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INVESTIGATIONS OF SINGLE-ELECTRON'S BEHAVIOUR IN A PROPORTIONAL DRIFT TUBE

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ABSTRACT

Investigation on the single-electron's behaviour in a proportional drift tube has been carried out with a pulsed N_2 laser set-up. The study consists of two major aspects: the timing property and the fluctuation of gas avalanche.

For the timing measurement the total drift time from cathode to anode wire, time resolution, as well as spatial resolution have been measured for the following gas mixtures: Ar/CO_2 (50/50), Ar/C_2H_6 (50/50), Ar/CH_4 (90/10), and various mixing ratios of Ar/CF_4 and CF_4/isobutane. In our experiment using a pulsed N_2 laser beam to release single photoelectron from cathode has been proved to be quite successful and therefore provide a direct and efficient way to measure timing properties for cylindrical type of drift chamber.

In the study of single-electron's avalanche comparison between the single-electron's avalanche and the one initiated by Fe^{55} x-ray reveals the link of energy resolution and the electron attachment, indicates a serious electron attachment may exist in CF_4/Ar mixture.

The detailed information of single-electron drift and avalanche behaviour has a basic interest in an investigation of gas chamber performance. Its timing, avalanche distribution, attachment by the working gas mixtures, etc., provide various criteria for choosing the best suitable gas mixture under a specific experimental circumstance. In order to get the single-electron in a proportional counter, a pulsed nitrogen laser has been employed to release photoelectron from the proportional tube's wall. Careful adjustment of the laser beam intensity can ensure most of the events recorded being the single electron events, which have been used to investigate their timing and gas avalanche behaviour.

1. Timing of single-electron

(1) Experimental set-up

UV light sources have been used to generate photoelectrons from photosensitive plates for time-of-flight measurement of electron in different gases.[1,2] Also, several papers report on the use of laser-induced ionization in drift chambers to mimic the track of a minimum-ionizating particle.[3−6] Our present interest is in the timing properties of a single-electron in a cylindrical 'straw-tube' drift chamber.

A sketch of the experimental set-up is shown in Fig. 1.

Fig. 1. Sketch of the experimental set-up.

The N_2 laser generates pulsed 337-nm (3.67-eV) UV photons, with a pulse length of about 350 ps. The pulse energy is about 100 μJ, corresponding to about 2×10^{14} photons. The test drift tube was made of 7.67-mm-diameter aluminum tubing. The photoelectric work function of aluminum is 4.08 eV, which is larger than laser-beam energy, therefore the quantum efficiency for producing the photoelectron from the wall is expected to be very small. But due to the large number of photons per pulse we still can get enough photoelectrons. We are most interested in single-photoelectron events, so we use an iris diaphragm to reduce the beam intensity.

The laser beam was focused onto the inner wall of aluminum tube after passing through a 1-mm-diameter hole in the wall. The hole is offset by 1 mm from the center line of the tube. Because the beam spot on the inner surface of the tube is quite small, we can neglect mechanical imperfections and consider

Fig. 2. Block diagram of the electronics.

that the drift distance of the photoelectrons was just the radius of the tube. A beam splitter was used to reflect part of the laser beam to a photodiode (RCA C30905E), which generates a fast, large electric pulse as a start signal for TDC system. A preamplifier was directly connected to the test drift tube through a high-voltage capacitor. The drift-tube signal was used as a stop signal. The electronic block diagram is shown in Fig. 2.

Two different preamplifiers have been used in our measurements, LeCroy TRA 402 and AT&T preamplifier. AT&T preamplifier was used for studying the performance of CF_4/Ar and CF_4/isobutane mixtures with different mixing ratios. The rest of various gas mixtures were measured by LeCroy preamplifier.

The sensitivity and noise performance of these two preamplifiers have been measured, as shown in Fig. 3. The sensitivity measurement was carried out by charging a small capacitor with an EG&G ORTEC 419 precision pulser, therefore known amount of charge, as an input signal, being amplified by the preamplifier, and measuring the amplitude of the output signal on the HP 54502A digital oscilliscope. The noise *vs.* input capacitance was measured by attaching various number of BNC connectors to the input of preamplifier and reading the V_{rms} value on the digital scope. The capacitance of these BNC connectors were then measured with HP 4815A RF vector impedance meter at 100 MHz frequency.

Under our experimental circumstances AT&T preamplifier seems to be

Fig. 3(a) Sensitivity and noise performance of LeCroy TRA 402

Fig. 3(b) Sensitivity and noise performance of AT & T preamplifier

5 times more sensitive than LeCroy TRA 402. The typical E.N.C. at 10 pF input capacitance is about 1600 electrons for AT&T preamplifier, 17000 electrons for LeCroy TRA 402. When 2 meter long, well shielded straw tube (7 mm in diameter, 0.025mm anode wire) was attached to AT&T preamplifier, E.N.C. was about 2000 electrons. The threshold of the discriminator followed the preamplifier was set at 30 mV, it means the gas gain of single-electron avalanche has to be greater than 5×10^4 (AT&T) and 2.6×10^5 (LeCroy TRA 402), respectively.

(2) Gas control system

In order to be able to blend different ratio of gas mixtures and to adjust the gas pressure with high precision, a bench-top gas system has been installed, as shown in Fig. 4.

The accuracy of the gas flow rate control is 2% of reading and the

Fig. 4. Gas control system

accuracy of pressure measurement is 0.15% of reading. The fluctuation of the pressure under control has been within $\pm 1 Torr$ around the set point.

The piping of whole system was made of copper tubing. An oxygen filter and a moisture filter were installed directly in front of the test prototype. According to the manufacture's specification the gas clean oxygen filter removes oxygen, traces of sulphur and chlorine compounds from the gas, concentration of oxygen is brought down to less than 1 ppm. The moisture filter removes water, oil and other foreign material. A short branch in parallel with these filters is aimed at providing a gas flush path instead of going through the filter when the upper stream gas piping has been disconnected for swithing gas bottle and big amount of air has entered the gas system, which may shorten the lifetime of the filters.

Two manual needle valves were added in parallel with mass flow control

valve and pressure control valve for speeding up the procedure of setting different gas pressure.

(3) Time spectrum

Several kinds of gas mixtures have been tested with this setup. Due to the very small quantum efficiency and large number of primary UV photons, the number of photoelectrons in each pulse should vary according to a Poisson distribution. We reduced the aperture of the iris diaphragm until at most 1 in 4 laser pulses yielded any photoeletrons, and hence at least 90% of recorded events were initiated by single photoelectrons.

Some typical events are shown in Fig. 5 as recorded by a digital oscilliscope under constant gas pressure and high voltage for a P-10 gas mixture, but with different time and voltage scales. These events are multi-electron's events. The time jitter of the signal's leading edge can be clearly seen. Fig. 5(c) also shows the after-pulses which are due to photoelectrons released from tube's wall by the UV photons of the gas avalanche itself. The time difference between original pulses and after-pulse is just equal to the drift time for the entire radius. Fig. 6 shows single-photoelectron events, for which fluctuations in the gas avalanche are large.

The measured time spectra along with their Gaussian fits are shown in Fig. 7. The fittings are very satisfactory.

(4) Drift Time

Based on energy conservation, the following equation holds,[7]

$$eEw = \langle \Lambda \epsilon v/\ell_e \rangle \tag{1}$$

where E is the electric field, w is the drift velocity, ϵ is the kinetic energy, $\Lambda(\epsilon)$ is the mean fractional energy loss in a collision, v the random electron velocity, and $\ell_e(v)$ the mean free path for collision of the electron with the gas molecules. The left side represents the energy gained between collisions, and the right side is the energy lost in atomic collisions. Assuming ℓ_e is independent of v and the distribution of electron energy is narrow, and taking into account the following equations,[7]

$$w = \frac{2}{3}\frac{eE}{m}\left\langle \frac{\ell_e(v)}{v} \right\rangle + \frac{1}{3}\frac{eE}{m}\left\langle \frac{d\ell_e(v)}{dv} \right\rangle,$$

$$\epsilon = \frac{1}{2}mv^2,$$

it follows that

$$w \simeq \sqrt{\frac{2}{3}\sqrt{\frac{1}{3}}\Lambda\frac{eE\ell_e}{m}}. \tag{2}$$

(a)

(b)

(c)

Fig. 5. Photodiode and drift-tube signals for multielectron events. P-10 mixture, $P = 760$ torr, $V = 1600$ V. The upper trace shows the drift-tube signals, the lower shows the photodiode signals. **(a)** Vertical scale of upper trace is 40 mV/div; **(b), (c)** vertical scale of the upper trace is 400 mV/div; notice the different time scales.

Fig. 6. Photodiode and drift-tube signals for single-photoelectron events. P-10 mixture, $P = 760$ torr, $V = 1600$ V. The upper trace shows the drift-tube signals, the lower shows the photodiode signals. Vertical scale of upper trace is 100 mV/div.

Since ℓ_e is inversely proportional to gas pressure P,

$$\ell_e = \ell_{eo}/P,$$

where ℓ_{eo} as ℓ_e at 1 atm, therefore

$$w \simeq \sqrt{\frac{2}{3}\sqrt{\frac{1}{3}}\Lambda\frac{e\ell_{eo}}{m}}\sqrt{\frac{E}{P}}. \tag{3}$$

This is the well-known result that the drift velocity should depend only on $\langle E/P\rangle$.

Using simplified formulae to approximate the published curves on the drift velocity *vs.* E/P, we are able to calculate the total drift time. Adjusting the parameters in the formulae to get the best fit of our data, the results are shown in Fig. 8. The agreement is impressive. Because our data are collected under various pressures, and the drift velocity curves used in our fitting were measured or calculated at 1 atm, our results further confirm $w \propto f(E/P)$. The previously reported drift velocity of Ar/C_2H_6 (50/50) is nearly constant, with a slightly downward slope. It agrees well with our drift-time data, which are nearly constant with only a very small upward slope.

Fig. 7(a) Drift-time spectrum for Ar/CO_2 (50/50).

Fig. 7(b) Drift-time spectrum for Ar/C_2H_6 (50/50).

Fig. 7(c) Drift-time spectrum for Ar/CH_4 (90/10).

Fig. 8(a) Drift velocity and drift time of Ar/CO_2 (50/50).

Fig. 8(b) Drift velocity and drift time of Ar/CH_4 (90/10).

Fig. 8(c) Drift time of Ar/C_2H_6 (50/50).

(5) Spatial resolution

From the same argument as in previous section, it follows that[7]

$$\epsilon_k = \langle \epsilon \rangle \simeq \frac{3\ell_{eo}}{\sqrt{3\Lambda}} \frac{E}{P}, \tag{4}$$

where ϵ_k denotes the characteristic energy, which is a function of E/P. The spatial resolution σ

$$\sigma_x = \sqrt{\frac{2\epsilon_k x}{eE}}, \tag{5}$$

where x is the drift distance. Using (4) instead of ϵ_k in (5) we arrive at

$$\sigma_x = \sqrt{\frac{2\ell_{eo}}{\sqrt{3\Lambda}}} \sqrt{\frac{x}{P}} \tag{6}$$

While $\Lambda(\epsilon)$ is a function of electron energy ϵ, ϵ remains at a constant value up to rather high E field for a "cool gas" such as CO_2, for which Λ remains effectively constant. In such cases we conclude from (6) that

$$\sigma_x \propto \sqrt{\frac{1}{P}}.$$

We have directly measured the value of σ_t, and converted to σ_x using the x *vs.* t curve near the tube wall. Fig. 9 shows our data as well as a fit of the form

$$\sigma_x = \sigma_0 + A/\sqrt{P}$$

for Ar/CO_2. The results for Ar/CH_4 and Ar/C_2H_6 are shown in Fig. 10.

Fig. 9. Spatial resolution of Ar/CO_2 (50/50).

Fig. 10(a) Spatial resolution of Ar/C_2H_6 (50/50).

Fig. 10(b) Spatial resolution of Ar/CH_4 (90/10).

(6) Discussion

The total drift times over the radius of our proportional tube agree well with the published data. Direct comparison with the published data of our results on spatial resolution are difficult due to very limited existing data.

F. Pius[8] measured the longitudinal diffusion of electron in Ar/C_2H_6(50/50), with results shown in Fig. 11(a). Fig. 11(b) shows the results of Jean-Marie *et al.*[9] We infer that $\sigma_{0l} \simeq 210\ \mu m/\sqrt{cm}$ from F. Pius and

$\sigma_{0l} \simeq 125\ \mu\text{m}/\sqrt{\text{cm}}$ from Jean-Marie *et al.*Then for a 0.3835-cm drift distance the spatial resolutions should be 130 μm and 77 μm, respectively. Our result for 760 torr is 100 μm, in reasonable agreement.

The spatial resulution with Ar/CO_2 (50/50) is much better than with the other two gases due to its very slow drift velocity near the tube's wall as well as its being a "cool gas." While the results for Ar/CO_2 appear insensitive to the electronic time resolution, this will not necessarily be so for signals originating close to the anode wire, noting that $x \propto \sqrt{t}$ (x distance from anode wire, t drift time), as shown in Fig. 12.[10]

(7) Timing performance of gas mixtures containing CF_4

Being convinced by the good agreement of our measurement with the published data for the mentioned three general gas mixtures, we made a further investigation for the gas mixtures containing CF_4, which is believed to be one of the most atractive candidate under SSC environment. In this investigation AT&T preamplifier has been employed. The superior noise performance of the amplifier meets the requirement of very narrow time distribution for CF_4 contained gas mixtures. The time spectra of CF_4/Ar and CF_4/isobutane are shown in Fig.13. We summarize the drift time results in Fig.14. The only available published data on the drift velocity of CF_4/isobutane (to our knowledge) are compiled in Fig. 15.[11,12] Due to very limited E/P region of these data there is no possible to infer the total drift time from them. The general trend of drift time *vs.* percentage of CF_4 in CF_4/isobutane mixtures and drift time *vs.* V/P looks reasonable. But the peculiar twisting behaviour between Ar/CF_4 (20/80), (0/100) and the other three mixtures may need further study to be confirmed, because the first two mixtures were measured before oxygen and moisture filters being installed, it may bring some systematic effects into drift velocity. However the dependence of the drift time on the percentage of CF_4 and V/P is insensitive for Ar/CF_4.

Fig. 16 shows the time resolution, slight improvement with increasing gas pressure can be seen. The time resolutions are within $0.55ns \sim 0.75ns$ range for Ar/CF_4 mixtures, and $0.55 \sim 1.0ns$ for CF_4/ isobutane mixtures. Using Fig. 15 data we are able to infer spatial resolution for Ar/isobutane near the tube wall. Except pure CF_4, all of the points are located at $25 \sim 50\mu m$, as shown in Fig. 17. The big gap between pure CF_4 and the rest of gas mixtures is attributed to the big gap of drift velocity data compiled in Fig. 15, which we have used to convert time resolution into spatial resolution directly. Because there is no existing drift velocity data for CF_4/isobutane (83/17), (67/33), we have adopted (80/20), (70/30) data instead, it also intended to increase this gap artificially.

Fig. 11(a) Longitudinal diffusion of an electron in $Ar/C_2H_6(50/50)$ gas mixture from F. Pius.[8]

Fig. 11(b) Longitudinal diffusion of an electron in $Ar/C_2H_6(50/50)$ gas mixture from Jean-Marie.[9]

Fig. 12. Time-to-distance relationship in $Ar/CO_2/CH_4(49.5/49.5/1.0)$ for straw-tube drift chamber.[10]

Fig. 13(a) Time distribution of CF_4/Ar (50/50)

Fig. 13(b) Time distribution of CF_4/isobutane (50/50)

Fig. 14. Total drift time of CF_4/Ar and CF_4/isobutane

Fig. 15. Compilation of drift velocity in CF_4/isobutane

2. Fluctuation of single-electron avalanche

A detailed Monte Carlo study [13] has revealed that although the author has tried very hard to discover some trick in the timing method, the conclusions are not unexpected. The best accuracy one can obtain in small drift chambers

Fig. 16. Time resolution of CF_4/AR and CF_4/isobutane

Fig. 17. Spatial resolution of CF_4/isobutane

is still based on the first electron timing technique. Therefore the fluctuation of the single-electron avalanche plays important roll in timing measurement.

The experimental set-up is same as timing measurement, but we use EG&G ORTEC 142PC charge sensitive preamplifier instead of transresistance preamplifier, which used for timing measurement. Fig.18 shows the electronic

Fig. 18. Electronics for single-electron avalanche measurement

block diagram.

For each gas mixture under testing we at first used the timing measurement set-up to adjust the diaphram until about one in $10 \sim 20$ laser pulses yielded any photoelectron, and also looked at the photodiode and drift tube signals on a digital oscilliscope to verify the drift tube working properly. Then the output of drift tube was pluged into an EG&G ORTEC charge sensitive amplifier. A wide gate signal generated by the photodiode was used to make coincidence with drift tube's signal after charge amplifier. Under such arrangment, virtually there no any backgroud event was left over, therefore no background subtraction was needed in data analysis. The only limitation for getting a complete single-electron spectrum was the threshold of whole system, which was set to cut the noise. It set the lower boundary for all of the spectra presented in this article.

(1) A brief review of the single-electron avalanche distribution

The statistics of the single-electron avalanche in a gas chamber was first

Fig. 19. E/α *vs.* E/P for methane

investigated by Snyder,[14] and then by Wijsman.[15] They have shown that in the absence of electron attachment and molecular dissociation, the probability function of having n electrons in an avalanche will be the Furry distribution,

$$p(n) = \frac{1}{\bar{n}} e^{-n/\bar{n}},$$

where $\bar{n}$ is the mean avalanche size, which in the case of a uniform electric field is given by $\exp(\alpha d)$, α is the first Townsend ionization coefficient, d is the distance between cathode and anode plates. This distribution has been confirmed experimently under the circumstance of low E/P. At high value of E/P, Schlumbohm[16] found that the distribution was no longer satisfied by the Furry form, but exhibited a maximum at low value of n. The reason for the unsatisfactory was attributed to a failure of the condition required for establishing the Furry distribution, namely that each electron has the same probability of an ionizing collision in an interval dx and that this probability is independent of the path travelled from the previous ionizing collision. The condition fails when $1/\alpha$, the average distance between ionizing collisions is no longer very much greater than V_i/E, the minimum distance over which an electron can gain the ionization potential V_i. Schlumbohm[16,17] showed the value of the quantity $H = E/\alpha V_i$ determines the type of distribution, not only for uniform fields but also for the non-uniform fields used by Curran *et al.*[18] Because of the strong dependence of α on E, E/α should be as a function of E/P. Fig. 19 shows E/α *vs.* E/P for methane.[19] E/α, therefore H, is decreasing, when increasing E/P.

The peaked distribution attained at high H value are found to be in close agreement with the Polya distribution. This distribution can be obtained in a manner similar to that for the Furry distribution by considering that the ionization coefficient α is a decreasing function of the avalanche size n of the form

$$\alpha(n,x) = \alpha(x)[1 + (\theta/n)],$$

where α(x), but not θ, is a function of x and θ is an empirically defined parameter. A detailed treatment shows that p(n,x) is distributed according to Polya law, which for large value of n(x), adopts the form

$$p(n,x) \simeq a[bn/\bar{n}(x)]^{b-1} e^{-bn/\bar{n}(x)},$$

where $b = 1 + \theta$. The exact physical significance of the parameter θ is not clear and objections have been raised[20] to one interpretation which has been proposed for it.[19]

All theoretical aspects mensioned above are concerned with multiplication based on ionization by electron impact only and secondary processes taking place at the cathode or elsewhere are ignored. When secondary processes become significant, avalanche breeding may take place and avalanche chains are detected in place of single avalanche.[21]

A theoretical analysis of avalanche chain formation,[22] which taking the distribution of individual avalanche and the distribution of the number of avalanches whithin the chain into account, assumed the asymptotic form

$$p(z) \simeq Bz^{-3/2} e^{Cz}, z = n/\bar{n}.$$

Bryne *et al.*tested this theory at values of n much larger than the mean with a P-10 proportional counter. The experimental distribution was in general agreement with the theoretical prediction when the asymptotic negative logarithmic derivate $-(1/p(z))dp(z)/dz$ *vs.* $1/z$ was plotted, but there was a spread in the observed asymptotic slopes about the predicted value of 3/2.

(2) Experimental results

Ar/CF_4 and Ar/isobutane under different mixing ratios have been measured for their single-electron's avalanche spectra. For each gas mixture the Fe^{55} spectra at several different high voltage settings were recorded. The single-electron avalanche spectra were then fitted with the Polya distribution

$$p(A) = a(bA/A_{mn})^{b-1} e^{-bA/A_{mn}}.$$

Typical experimental distributions with their Polya fitting curves are shown in Fig. 20.

Fig. 20. Single-electron avalanche distribution with their Polya fittings for Ar/isobutane(70/30).

The physical meaning of A_{mn} is the mean gas gain, b is a measure of the fluctuation of gas gain, $\sigma_A = 1/b$. Since we also measured the gas gain with Fe^{55} and assumed that there was no electron attachment, all of the primary electrons released by 5.9 keV x-ray reached anode wire and each of these electrons initiated an avalanche, we can compare these two gas gain measurements. The results are shown in Fig. 21 and 22.

For Ar/isobutane gas mixture all of three different mixing ratios gave rather consistant results both from single-electron as well as Fe^{55} measurements. It convinced us that the whole gas system had no big contaimenation and the technique for single-electron avalanche measurement was reliable. But when Ar/CF_4 gas mixtures were tested, the big discrepancy between these two measurements indicated that CF_4 may have serious electron attachment.[11] The gas gain from single-electron was about ten times higher than one from Fe^{55}. A possible explanation for this discrepancy is the number of primary electrons which were released by 5.9 keV x-ray ($\sim$ 200 electrons) may be reduced on the way of drifting towards anode wire due to its attachment to CF_4. The processes of the attachment are summarized in Table 1.[11]

The another evidence for the explanation is the poor energy resolution for Ar/CF_4 mixtures. The authors of reference [11] also attributed the poor energy resolution of Ar/CF_4 to the electron attachment. They claimed the energy resolution of Ar/CF_4 with the mixing ratios of 95/5 and 90/10 was $\sim$ 60% and $\sim$ 75%, respectively. We have measured the energy resolution for the mixing ratios of 80/20, 70/30, 60/40 and 50/50 under different gas pressures,

Fig. 21. Gas gain of single-electron and Fe^{55} in Ar/isobutane.

the typical values are summarized in Table 2, and some spectra are shown in Fig. 23.

Appearantly the energy resolution of Ar/CF_4 is getting worse when increasing the gas pressure and the percentage of CF_4 in the mixture. In contrast the dependence of energy resolution on gas pressure for Ar/isobutane is not quite

Fig. 22. Gas gain of single-electron and Fe^{55} in Ar/CF_4.

clear.

(3) More discussion on energy resolution

The statistical model of the energy resolution of proportional counter has been well established. There are two basic contributions to the overall gas

Table. 1. Negative ions formed by electron impact on CF_4

Ion	vskip4pt Process	Appearance potential(eV)	Position of maximum(eV)	Reference
F^-	$CF_4 + e \rightarrow F^- + CF_3$	4.65 ± 0.1	6.15 ± 1	24
		4.7 ± 0.1		25
		4.5 ± 0.3		26
F^-	$CF_4+ \rightarrow F^- + CF_3$	$6.2 \sim 6.5$	~ 7.5	24
	or			
	$CF_4 + e \rightarrow F^- + F + CF_2$			
CF_3^-	$CF_4 + e \rightarrow CF_3^- + F$	5.4 ± 0.1	6.9 ± 0.1	24
		5.4 ± 0.1		25
		4.9 ± 0.3		26

Fig. 23. Charge spectra of Fe^{55} in Ar/CF_4 and Ar/isobutane

gain fluctuation, which can be expressed as the following[27]

$$\left(\frac{\sigma_A}{A}\right)^2 = \left(\frac{\sigma_{n_0}}{n_0}\right)^2 + \frac{1}{n_0}\left(\frac{\sigma_a}{a}\right)^2,$$

$$\left(\frac{\sigma_{n_0}}{n_0}\right)^2 = \frac{F}{n_0},$$

$$\left(\frac{\sigma_a}{a}\right)^2 = \frac{1}{b},$$

Table 2. Energy resolution of Ar/CF_4 and Ar/isobutane

Ar/CF_4	P	H.V.	Gas Gain	Resolution(Fe^{55}
80/20	760	1300	98.8	48%
	1160	1600	105.9	61%
	1960	2100	107.2	82%
50/50	760	1500	119.0	53%
	1160	1800	92.2	63%
	1960	2400	89.1	98%
Ar/isobutane				
80/20	760	1100	206.0	16%
	1160	1300	377.1	18.4%
	1960	1700	243.8	17.3%
70/30	760	1200	210.5	16.4%
29/71	760	1800	994.9	16.7%
90/10	760	900	188.5	13.3%
	1160	1200	2564.0	12.5%
	1960	1500	1861.0	15.2%

where F is the Fano factor and b is the parameter of Polya distribution. Finally we obtain

$$\left(\frac{\sigma_A}{A}\right)^2 = \frac{1}{n_0}\left(F + \frac{1}{b}\right). \tag{8}$$

The typical value of F and b are $0.05 \sim 0.2$ and $1 \sim 2$, respectively. Since n_0 is the number of ion pairs created by the incident radiation,

$$n_0 = E/w,$$

E is the radiation energy, for Fe^{55} case, it equals 5.9 keV, w is the energy loss per ion pair created, $25 \sim 35eV$. For all of the gas mixtures we have tested, n_0 is ~ 200. The Polya parameter b for these gas mixtures are summarized in Fig. 24. All of them are greater than 1. A rather surprising fact is that even under the worst case of F and b, the energy resolution of 5.9 keV x-ray still should be better than 18.2%. For Ar/CF_4 case the measured energy resolution is much worse than expected by a fact of $3 \sim 5$. If n_0 has been reduced by a fact of $9 \sim 25$ due to electron attachment, it could explaine this discrepancy. On the other hand it also will reduce the gas gain by the same factor, which is supported by our measurement, shown in Fig. 22.

3. Conclusions

1. Single-electron's behaviour in a proportional counter has been successfully studied with a pulsed N_2 laser set-up. The drift time measurement for three kinds of well understood gas mixtures are in good agreement with the published data.

2. The drift velocity in CF_4/isobutane is sensitive to the percentage of isobutane. The best time resolution in $7.67mm$ thick proportional drift tube with these mixtures can reach $\sim 0.6ns$.

3. In contrast, the total drift time in CF_4/Ar is not sensitive to the mixing ratio, and very fast. For five different mixing ratios tested the total drift time is varying between $40 \sim 50ns$, also the time resolution is around $0.6ns$.

4. The Polya distribution fits the spectrum of the single-electron avalanche rather well. The Polya parameter b, which indicates the width of the fluctuation, has been given gor various mixing ratios of Ar/CF_4 and Ar/isobutane.

5. Comparison of the gas gains obtained from single-electron as well as Fe^{55} x-ray has revealed the possibility of serious electron attachment in Ar/CF_4 gas mixtures. It is certainly attributed to the CF_4.

6. Energy resolution of Fe^{55} x-ray is correlated to the loss of primary electrons due to electron attachment, therefore in searching for a good gas candidate used for drift chamber should be brought the energy resolution into consideration.

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