FLASH CHAMBERS OF PLASTIC MATERIAL

M. Conversi^{*)} and L. Federici^{**)}

Istituto di Fisica dell'Università, Rome, Italy

ABSTRACT

We describe a type of electrically-pulsed chamber, easy to realize at a low cost even in big size, consisting of a large number of thin, tubular "sensitive cells" of plastic material filled with a noble gas mixture at atmospheric pressure. The luminous discharges that occur in the cells traversed by ionizing particles upon application of the high-voltage sensitizing pulse, yield the tracks -- and under certain conditions also the instants of traversal -- of the particles themselves, with no severe restriction for their maximum number.

Various optical or electrical read-out systems can be utilized to extract the information from the discharged cells.

Examples of application of the technique in high-energy physics are given.

Geneva - 15 August 1977

(Submitted to Nuclear Instruments and Methods)

---

^{*)} Present address: CERN, Geneva, Switzerland.

^{**)} Present address: Laboratori Nazionali INFN, Frascati, Italy.

1. INTRODUCTION

In this article we report the main results of a systematic investigation carried out mostly in Rome three years ago¹⁾ on a new version of the 22-year-old flash-tube hodoscope chamber²⁾. As it is known³⁾, this was the first example of an electrically-pulsed track detector⁴⁾ of the spark-chamber type ever developed, and the application of its basic principle (that of the "selective electronic trigger") led, in fact, to the "triggered spark counter"⁵⁾ and the "discharge chamber"⁶⁾, from which the final version of the ordinary optical spark chamber was derived in 1960.

The original hodoscope chamber technique -- further developed especially by Wolfendale and his collaborators in England, and by S. Fukui and S. Miyamoto in Japan -- found a large number of applications in cosmic-ray physics⁷⁾. But the range of potential applications of the technique was considerably enlarged in 1972-73 by showing that the electrode-less neon-filled glass flash-tubes can be replaced by sensitive elements or "cells" of plastic material⁸⁾ and, in particular, that large "plastic chambers" can be quickly constructed by utilizing plates of extruded polypropylene commercially available at a very low cost in simple honeycomb structures^{1,9)}. With the development of this last type of chamber, essentially free of "dead space", we also overcome the drawback associated to the necessity of constructing and dealing with a large number of distinct sensitive elements, which in the case of the original hodoscope chamber, had the additional disadvantage of being made of fragile glass. Nevertheless, the cells of the honeycomb-structured plastic chamber are entirely independent from the viewpoint of the electric discharge, so that the characteristic feature of the flash-tube chamber, that of being an efficient detector of multi-track events with any track-angular inclination, is fully retained.

In all types of plastic flash chambers, an ordinary Ne-He gas mixture is made to flow slowly through their cells, in each of which simple probes can be inserted so as to obtain an electrical signal (of typically a few V on a 50 Ω grounded resistor) from each of the discharged cells. Hence, both optical and electrical read-out systems can be utilized starting from the luminous electrical discharges that occur in the cells traversed by ionizing particles and subjected to the "sensitizing" high voltage (HV) pulse. Furthermore, it has recently been shown by still preliminary tests¹⁰⁾, that plastic flash chambers can apparently also work when sensitized by HV pulses as long as a few msec, so that they can be operated synchronously with the "slow" beam spill-out of high-energy particle accelerators. In these cases, the instant of each particle traversal can be derived from the time position of the probe signals (or of the light flashes themselves) for all ionizing particles traversing the chamber during the beam spill-out. Under these

circumstances the flash chamber behaves, therefore, as a detector yielding jointly information on the space and time coordinates of the recorded particles.

In connection with the facility represented by the many low-impedance electrical signals derivable from the discharged chamber cells, we wish to point out, finally, the possibility of its utilization to operate "logical decisions" in real time. With fast electronics such decisions can often be taken in times of a few microseconds¹¹⁾, short enough to sensitize via a second triggered HV pulse¹²⁾, whenever required, other special-purpose electrically-pulsed detectors.

The adaptability of the plastic chamber technique to a variety of applications in different fields of physics has been stressed on various occasions⁷⁻⁹⁾. In the field of high-energy physics its applicability was envisaged¹³⁾ especially for "calorimetric measurements" of electromagnetic or hadronic cascade showers, such as those often required, in particular, in high-energy neutrino physics.

The behaviour of shower detectors consisting of alternate layers of honeycomb-structured plastic chambers and inert plates of dense material, was investigated last year in exposures to electron and pion beams of the CERN 28 GeV Proton Synchrotron (PS). The relevant results of this investigation were first reported in a brief note¹⁴⁾, whereas a full account of them is given in the following paper¹⁵⁾. The wide energy range of linear response, the comparatively good energy resolution, and the very low cost of such shower detectors, easy to construct in huge dimensions, raised interest in various laboratories, where the technique has been further tested, leading to large-scale experimental proposals¹⁶⁾ which utilize extensively big honeycomb-structured flash chambers.

The possibility of installing flash chambers of suitable plastic material in the liquid of a hydrogen bubble chamber¹⁰⁾, opens up other ranges of applications to high-energy physics¹⁷⁾, some of which are briefly discussed later in this article.

2. MAIN FEATURES OF PLASTIC FLASH CHAMBERS

2.1 Principle and modes of operation

The principle of operation of a plastic flash-tube chamber can be stated (with the clarification given in the following paragraph) in the words of the first paper on the original triggered hodoscope²⁾: "If a strong electric field is produced soon after the passage of an ionizing particle in a region of space filled with a (noble) gas, then a luminous discharge occurs all over this region¹⁸⁾ as a consequence of the processes following the acceleration undergone by the electrons freed by the impinging particle".

The main condition for the luminous discharge to occur is indeed that *electrons be present in the gas at the time of application of the high-voltage (HV) pulse* which creates the above-mentioned "strong electric field". This main condition does not imply that the field be necessarily produced, as stated above, "soon after the passage of an ionizing particle"; even though this is actually done under what we will call here the chamber "normal mode" of operation (the one normally applied to all electrically-pulsed chambers) where d.c. operated counters are used to trigger the sensitizing HV pulse with the help of some suitable "logic". In fact, this normal mode of operation is the only one applicable when the chamber is used, as, for instance, in cosmic-ray research, to detect events that occur at random in time.

There is another mode of operation, however, which can be applied in principle -- but has never been applied as yet -- to experiments with high-energy particle accelerators that produce bursts of secondary particles regularly spaced and well separated in time. In such cases -- as already mentioned in Section 1 -- one may sensitize the chamber, at the occurrence of each burst, by applying synchronized HV pulses lasting -- if possible -- as long as required to cover the whole beam spill-out time, or the sensitive time of some associated detector (for example, a large bubble chamber). Under this "*synchronized mode*" of operation the chamber flash-tubes can be utilized -- as first pointed out by Mannelli¹⁰⁾ -- as timing devices, since the light signals, or the associated electric signals observable by means of a probe, occur with a small jitter soon after the instant of particle traversal.

2.2 Mechanical structure

While the neon-filled sensitive elements of the original hodoscope chamber are cylindrical glass tubes that allow one to "see" the particle trajectories in projection on planes perpendicular to the cylinder axes, the sensitive elements of a plastic chamber are often flexible⁸⁾ and can therefore be adapted to any desired detector geometry. Examples of cylindrical chambers, suitable for installation over the vacuum chamber of a colliding beam machine, have been shown in previous reports^{8,9)}.

As mentioned already (Section 1), the honeycomb-structured chambers made of extruded polypropylene plates can be quickly obtained at a very low cost, in the form of large parallelepiped chambers in which the flash-tubes are cells already assembled together, in a way essentially free of "dead space". This type of plastic chamber, especially useful in large-size shower detectors, will be described in detail in Section 4.

Clearly, many other mechanical structures can be conceived in addition to the cylindrical and parallelepiped examples mentioned above. Provision has to be made in all instances, of course, for the installation of the "hot" electrodes to which the HV pulse will be applied, and for the circulation of the noble gas mixture through the sensitive elements, which is in general required for the reasons explained below.

2.3 Gas filling and gas circulation

Sample flash-tubes made of different plastic materials have been tested successfully (see Section 3) with various noble gas mixtures flowing through them at appropriate speeds. The necessity of this gas circulation (never required in the case of glass flash-tubes) is a consequence of the fact that most plastic materials emanate electronegative impurities at room temperature. The effect of these impurities is to make the disappearance of free electrons possibly present in the gas, faster, through attachment and recombination. If, in particular, the chamber is operated under the normal mode (Section 2.1) the disappearance of the electrons freed by the ionizing particles traversing the flash-tubes has to occur in a time t_s greater than the minimum time t_m , required to form and apply the HV sensitizing pulse (if $t_s < t_m$, all ionization electrons have disappeared when the HV pulse is applied and no flash will occur). Since t_m is usually of the order of, or greater than, about 100 nsec, the speed of gas flow has to be regulated accordingly, so as to keep $t_s > t_m \approx 100$ nsec. On the other hand, the types and emission rates of impurities emanated from the tube walls depend widely on the nature of the plastic material; so that for a given geometry of the cells, the speed of the flowing gas will have to be regulated according to the type of plastic employed.

For some plastic materials (such as teflon and polypropylene, see Section 3), the required speed of flowing gas is comparatively very small, even at room temperature, so that circulation can be made in an "open circuit", letting the gas go out into the open air, through a "bubbler", with little waste. In the case of large chamber installations, or when the chamber cells are made of plastic material requiring comparatively high speeds of gas flow, it may be convenient to force the noble gas mixture to circulate in a "closed circuit" containing a trap which retains the impurities. We have found that in some cases (e.g. with large samples made of ordinary plexiglass) a liquid nitrogen trap or a common freezer trap are sufficient for the purpose, leading to no appreciable decrease in detection efficiency over periods of the order of one day. We believe that this simple method is applicable to concrete cases because, in contrast to the case of a spark chamber, there is no high-intensity current involved in the flash-tube discharge and no appreciable deterioration of the inner plastic walls should occur, therefore, even after a large number of discharges.

Except in the case of very small chambers, the gas should circulate "in parallel" through the many cells of a plastic chamber, especially in order to avoid accumulation of impurities towards the gas-out region, resulting in a decrease of the chamber detection efficiency over that region.

2.4 Sensitive time and recovering time

While we refer to Section 2.2 of Reference 7a for a quantitative definition of these flash-tube "characteristic times", here we briefly recall their meaning.

The sensitive time t_s , can be regarded as the memory time of the passage of the particle through the flash-tube, being essentially the time required for most of the few "ionization electrons" freed by the impinging particle to disappear, via attachment to the tube wall or to the gas impurities. The smaller t_s , the greater the maximum background rate to which the chamber can be exposed without inconvenience. Nevertheless, if the chamber is operated under the normal mode, the condition $t_s > t_m$ has to be fulfilled for the reasons explained above in Section 2.3.

The recovery time t_r , can be regarded in turn as the memory time of the discharge. It is, in fact, the time required for the many electrons produced in the tube discharge to disappear; so that if the tube has flashed because of the passage of a particle, and a second HV pulse is repeated after a time $t > t_r$, the "re-ignition probability", i.e. the probability that the tube flashes again even if not correlated particle is traversing it, is conveniently small (say, smaller than 10%). The smaller t_r , the greater, of course, is the speed of acquisition of data one can extract from the chamber-sensitive elements through some read-out system (see Section 2.6). Typical values of t_r (see Section 3) range from some 10 msec to some 100 msec. Methods for making t_r shorter, without affecting t_s to the same extent, have been studied and applied successfully to glass flash-tubes¹⁹⁾ for which repetition rates of the order of 10^3 triggers per second have been reported²⁰⁾. Attempts to extend this work to the case of flash-tubes of plastic material are now being made¹⁷⁾.

It is worth pointing out that if the chamber is operated under the "synchronized mode" as defined in Section 2.1 above, then the condition $t_s > t_m$ is no longer required; so that it should be possible to achieve smaller values of t_r (and hence higher values of the maximum tolerable trigger rate) without appreciable loss in chamber detection efficiency.

2.5 Detection efficiency

As discussed in various articles⁷⁾, the detection efficiency η , of glass flash-tubes operated under the normal mode, is a function of various parameters,

and, in particular, of the time delay θ , between the instant of particle traversal and the instant at which the HV sensitizing pulse is applied. Minimum ionizing particles produce several ionization electrons in traversing 1 cm of noble gas at atmospheric pressure: ~ 33 ion pairs per cm are produced, for instance, in the case of neon. High detection efficiencies are therefore easily obtained, within a large range of peak values of the electric field and of pulse shape of the HV pulse, for 1 cm diameter tubes filled with neon at atmospheric pressure, provided that θ is sufficiently short to have only a small electron recombination effect. The efficiency versus delay curve $\eta(\theta)$ observed experimentally (and, in general, well understood theoretically) is used to determine the flash-tube sensitive time t_s with the condition⁷⁾:

$$\eta(\theta = t_s) = \frac{1}{2} \eta(\theta = 0) . \quad (1)$$

We point out that in the case of a plastic flash-tube the curve $\eta(\theta)$ will depend, in general, on the type of plastic material and the speed of gas flow, for the reasons explained above (Section 2.3).

2.6 Read-out possibilities

As already mentioned, both optical and electrical read-out systems can be utilized⁸⁾ in order to record the luminous discharges of the chamber cells that were traversed by ionizing particles.

Under ordinary conditions of gas filling (any Ne-He mixture circulating at approximately atmospheric pressure) the intensity of the light flash is largely sufficient for photographic or iconoscopic recording, even if the light is transported through optical fibres a few metres long, rather than being directly recorded.

An optical iconoscopic system, based on the use of a vidicon tube and of a recording magnetic tape with triggered step-by-step advance, has been developed²¹⁾ and applied to extract the information from the shower detector described in the subsequent article¹⁵⁾.

The electrical read-out system consists of simple probes, placed at either end of each chamber cell, grounded through a resistor R_0 , as shown schematically in Fig. 1.

The characteristics of the electric signal at the probe depend on the amplitude of the sensitizing HV pulse, the value of R_0 , and the positioning of the probe relative to the chamber sensitizing electrodes (the distance indicated by d in Fig. 1). These characteristics have been studied, in particular, for a probe installed on an "electrically-pulsed counter" of useful area $32 \text{ cm} \times 32 \text{ cm}$, and 2 cm thick^{12,22)}, operated with a sensitizing pulsed electric field of 3.5 kV/cm.

Such a counter can be regarded as the cell of an ideal huge flash-chamber made of large plexiglass cells. For a 30/70 Ne/He gas mixture flowing in this cell and for $d \approx 0.5$ cm, $R_0 = 50 \Omega$, the signal is a large pulse which occurs typically with a delay of ~ 100 nsec, and an asymmetric jitter of about +30 nsec and -10 nsec. It rises in ~ 40 nsec to its peak value of ~ 30 V and then decreases with an exponential decay constant of ~ 200 nsec. Signals of quite a similar type, even through of smaller amplitudes and exhibiting larger jitters, are observed on the electrical probes of smaller cells, such as those of the flash chamber described in Section 4, which are thin-wall propylene rectangular tubes of $3.5 \text{ mm} \times 5 \text{ mm}$ transversal dimensions.

A simple method has been developed²²⁾ to obtain the probe signal entirely free from the "noise" due to the induction of the applied HV pulse. In any case, discrimination against this noise pulse is, in general, easy because the signal/noise ratio is large and the signal occurs with a time delay of, typically, some 100 nsec relative to the noise.

3. PERFORMANCE OF SAMPLES OF DIFFERENT MATERIAL

3.1 Experimental procedure

The method by which the characteristics of flash-tube samples were derived, is the same described in detail in a previous paper²³⁾. The set-up, shown in Fig. 2, was conceived so as to allow us to investigate the performance of flash-cell samples of different materials, fillings, and dimensions. By exposing each sample to the β -rays from a ^{106}Ru source and utilizing the electrical probe described above, we could promptly derive the following curves with the set-up shown in Fig. 2:

- a) the efficiency versus delay curve $\eta(\theta)$, where θ is the time elapsed between the instants of particle traversal and application of the HV pulse;
- b) the curve giving the "re-ignition probability" $P(T)$, where T is the time elapsed between the instants of application of two subsequent HV pulses, the first of which caused the luminous discharge (flash).

From the former curve one derives the flash-cell sensitive time t_s , through Eq. (1). From the latter curve one can derive the flash cell recovery time through the condition^{7a)} $P(T \geq t_r) \leq 0.1$.

For all plastic materials on which tests have been made, the probability of "spurious flashes" (i.e. flashes occurring on the application of HV pulses uncorrelated in time with particle traversals) was found to be negligibly small.

The sample flash-cells (SC) were tested by placing them between two metal plates (M and M' in Fig. 2) between which the sensitizing HV pulse was applied. The generator G of this HV pulse was triggered at the occurrence of time-coincident pulses of two thin-wall counters A and B. (The coincidences AB -- mostly due to the β -rays from the ^{106}Ru source -- had to occur, however, out of the "paralysing time" defined below.) An alternate signal (AS) could also be supplied to the "hot electrode" M', in order to produce an alternate clearing electric field over the region occupied by the sample. As it is known^{19,23,24)}, and well understood²⁴⁾ from the study of the glass neon flash-tube, both characteristic flash-tube times t_s and t_r (Section 2.4), are affected by the application of an alternate electric clearing field, but not of a d.c. clearing field⁷⁾.

A "paralysing circuit" P, prevented the coincidence circuit C, from giving other output pulses after the first one, for a time t_p that could be varied within wide limits; so that the rate of applied HV pulses could be changed from several per second to less than one per minute. Nevertheless, contrary to the case of the neon flash-tubes²⁵⁾, in the case of flash-cells made of plastic material the efficiency (measured, for instance, at $t \approx t_s$) does not appear to depend at all on the rate of flashes.

The "repetitor" circuit R, transformed each single input pulse into two output pulses separated in time by a distance t , that could be changed from about 1 msec to about 1 sec. The flash-cell recovery time t_r , was determined by requiring that the re-ignition probability was smaller than 10% for $t > t_r$. Such a probability was determined by comparing the numbers recorded by two scalars: one counting the number of flashes produced by the particles from the radioactive source; the other counting the number of pulses directly on the electric probe, i.e. the sum of flashes and re-ignitions.

The luminous discharges occurring in the sample could also be observed directly with the naked eye.

3.2 Main results

Tests have been carried out, by the method outlined above, on a number of sample "sensitive cells" made of different plastic materials: polyvinyl, polyethylene, nylon, plexiglass, polypropylene ("moplen"). Very recently, tests have also been made on a small flash-chamber of lexan²⁶⁾ in view of the possibility to install flash-chambers of such a material inside liquid hydrogen bubble chambers^{10,17)}. The results of these last tests are still preliminary and will not be discussed here, even though they indicate sensitive times in the microsecond region at room temperature and at reasonable speeds of the flowing noble gas mixture (30/70 Ne/He). On the other hand, the behaviour of lexan sample flash-cells under the most interesting conditions, i.e. at the temperature of liquid hydrogen, needs still be investigated.

The study of samples made of the other above-mentioned materials was carried out bearing in mind especially applications with large flash-chambers operated in the normal mode (Section 2.1). Under this mode of operation and in the case of large-scale installations, the chamber sensitive time t_s has to be at least 1 μ sec. Even though for the reasons explained in Section 2.3 one can increase t_s by increasing the speed of gas flow, it is clearly preferable -- for these applications -- to select plastic materials with small content of electronegative impurities²⁷⁾, so as to keep that speed at reasonably small values. Hence, only samples of these selected materials exhibiting comparatively large values of t_s at low speed of gas flow have been extensively studied. For all samples, however, we derived experimentally the efficiency versus delay curve $\eta(\theta)$, from which the sensitive time t_s is obtained [see Eq. (1)].

In Fig. 3 we give two examples of curves $\eta(\theta)$, for two plastic materials. The advantage of using "moplen" (polypropylene) rather than PVC (polyvinyl), at least for applications under the normal mode, is apparent (much lower rate of gas flow required to achieve sensitive times in the microsecond region).

The main characteristics of the various sample cells, as derived from our tests, are summarized in Table 1.

For materials -- such as teflon -- which exhibit large sensitive times even at very small speeds of gas flow, it may be convenient to control the value of t_s by an alternate clearing field; a method which has already been adopted to shorten the sensitive time of ordinary neon flash-tubes^{7,19)}. The effect of an alternate (square wave) clearing field on the sensitive time of a sample cell made of teflon is illustrated in Fig. 4.

Speed of gas flow and alternate clearing field affecting t_s , in general, also affect t_r , the flash-cell recovery time. This can be illustrated on the example of flash cells made of teflon, for which we found that application of an alternate clearing field of 50 Hz frequency, 50 V/cm amplitude, reduces t_r from 150 msec to about 70 msec.

Inspection of the data reported in Table 1 shows that amongst the plastic materials subjected to our investigation, teflon and moplen are those most suited for use in large flash-chambers operated under the normal mode. In selecting the type of material for such a use, preference will be given to moplen, which is produced commercially at very low cost in extruded plates with honeycomb-structures of convenient sizes, is a low-Z material and can easily be machined.

The efficiency versus delay curve $\eta(\theta)$ for sample cells of moplen is typically as shown in Fig. 5b. The curve is derived from measurements with low speed gas-flow and no alternate clearing field. The corresponding recovery time is found

to be approximately 80 msec. In the same curve we show the dependence of the sensitive time on the intensity of the sensitizing electric field (curve a) and the dependence of the sample detection efficiency upon the rate of gas flow (curve c).

In no case of investigated plastic cell behaviour did we observe the "long-lasting effects"^{7a)} noticed²⁵⁾ with glass neon flash-tubes.

4. HONEYCOMB-STRUCTURED FLASH CHAMBERS

Honeycomb-structured plastic chambers can usually be realized promptly by assembling a certain number of units, or moduli, each of which is made of a given number of extruded plates. It is convenient to choose an even number of plates so that the "hot electrodes" remain inside the chamber moduli, well protected.

Figure 7 illustrates the case of a modulus consisting of four plates of extruded "moplen". This is the commercial name of a type of polypropylene, available on the market at a very low price, commonly employed for packing. The characteristics of this material from the viewpoint of the flash chamber operation have been shown to be particularly good by the results of the measurements reported in the previous section.

The mechanical structure, as is shown in the "exploded view" in Fig. 7b, takes into account the requirement of having the gas flowing in parallel through the modulus cells, so that the efficiency measured at a given flowing rate, is essentially constant over the chamber area. As is shown from the exploded view, the four plates assembled in a modulus are contained in a thin-wall plexiglass box. Thin aluminium foils or conductive varnish can be applied to the two large-area sides of each extruded moplen plate in order to have sensitizing electrodes with a minimum amount of low-Z material on the particle path.

The main characteristics of this type of chamber can be summarized as follows:

- a) space resolution in the mm region;
- b) lack of dead space;
- c) "modularity" and adaptability to many different geometries;
- d) high-efficiency in recording multi-track events;
- e) small amount of low-Z material on particle path;
- f) time resolution (sensitive time t_s) in the microsecond region;
- g) recovery time, for $t_s = 1 \mu\text{sec}$, of about 80 msec with no clearing field;
- h) wide choice of read-out systems;
- i) ruggedness and easiness in constructing large chambers for huge detectors at a very low cost.

5. CONCLUSIONS

The technique described in this article can have a variety of applications^{8,9)} in different fields of research. In particular, the feasibility of constructing huge flash-chambers at a comparatively small cost, opens up new possibilities in cosmic-ray research and in some areas of high-energy particle physics. We shall not try to give here a full account of the many possible applications, but merely present a few illustrative examples.

As a first example of application to the field of high-energy particle physics we show in Fig. 7 a sequence of honeycomb-structured flash-chambers alternated with thick absorbers (of iron in the figure, as an example), which represents the sketch of an ideal muon identifier, provided the events to be recorded occur with a frequency not in excess of a few per second, under instantaneous background rates compatible with the chamber sensitive time. This time cannot be much shorter than 1 μ sec if the chambers are operated under the "triggered" or "normal mode", but could be indeed much shorter if they were operated under the "synchronized mode" (Section 2.1). It is worth while pointing out that the same detector sketched in Fig. 7 can also be "interpreted" as a "hadron calorimeter" capable of measuring with some accuracy the energy of a high-energy hadron, as we shall show in the following article.

Sensitive chamber cells of flexible plastic material can be adapted to complicated geometries, to cover, when required, large solid angles. Examples of similar applications in experiments with colliding beams have been considered elsewhere⁸⁾.

Further applications in high-energy particle physics might result from the attempts now in progress¹⁰⁾ to successfully operate flash-chambers of lexan in liquid hydrogen. Flash-chambers operated in the synchronized mode, installed inside, on the walls of a large bubble chamber, would allow one to accurately determine the instant of traversal of each outgoing particle. The time correlation with any external particle identifier would allow then to remove ambiguities in the particle identification, thus greatly improving the performance of the over-all system.

Shower detectors containing a few alternate layers of plastic flash-chambers and inert plates could also be installed inside a bubble chamber to identify high-energy photons resulting from the investigated process¹⁷⁾.

Thin-wall flash-chambers might also be applied, of course, in nuclear physics, for example in ionization measurements based on a method already suggested for and applied to experiments utilizing ordinary glass neon flash-tubes²⁸⁾. Suppose, for instance, that a large number N , of small thin-wall flash cells is traversed by a charged particle of primary ionization j , and let p be the average probability that one cell is discharged as a consequence of the ionization released in it by

the incoming particle. Since p is a function of j , one can obtain this latter quantity by measuring the number n of flashed cells which occurs with a probability $P(n) = \binom{N}{n} p^n (1 - p)^{N-n}$.

In all above-mentioned applications it is assumed that the chambers are operated at rates of no more than a few per second, under background conditions compatible with their sensitive time. Read-outs by optical or electrical systems are optional, but preference should perhaps be given to the former when the number of cells becomes so large as to make the wiring for the electrical read-out unpractical.

REFERENCES AND FOOTNOTES

- 1) L. Federici, thesis, University of Rome (1974) (unpublished).
- 2) M. Conversi and A. Gozzini, *Nuovo Cimento* 2, 189 (1955).
M. Conversi, S. Focardi, C. Franzinetti, A. Gozzini and G.P. Murtas, *Suppl. Nuovo Cimento* 4, 234 (1956).
G. Barsanti et al., *Proc. CERN Symposium on High-Energy Accelerators and Pion Physics*, Geneva, 1956 (CERN, Geneva, 1956), Vol. 2, p. 55.
- 3) Harrie S.W. Massey, *in* *The new age in physics* (Elek Books, London, 1966), p. 178. See also, for example: G.K. O'Neill, *Sci. Am.* 207, 37 (1962).
D.G. Davis, *Endeavour* 22, 19 (1963).
- 4) The denomination "electrically-pulsed chambers" was adopted at the 1973 Internat. Conf. on Instrumentation for High-Energy Physics (Frascati, 1973; see Session 2 of the Proc. of this Conf.) to designate the new family of particle detectors originated by the 1955 hodoscope chamber.
- 5) T.E. Cranshaw and J.F. De Beer, *Nuovo Cimento* 5, 1107 (1957).
- 6) S. Fukui and S. Miyamoto, *Nuovo Cimento* 11, 113 (1959).
- 7) We refer the reader to the following review articles which appeared a few years ago, both on the technique and on its main applications to physics:
a) M. Conversi and G. Brosco, *Ann. Rev. Nuclear Sci.* 23, 75 (1973).
b) J.M. Breare, *The neon flash-tube technique in Cosmic rays at ground level* (1973).
c) M. Conversi, *Rivista del Nuovo Cimento* 3, 233 (1973); *Proc. of the Internat. Conf. on Instrumentation for High-Energy Physics* (Frascati, 1973), p. 126.
- 8) M. Conversi, *Nature (Phys. Sciences)* 241, 160 (1973).
- 9) M. Conversi, L. Federici and Q. Taccetti, *Proc. of the Internat. Conf. on Instrumentation for High-Energy Physics* (Frascati, 1973), p. 184.
- 10) I. Mannelli and E. Rosso, CERN report EF/ER/mk (17.2.1977). Similar results have been obtained also by D. Miller (private communication).
- 11) One of us (M.C.) wishes to thank Dr. R. Verkert for stimulating discussions on this point.
- 12) M. Conversi, *Rev. Sci. Instrum.* 45, 1411 (1974).
- 13) G. Brosco, thesis, University of Rome (1972) (unpublished). See also Reference 7c.
- 14) M. Conversi, L. Federici, G. Gentile and M. Nardi, CERN EP Internal Report 76-20 (1976).
- 15) Following article in this issue.
- 16) See, for instance: J.K. Walker et al., *Proposal for a new neutrino detector at Fermilab* (1977).
L.N. Hand et al., *A proposal to search for short-lived particles produced by antineutrinos and neutrinos* (Fermilab Proposal N 553, 1977).
- 17) D. Zanello, private communication.

- 18a) The propagation of the discharge all over the region (i.e. usually all over the volume of the flash-tube) occurs via photo-ionization processes due to photons emitted from the electron avalanches (see, for example, Section 3 of Reference 7a).
- b) G. Brosco and Q. Taccetti, Internal Note No. 553, Istituto di Fisica dell'Università di Roma (1974).
- 19) C. Bemporad, M. Calvetti, F. Costantini, C. Guidi and P. Lariccia, Proc. of the Internat. Conf. on Instrumentation for High-Energy Physics (Frascati, 1973), p. 193.
J.M. Breare, J.E. Chaney and W. El Disouki, *idem.*, p. 215.
See also Reference 7c.
- 20) J.E. Chaney, J.M. Breare, Nuclear Instrum. Methods 124, 61 (1975).
- 21) M. Nardi, O. Ciaffoni, L. Federici and A. Pecchi, LNF Internal Report (in preparation) (Frascati, 1977).
- 22) M. Bertino, M. Conversi and Q. Taccetti, Internal Note No. 552, Istituto di Fisica, Università di Roma (1974) (unpublished).
- 23) G. Brosco, M. Conversi and M. Giovannini, Nuclear Instrum. Methods 111, 477 (1973).
- 24) J.E. Chaney, W. El Disouki and J.M. Breare, Nuovo Cimento Letters 6, 339 (1973).
- 25) H.F. Crouch, Case Western Univ. Internal Report UCI-10-P 19-20 (unpublished).
H. Ferguson and B.C. Rastin, Nuclear Instrum. Methods 96, 405 (1971).
F. Ashton, J.M. Breare, F.W. Holroyd, K. Tsuji and A.W. Wolfendale, Nuovo Cimento Letters 2, 707 (1971).
- 26) The suggestion of studying the performance of lexan flash-chambers was made by Dr. P. Reinhard, in connection with the possible application mentioned in the text. We wish to thank Dr. Rosso for his essential contribution in the realization of the sample lexan chamber utilized in our latest tests.
- 27) The electronegative impurities affecting the flash-tube sensitive times do not depend only on the kind of polymer of the plastic material, but also on the specific treatment to which the latter was submitted.
- 28) F. Ashton, R.B. Coats, J. King and A.W. Wolfendale, J. Phys. A 4, 895 (1971).

Table 1

Main characteristics of flash-cells of various plastic materials containing a 30/70 Ne/He noble gas mixture at atmospheric pressure flowing at the rate required to just reach maximum (plateau) efficiency. HV pulses creating the peak field E_0 and lasting for a time approximately τ were applied to the samples. (No clearing field applied.) All samples were cylinders of approximately 1 cm inner diameter, except the moplen samples for which (a) was a cylinder of 2.4 cm diameter and (b) a rectangular tube of 0.35 cm $\times$ 0.5 cm cross-section. The density d , and resistivity ρ of the materials are also reported.

Material	t_s (μ sec)	t_r (msec)	E_0 (kV/cm)	τ (μ sec)	d (g/cm ³)	ρ ($\Omega \cdot$ cm)
PVC (polyvinyl)	0.13	100	10	5	1.39	
Polyethylene	0.6		10	5	0.92	
Flexiglass	0.35	50	10	2	1.18	10^{15}
Nylon	0.3	50	10	2	1.13	4.5×10^{13}
Teflon	6.5	100	10	2	2.2	10^{19}
Moplen (a)	11.5	300	6.3	2		
(b)	2.5	80	10.5	0.15	0.9	1.2×10^{16}

Figure captions

- Fig. 1 : Sketch of electric read-out probe set at one end of a plastic cell of a flash-chamber. Large output signals that need no amplification are obtained when the cell flashes, for $R_0 \geq 50 \Omega$.
- Fig. 2 : Set-up used to investigate performance of sample cells (SC) of different plastic materials, traversed by the β -rays of a radioactive source of ^{106}Ru .
- Fig. 3 : Two examples of efficiency versus time-delay curves.
a) Extruded plate of PVC with tubular cells ~ 40 cm long, of $2.5 \text{ cm} \times 3 \text{ cm}$ rectangular section, in which a 30/70 Ne/He mixture flows at a speed of $\sim 1 \text{ l/min}$ ^{18b)}.
b) Moplen cylindrical tube of 1.2 cm radius filled with the same Ne/He mixture ¹⁾, with no gas circulation since ~ 40 hours.
- Fig. 4 : Effect of an alternate (square wave) clearing field of 50 Hz frequency, on a sample flash-tube of teflon 40 cm long, of 1 cm inner diameter. The sample contained a 30/70 Ne/He gas mixture at 1200 g/cm^2 pressure flowing at a rate of 0.5 l/hr and was sensitized by HV pulses of 10 kV peak value decaying with a $2 \mu\text{sec}$ time constant.
- Fig. 5 : Performance of a sample of honeycomb-structured extruded plate of moplen filled with a 30/70 Ne/He mixture.
a) Dependence of sensitive time (t_s in μsec) upon peak value (E_0 in kV/cm) of the electric field created by the sensitizing HV pulse.
b) Efficiency versus delay-time curve, for two values of E_0 : upper curve $E_0 = 12 \text{ kV/cm}$; lower curve $E_0 = 10.5 \text{ kV/cm}$.
c) Efficiency versus rate of gas flow.
- Fig. 6 : Four-layer modulus of a honeycomb-structured plastic chamber.
a) View of modulus assembled.
b) Exploded view, showing detail of modulus structure.
- Fig. 7 : Sketch of a detector made of alternate layers of flash-chambers and inert metal plates. The inset shows the honeycomb structure in detail. Such a detector can be considered as a piece of a "muon identifier", or of a "hadron calorimeter", or even of an "electromagnetic shower detector" if the inert plates are thin layers of high-Z material (e.g. 0.5 cm thick Pb plates, see next article in this issue).

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

 

144-1
15
16