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The Operation of a Proportional Counter with the Penning Mixture Ne/Ar at Low Temperatures

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Electron multiplication and energy resolution of a cylindrical proportional counter filled with the Penning mixture Ne/Ar have been examined at room (~300 K) and liquid-nitrogen (77 K) temperatures. The best energy resolution for the 5.9-keV X ray from ^{55}Fe is 12.6±0.4%; the gas mixture is Ne+2%Ar with a pressure of 600 Torr at 300 K, anode radius is 10 μm and gas gain is 110. It has been found that, at the optimized condition for the energy resolution, the gas gain diminishes by the order of 5~10% at 77 K while the energy resolution does not change appreciably.

KEY WORDS: Proportional counter/ Low temperatures/ Penning ionization/ Ne/Ar/

1. INTRODUCTION

Quenching-gas systems are usually employed in proportional counters, which consist of noble gas with an admixture (1~10%) of polyatomic molecular gas, e.g., CH_4 and CO. The polyatomic molecule is necessary to quench continuous electric discharges caused by ultra-violet photons when the counter is operated with high gas gains ($>10^3$); these photons are emitted through some decay processes of excited noble gas atoms, which are mainly produced in the electron multiplication near anode wire. With the quenching-gas systems, it is quite easy to obtain gas gains higher than 10^3. Some mixtures, such as He/iso-C_4H_{10} (~1%), make it possible to operate the counter in the Geiger-Müller region with gas gains higher than 10^6.

Gas mixtures, Ne/Ar and Ar/C_2H_2, are used in order to achieve an energy resolution better than that of quenching-gas systems. When metastable states (E_m) of noble gas atom are higher than the ionization potential (E_i) of admixture atom or molecule, the ionization yield is considerably increased by mixing a small amount of the admixture ($<1\%$) in the main gas. This so-called Penning effect[1] is due to the following ionization process:

$$R^m + X \rightarrow R + X^+ + e\,, \qquad (1)$$

where R is a noble gas atom, R^m is that in a metastable state, X is an admixture atom or molecule and X^+ is an ionized admixture. The difference $E_m - E_i$ for some mixtures is listed in Table I. The value of $E_m - E_i$ is very small for Ne/Ar and Ar/

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Table I. The energies of metastable states of main noble gas atoms and the ionization potential of admixture gas element.

Components (main/admixture)	Metastable energies of main gas, E_m (eV)	Ionization potential of admixture, E_i (eV)	Difference E_m-E_i (eV)
Penning mixture			
Ne/Ar	16.62 ($^3P_2$)	15.76	0.86
	16.72 ($^3P_0$)		0.96
Ar/C_2H_2	11.53 ($^3P_2$)	11.4	0.13
	11.72 ($^3P_0$)		0.32
Quenching-gas system			
Ar/CH_4	11.53 ($^3P_2$)	13.04	—
	11.72 ($^3P_0$)		—
Ar/CO	11.53 ($^3P_2$)	14.0	—
	11.72 ($^3P_0$)		—
He/CH_4	19.81 ($^3S_1$)	13.04	6.77
	20.62 ($^1S_0$)		7.58
He/CO	19.81 ($^3S_1$)	14.0	5.81
	20.62 ($^1S_0$)		6.62

C_2H_2 while that of ordinal quenching-gas systems is relatively large or negative, as seen in the table. The Penning effect in Ne/Ar and Ar/C_2H_2 results in remarkable improvement of the energy resolution, decreasing the Fano factor F, the relative variance of gas gain f and the average ionization energy of filling gas W; with the parameters F, f and W, the energy resolution is expressed by

$$R(\%) = 235 \sqrt{(F+f)W/E}\ , \tag{2}$$

where E is the energy of the incident radiation.[2] The proportional counter operation of Penning mixtures, especially Ne/Ar, was extensively examined by Sipilä and his co-workers;[3-8] They experimentally verified that the resolution of Penning mixtures is much better than that of ordinal quenching-gas systems.

The proportional counter operation of some quenching-gas systems at 77 K was investigated in our previous works.[9,10] The Penning mixture Ne/Ar is not liquefied at 77 K as long as the filling pressure is not so high or, to say exactly, the partial pressure of Ar at 77 K is lower than 203 Torr as discussed in our previous work.[11] Therefore, it is interesting to examine its operation at low temperatures near 77 K. In this paper we report our recent investigation on the operation of Ne/Ar at 77 K.

2. PERFORMANCE

Notations P_o, X_{Ar} and r_a are used in the following descriptions:

P_o =pressure of Ne/Ar mixture at 300 K,

X_{Ar}=fraction of Ar in the mixture,

r_a =anode radius.

Then, the pressure at 77 K is given by 0.26 P_o.

The counter assembly is the same as that used in the previous work; the sensitive volume is 5 cm diam. $\times$15 cm length.[9] In order to cool the counter, it was directly immersed into liquid nitrogen. The gas mixture Ne/Ar was filled in the counter at 300 K. Relative gas gains and energy resolutions of the Ne/Ar mixture under a variety of conditions were measured with the 5.9-keV K X rays ($\sim 10^3$/sec):

1) r_a=5, 10 and 20 μm,
2) P_o=200, 300, 600 and 760 Torr,
3) X_{Ar}=0.2, 0.5, 1.0, 2.0 and 4.0%.

2.1. Gas gain

An anode wire of 20-μm radius was used in a series of measurements to obtain the relative gas gain. Absolute values of gas gain, $M(V)$, as a function of the anode voltage V were determined rather approximately by the method proposed by Hendricks.[12,13] A part of results are shown in Fig. 1; closed circles are $M(V)$ at 300 K while open circles are those at 77 K. The lowest $M(V)$ observed is 5$\sim$10 while the highest $M(V)$ is $2\times10^2 \sim 5\times10^3$, depending on P_o and X_{Ar}.

Figure 1 indicates a dependence of $M(V)$ on the concentration X_{Ar} when P_o=760 Torr: X_{Ar}=1.0, 2.0 and 4.0%. As seen from Fig. 1, the counter works more stably with increasing X_{Ar}; the electron multiplication begins at a higher voltage, the counter can be operated at higher gas gains and the slope of $M(V)$ is

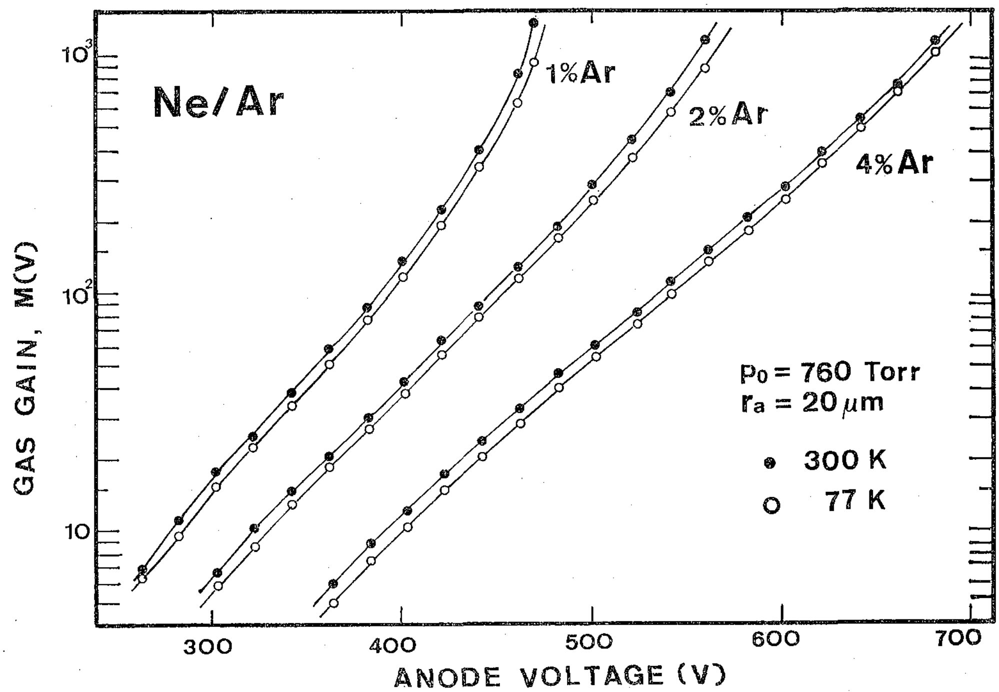

Fig. 1. Gas gain $M(V)$ determined for Ne+1%Ar, Ne+2%Ar and Ne+4%Ar at room ($\sim$300 K) and liquid nitrogen (77 K) temperatures.

more gentle. The difference between $M(V)$ at 300 K and that at 77 K is interesting; for all mixtures with P_o=760 Torr and X_{Ar}=1–4%, $M(V)$ at 77 K is 5–10% less than that at 300 K in the whole region presently measaured.

2.2. The energy resolution.

Alkhazov investigated the statistics of electron multiplication and its influence on the energy resolution, concluding that the relative variance of gas gain, f, is a dominant factor of the resolution.[14] His interesting conclusions are as follows:

1) f decreases rather steeply as M decreases in the region of $M<10$.

2) As long as M is kept constant, f is smaller with a decreasing product of $P_o \cdot r_a$.

Notwithstanding a lot of measurements, the present results are not sufficient to be compared quantitatively with his predictions. Main results on the resolution $R(\%)$ are summarized as follows:

1) $R(\%)$ is worse with increasing M. This tendency is more dominant when P_o is decreased.

2) When P_o is increased, the counter can be operated with a higher M but $R(\%)$ is worse at higher M.

Table II. The energy resolution $R(\%)$ measured as a function of anode radius r_a[a]

anode radius r_a (μm)	energy resolution $R(\%)$
20	14.0±0.4
10	12.6±0.4
5	12.6±0.4

[a] P_0=600 Torr, X_{Ar}=2% and M=110.

Table III. Energy resolutions $R(\%)$ measured for various gas mixtures

Mixtures	$R(\%)$[a] 300 K	77 K	Conditions P_o (Torr)	r_a (μm)	M
Ne+2%Ar	12.6±0.4	12.6±0.4	600	10	110
Ne+0.5%Ar[b]	10.7	*	2250	6.5	70
Ar+10%CO	16.1±0.4	17.5±0.4	760	20	10^3
Ar+10%CH_4	15.3±0.4	16.8±0.4[c]	760	20	10^3
He+10%CO	16.5±0.5	18.2±0.8	760	20	10^3
He+10%CH_4	15.8±0.5	17.2±0.6[c]	760	20	10^3
He+4%CH_4	15.8±0.5	17.2±0.6	760	20	10^3

[a] The resolutions for Ne/Ar, Ar/CO and Ar/CH_4 was measured with the 5.9-KeV X ray from ^{55}Fe while that for He/CO and He/CH_4 was measured with the 7.2-keV conversion electrons from ^{57}Co.

[b] by Järvinen and Sipilä (Ref. 8).

[c] partially liquefied at 77 K.

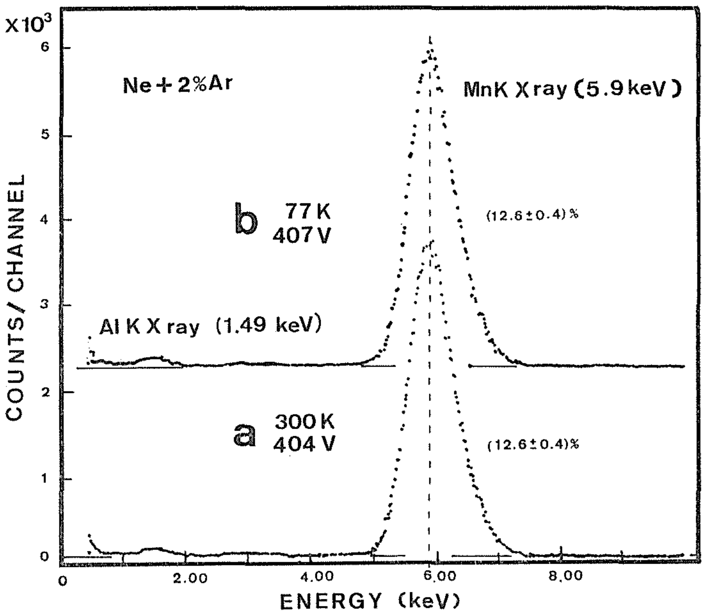

Fig. 2. Energy spectra of 5.9-KeV K X rays from ^{55}Fe measured at room (~300 K) and liquid nitrogen (77 K) temperatures.

3) An example for a dependence of $R(\%)$ on X_{Ar} is shown in Table 2. Anodes with $r_a=5$ and 10 μm resulted in a better resolution than that with $r_a=20$ μm, but the difference between $R(\%)$ for $r_a=5$ μm and that for $r_a=10$ μm was not appreciable.

$R(\%)$ measured for the Ne/Ar mixture and some quenching-gas systems are listed in Table 3. In Fig. 2 are shown energy spectra of the 5.9-keV K X ray measured with Ne+2%Ar: (a) at 300 K and (b) at 77 K. It is seen that $R(\%)$ at 77 K is the same as that at 300 K. With other conditions in the present work, no evident difference between $R(\%)$ at 300 K and that at 77 K was not observed with Ne/Ar mixtures. On the other hand, $R(\%)$ of the quenching-gas systems is worse at 77 K, as seen from Table 3. This is probably due to the operation with relatively high gas gain ($M=\sim 10^3$); the gas gain for Ne/Ar is 110. This difference between our datum and that obtained by Järvinen and Sipilä is discussed in the next section.

3. DISCUSSION

3.1. The decrease of gas gain at 77 K

One of typical results obtained by the present work is that the gas gain with the Ne/Ar mixtures ($X_{Ar}=1\sim 4\%$, $P_o=760$ Torr) decreases by 5~10% at 77 K. In our previous work, similar phenomena were observed with quenching-gas systems, He+10%CO and Ar+10%CO. These are not liquefied at 77 K as long as the filling pressure is 760 Torr at room temperature. The gas gain for Ar+10%CO at 77 K is about 5% lower than that at 300 K in the whole region of the applied voltage

(1600∼2400 V) while the decrease in gas gain for He+10%CO is 10∼40%, depending on the applied voltage. The origin of the decrease at 77 K is not clear. Theoretical studies from a standpoint of atomic collision processes are necessary to make clear the mechanism of electron multiplication at low temperatures.

3.2. Effect of impurities on the counter operation

The present counter assembly has not been specially designed for suppressing outgassing products. The amount of such impurities in the Ne/Ar mixture is $10\sim10^3$ ppm, depending on the cleanness inside the counter and on the temperature of filled gas. All surfaces inside the counter are slightly contaminated by organic substances from oil pumps although cold traps are used to remove oil vapour. These organic gases freeze on the surfaces when the counter is cooled at liquid nitrogen temperature. This change of the amount of impurity gas in the Ne/Ar mixture greatly influence the counter operation when the concentration of Ar, X_{Ar} or the pressure of filling gas at 300 K, P_o, is low. We could not obtain consistent data of gas gain when $X_{Ar}<0.5\%$ or $P_o<500$ Torr.

3.3. Electronic noises

Electronic noises from the preamplifier results in a serious deterioration of energy resolution in the region of $M<50$; the noise of the preamplifier connected with the present counter is equivalent to the charge of 390 ion pairs. In order to be free from the noise, the counter had to be operated at $M>100$. The best energy resolution was $(12.6\pm0.4)\%$ with $r_a=10$ μm, $P_o=600$ Torr, $X_{Ar}=2.0\%$ and $M=110$. This is not as good as that obtained by Järvienen and Sipilä, i.e., 10.7%, which was probably due to their better operating condition with their cooled preamplifier and their better control to purify the filling gas.

4. CONCLUDING REMARKS

It has been shown by the present work that the Penning mixture Ne/Ar is available for the proportional counter operation at the low temperature 77 K. However, the apparatus presently employed is not sufficient to examine the operation systematically, specially in the case that the concentration X_{Ar} or the filled pressure P_o is low. The following improvements are desired:

1) The amount of impurity gas in the Ne/Ar mixture should be decreased, e.g., below 1 ppm, if possible. The counter should be constructed with materials which can be outgassed by baking. A device for purifying the mixture is also necessary.

2) The noise level of the preamplifier should be decreased in order to examine the counter operation with low gas gains below 10. A preamplifier with cooled FET is desirable.

Refined measurements with improved apparatus are now in plan.

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