}) and a collimated \textsuperscript{90}Sr source. The measurements on the drift velocity of electrons, its change as a function of a drift field, gas gain and diffusion are performed at this laboratory course.

Introduction

When a charged particle passes through a gas, it will interact electromagnetically with nearby atomic electrons, resulting in the creation of electron/ion pairs along the path of the particle. The number of such pairs created depends on the energy of the particle and the type of gas, but for a typical gas at STP and a particle with unit charge, the mean number of electron/ion pairs formed will be on the order of 100 cm\textsuperscript{-1} atm\textsuperscript{-1}.

If an electric field is applied, the electrons will start to drift through the gas towards the positive electrode, undergoing repeated collisions with the gas molecules. (The ions also drift in the opposite direction. However, their drift speed is much less than that of the electrons, so they can be ignored in this discussion.). If the electric field near the anode is strong enough, an electron can acquire enough energy between collisions to knock an additional electron free from a gas molecule. This additional electron can then go on to ionize more gas molecules; in this way, an avalanche is formed in which the number of electrons increases exponentially. When this avalanche reaches the positive electrode, it gives rise to a measurable current, the size of which is proportional to the original number of ions created. The ratio between the final number of electrons collected and the initial number deposited is called the gas gain, and for practical detectors is typically on the order of 10\textsuperscript{4}–10\textsuperscript{6}.

The large electric field needed to obtain gas amplification is usually obtained by forming the anode from a very thin (20-100\textmu m) wire. An electron sitting in the gas far away from the anode will see a much smaller electric field, and will drift towards the anode with a velocity roughly proportional to the field. When it gets close to the anode, the electric field will start to rapidly increase, and the electron will initiate an avalanche.

The fact that an electron drifts with a predictable speed over most of the distance to the anode implies that one can turn a measurement of the time an electron took to drift to the anode into a measurement of the distance of the original source particle from the anode. A device designed for this type of measurement is called a drift chamber.

In this way, the drift chambers are electronic detectors providing accurate measurement of the position of a charged particle. The theory behind the drift chamber was first studied by Bressani, Charpak, Rahm and Zupancic in 1969. The first fully operational drift chamber was used to study particles by Prof. A.H. Walenta, Heintze and Schürlein in 1971.
The drift chamber works because of ionization. As a charged particle passes through the gas, it ionizes the gas atoms. These atoms then feel the force of an electric potential and drift towards wires that register a signal. Knowledge of the drift time (time from ionization to signal) and the drift velocity in the gas allows one to determine the position of the incoming particle. Stacking several drift chambers on top of one another allows one to resolve a track left by the particle, which can give information such as incoming angle. If there is an applied magnetic field, the track will curve and one can then determine the momentum of the particle. Drift chambers can achieve spatial resolution of 50 µm or better. A schematic for a drift chamber is shown in Figure 1 below. The screening electrodes are the conductive shielding around the chamber.

![Figure 1: Schematic of basic drift chamber features (Adapted from Figure 6.16 of Leo)](image)

The chamber is surrounded by a conductive medium because the cathode drift wires carry a non-uniform negative voltage, which varies from ground close to the anode wire down to a high negative voltage close to the field wire. The anode wire is where electrons from ionized gas atoms will drift and be collected (more on that in a moment). The field wires are there to keep the equipotential lines (also shown in Figure 1) linear over a larger range. For a larger coverage, several such cells can be put together into a single chamber. In order to resolve spatial coordinates, the drift chamber must have a trigger to signal when a charged particle is present. That way we can calculate the time between the passage of the charged particle and the arrival of a signal on the anode wire.

The basic principle of operation makes use of the fact that the timing of the signal in a proportional counter shows a time lag with respect to the moment of particle passage (and consequently the moment of creation of the ionization along the particle track in the gas of the detector volume). This time lag is related to the time the electrons from the ionization take to travel (drift) to the amplifying anode wire (Figure 2). In proportional counters this time lag is considered as a nuisance limiting the time resolution of the detector. If, however, the timing of the particle passage is determined with higher precision by scintillating counters (hodoscopes) or by the timing of the accelerator bunch, the time lag can be used to determine the exact position of the ionization with respect to the anode wire. It is clear that the quality of the relation drift time vs. drift distance determines the quality of the position measurement.

![Figure 2: Principle of proportional counter](image)
Mathematically the measured drift time $t_{\text{drift}}$ is related to the drift path (for zero magnetic field along the electrical field lines) from the location of ionization creation along the track to the anode by:

$$t_{\text{drift}} = \int_{\text{track}}^{\text{anode}} \frac{ds}{v_{\text{drift}}(x)}$$

(1)

For operational devices two basic schemes have been conceived: the method of constant drift field (Figure 3a) giving a simple dependence for the drift distance $d = t_{\text{drift}} \cdot v_{\text{drift}}$ with $v_{\text{drift}} = \text{const.}$ and the second method with variable drift field (mostly radial dependence as in a cylindrical geometry of a proportional counter tube) where the gas is chosen such that the drift velocity is independent or only slightly dependent on the drift field. For the latter a calibration procedure is applied determining the closest approach of the track $s_{\text{min}}$ to the anode (Figure 3b).

\[\text{Figure 3: Principle of drift chambers.}
\text{a) constant drift field, b) multiwire drift chamber}\]

In order to cover larger surfaces these cells have to be repeated which requires in addition a solution for the right-left ambiguity. This can be achieved by the “double wire method” (Figure 4a) or by the “staggering method” (Figure 4b).

\[\text{Figure 4: Right-left ambiguity in drift chambers.}
\text{a) double wire type, b) double chamber type}\]
Theoretical Background

- Drift and diffusion in gases.

The motion of an electron in the gas is governed by two physical phenomena: drift and diffusion. Diffusion is the random motion caused by the thermal energy of the electron. The result is that after a time $t$, a collection of electrons originally distributed in a straight line at $x = 0$ will be distributed in a Gaussian distribution of the form:

$$\frac{dN}{dt} = \frac{N_0}{(4\pi Dt)^{1/2}} \exp\left(-\frac{x^2}{4Dt}\right)$$

Where $N_0$ is the total number of charges, and $D$ is the diffusion coefficient given by:

$$D = \frac{2}{3 \sqrt{\pi}} \frac{1}{p \sigma_0} \left(\frac{kT}{m}\right)^{1/2}$$

Where $T$ is the temperature, $k$ is the Boltzmann’s constant, $p$ is the pressure, $m$ is the mass of the electron and $\sigma_0$ is the cross section for an electron to collide with a gas molecule.

The velocity due to drift can be determined from the mobility of a charge in a gas, which is given by:

$$v_{\text{drift}} = \mu E$$

Where $v_{\text{drift}}$ is the drift velocity, $\mu$ is the mobility and $E$ is the electric field strength. The mobility is related to the diffusion coefficient by the Einstein relation:

$$D = \frac{\mu kT}{e}$$

Where $e$ is the charge of electron. For a further explanation of these expressions, see Leo (1987).

In a uniform electric field the electrons will drift with a constant velocity on the order of 1 to 10 cm/µs (10 to 100 microns/nsec (or mach 300)) at optimum voltage. The velocity is a constant because the electrons collide frequently which slows them down while the electric field accelerates them. The drift velocity is the equilibrium condition. Typically the velocity as a function of electric field has a broad maximum which is usually the field used in a drift chambers so as to be insensitive to variations in voltage, temperature and pressure. The drift velocity $v_{\text{drift}}$ versus field $E$ is pressure dependent since the collision time depends on the pressure, so that $v_{\text{drift}}$ versus $E/p$ is the correct variable to plot. Where $E/p$ is the reduced electric field.

The first ion that a charged particle creates is appropriately called the primary ionization. As the electron from this ionization is accelerated by the electric field, it will eventually gain enough energy to ionize other atoms. Then these secondary ionizations can gain enough energy to cause further ionizations, and so on. This effect is called avalanche multiplication, and is important for the gain of the chamber. The electric field is constant through most of the chamber, except very near of the anode wire, where it goes as $E/1/r$, where $r$ is the radius of the wire. Thus most avalanche multiplication takes place within a few radii of the wire. (See Figure 3c)

- Ionization by charged particles.

As a charged particle passes through a gas, it actually loses energy via 2 mechanisms: excitation and ionization. In excitation, the particle passes a specific amount of energy to a gas atom. The cross section for that is around $10^{-17}$ cm$^2$. In ionization, the particle knocks an electron off the gas atom, and
leaves a positively charged ion. The cross section for ionization is about $10^{-16}\text{cm}^2$. It is only ionization that will lead to a signal in the drift chamber, so excitation isn’t directly useful. However, excited atoms can still participate in reactions that lead to ionization, so the energy is not lost. An example of this is the Penning Effect where an atom stays excited long enough to collide with another atom and ionize it.

In Figure 3, the track of the charged particle is indicated as a dashed line, which may be interpreted as the path of the projectile. This is a rather abstract representation of the reality consisting of an accumulation of ionization clusters (Figures 5 and 5a).

The ionization clusters are produced in the following way: the time dependent electrical field of the passing particle couples to the electrons of the gas atoms and may have enough impact to kick out the electron of an atomic shell, say the L-shell, causing an energy transfer $E'$. The excess energy $E_{\text{kin}} = E' - E_L$, represents the kinetic energy of this liberated electron which in turn may ionize again. In this case it is considered as a new charged particle and is called $\delta$-ray. If the excess energy is low it will not ionize and thermalize quickly. The ionization left behind by these individual encounters, including the rearrangement of the L-shell, mediated by Auger-electrons or x-ray emission, is called a cluster and the sum of the clusters represents the footprint of the charged particle, which will be detected in the drift chamber. Therefore it is important to know some features:
1. The number of the clusters per track length
2. The spatial distribution along the track
3. Their size, measured in terms of the number of free electrons belonging to them
4. Their spatial extension

**Ionization energy loss of charged particles**

Tracking detectors designed to make position measurements along the trajectories of charged particles can simultaneously be used to identify particle species by measuring the mean ionization loss along the tracks. This applies to any detector in which particles lose energy to ionization, e.g., gas-filled wire chambers or silicon strip detectors. Since the pulse height on each wire or strip must be read out, this technique requires the use of analog readout electronics. Because the ionization energy loss is a statistical process with large fluctuations, many measurements are needed along each track to get a precise mean.
For gas-filled detectors, the statistics are improved by operating at higher gas pressure, since this result in more primary ionizations along the particle path. The precision of the mean is improved by using the method of “truncated mean” whereby a certain fraction of the signals of largest size are removed in taking the average.

The energy loss mechanism for a charged particle passing through a gaseous medium is mainly by interactions with atomic electrons i.e. ionization loss. The ionization energy loss of charged particles is fundamental to most particle detectors. The multiwire proportional counter (MWPC) can be given as an example of such gas detectors. These are widely used whenever measurement of energy loss of radiation is required. These are also sensitive to the position at which an incident charged particle interacts.

The basic MWPC (Figure 6) usually consist of a set of thin, parallel and equally spaced anode wires, symmetrically sandwiched between two cathode planes. An ionizing particle passing through the chamber creates electron-ion pairs depending on its energy. The generated electrons cause an avalanche multiplication in the vicinity of one of the wires that behave as cylindrical counter. The incident particle can thus be located by observing signals from the wires that separately amplified and displayed.

\[
\Phi(E', E) \, dE' \, d\tau = \frac{\lambda \rho}{\beta^2} \frac{1}{E_{\text{min}}^2} \, dE' \tag{7}
\]

With \( \rho \) the gas density, \( \beta = v/c \), and \( \lambda = 0.1536 \, Z/A \, \text{MeV cm}^2 \, \text{g}^{-1} \); again \( Z \) is the atomic number and \( A \) is the atomic weight respectively.

Inserting 7) into 6) yields:

\[
\langle dN/dx \rangle = \frac{\lambda \rho}{\beta^2} \left( \frac{1}{E_{\text{min}}} - \frac{1}{E_{\text{max}}}^2 \right) \approx \frac{\lambda \rho}{\beta^2} \frac{1}{E_{\text{min}}} \tag{8}
\]
Which takes into account that \( E'_\text{max} \gg E'_\text{min} \). For the calculation of \( E'_\text{min} \) the quantum mechanical effects cannot be neglected and therefore a simple formula has not been developed.

Since the generation of an individual ionization cluster is completely random the actual number in a chamber \( m_p \) varies according to a Poisson distribution. This is responsible as well for the random distribution along the track resulting in an exponential probability distribution of the gaps between two clusters.

The cluster size distribution is governed by the energy loss distribution described by \( \Phi (E', E) \) such that the number of electrons is typically \( E'/W \) with \( W \) the energy necessary to create an ion pair. Following the steep decrease of \( \Phi (E', E) \) most of the clusters will be single electron clusters and larger clusters will occur only occasionally. These large clusters can be considered as small tracks on their own (\( \delta \)-rays) and their range is responsible for the spatial extension of the clusters, which may reach a few hundred microns in a counting gas at NTP.

In a similar way as the mean number of clusters in equation (6) the mean energy loss for a track segment is obtained by

\[
\langle \frac{dE}{dx} \rangle = \int_{E'_\text{max}}^{E'_\text{min}} E' \Phi (E', E) dE' \tag{9}
\]

This is called the mean energy loss.

Taking into account relativistic effects and relation (7) the well-known Bethe-Bloch formula is obtained:

\[
\langle \frac{dE}{dx} \rangle = \frac{\tilde{I} \rho}{\beta^2} \left( 2 \ln \frac{2m_e c^2}{I} + 2 \ln \beta \gamma - 2 \beta^2 - 2 \delta \right) \tag{10}
\]

Where \( \tilde{I} \) is the mean ionization potential and \( \delta \) the density correction.

The fluctuations of the energy loss are given by an asymmetric rather broad Landau distribution with a long tail towards higher energy. A good description of this distribution is obtained using the most probable energy loss \( E_{mp} \) and the full width at half maximum \( \Delta E \). The properties of this distribution become important in the light of a possible application for particle identification using either the \( 1/\beta^2 \) dependence in the non relativistic case or the logarithmic rise in the relativistic part of the energy loss formula 10). Since the fluctuations of the Landau distribution are rather large (\( \Delta E/E_{mp} = 0.40 \ldots 1.0 \)) only a method of multiple sampling yields the necessary resolution of about 6%.

### The proportional gas gain

Originally the proportional counter is used in cylindrical geometry, i.e. a wire with a radius \( r_i \) of less than 50 \( \mu \)m is stretched in the center of a tube (outer cylinder) with a radius \( r_a \) of typically a centimeter (see figure 2). The inner wire is held at positive potential \( U_0 \) with respect to the outer cylinder resulting in the known potential \( U(r) \) and field distribution \( E(r) \) of a cylindrical capacitor:

\[
E(r) = \frac{U_0}{r} \frac{1}{\ln \frac{r}{r_a}} \tag{11}
\]

and

\[
U(r) = \frac{U_0}{\ln \frac{r}{r_a}} \frac{\ln \frac{r}{r_a}}{r_a} \tag{12}
\]
The sealed tube is filled with a counting gas adapted to the desired performance of the detector. For most applications an Argon mixture is sufficient (P-10: =0.9 Ar + 0.1 CH₄) which exhibits excellent counting performance. A quencher gas (e.g. CH₄, CO₂) is added in order to obtain lower diffusion of the drifting electrons and in order to control the gas gain. For the efficient absorption of x- and γ-rays a dense gas with high atomic number (Xe) is used. The latter takes place in the vicinity of the anode wire where the field strength becomes large enough to generate an avalanche. Each primary electron contributes to the total charge in the avalanche G ion pairs, where G is called gas amplification.

Using the assumption that the gas multiplication is only due to the accelerated electrons ionizing the gas atoms, then the increase, \(dn\) in the number of electrons, \(n\), (the growth of the avalanche) on the path length \(dr\) is described by the Townsend process 

\[dn = \alpha \cdot n \cdot dr\]

where the probability of ionization is defined by the first Townsend Coefficient \(\alpha\) and consequently for the total avalanche the gain \(G\) is calculated:

\[\ln G = -\int_{r_1}^{r_2} \alpha(r) dr = \int_{r_1}^{r_2} \alpha(r) dr\]  

(13)

The integration extends from the threshold radius \(r_1\) to the surface of the anode wire \(r_2 = r_i\). For simplicity the integration can be carried out from the outer (cathode) radius \(r_a = r_k\) since the additional contribution will vanish. The Townsend coefficient \(\alpha\) is a function of the electrical field strength and therefore it becomes a function of \(r\) as well. In practice the evaluation of the integral fails because of the limited knowledge of \(\alpha\). Mostly simple (linearized) approximations are used resulting in formulas for the gas gain of limited use. A more satisfactory parameterization of \(\alpha\) is obtained in the form:

\[\frac{\alpha}{p} = A \exp(-B(\frac{p}{E})^k)\]  

(14)

with \(A\), \(B\) and \(k\) experimental parameters.

It was found that \(k=0.65\) describes well measurements with noble gas-hydrocarbon mixtures (Ar/CH₄) and pure hydrocarbon (ref. Lehnert). Under this assumption the formula contains only two experimental parameters. This parameterization still leads to a complicated integral but numerical integration is straightforward. The parameter \(A\) defines the plateau, which is related to the max cross section for ionization by electron impact. The parameter \(B\) defines the onset of the rise and is related to the energy distribution of the electrons in the swarm and therefore is influenced by the inelastic cross section of electron scattering. Small admixtures of molecular gases have a strong influence. The parameter \(k\) changes the slope in the steeply rising section. Since the gas gain takes place in the field region \(E/p = 10^{-3} \text{ to } 10^{-2} \text{ kV/mmTorr}\); the most important parameter is \(B\) which is responsible for the high voltage needed for sufficient gas gain.

In summary it can be stated that the integration of the Townsend coefficient parameterized in the given form reproduces well the observed gas amplification in proportional counters. Clearly the extreme effects caused by different discharge phenomena are not described as limited proportional or streamer mode where the propagation and ionization of uv-quanta plays an important role. In these cases the second Townsend coefficient has to be taken into account. Here we are limited to the pure proportional mode.

**Drift and Diffusion in a “mean electron model”**

As relation (1) indicates the drift velocity of electrons in gases as function of the electric field is of foremost importance for the proper operation of a drift chamber. The basic process of the motion of free electrons in gases is described by the diffusion of thermalized electrons superimposed by a
directional motion of drift under the force created by the electrical field acting on the charge of the electrons.

In a “mean electron model” (where the Maxwell-like energy distribution of the electrons is replaced by an appropriate mean energy \( \epsilon \) or the mean velocity \( c = \sqrt{8/3\pi \cdot \sqrt{2\epsilon/m}} \) the diffusion is described by a broadening of an initial delta function for the spatial distribution into a gaussian distribution with

\[
\sigma = \sqrt{2Dt}
\]

(15)

Where the diffusion coefficient is given by

\[
D = \frac{1}{3} c \lambda
\]

(16)

With \( \lambda \) the mean free path.

The drift velocity in this model is given by

\[
v_{\text{drift}} = \frac{8}{3\pi m} \frac{eE}{c} \lambda = \mu E
\]

(17)

With \( \mu \) the mobility and \( E \) the electrical field strength.

It is seen that the mean free path \( \lambda \) (and consequently the cross section for electron scattering at the atoms) as function of the mean electron energy and the mean electron energy as function of the reduced electric field \( E/p \) determine the motion parameters \( v_{\text{drift}} \) and \( D \). (Remember that as the Townsend coefficient \( \alpha \) gives the number of ionizations per unit length, \( 1/\alpha \) is the mean free path for ionization and consequently the average distance over which electrons are accelerated by the electric field).

In the usual drift gases a mixture of a noble gas (mostly Ar) with a molecular admixture (mostly hydro-carbons like \( C_n H_m \)) are used. In order to emphasize the atomic and molecular physics, the mobility \( \mu \) is considered: with increasing field \( E \) the electrons are accelerated but the velocity \( c \) is increasing only to a limit since the onset of inelastic cross sections (rotational and excitational processes) absorbs most of the energy from the field. However, the small change in \( c \) reduces the total cross section considerably due to the Ramsauer effect, where atoms become transparent to the electrons. Therefore the mobility rises sharply for small fields. At somewhat higher fields and energies the rotational cross sections become constant, therefore \( c \) rises quickly reducing the mobility. In concert with the increase of the cross section behind the Ramsauer minimum, the mobility may even drop to an extent that the drift velocity is dropping as well. This effect can be seen very well in the standard P-10 mixture (90% Ar, 10% CH4). Clearly, the proper choice of the gas mixture allows over a wide range of \( E \) to obtain an almost constant drift velocity which is important for a good position resolution and a stable operation.

In order to obtain some insight to the diffusion process it is useful to consider the following relation (Einstein relation):

\[
e \frac{D}{\mu} = kT_e
\]

(18)

Where \( e \) is the electron charge and \( T_e \) is the electron temperature which coincides with the gas temperature if the "heating" of the electrons by the electric field is negligible. For gases with large inelastic cross section for electron collisions this will be the case even for large electric field strength (cool gases). For noble gases or noble gas mixtures with a small admixture of molecular gases (e.g. P-10) the deviation starts already at small drift field. This is best seen by the relation obtained for the
experimentally accessible quantity $\sigma$ as function of $E$ and $l$ (the drift length) by combining equations. 1,6,8,9:

$$\frac{\sigma^2}{l} = \frac{2kT}{eE}$$  \hspace{1cm} (19)$$

The measured quantity $\sigma^2/l$ representing the quality of the drift process (comparable to a dispersion for electrical signals on a transmission line) depending inversely on $E$ while the minimum is governed by the relation $kT/E$, the thermal limit. If measurements are found above this limit, the electrons are not in equilibrium with the gas. The cooling effect of the molecular gases is clearly seen. The goal of the choice of gas in a drift chamber must be to optimize this cooling which is not always evident since other practical considerations besides the drift velocity have to be taken into account: specific energy loss, photon absorption cross section, Townsend coefficient (for gas gain), magnetic deflection, electron attachment, safety regulations etc.

**Experimental Set-up**

An artist view of the set-up is shown in Figure 7 displaying the main features of operation: the single sided, single cell drift chamber is moved via a sliding table through a fixed collimated beam of fast electrons ($\beta$-rays from the source Sr-90). The time of the particle passage is recorded by the signal from the photomultiplier coupled to the scintillator and the drift time is obtained from the amplified signal of the drift chamber. This time lag is measured for different positions of the drift chamber.

![Figure 7: Set-up of drift chamber and source collimation.](image1)

![Figure 8: Functional set-up of experiment with drift chamber and electronics.](image2)

A schematic view of the drift chamber is shown in Figure 8 indicating the drift electrodes connected to a resistive divider chain producing a constant drift field. The electrons are amplified at three anode wires of which the two outer ones are connected together. The side view (Figure 9) shows some construction details: the drift electrodes are fabricated in hybrid (thick film) technology with structured conducting electrodes (silver-palladium) and resistors deposited in a baking process on ceramic ($\text{Al}_2\text{O}_3$) substrate.
In principle the ceramic is thin enough to allow x-rays to penetrate. In order perform measurements with minimum ionizing $\beta$-rays a slot at half height is cut into the ceramic. The electrodes are bridged by wires soldered to the conducting strips on both sides. The amplifying structure at the end of the drift cage consists of three anode wires enclosed by 4 potential wires in order to generate a controlled transition from the drift field to the almost cylindrical amplification field around the anode wires. The operation of the drift chamber is controlled by two independent power supplies: one for the drift field (negative) and one for the gas gain (positive).

The preamplifier and shaper of the anode signal is optimized for low noise and a shaping allowing at the same time to record the phase of the signal (drift time) with good precision and the shape due to broadening from diffusion. This is achieved by an integrating input stage and the following pole-zero cancellation. A second pole-zero cancellation removes the tails from the signal generation process in the proportional gas gain. Two more integration time constants (not shown) define an approximately gaussian width of the output pulse of ca. 150 ns. The shaped signals are recorded in a digital storage oscilloscope with respect to the trigger from the photomultiplier signal. The averaging mode of the scope allows the recording of fluctuating individual signals from the detector with good precision.

For the timing precision of the trigger signal from the scintillator-photomultiplier combination a value of about 1 ns may be easily reached, good enough for the drift time measurement. But the trigger signal also defines a spatial selection of an ionizing particle crossing the drift space at a well-defined location. This is achieved by collimators placed at the source and the entrance of the scintillator. Beyond the geometrical limitation also bremsstrahlung and multiple scattering broaden the accepted beam. Therefore the chamber thickness has been minimized and the collimator consists of low Z material (Lucite). The gas supply consists of a gas mixing system (Figure 10) where the gas is supplied from a pressurized bottle. The gas mixture is controlled by calibrated flow meter. The gases are argon (90%) and methane (10%).

**Measurements and experimental results for a radiation source of 1 milliCi.**

1. **Preparation of the detector.**
   After regulation of the gas flow allow about 5 minutes for full exchange of the gas in the detector. Control the flow at the outlet of the chamber. Check the operation of the amplifier by observing the noise in the single shot mode of the scope or using an analogue scope. Observe the photomultiplier signals on the scope and adjust the voltage such that in the mean a few 100 mV are obtained. Control the output of the discriminator and adjust the threshold.

2. **Drift velocity experiment.**
   The drift time is recorded at an appropriate number of detector positions. In principle a straight line should be obtained for measurements not too close to the anode. This measurement is repeated for a number of drift voltage settings and gas mixtures. It is important to control each time the gas gain.

   *Radiation, gas and high voltage specifications.*
• Collimated Source $^{90}$Sr: 1 milliCi.
• Gas pressure: 1 bar.
• Gas mixture: P-10 (0.9Ar + 0.1CH₄)
• Anode Voltage: +950 Volts.
• PMT Voltage: +900 Volts.
• Field Voltage: from –300 up to –1200 Volts.

Experimental results:

| Field Voltage $[V]$ (Drift Field) |
|-----------------------------------|
| Distance $[mm]$                  | -300 | -600 | -900 | -1200 | -1500 | -2000 | -3000 | -4000 |
| 37  | 590  | 470  | 456  | 440   | 460   | 450   | 480   | 320   |
| 40  | 790  | 572  | 476  | 496   | 500   | 540   | 570   | 390   |
| 45  | 1180 | 720  | 640  | 616   | 600   | 640   | 700   | 530   |
| 50  | 1540 | 880  | 736  | 672   | 700   | 730   | 820   | 680   |
| 55  | 1900 | 1020 | 850  | 816   | 800   | 850   | 940   | 820   |
| 60  | 2290 | 1160 | 960  | 892   | 910   | 950   | 1050  | 950   |
| 65  | 2660 | 1310 | 1070 | 1012  | 1000  | 1070  | 1180  | 1080  |
| 70  | 3100 | 1450 | 1170 | 1120  | 1100  | 1170  | 1310  | 1250  |

*Slopes (mm/nsec) 73,776 31,265 22,931 22,448 20,191 21,417 25,356 26,332

*Drift Time ($\Delta t$).
3. Determination of the reduced field
The determination of the reduced field strength E/p results in values to be compared to literature. The plots of drift velocity vs. E/p for different gas mixtures allow the discussion of the mean electron energy and the cross sections for elastic encounters (Ramsauer effect) and inelastic encounters (rotational and excitational levels in molecules).

Radiation, gas and high voltage specifications.

- Collimated Source $^{90}\text{Sr}$: 1milliCi.
- Gas pressure: 1 bar.
- Gas mixture: P-10 (0.9Ar + 0.1CH₄)
- Anode Voltage: +950 Volts.
- PMT Voltage: +900 Volts.
- Field Voltage: from –300 up to –1200 Volts.
Experimental results:

| Drift Field [Volts] | E Field [Volts/(cm*Torr)] (Reduced Field) | Drift Velocity [cm/µsec] |
|---------------------|------------------------------------------|--------------------------|
| -300                | 0.056390977                              | 1.32± 0.3296             |
| -600                | 0.112781955                              | 3.38± 0.2857             |
| -900                | 0.169172932                              | 4.47± 0.7767             |
| -1200               | 0.22556391                               | 4.86± 0.3739             |
| -1500               | 0.281954887                              | 5.06± 0.3739             |
| -2000               | 0.375939885                              | 4.64± 0.4541             |
| -3000               | 0.563909774                              | 4.05± 0.3504             |
| -4000               | 0.751879699                              | 3.57± 0.3727             |

Drift velocity vs. reduced field for several gases (CH4, C2H6, C3H8: T.L. Cottrell and I.C. Walker, Trans. Faraday Soc., 61 (65) 1585, Ar, Ar/CH4: D. Mattern, Thesis, Siegen 1988)

4. Gas gain

For a medium setting of the drift field (ca. 2 kV) the anode voltage is increased until signals appear occasionally. For each gas mixture a maximum allowable voltage is given (by the assistant) which never should be exceeded, otherwise the detector will be destroyed. If this voltage is reached without observing signals, check the system again. In the averaging mode the proper signal height is adjusted by fine-tuning the gain voltage.

Radiation, gas and high voltage specifications.

- Collimated Source $^{90}$Sr: 0.1µCi.
- Gas pressure: 0.5 bar. Gas mixture: P-10 (0.9Ar + 0.1CH4)
- Field Voltage: -2000 Volts.
- PMT Voltage: +900 Volts.
- Anode Voltage: from +650 up to +900 Volts.
- Fixed Distance: 37 mm.
Experimental results:

| Anode Voltage [Volts] | Amplitude [millivolts] (Drift Field :-2000V) | Log(Amplitude) (Volts) (Drift Field :-2000V) |
|-----------------------|--------------------------------------------|---------------------------------------------|
| 725                   | 0.8                                        | -0.096910013                                |
| 750                   | 1.58                                       | 0.198657087                                 |
| 775                   | 1.76                                       | 0.245512668                                 |
| 800                   | 2.56                                       | 0.408239965                                 |
| 825                   | 3.84                                       | 0.584331224                                 |
| 850                   | 4.8                                        | 0.681241237                                 |
| 875                   | 7.12                                       | 0.852479994                                 |
| 900                   | 8.8                                        | 0.944482672                                 |
| 925                   | 16.8                                       | 1.225309282                                 |
| 950                   | 23                                         | 1.361727836                                 |

Typical Error: 0.05361

| Anode Voltage [Volts] | Amplitude [millivolts] (Drift Field :-4000V) | Log(Amplitude) (Volts) (Drift Field :-4000V) |
|-----------------------|--------------------------------------------|---------------------------------------------|
| 725                   | 0.8                                        | -0.096910013                                |
| 750                   | 1.2                                        | 0.079181246                                 |
| 775                   | 1.44                                       | 0.158362492                                 |
| 800                   | 2.16                                       | 0.334453751                                 |
| 825                   | 3.44                                       | 0.536558443                                 |
| 850                   | 4.72                                       | 0.673941999                                 |
| 875                   | 6.4                                        | 0.806179974                                 |
| 900                   | 7.68                                       | 0.88536122                                 |

Typical Error: 0.03699
Gas Gain Measurement

Anode Voltage [KVolts]

Log(Amplitude) (Gas Gain)

Field Voltage -2000V

Field Voltage -4000V

P-10, ra=7.5µm

C4H10, ra=7.5µm

P-10, ra=15µm

C4H10, ra=15µm

measured P-10

measured C4H10

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