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SELF-TRIGGERING STREAMER CHAMBER AND ITS APPLICATIONS TO NUCLEAR PHYSICS*

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ABSTRACT

Some studies have been made on the self-triggering streamer chamber which is a new promising particle detector suitable for low energy nuclear physics. For this purpose, the self-triggering spark chamber and the streamer chamber have also been studied. A method of detecting gas scintillation from neon has been investigated and the gas mixture consisting of neon (99.5 %)+nitrogen (0.5 %) has been found to be suitable for the self-triggering operation of the streamer chamber. Successful operation of the self-triggering streamer chamber has been demonstrated by using a weak polonium α source.

1. Introduction

In high energy physics, some track detectors have been used as powerful instruments for experimental studies. In fact, the bubble chamber has been widely used because it has the property of giving good spatial resolution of particle tracks, and the high density. Such detectors as the spark chamber(2) and streamer chamber(3) have also favorable characteristics in experimental studies of high energy physics.

On the other hand, these track detectors are not always suitable for experiments of low energy nuclear physics. The bubble chamber, for instance, cannot be useful for detecting particles with low momenta. The spark chamber have also scarcely been used in low energy nuclear physics, except for a few cases(+). However, in order to investigate the low energy nuclear reactions in which more than three charged particles are produced and whose occurrence is very rare, some spark chamber-like detectors might be quite useful.

From this viewpoint, a few years ago, a self-triggering spark chamber was proposed by S. Yasumi et al.(6) as one of the promising devices to make spark chambers generally useful in studies of low energy nuclear physics. It is a

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(*) A part of this paper was published in Nuclear Instruments and Methods.(1)

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(+) An example of using the spark chamber for studies in nuclear physics was firstly presented in an attempt to search for double β-decay from ^{48}Ca.(4) Another example was presented in p-^{4}He scattering experiments(5) with proton energies of 70-80 MeV.

(−) The self-triggering method was firstly used by C. Cavalleri et al.(7) in their studies of spark track formation with the oscillating electric field.

spark chamber triggered with pulses due to gas scintillation-) produced by the passage of ionizing particle through a chamber.

As they used a one-gap track projecting chamber, it had defects such as the two-dimensional property of spark tracks, the small solid angle for particle detection and the difficulty of light collection to photomultipliers. These difficulties can, however, be overcome by employing the streamer chamber instead of the track projecting spark chamber. Thus one can reproduce completely three-dimensional trajectories of particles with low momenta without any devices for triggering outside the chamber.

The self-triggering device provides not only a triggering method suitable for detecting such particles, but also a useful method of selecting wanted events by utilizing the characteristics of gas scintillation. In the course of development of these apparatus, it was one of the essential points how one can detect light signals due to gas scintillation efficiently.

Section 2 describes the self-triggering spark chamber. The experimental results obtained by using the helium scintillation chamber are also presented in this section. In section 3, some studies on the streamer chamber are described. In order to construct the self-triggering streamer chamber, it is especially important to choose some suitable gas or gas mixture. In such a choice one should make compromise between the counting efficiency of gas scintillation and the desirable quality of streamer tracks. Section 4 explains a method to shift wavelength of light from neon gas scintillation to a sensitive range of photomultipliers. A few of the photographs which show the successful operation of the self-triggering streamer chamber will be given in this section for demonstration. Finally some remarks on the promising applications of the self-triggering apparatus will be made in the last section.

2. Self-triggering spark chamber

One of the essential points in operating the self-triggering spark chamber is the gas scintillation counting. The mechanism of gas scintillation is summarized in what follows. When ionizing particles pass through a gas volume, they lose their kinetic energies by the interactions with atomic electrons which lead to the excitation and ionization of the gas atoms. In the deexcitation and recombination process, photons are emitted.

Several authors pointed out that the wavelength of the light emitted from most of the noble gases is too short to be detected efficiently by ordinary photomultipliers and that the light output decreases when some impurities are present in noble gas. On the other hand, such impurities as nitrogen can be used as the gas wavelength shifter, when they are mixed in an appropriate proportion into noble gas.

Helium gas was employed to testify the scintillation by using a scintillation vessel as is shown in Fig. 1. The α particles from polonium source were incident to the gas. The scintillation vessel was designed so that the α particles were stopped in gas volume when the gas was filled with a pressure more than about 1.5 atm. To identify the scintillation due to α particles, a shutter was installed in front of a collimator, which was controlled from outside the vessel if necessary.

Scintillation signals from two photomultipliers (56 UVP) mounted directly to the quartz windows of the vessel were counted in coincidence. Also signals from one of the photomultipliers were measured with a pulse height analyzer. Measured pulse corresponds to the light signal which is fallen within a gate time of 100 nanosec initiated by the coincidence signal. Purity of helium used in the experiment was estimated to be 96.6 % by the mass spectrometry. The

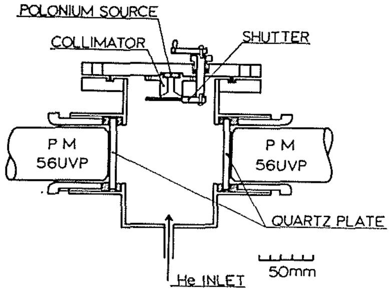

Fig. 1. A cross sectional view of the scintillation vessel used for detecting the scintillation from helium gas. The inner surface of the vessel was smoked with a layer of MgO by burning magnesium ribbon.

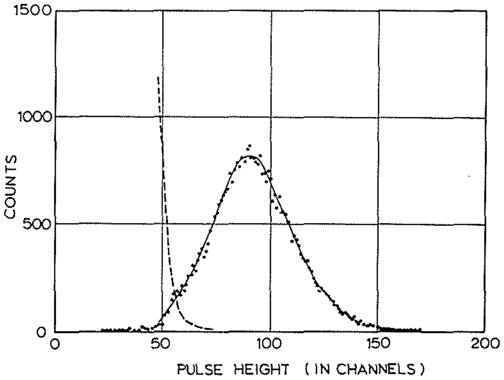

Fig. 2. A pulse height distribution obtained by using the scintillation vessel. The noise level is indicated in a dashed line.

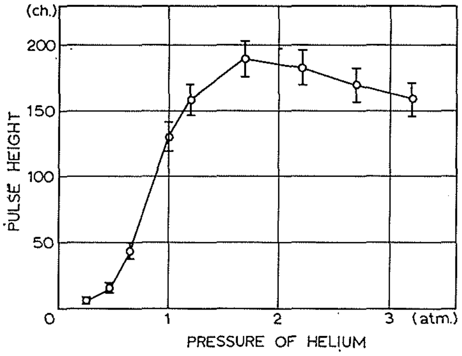

Fig. 3. Pulse height plotted as a function of the pressure of helium gas. The increase in pulse height is due to the change in the energy loss of α particles in the gas volume.

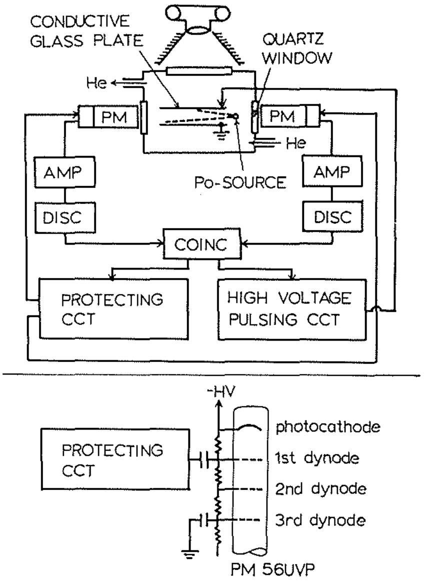

Fig. 4. Schematic diagram of the self-triggering spark chamber.

major impurities of the gas were nitrogen (2.2 %), oxygen (0.5 %) and carbon dioxyde (0.2 %).

Typical pulse height distributions obtained by using the scintillation counting system of Fig. 1 are shown in Fig. 2. The similar pulse height distributions were obtained when the photomultipliers were replaced by the ordinary ones (56 AVP). This fact might indicate that some of the impurity gases work as the wavelength shifters.

Fig. 3 represents the relative pulse height plotted as a function of total pressure of helium gas. In this figure, the increase of the pulse height with pressure may be understood as the increase of the energy loss of the α particles in the gas, and the increase of the efficiency of light collection to the photomultipliers.

The spark chamber was designed so as to be tolerable to gaseous pressure of about 5 atm. The construction of the spark chamber is shown in Fig. 4. It contained a pair of parallel electrodes, which consisted of a transparent conductive glass plate and an aluminium plate with a spacing of 10 mm from each other. Polonium source was placed at the viewing position of the working volume between the plates. Photons produced by the passage of the α particles were directly detected by two photomultipliers (56 UVP) viewing inside the chamber through quartz windows, and then the output signals from the photomultipliers were fed to the coincidence circuit. The output pulse from this circuit drives a high voltage pulsing circuit which generates the high voltage pulse of about 10 KV, while the same pulse is also fed to the so called "photomultiplier protecting circuit". The protecting circuit can produce the pulse high enough to make the potential of the first dynode of photomultiplier higher than that of the second and the third dynode during the breakdown of spark

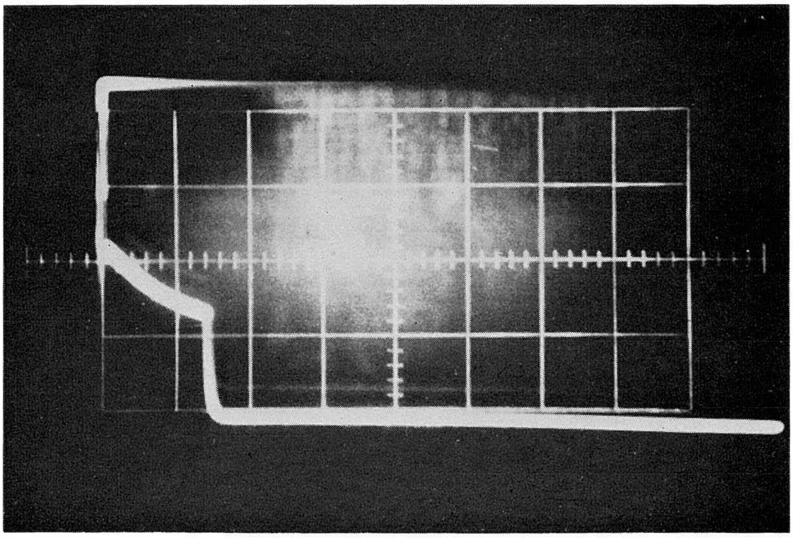

Fig. 5. A photograph indicating the effect of the protecting circuit. The protecting circuit generates a pulse with long duration, whose pulse height is more than 200 V. No scintillation pulses due to strong ^{60}Co gamma rays are seen in this figure while the protecting pulse is applied to the photomultiplier. The horizontal sweep of this figure is 50 μ sec/div.

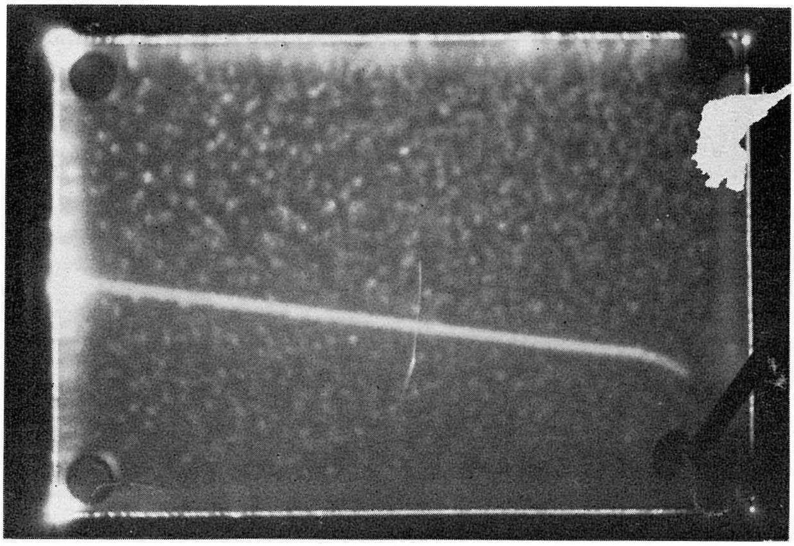

Fig. 6. Typical photograph of the α particle track from polonium source taken by the self-triggering spark chamber, viewed along the direction of electric field.

chamber. Thus this device can protect the photomultipliers against intense light emitted at the sparking of chamber.

Fig. 5 shows a synchroscope photograph which represents the effect of this cirucit protecting the photomultiplier against a number of photons from a plastic scintillator under irradiation with strong ^{60}Co gamma rays. The shape of pulse produced from the protecting circuit is also presented in the same figure.

It is clearly shown in Fig. 6 that this chamber is successfuly operated. Such photographs can be taken at every triggering. Without the self-triggering device, it can be estimated that one must take almost one thousand photographs with such a weak source before one can obtain only one α track by random pulsing.

3. Streamer chamber

The streamer chambers have been constructed in many laboratories and used in a few experiments. The mechanisms which are relevant to the streamer formation in gas were discussed by many authors.[8]

In constructing the streamer chamber, efforts should be made mainly to produce the high voltage pulse with a short duration enough to achieve the good spatial resolution of the particle track. However, the possible spatial resolution in the streamer chamber is limited, because the increase of spatial resolution results in the decrease of the number of photons emitted from the streamers.

The seven-stage Marx generator[*] was used to produce the high voltage pulses. They were shaped into the wave form suitable for the streamer mode operation by using the pulse shaper consisting of a series gap, a shorting gap

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[*] The Marx generator was manufactured by Nisshin Electric Co., Ltd.

and a shunting gap. The equivalent cirucit analysis of such a high voltage generator with a pulse shaper is described by E. Gygi and F. Schneider⁹⁾. By using these circuits, we had succeeded in observing the streamer tracks of cosmic ray particles¹⁰⁾. This device was found to have the following characteristics from the observation of output pulses.

Pulse height : up to 200 KV
Rise time : less than 5 nsec
Pulse duration : nearly 15 nsec
Time delay : 300 nsec
Time jittering : 50 nsec

The above-mentioned pulse shaper has a noticeable character that the track quality closely depends on the gap spacing of the shunting gap. By suitably setting this gap, one can obtain the streamer tracks with their lateral length less than 4 mm of the cosmic ray particles. Fig. 7 shows a schematic diagram

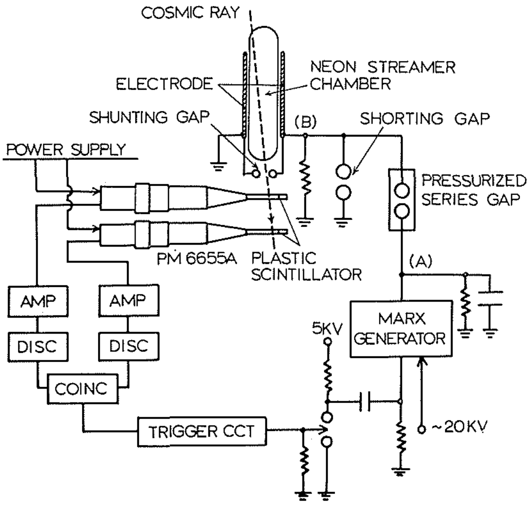

Fig. 7. Schematic diagram of the streamer chamber device used for detecting cosmic ray particles. The chamber was filled with pure neon at an atmospheric pressure.

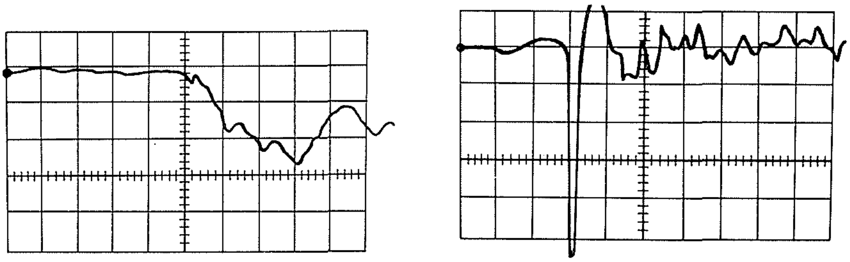

Fig. 8. Wave forms of the high voltage pulses. Figures (a) and (b) represent the pulses measured at the points of (A) and (B) in Fig. 6, repectively.
Vertical scale : 20 KV/div. in both (a) and (b).
Horizontal sweep : 20 nsec/div. in (a), and 50 nsec/div. in (b).

of the streamer chamber device used for detecting cosmic ray particles. The output pulse from the external counter logic was amplified and was used as the trigger pulse of the Marx generator. The typical wave forms of the high voltage pulses measured at the points (A) and (B) in Fig. 7 are shown in Fig. 8. Typical streamer track of cosmic ray particle taken with this apparatus is shown in Fig. 9.

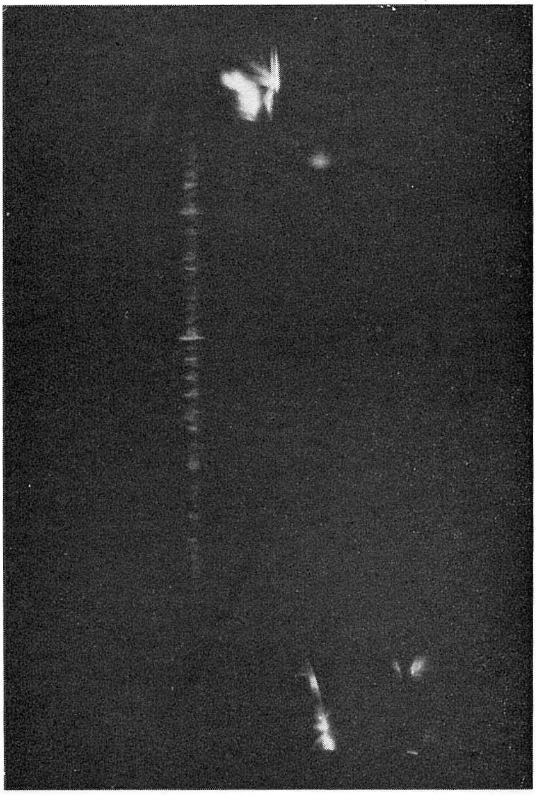

Fig. 9. Typical streamer chamber photograph of a cosmic ray particle observed from the direction perpendicular to the electric field. The streamer spread in the direction of electric field was only about 5 mm.

4. Self-triggering streamer chamber

In constructing the self-triggering streamer chamber,*) we had to search for the suitable gas or gas mixture which gives the sufficient light without deteriorating the streamer mode operation. Use of helium or argon together with some wavelength shifter is fitted for detecting the gas scintillation, but it seems to be unprofitable for operating the streamer chamber. On the contrary neon is the most suitable for operating the streamer chamber, but it seems to be unfavorable for a scintillator, because it gives the scintillation with too long wavelength to be detected with ordinary photomultipliers except for rather weak scintillation light[11)] of about 5860 Å.

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*) The self-triggering streamer chamber is abbreviated as the STSC hereafter.

It was once suggested by C. Eggler and C. M. Huddleston that use of the PbS photoconductor might respond to the scintillation from pure neon[12]. The response of the photoconductor is, however, generally too slow for the purpose to utilize it for operating the streamer chamber. Then it was considered that some gas wavelength shifters might be one of the solutions of this problem, because they seemed to be more preferable than the organic solids especially for constructing the STSC.

Nitrogen gas was sometimes used as a gas wavelength shifter[13] for most of the noble gas scintillations. It seemed from our experience that nitrogen might be expected to work well as a gas wavelength shifer for the neon gas scintillation. The feasibility of nitrogen was then examined. Using pyrex test chambers* filled with pure neon or neon-nitrogen gas mixture at an atmospheric

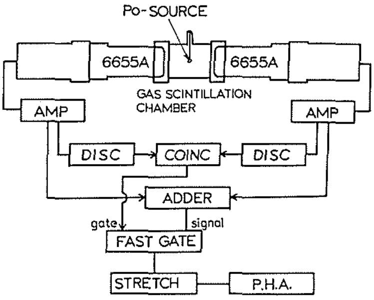

Fig. 10. A schematic diagram of the electronics used for measuring the effects of nitrogen mixing to neon gas scintillation. Pulses from the photomultiplier (6655 A) were clipped to 3.3×10^{-8} sec.

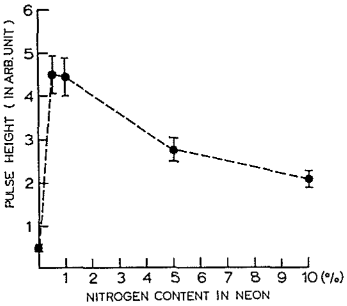

Fig. 11. Pulse height plotted as a function of the nitrogen concentration in neon. The optimum concentration of nitrogen was determined as 0.5% in pressure.

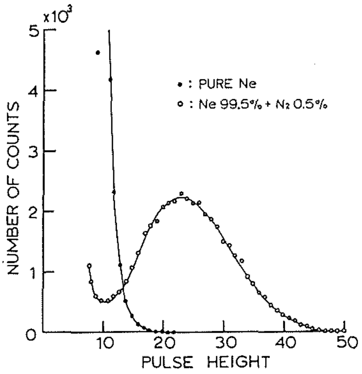

Fig. 12. Pulse height distributions of the light outputs from pure neon and neon (99.5 %)-nitrogen (0.5 %) gas mixture.

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*) The pyrex test chambers were evacuated below 10^{-5} mmHg, and baked at about 500°C before filling the gas or gas mixture, then they were sealed off. The amout of impurities in these gases was supposed to be less than 100 ppm. The pulse heights due to gas scintillation did not change during experiment.

pressure, scintillation pulse heights were measured for various concentration of added nitrogen. The incident particles are α particles from polonium source which was housed in the chamber. The electronic circuits which were used in this measurement are shown in Fig. 10. The results thus obtained are seen in Fig. 11. From this figure, nitrogen was found to be feasible for detecting the neon gas scintillation. It was also found that the optimum concentration of added nitrogen was about 0.5 % in pressure, although the detailed behavior below 0.5 % did not examined. Some typical pulse height distributions are presented in Fig. 12 for pure neon and neon (99.5%)+nitrogen (0.5%) mixture.

Very recently, H. Kohler et al. examined the neon-nitrogen gas mixture[14]. They obtained the optimum light output at 0.3 % of nitrogen concentration in the gas. They reported also that the primary and secondary scintillation comes from the identical excitation mechanisms of nitrogen molecules through the impact of free electrons. In operating the STSC, the use of the secondary scintillation, which is realized by applying the electric field to the chamber, seems to be inadequate for obtaining the good spatial resolution.

The STSC shown in Fig. 13 was constructed by using the gas mixture consisting of neon (99.5 %) and nitrogen (0.5 %). The next problem is to testify whether this gas mixture ensures the good operation of the streamer mode or not. To examine the operation, we placed the pyrex cubic chamber between

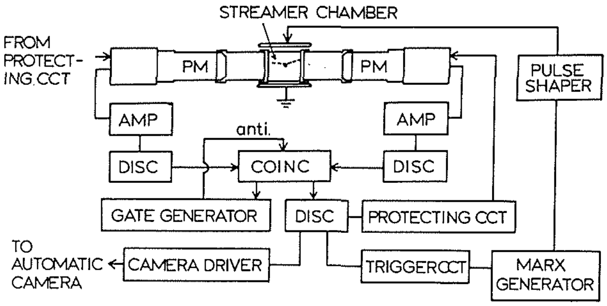


Fig. 13 (a). Schematic diagram of the apparatus to examine the operation of the STSC. The gate pulse generator produces the pulses with the appropriate duration, and they are fed to the anti-coincidence circuit. Therefore the successive coincidence pulse is inhibited until the film is advanced.

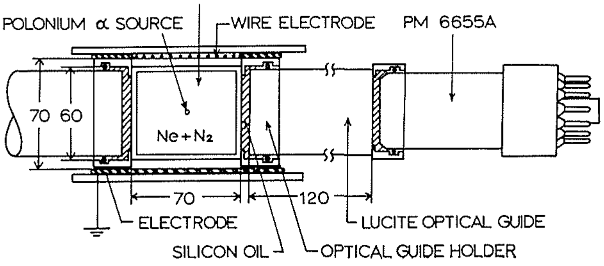
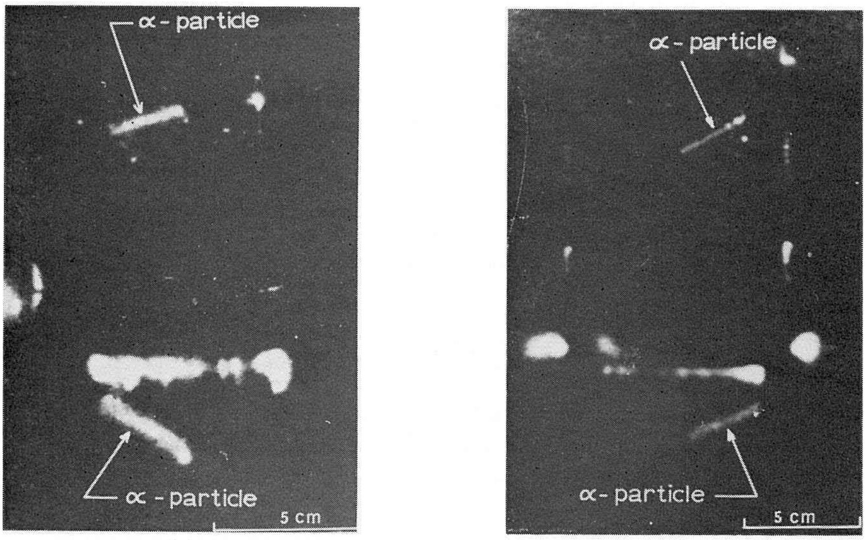


Fig. 13 (b). Construction of the STSC in detail. Optical guides were needed to reduce electric disturbances induced in photomultipliers. Numbers in this figure are in mm units.

two parallel plane electrodes, one of which consists of copper wire grid (0.3 mmϕ) so as to take photographs through it. In the chamber, a polonium α source was stuck to one end of glass rod ($\sim$1 mmϕ), whose direction was parallel to the plane of electrodes, fixed on one wall of the chamber. The intensity of this source was weak enough to convince us the good operation of the self-triggering.

High voltage pulses of about 90 KV were fed from the pulser described in section 2. The protecting circuits were also used, although in this case much less photons are emitted than in an ordinary spark chamber. Typical stereoscopic photographs of the streamer tracks of α particles are shown in Fig. 14, being taken with the STSC as is schematically shown in Fig. 13. In Fig. 14, these tracks show quite different looks from those of the streamer tracks of high energy cosmic ray particles. This fact seems to be explained, at least partly, by the heavy ionization of α particles.

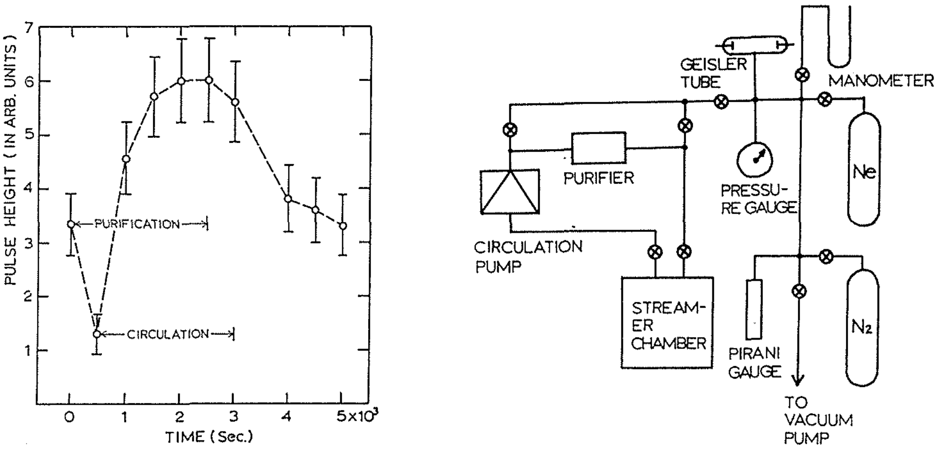


(a) (b)

Fig. 14. Stereoscopic photographs of the α particles from the polonium source taken by the STSC, viewing along the direction of the electric field (above) and the perpendicular direction to the electric field (below). Photographs were taken with f/0.95 lens on Fuji SSS film.

In order to carry out the experiments, a large STSC is demanded. The STSC made of glass had some limitation to increase its dimensions. Then we tried to construct first the steel vessel which contains the electrodes and the gas mixture. This construction was however, suffered frequently from the spurious discharges even at the rounded edges of the electrodes. In our experience, the spurious discharges were always seen when both electrodes were completely surrounded by the chamber gas.

Then, a Lucite chamber was constructed so as to fit the nuclear experiments, whose dimensions were $80\times100\times110$ mm^3. The chamber was evacuated to 10^{-3} mmHg before the gas filling. By the air remaining in the chamber and the outgas from the Lucite wall, the efficiency of the self-triggering was observed



(a) (b)

Fig. 15 (a). Pulse height of the light output from the Lucite chamber as a function of time. When the heater of the purifier was switched on and the gas was circulated, the pulse height was observed to increase.
(b). Schematic diagram of the gas purifying system.

to decrease in time. This fact suggests that the impurities other than nitrogen should be removed continually, because in our case the gas used is the binary gas mixture of neon and nitrogen. Such a gas purifier is, for instance, zirconium or magnesium. They can remove H_2, O_2 and CO_2 efficiently at about 400°C, but are almost inactive to nitrogen. Fig. 15 (a) represents the effect of gas purifier under the operation of the apparatus shown schematically in Fig. 15 (b). The noticeable increase in the scintillation pulse height was observed with this purifier. In this figure, the initial decrease in pulse height may be caused by outgasing from the purifier. The Lucite STSC was found to be feasible by observing the α tracks emitted from the polonium source.

5. Discussion

The promising applications of the STSC are discussed in this section. As is mentioned in the first section, this device can be useful for the experiments of low energy nuclear physics. The usefulness of the STSC comes from the fact what follows; one can obtain much physical information from the measurement of all the momentum vectors of charged particles which is produced from certain nuclear reaction and lose their kinetic energies completely in the gas volume. The accuracy of the track measurement may be superior to that in the nuclear emulsions. In fact the accuracy in measuring energy and direction of 5.3 MeV α particles by using the neon STSC at an atmospheric pressure is $\delta E \sim \pm 0.15$ MeV and $\delta\theta \sim \pm 0.05$ rad, respectively. This accuracy is much better than that by using the nuclear emulsions. It will be increased further by using the STSC with lower pressure.

Let us, for example, consider the reaction $^{12}C\ (n, n')\ 3\alpha$. Since all particles in the final state are charged except a scattered neutron, the STSC will enable us to measure all the momenta of α particles concerned in the reaction, if the energy of incident neutron is known. When incident neutrons are replaced by photons, the situation also stays the same. If we measure these reactions by means of the nuclear emulsions, we should select the wanted events (3α prongs) among the heavy background events, and therefore may introduce some uncertainties.

On the other hand, the STSC will give us information on almost pure 3α events, when we utilize the characteristics of gas scintillation that depends only on the energy loss of particle in the gas volume and is insensitive to its mass and charge[15]. In the photoreaction studies, this property can be used to suppress scintillation pulses due to copious electrons liberated by incident gamma rays, and to select the wanted events easily by biasing on the appropriate circuits in electronics. Thus the STSC is expected to be valid for many experiments of the nuclear reactions initiated by neutral particles.

When incident particles are charged, it will be necessary to make some modification for the STSC, by which one can suppress pulses due to gas scintillation following the passage of incident charged particles.

In performing many experiments, it is necessary to compromise between the accuracy of track measurement and the energy resolution of gas scintillation produced by particles dissipating their total energies in the chamber gas, by varying the pressure of gas. Also in order to preserve the efficiency of the self-triggering operations, the purity of gas or gas mixture must be kept at constant during experiments.

We are now planning to investigate the $^{12}C\,(n, n')\,3\alpha$ reaction by using a large STSC suitably constructed. For detecting low momentum α particles produced in this reaction, the STSC with low pressure might be quite feasible. Investigations of this reaction will give us much information. We shall be able to clarify, for instance, whether or not the reaction has proceeded via such an intermediate state as ^8Be or ^5He. We shall also obtain useful information concerning the cluster structure of ^{12}C nucleus through the measurement of some quantities of the excited states. It is interesting to investigate whether some excited states of ^{12}C nucleus have high moment of inertia, whose existence was reported to be the case in ^{16}O nucleus[16].

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