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Fast Counting of Alpha Particles in Air Ionization Chambers*

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It was assumed in the past that counting of alpha particles in air-ionization chambers could only be based on the collection of ions since electrons produced in the alpha track quickly form negative ions in electronegative gases. This leads to time resolutions of the order of a millisecond. It is shown in the present work that the motion of the electrons before attachment produces a sharp initial rise in the pulse profile which, although small, can be detected and utilized for high speed counting. Time resolutions of the order of a few microseconds with good signal-to-noise ratios are realized in atmospheric air, and therefore counting speeds similar to those in non-electronegative gases are obtained.

1. Introduction

In ionization chambers containing electronegative gases the electrons produced by high energy particles are quickly captured forming negative ions. Since a counting operation consists of detecting voltage pulses caused by the motion of charges between opposite electrodes, it was generally assumed [1, 2] [1] in the past that the speed of such operations was limited by the drift velocities of ions, about 10^3 cm/sec at atmospheric pressure and 1 kv/cm field strength. Thus the total charge collection time for ions is of the order of a millisecond in chambers of usual design. The resolving time of a counting arrangement (chamber and electronic equipment) can be made less than a millisecond by the use of differentiation and pulse shaping techniques [1]. Using these techniques in preliminary experiments we have realized resolving times of about 0.1 millisecond for the counting of the alpha particles from Po^{210}. This limited speed of counting is especially disadvantageous for ionization work in air, which is electronegative due to its high concentration of oxygen. Since several of the ionization constants are defined or related to those in air, air is a very important gas in ionization work. Besides, air is the most convenient filling gas for an ionization chamber counter. Therefore, it seems desirable to achieve higher counting speeds in air.

It is well known that much higher counting speeds (shorter resolving times) for alpha particles can be achieved in ion chambers containing non-electronegative gases. In these the counting operation is based on the collection of electrons. Since the drift velocity of electrons under similar conditions is three orders of magnitude higher than that of ions, the dead time of such counters can be made as small as a few microseconds.

It appears that the possibility of increasing appreciably the speed of alpha counting in air ion chambers has been overlooked in previous work. Before attachment the electrons move with a high-drift velocity and thus produce a sharp rise in the pulse profile. Although small, this sharp rise can be detected. Basing the operation on this sharp pulse, one obtains time resolutions as small as a few microseconds, even in an ion chamber at atmospheric pressure. Thus counting speeds comparable to those in ion chambers with non-electronegative gases are achieved.

2. Estimated Electronic Pulse

In a parallel plate ionization chamber, the pulse, $P_e(t)$, due to the motion of electrons (neglecting the ionic motion) is given by [2]

$$P_e(t)=\frac{Q_e}{C}\frac{vt}{d}, \tag{1}$$

where t is the time, d the plate separation, C the chamber capacity, v the electron drift velocity and Q_e the total electronic charge.

According to data available [3, 4], it is a reasonable estimate that in air at atmospheric pressure and for field strengths of 1 kv/cm, electrons travel, on the average, a distance of the order of a millimeter before being attached. Thus with $\overline{vt}=0.1$ cm, $d=5$ cm, $C=10$ pf and $Q_e=2.4\times10^{-14}$ coulombs for about 5 Mev alpha particles, $P_e\sim50$ μv.

This estimate of $\overline{vt}$, and thus P_e, is uncertain due to inaccuracies in the electron attachment coefficient [5], h, (probability of attachment per collision) measured at reduced pressures and extrapolated to atmospheric pressure. Bradbury [6] has shown that h in O_2 and air is pressure dependent and recently Hurst and Bortner [7] have shown that α (the probability of attachment per cm per mm Hg pressure) in N_2–O_2 mixtures depends on the partial pressures of both gases.

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*A preliminary report on this work was published in reference 11.

[1] Figures in brackets indicate the literature references at the end of this paper.

Due to the short path and high drift velocity, the electronic pulse rises to the height estimated above in approximately 0.1 μsec. This pulse can be taken as a step function for an amplifier with 400 kc/s bandwidth which gives an output pulse rise time of less than 1 μsec. It is known [1, 8, 9] that such amplifiers can be made to operate with input noise levels of a few microvolts. Therefore the above estimate indicates the possibility of using the electronic component of the alpha pulse for fast counting in air and observations verified this expectation.

3. Experimental Details

The construction of the ionization chamber and the block diagram of the electronic equipment is shown in figure 1. The grounded preamplifier chassis, *d*, supports the ionization chamber, providing for a short connection between the chamber electrode and the first grid. The high voltage plate, *a*, is a flat circular disk of 100 mm diameter. It is entirely supported by the high voltage cable jack, *e*, mounted on the grounded cylindrical housing, *c*. The Po^{210} alpha source, *h*, deposited on Palladium coated 25mm diameter silver disks (as used in the radioactivity standardization program at the National Bureau of Standards), is placed on the pulse electrode, *p*. Changing of sources can be quickly done by lifting the housing, *c*, without removing the chamber voltage. After replacing *c*, counting can be immediately resumed. The pulse electrode, *p*, is mounted in the center of the lucite plate, *g*, which also holds the guard ring, *f*. The guard ring is kept at dc ground potential through a 10^9 ohm resistor and serves to reduce the effective capacity of the pulse electrode to ground. The measured high frequency capacity of *p*, was 6 pf in this arrangement as compared with 12 pf in previous experiments without the guard ring.

In order to obtain rather high electric field strengths ($\sim$4 kv/cm) at relatively low chamber voltage (5–6 kv) the electrode separation (distance between *a* and *h*) was chosen about 1.5 cm. It is true that with this condition the alpha particles spend only a portion of their total energy (5.3 Mev, corresponding to a full range of 3.8 cm in atmospheric air) in the chamber gas producing ionization dependent upon the angle of emission; but this is permissible in counting experiments as dealt with in the present paper. In other experiments [10] where the counting of alpha particles was connected with a simultaneous measurement of the total ionization for Po^{210} alpha particles (and for which experiments the counting technique described here has been developed) the electrode separation was chosen longer than the full range and correspondingly higher chamber voltages (up to 20 kv) have been applied. Experiments showed that the small electrode separation as applied here still gives adequate signal-to-noise ratios even for the smallest alpha energy expended in the gas.

The chamber voltage (either positive or negative at plate A) is introduced through a smoothing RC "T" filter to diminish the ripple present in the output of the high voltage supply and to reduce pickup disturbances.

In the course of development two preamplifiers have been successfully used. One is a simple RC coupled two stage amplifier using 6AK5 pentodes. The input pentode was selected for low grid current and battery operated with low plate and screen voltages of about 20 v. The rise time of this preamplifier was 0.5 μsec for a step function input.

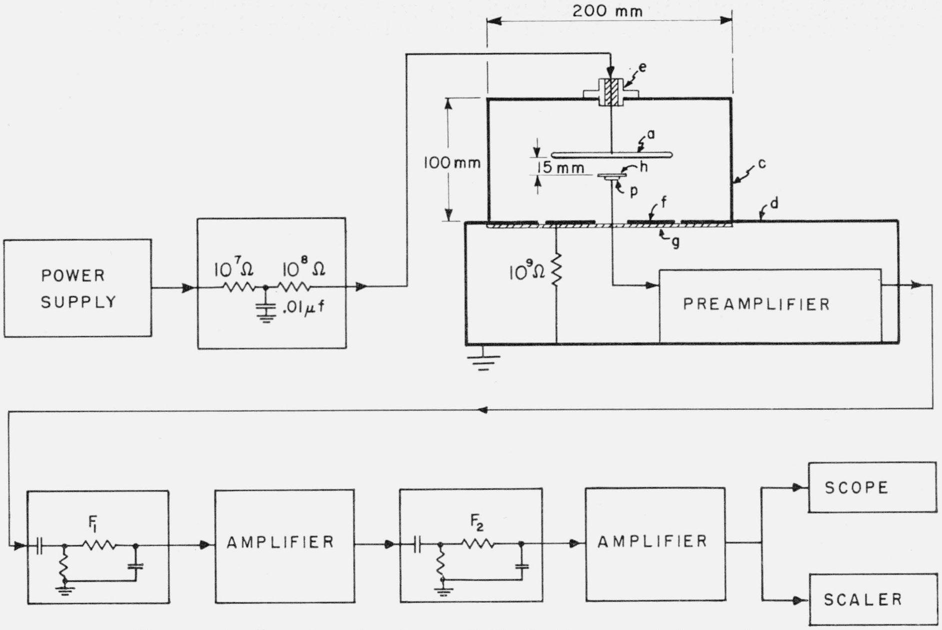

FIGURE 1. *Counting chamber and block diagram of the equipment.*

Wide-band amplifiers are used so that the pulse shaping is exclusively done by the filters F_1 and F_2.

For lower noise level a cascode input type preamplifier [8] similar to that described by C. Cottini et al. [9], was used with the pulse electrode connected to the floating input grid. While changing the chamber voltage this grid is shunted by a 100 μf condenser to prevent excessive charging of the floating grid.

The output pulse shape was controlled by the use of two filters, F_1 and F_2 in figure 1. Each filter contained a high and low pass RC network with equal time constants. The amplifiers were designed to have bandwidths in excess of a megacycle. Since this is much greater than the bandpass of the filters, the amplifiers have negligible effect on the output pulse shape. In each filter one of three different time constants, of 1, 2, and 4 μsec, could be selected by switches.

When both filters have been inserted in the amplifier chain and the time constant of 1 μsec was used, the rms noise as related to the input was $\sim$6 μv for the pentode-preamplifier, and $\sim$3 μv for the cascode type preamplifier.

4. Results and Discussion

For networks of time constants of the order of a microsecond, the pulse profile after the appearance of an alpha track in the chamber can be considered to be composed of a step pulse caused by electrons before attachment, followed by a long rise (linear in the first approximation) due to ionic motion. The presence of both components in the alpha pulse profile is clearly shown by figures 2a, b, and c, photographs of the output pulses on an oscilloscope when only one filter, F_1 with $RC=1$, 2, and 4 μsec respectively, and the cascode preamplifier is used. The fast rising and decaying part of the output pulses is due to the short electronic motion while the approximately constant tail is caused by the long uniform motion of the ions. For comparison output pulses were photographed in figures 2d, e, and f with the same settings of the equipment but introducing pulser step pulses which, instead of having been followed by a slow linear rise like the alpha pulses, decayed in 350 μsec. The negative slope of this decaying part of the pulser pulses is negligibly small as compared to the positive slope of the alpha pulses resulting from the motion of the full ionic charge through the entire chamber separation. It is seen from figures 2d, e, and f that while these output pulses successfully simulate the electronic components of the alpha pulses, the constant tails are missing.

The triggering level is chosen such that the scope is triggered with about equal frequency ($\sim$60/sec) on the alpha pulses and on noise. The noise observed when using the pulser (figures 2d, e, and f) is smaller than that obtained for alpha pulse operation (figures 2a, b, and c). This is readily explained by the low output impedance of the pulser (100 ohm) coupled to the preamplifier grid as compared to the high impedance when the grid is floating. The time scale is 5 μsec per division and the amplifier gain is the same ($\sim 10^6$) in all pictures of figure 2.

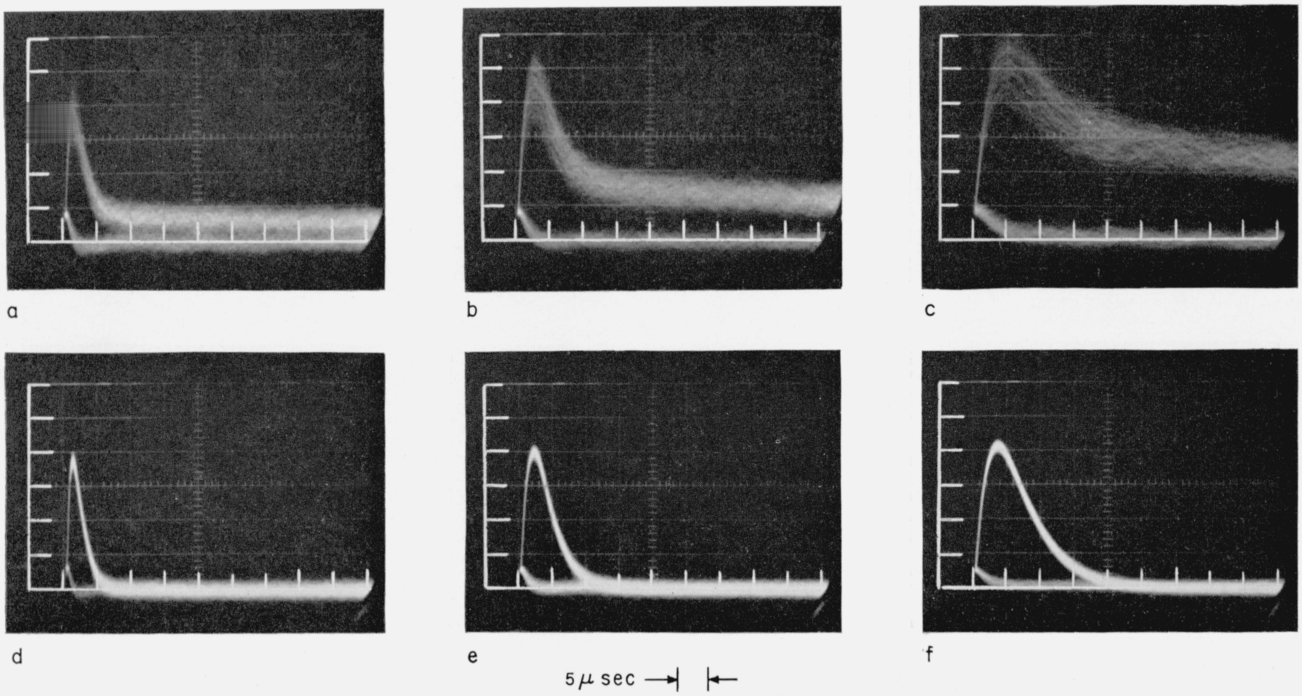

FIGURE 2. *Oscilloscope photographs of the output pulses using one filter F_1.*

Pictures a, b, and c are of alpha pulses with filter time constants of 1, 2 and 4 μsec respectively. The first short pulse is caused by the fast motion of electrons before attachment, the long tail (the height of which increases with increasing filter time constant) is the contribution of the slow ionic motion. For calibration pictures d, e and f, corresponding to a, b and c, are taken with 87 μvolt step pulses from a pulser. The overall amplifier gain is the same ($\sim 10^6$) in all pictures and the time scale is 5 μsec/division.

The output voltage, $V_1(t)$, after the filter F_1, is

$$V_1(t)=a\frac{t}{\mathrm{RC}}e^{-\frac{t}{\mathrm{RC}}}+\alpha\left[\mathrm{RC}-(\mathrm{RC}+t)e^{-\frac{t}{\mathrm{RC}}}\right] \quad (2)$$

where a is the amplitude of the step input appearing at $t=0$, and α is the constant slope of the linear rise beginning at $t=0$. While the first term reaches (at $t=\mathrm{RC}$) a maximum of ae^{-1}, which is thus independent of RC, the second term approaches the value α RC (proportional to the ionic charge collected within one RC) and depends on RC. This proportionality of the amplitude of the tail with increasing RC is clearly shown in figures 2a, b, and c. The amplitude of the electronic component appears to be independent of RC, thus proving that the duration of the free electronic motion, before attachment is shorter than the smallest applied RC=1 μsec. After subtracting the ionic contribution of the output pulse and using the calibration step pulses of the pulser in figures 2d, e, and f (each taken with 87 μv amplitude), the electronic input pulse from the alpha tracks was calculated to be ~80 μv. This value agrees with the estimate given above. It should be recalled that the estimate was rather uncertain due to the lack of precise knowledge of the attachment coefficient in atmospheric air. Also, the field in the chamber is not uniform and the alpha energy spent in the chamber is dependent on the angle of emission.

It is interesting to note that by the use of a proper chamber geometry, uniform field and uniform alpha energy, the techniques presented here could be used for an experimental determination of the electron attachment coefficient at pressures higher than usually permitted in other methods of measurement.

For alpha particle counting with the shortest resolving times the introduction of another filter F_2 appears useful. The output voltage after F_2 is

$$V_2(t)=a1/2\left(1-\frac{t}{3\mathrm{RC}}\right)e^{-\frac{t}{\mathrm{RC}}}+\alpha\frac{1}{3!}\frac{t^3}{(\mathrm{RC})^2}e^{-\frac{t}{\mathrm{RC}}} \quad (3)$$

There are two advantages of the use of $V_2(t)$ as compared to $V_1(t)$.

The second term in $V_2(t)$ is diminished in amplitude (a maximum of $\frac{9}{2}e^{-3}\,\alpha\,\mathrm{RC}\sim 0.23\,\alpha\,\mathrm{RC}$ appears at $t=3$ RC) and cut short in time as compared with the long tail in $V_1(t)$.

The great advantage for a counting experiment is provided by the first term in $V_2(t)$ which passes through zero at $t=3\mathrm{RC}$, giving thereby an output pulse duration (approximate resolving time of counting at low discrimination levels) independent of the spread in amplitude a of the alpha pulses. These pulses have a maximum of

$$a\frac{(3-\sqrt{3})^2}{2}\left(1-\frac{3-\sqrt{3}}{3}\right)e^{-(3-\sqrt{3})}\sim 0.13a$$

at $t=(3-\sqrt{3})\mathrm{RC}\sim 1.27$ RC, a minimum (undershoot) of ~40 percent of the maximum at $t=(3+\sqrt{3})\mathrm{RC}\sim 4.7$ RC.

Figures 3 a, b, and c demonstrate these expected pulse shapes for the alpha pulses taken with the use

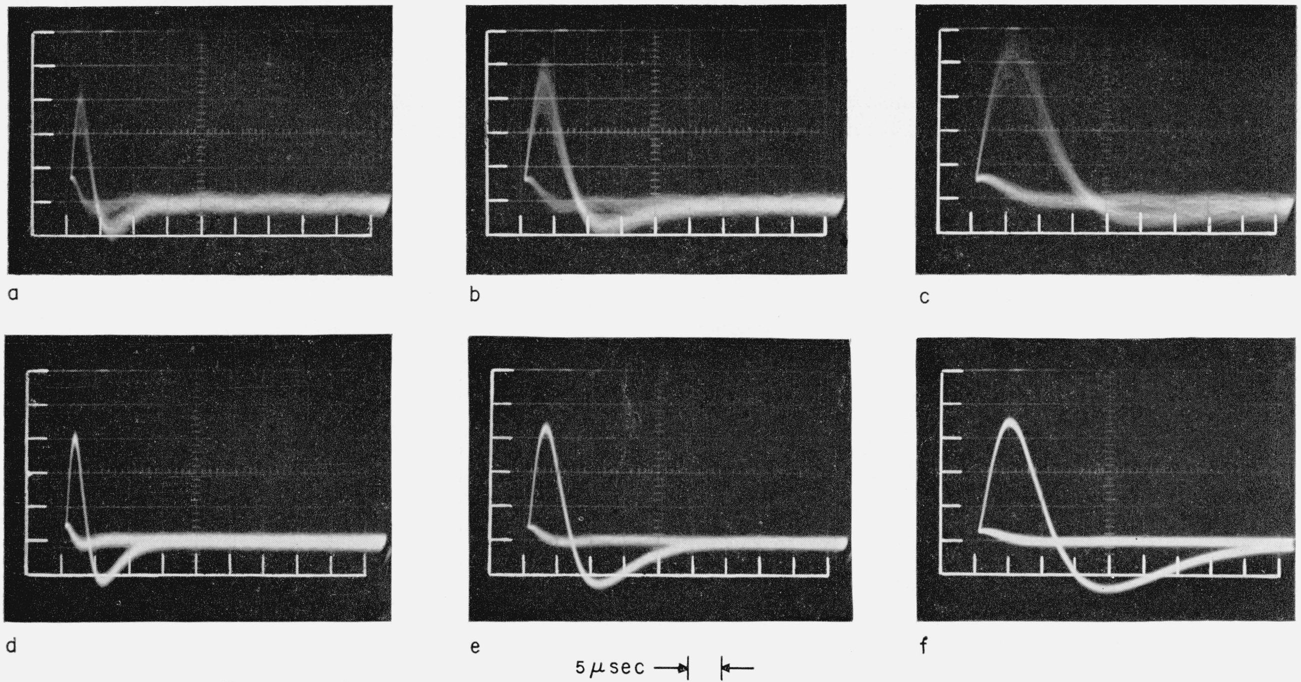

FIGURE 3. *Oscilloscope photographs of the output pulses using two filters F_1 and F_2.*

Pictures a, b, and c are of alpha pulses with filter time constants of 1, 2, and 4 μsec respectively. For calibration pictures d, e, and f, corresponding to a, b, and c, are taken with 100 μvolt step pulses from a pulser. Comparison with figure 2 shows that the use of the second filter F_2 nearly eliminates the contribution of the slow ionic motion from the alpha pulses and results in short pulse periods (resolving times) independent of the amplitudes. The overall gain is the same (~10^6) in all pictures and the time scale is 5 μsec/division.

of the two filters F_1 and F_2 with time constants 1, 2, and 4 μsec respectively. Figures 3 d, e, and f are taken with calibration step pulses of 100 μv amplitude from the pulser. The amplifier gain is the same ($\sim 10^6$) in all pictures of figure 3.

At RC=1 μsec (figs. 3 a and d) the alpha pulse and the calibration pulse are similar and both of ~ 3 μsec duration since the contribution of the slow ion pulse is small at this time constant. As the time constant increases (figs. 3 b and c), the contribution of the ion pulse becomes larger. This results in a compensation in part of the undershoot of the electronic pulse and also in a delay of the zero crossing (the pulse duration is larger than 3 RC). The time scale is 5 μsec per division. Due to the nonuniformity of the chamber geometry for the different alpha tracks at different angles within a 2 π solid angle, the alpha amplitudes display a spread of ~ 30 percent. This is not disturbing in counting experiments. As seen in figure 3, there is a definite and sufficient gap between the noise and the smallest alpha amplitudes even with the dead time of ~ 3 μsec.

Comparison of our counting results with those of the Radioactivity Section of the National Bureau of Standards (using a methane flow 2 π—proportional counter) showed agreement to better than 0.1 percent indicating that our counting efficiency is very nearly 100 percent.

5. References

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