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A Simple Method for Measurement and Regulation of the Memory Time in Streamer Chambers

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Abstract

The time resolution and memory time of streamer or spark chambers is determined by the lifetime of free electrons produced by an ionizing particle. It can be varied over a large range by an admixture of electronegative gases, e.g. 10^{-5}% sulfur hexafluoride (SF_6). We describe here a simple method which allows one to measure and regulate the memory time. The device consists of a small ionization chamber and an electronic circuit which has been tested for the 1 m DESY streamer chamber. It has been found that, for example, a memory time of 2 μs could be controlled to within 5 % accuracy.

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Introduction

Time resolution is an important property of all particle detectors in nuclear and high energy physics. The time resolution is the minimum time interval between events such that two events can be distinguished from one. This period is determined in the streamer chamber by the lifetime of free electrons along the path of the ionizing particle. This lifetime - the so-called memory time - can be longer than a few hundred microseconds in pure noble gases. Such a long memory time would severely limit the use of streamer chambers at accelerators, since only a small number of particles can be accepted per memory time.

A simple method to reduce the memory time is to introduce a small quantity of electro-negative gases into the chamber. The free electrons are captured by these molecules to form negative ions. The negative ions do not contribute to streamer formation because of their inertia in the electric field. One commonly uses electro-negative gases carbon tetrachloride (CCl_4), freon, and sulfur hexafluoride (SF_6). The latter is preferred, because SF_6 is effective in such small quantities that it has no influence on the streamer mechanism (1-3). To reduce the memory time from 100 μs to 2 μs we need only about 10^{-5}% SF_6 (Fig. 1) compared to 10^{-3} - 10^{-2}% Freon, because SF_6 has a large capture cross section for electrons: $\sigma_c = (1.7 \pm 0.2) \cdot 10^{-14} cm^2$ (1).

For streamer chamber operation in one experiment it is necessary to continuously measure and regulate the memory time. A number of SF_6-molecules are broken up in each streamer or spark. These molecular fragments are not as electronegative as the complete SF_6 molecule and thus do not serve to reduce memory time.

2. Measurement of the Memory Time

The simplest memory time measurement can be made by eye: The high voltage pulse can be delayed in short steps after the events have taken place. With increasing delay the number of streamers per track decreases. From this decrease, one can estimate the memory time. An improvement can be achieved by photographing a delayed tracks and counting the streamers per unit length. One can see from the diagram of the number of streamers n vs. delay time t that this number decreases exponentially. We define the memory time $t_m = 1/\lambda$ by the inverse slope of the curve $n \alpha \exp(-\lambda t)$. (3). This result is more exact and reproducible but does not permit continuous control.

The problem was to find a method which works without disturbing streamer chamber operation. We can achieve this by using the same effect which occurs in the chamber - namely the capture of free electrons - in a special ionization chamber. The electrons can be produced by ionizing the gas flowing out of the chamber with an α-particle source (1). Next one must separate the electrons from the SF_6^- ions. These two components can be separated because of their different masses in several ways:

1) A separation is possible in a spectrometer, but it is expensive.

2) One can use a proportional chamber, in which the number of free electrons can be amplified whereas the number of SF_6^- ions cannot, at atmospheric pressure.

3) The electron drift velocity in an electric field is about a factor of a thousand higher than the velocity of the SF_6^- ions.

We have tested points 2 and 3 experimentally, as described below.

3. Memory Time Measurements with Gas Amplification

The gas flows out of the streamer chamber through a cylindrical chamber with three parallel electrodes (Fig. 2). The α-particle source (Am 241, 500 μC) produces free electrons in the larger gap. The electrical field strength is low enough (100 V/cm) for the charge carriers to drift without amplification. While the positive neon and helium ions travel to the cathode, the electrons and SF_6^- ions drift in the direction of the grid. Since the field strength is much higher in the small gap (1 kV/cm), a large part of the negative particles cross the grid. In this field the electrons get enough energy to initiate avalanches. The current of all avalanches is easy to measure. The current of the non-amplified SF_6^- ions is negligible. The measured current is directly proportional to the number of electrons which cross the grid and therefore proportional to the memory time. One condition for faultless operation of this method is that the amplification factor be constant, i.e. Townsend coefficient α_T = const. . In the first tests, however, we found that very small quantities of air can reduce α_T strongly while exerting little influence on the memory time. Small amounts of impurities cannot be avoided in the operation of large streamer chambers with big foil windows. This is a disadvantage which leads to

wrong measurements, since the measurements are no longer sensitive to the SF_6 concentration.

4. Measurement Without Gas Amplification

For this measurement we use the same cylindrical chamber and α-particle source (Fig. 2) Now the cathode and grid have the same DC potential (-200 V) but they are AC-separated. The measurement is performed at the anode, which is at zero potential. This gives an electric field strength of 200 V/cm between the anode and the grid for a 1 cm gap. Now on top of this DC-voltage we superimpose a rectangular AC-voltage at the cathode. The conditions - amplitude and frequency - must be chosen such that as many free electrons as possible cross the grid in one half wave. They can then be measured at the anode without amplification, since the negative SF_6 ions move only a short distance in this time. Also, the positive ions travel only a short distance if the choice of parameters is right. Both positive and negative ions drift at the diffusion velocity, since $\int_0^T E(t)dt = 0$. They can recombine at the walls, the cathode, and the grid, but they cannot reach the anode. The distance is d = 7 cm between cathode and grid. As one sees in Fig. 3,the maximum current is reached at 700 V (100 V/cm). If we assume a square-wave voltage at the highest admissible frequency f_{max} and no influence by space charge effects, then we have:

$$d = u_e \cdot t = u_e \cdot 1/(2f_{max}),$$

where the electron drift velocity (4) $u_e \simeq a \sqrt{\frac{e}{m} E \lambda \sqrt{\delta}}$.

For a = 0.7, electron charge e, mass m, electron mean free path λ, and the energy transfer fraction in an electron-atom collision δ = 2m/M, one obtains $u_e = 2.6 \cdot 10^5$ cm/s and

$$f_{max} = \frac{u_e}{2d} = 18.5 \text{ kHz}.$$

The ions move only 10^{-2} cm in the same field, during the same time. The frequency can be tuned considerably lower than formerly before a noticeable part of the ions can reach the anode. The value of the electric field is not critical too, so long it is above 100 V/cm. This is important in the case of a sine-

wave voltage. In Figs. 3 and 4 we show the current-voltage diagrams for different frequencies in our ionization chamber. These measurements are made in gases without admixtures. Fig. 5 shows the current dependence of the memory time for two voltages. With a higher voltage (factor of two more) the sensitivity decreases because the higher drift velocity reduces the probability of forming a negative ion. On the left side of Fig. 5 are some points obtained when air is added to reduce the memory time. When the air admixture is higher than 1 % the streamer brightness decreases rapidly, but for this memory time measurement it is unimportant which kind of admixture is used.

5. Comparison of the Two Methods

For a comparison we used the following procedure: The chamber was filled with pure noble gas and the memory time was reduced with SF_6 additives to 5 and 2 μs, respectively. Then air was introduced into the chamber, stepwise up to 1 %. The decrease of the memory time was compensated by using less SF_6. The result of these measurements is shown in Fig. 6(a) and (b). For the method with gas amplification (a) air concentrations on the order of 10^{-2}% lead to faulty results, and at 1% the method is useless. The other method (b) - without amplification - does not change the result.

The only disadvantage in the AC method is the relatively small current, especially for very short memory times. Improvements are possible by variation of the chamber geometry or by using a stronger radiation source. In principle we can also use other electron sources, for example heated cathodes. We prefer the α-source because of its long-time stability and absence of space charge effects.

6. Electronics for SF_6 Admixture

A special apparatus was developed for the current measurement and the SF_6 admixture into the chamber. This arrangement has proved itself reliable in the experiment with the 1 m streamer chamber at DESY. Fig. 7 shows the electronic circuit and the special valve to put small SF_6 volumes into the noble gas flux.

The input current produces a voltage which can be compared with a reference voltage at the comparator. If the voltage exceeds the reference value, the relay R 1 is shut, opening the magnetic valve MV 1 for a few seconds, which causes high pressure (4 atm) nitrogen to depress the piston in the special

valve so that the opening containing some SF_6 comes into the neon-helium stream. When R 1 opens, MV 1 closes and the nitrogen pressure drops. The piston now returns to the first position and the opening can be filled again with SF_6. To avoid high SF_6 concentrations, the comparator is blocked up for a certain time after every switching process. This dead time is given by the length of tubing, the flux and the streamer chamber volume. These parameters determine the delay time between the admixture process and the effect of SF_6 in the special ionization chamber. For the DESY streamer chamber (250 ℓ volume, comparatively large lengths of tubing) this time is 4 minutes. With a nominal memory time of 2 μs we get a ripple (saw tooth) of about 100 ns, which corresponds to 5 % accuracy.

In summary, a method has been developed for the measurement and control of the memory time with high accuracy. This method offers the following advantages in streamer-chamber operation when high intensity beams are used for experiments:

1) The memory time can be made as short as the triggering system allows.
2) The stability of gas characteristics, which is very important for ionization measurements and track quality, can be regulated.
3) Good operation conditions can be achieved with this method when particle tracks are to be stored (3).

References

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2) V. Eckardt and A. Ladage, Proceedings, Int. Conf. on Instr. for High Energy Physics, Dubna, 1970

3) V. Eckardt, Lett. Nuovo Cim. Serie 2, Vol.1 (1971) 997

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Figure Captions

Fig.1 Memory time vs. SF_6 concentration

Fig.2 Ionization chamber for memory time measurement

Fig.3 Measurement current vs. cathode voltage at different frequencies

Fig.4 Measured current vs. grid voltage and at different frequencies

Fig.5 Current dependence of the memory time

Fig.6 Current vs. air concentration
a) DC ionization chamber
b) AC ionization chamber

Fig.7 Electronic circuit and valve for the memory time measurement device.

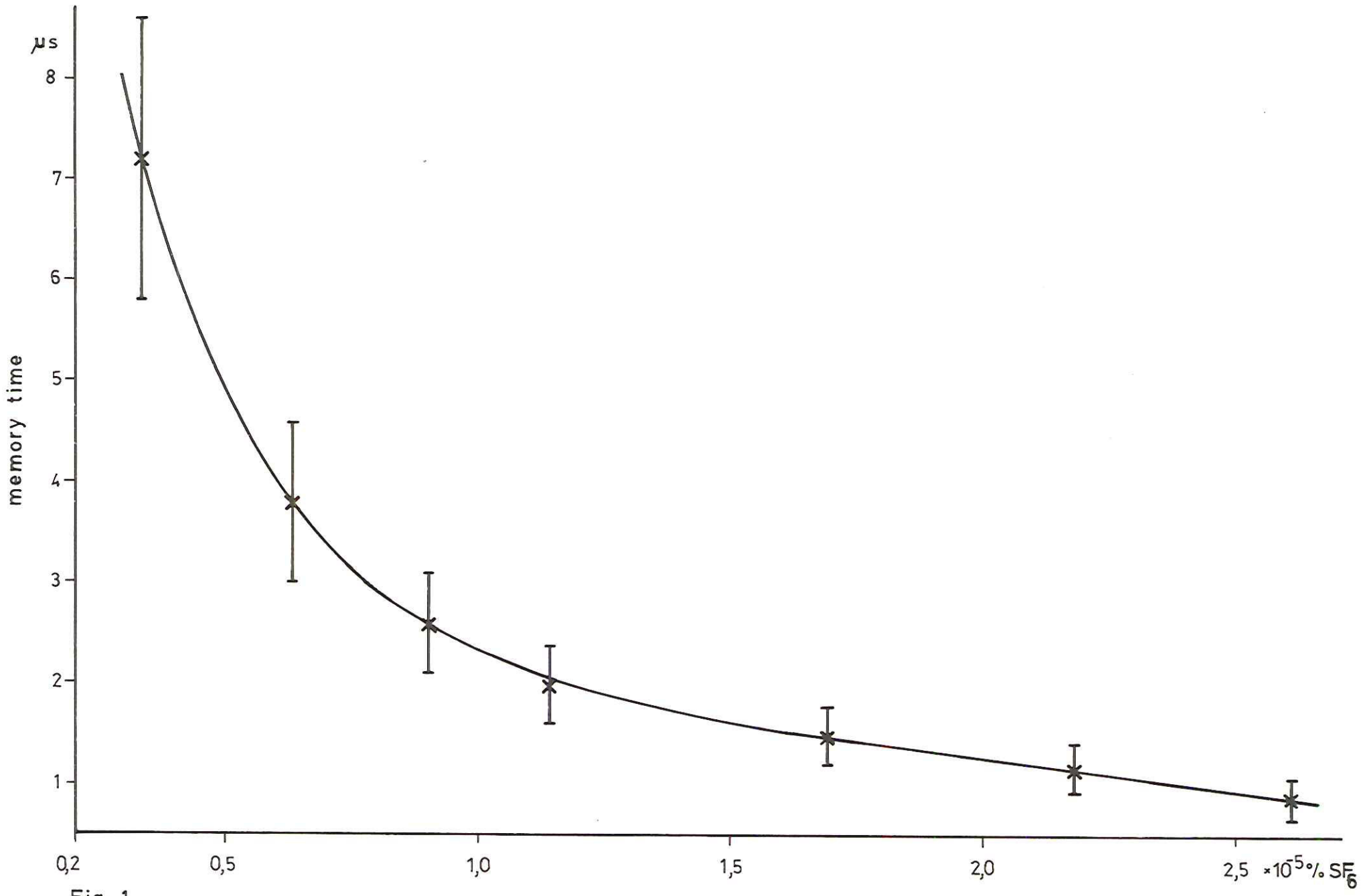

Fig. 1

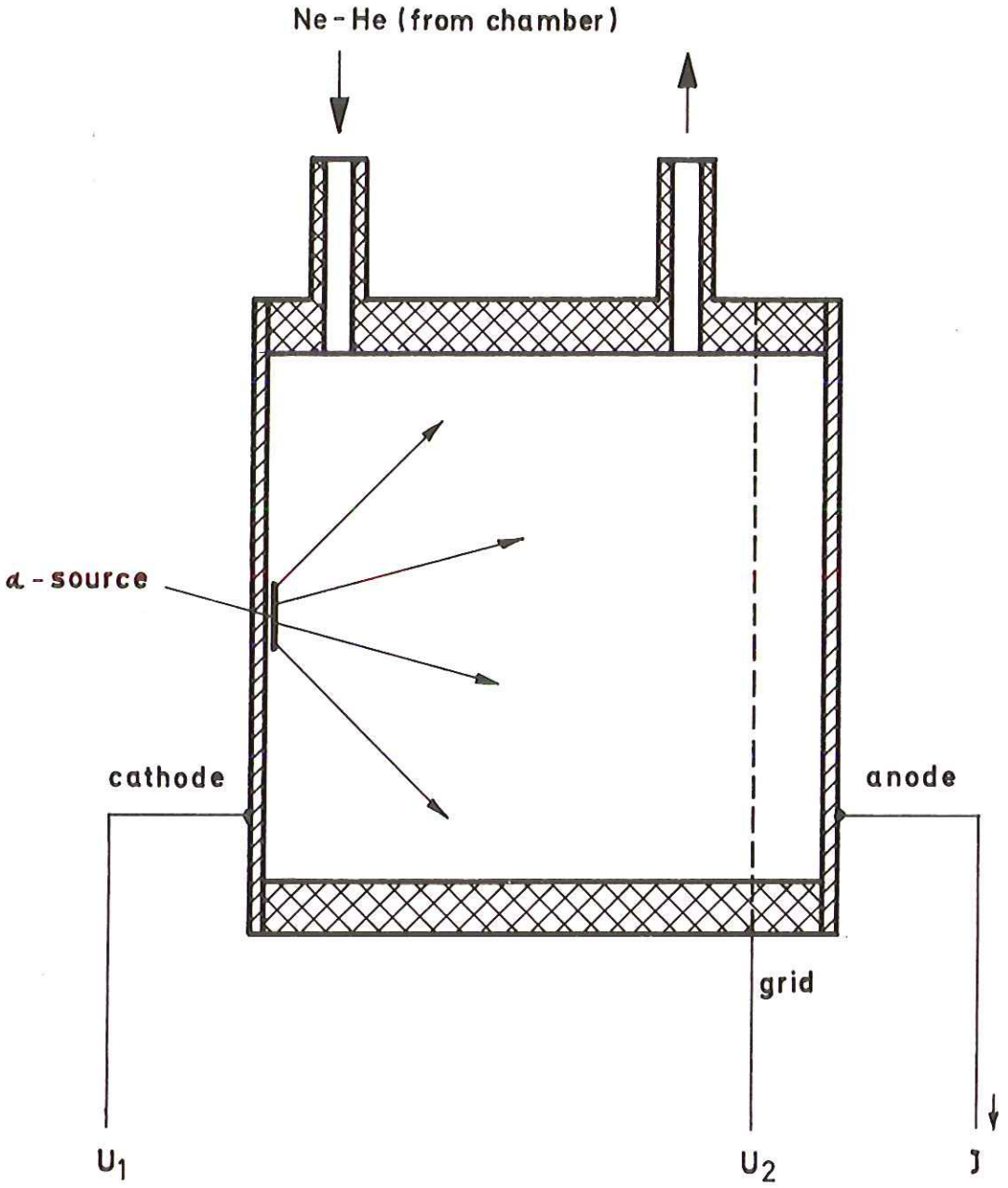

Fig. 2

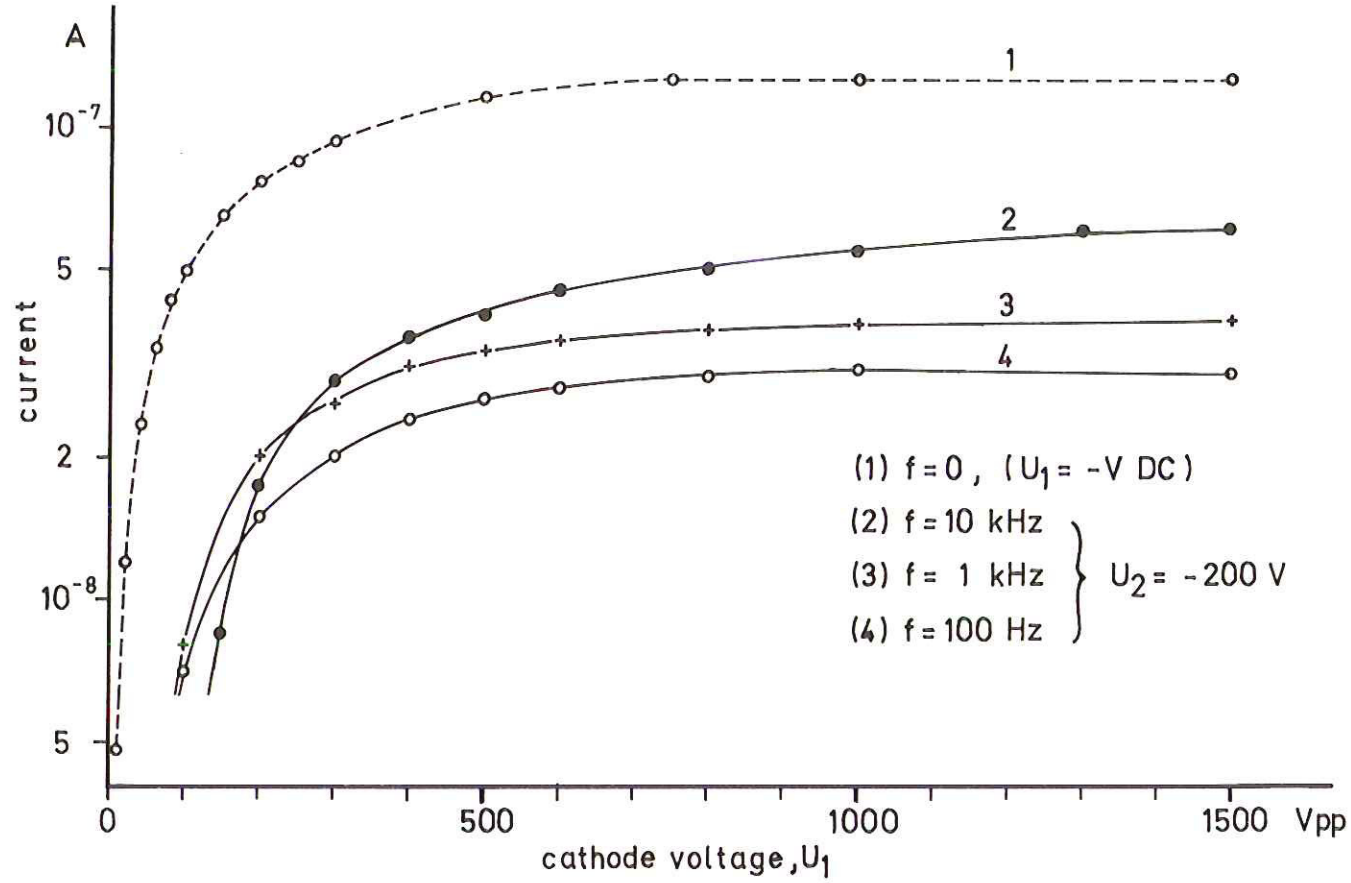
A
10^{-7}
5
2
10^{-8}
5
current
1
2
3
4
(1) f = 0 , (U_1 = -V DC)
(2) f = 10 kHz
(3) f = 1 kHz
(4) f = 100 Hz
U_2 = -200 V
0
500
1000
1500 Vpp
cathode voltage, U_1

Fig. 3

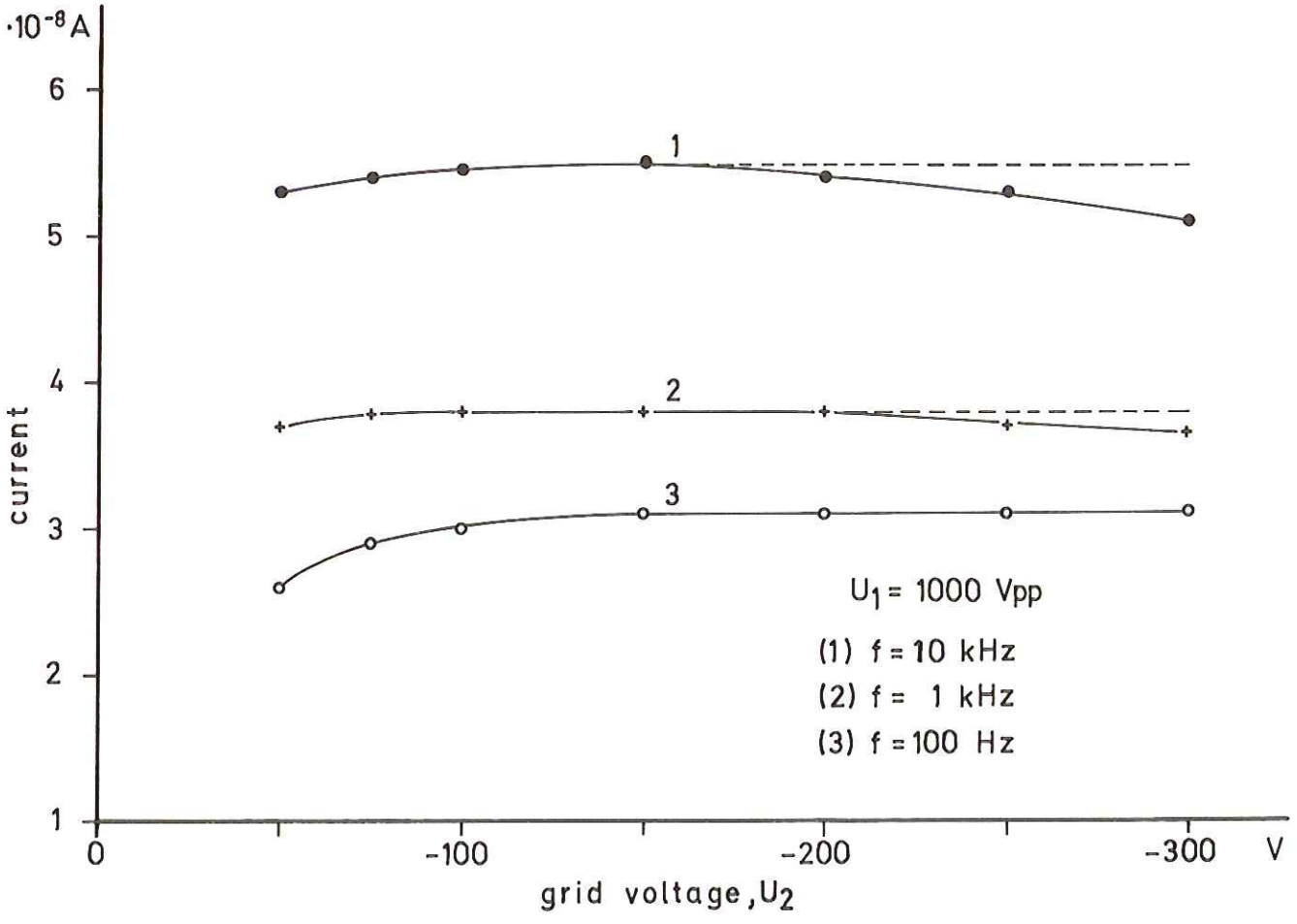
$\cdot 10^{-8}$ A
6
5
4
3
2
1
current
1
2
3
U_1 = 1000 Vpp
(1) f = 10 kHz
(2) f = 1 kHz
(3) f = 100 Hz
0
-100
-200
-300 V
grid voltage, U_2

Fig. 4

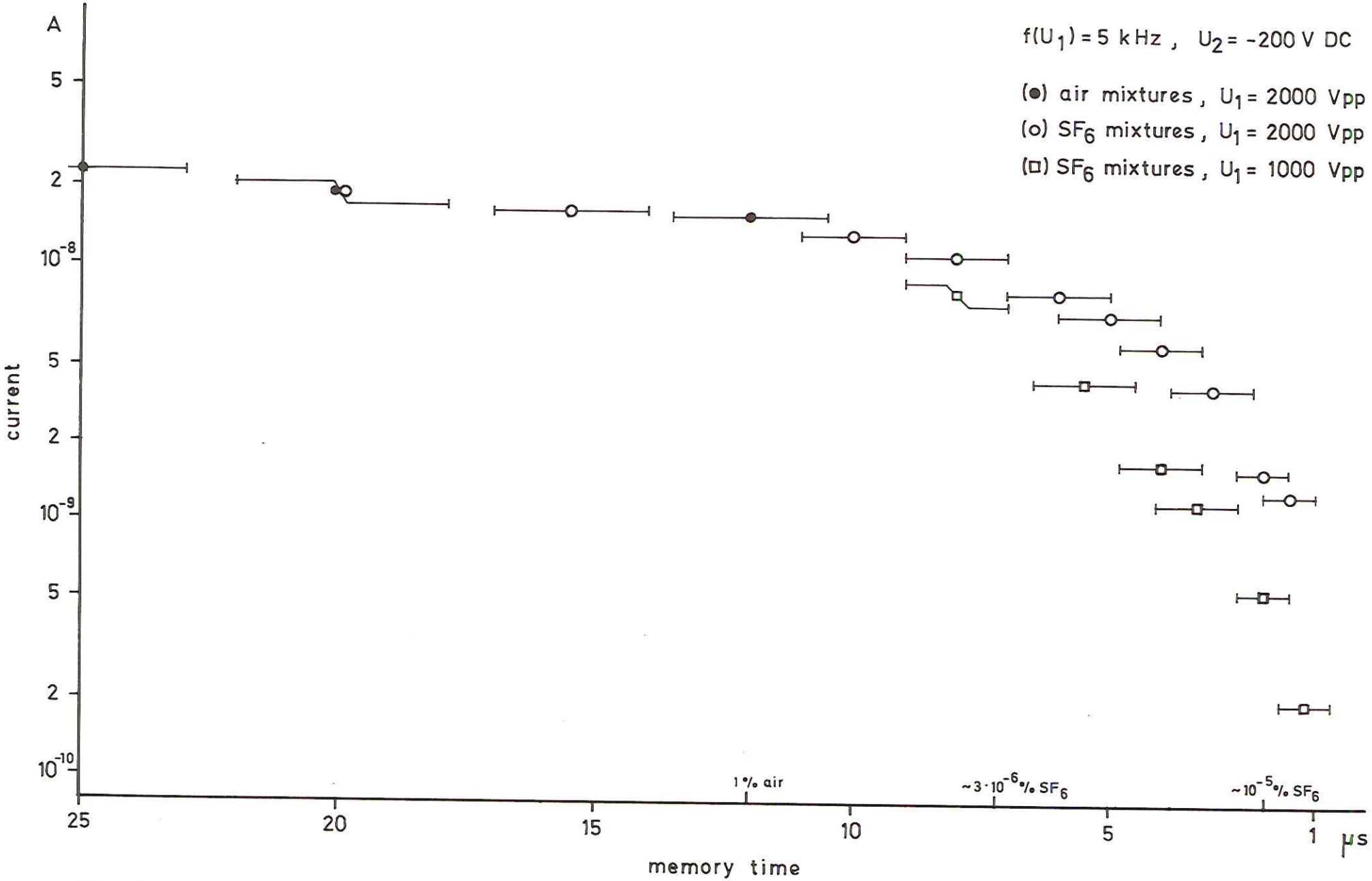
A
5
2
10^{-8}
5
2
10^{-9}
5
2
10^{-10}
current
$f(U_1) = 5$ kHz , $U_2 = -200$ V DC
(●) air mixtures , $U_1 = 2000$ Vpp
(o) SF_6 mixtures , $U_1 = 2000$ Vpp
(□) SF_6 mixtures , $U_1 = 1000$ Vpp
1 % air
$\sim 3 \cdot 10^{-6}$ % SF_6
$\sim 10^{-5}$ % SF_6
25
20
15
10
5
1
µs
memory time

Fig. 5

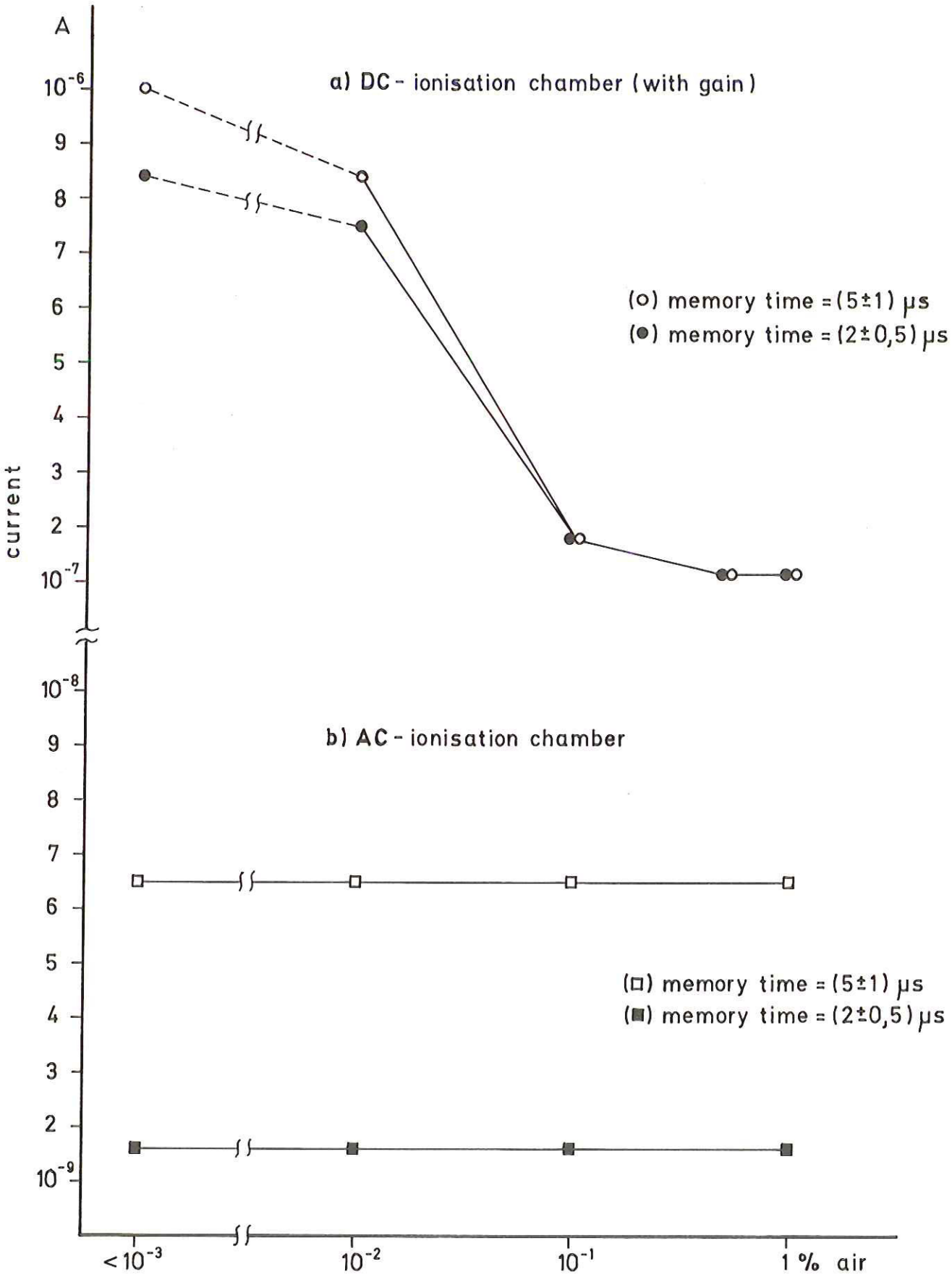
A
10^{-6}
9
8
7
6
5
4
3
2
10^{-7}
current
a) DC - ionisation chamber (with gain)
(o) memory time = (5±1) µs
(●) memory time = (2±0,5) µs
10^{-8}
9
8
7
6
5
4
3
2
10^{-9}
b) AC - ionisation chamber
(□) memory time = (5±1) µs
(■) memory time = (2±0,5) µs
$<10^{-3}$
10^{-2}
10^{-1}
1 % air

Fig. 6

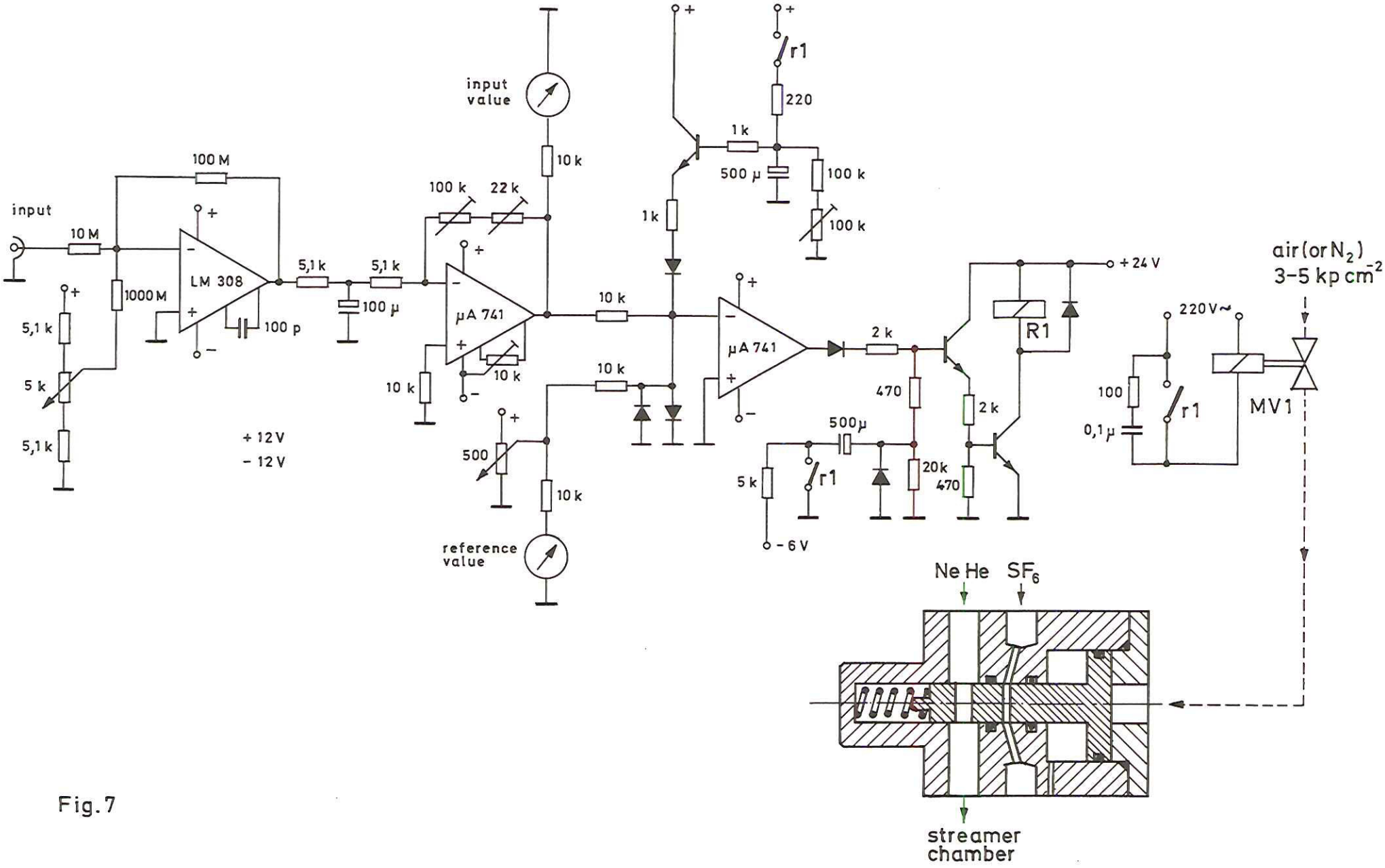
input
10 M
100 M
1000 M
LM 308
100 p
5,1 k
5 k
5,1 k
+ 12 V
- 12 V
5,1 k
5,1 k
100 µ
input value
10 k
100 k
22 k
µA 741
10 k
10 k
10 k
500
10 k
reference value
1 k
1 k
r1
220
500 µ
100 k
100 k
10 k
µA 741
2 k
470
500µ
5 k
r1
20k
470
2 k
R1
+ 24 V
- 6 V
air (or N_2)
3-5 kp cm^{-2}
220V~
100
0,1 µ
r1
MV1
Ne He SF_6
streamer chamber

Fig. 7