A SOLID ARGON IONIZATION CHAMBER *)

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Geneva - 19 October 1976

(Submitted to Nuclear Instruments and Methods)

*) Work performed at CERN.

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THE JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION
PUBLISHED WEEKLY
CHICAGO, ILL., MAY 1, 1935

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Liquid argon ionization chambers [1] are becoming accepted as charged-particle detectors, especially for hadron and photon calorimeters. Ionization pulses have also been observed in solid argon by previous workers [2]. The present work has been motivated by the need for a "fast" electronic detector which can work at about 30°K, to provide a link between neutrino-induced events observed in a large bubble chamber and the pulses produced by the same events in an external device (e.g. the EMI, or External Muon Identifier, for the BEBC bubble chamber [3]).

This note reports a test of solid argon as a detector of minimum-ionizing particles. Larger scale studies will be needed before any internal hodoscope can be designed to be mounted in a bubble chamber.

1. APPARATUS

A parallel-plate ionization chamber (see Figs. 1 and 2) was immersed in liquid argon in a stainless-steel dewar. The liquid was cooled by passing a stream of liquid nitrogen through a copper loop around the bottom of the cell. One plate of the cell (plate 2, Fig. 1) was extended sideways to touch fins on the cooling loop, in order to ensure good thermal contact. The plates were connected by vacuum lead-throughs to external electronics and HT supplies. The lead from plate 2 was grounded externally. A β source (15 μ Ci of ^{106}Ru), shielded by an aluminium cylinder, was mounted behind plate 1 with a 1.5 mm hole through the aluminium and copper to allow a collimated beam of electrons with energies up to 3.6 MeV to enter the cell. Plate 3 has an α source (2 μ Ci of ^{241}Am) electroplated onto a 7 mm diameter spot at its centre. Plate 4 was added to provide a measurable capacitance of ~ 6 pF with plate 3, in order to monitor the formation of the solid argon. Only five lead-throughs were available so the connection to plate 4 also served as one of the leads to the 100 k Ω resistor which was used as a thermometer. In order to reduce convection, a plexiglas "beaker" was fitted around the cell, with the cooling loop running around the inside of the bottom of the beaker.

The argon used for all the experiments was standard cylinder-gas with estimated impurities of less than 5 p.p.m. No special care was taken to purify the gas. The equipment was pumped down to $\sim 10^{-2}$ Torr for several hours before each filling.

2. ELECTRONICS

Figure 1 includes a schematic diagram of the circuit used. Plates 1 and 3 were connected to high-voltage supplies and, via 1000 pF isolating capacitors, to high sensitivity FET charge-amplifiers [1]. The signals from these preamplifiers were processed by shaping amplifiers for display or for counting. A separate input

to each preamplifier allowed a pulse of known amplitude to be fed in through a 1.6 pF capacitor to provide a charge calibration. After careful earthing and screening of all the components, it was possible to reduce the noise transmitted by the preamplifiers to the equivalent of less than 800 (r.m.s.) electrons per pulse. Pulse heights were measured directly on an oscilloscope.

The resistance thermometer was read to four figures with a FLUKE digital meter, and the capacitance-gap was measured to ~ 0.002 pF in 14 pF (including ~ 8 pF for leads) with a Wayne-Kerr automatic bridge.

3. PROCEDURE

Liquid argon was condensed in the dewar at an overpressure of about 0.5 atmospheres, using a manometer to monitor the argon gas pressure and to switch a solenoid valve controlling the liquid nitrogen flow through the cooling coil. When the cell and its beaker were completely covered, the dewar was pressurized with helium to 1.2 atmospheres and the liquid nitrogen was allowed to run slowly but continuously through the cooling loop. With approximately one litre of liquid argon in the dewar, it took 15 minutes for the temperature to drop from the condensing point to the freezing point, according to the resistance thermometer. The interface between liquid and solid could not be seen by looking through the window at the top of the dewar, though argon "ice" could be seen on the cooling tubes just above the liquid surface. At all times the material in the cell and in the surrounding beaker was perfectly clear, transparent and colourless, but when the beaker was pulled out rapidly from the dewar at the end of a session of observations it was possible to see the solid without a liquid covering, and to probe it with a screwdriver.

Three cool-downs were carried out with plate 3 at a negative high voltage and with the α particle pulses from liquid argon displayed on an oscilloscope. After about 90 minutes of cooling the pulses became smaller and disappeared within about two minutes. This was interpreted as the freezing of the argon in the conduction-gap between plates 2 and 3, followed by positive-ion poisoning of the solid near to the intense α source (see below). Two cool-downs were carried out with the bridge connected to the capacitance-gap. The capacitance increased slightly during the 15 minutes of temperature drop from boiling to freezing. It then remained steady for about three hours before rising smoothly to a new steady value, as the gap filled with the denser solid ($\rho_{\text{liquid}} = 1.41$, $\rho_{\text{solid}} = 1.62$ at melting point = 83.2°K [4]). The conduction gaps (plates 1 and 2, 2 and 3) froze more quickly than the capacitance gap because plate 2 was in direct contact with the fins on the cooling loop. The ionization effects reported below were observed during a number of runs and over periods of up to 24 hours after the conduction-gaps were known to be frozen.

4. IONIZATION OBSERVATIONS

4.1 α -particle pulses

The α source gave about 26,000 pulses per second, as measured in liquid argon. The pulses from the liquid were of uniform size. They formed a distinct band on the oscilloscope and the counting rate had a clear plateau as the high voltage was varied at a fixed discriminator level. The pulse height with -2000 V on plate 3 corresponded to about 1.8×10^4 electrons per pulse at the input of the preamplifier. No pulses due to the α source were seen with plate 3 positive; this was expected, since the induced charge in such an ionization chamber is proportional to the fraction of the applied potential difference through which the electrons move. With positive HT on the plane carrying the α source the electrons have only a few microns to travel, so they cannot give a pulse.

In solid argon very similar pulses were observed but they decayed away to zero over a period of about a minute. If the voltage on the conduction-gap was switched off, the gap recovered slowly, and the α signal reappeared when the negative voltage was switched on again. If a positive potential was applied to plate 3 the recovery was more rapid and lasted longer (see Fig. 3). The size of the reverse potential, if above +500 V, had little effect on the recovery, but the duration of the reversed potential was important, the α pulses surviving longer the longer the reverse potential had previously been applied. In no case did the α pulses last much more than a minute, before decaying away into the noise.

This phenomenon may be interpreted as a recombination effect due to the very high flux of α particles, stopping within about 50 μm , which produces a high density of positive ions in the solid close to the source. (In the liquid, where the pulse does not die away with time, recombination effects already reduce the pulse height from the expected value of 2×10^5 electrons to the observed value which is proportional to the applied voltage).

4.2 β -particle pulses

Pulses due to the β source were observed in both conduction gaps, with both positive and negative high voltages and with both liquid and solid argon in the cell. The gap formed by plates 1 and 2 gave about 10^3 β pulses per second, above a discriminator threshold set to exclude all noise pulses. Coincidences were found between β signals from the two conduction gaps, and a clear, broad peak was seen in a coincidence delay curve (Fig. 4). The β pulses in both gaps had a very wide range of pulse heights and the coincidence resolution time was about 200 nsec. About 25 coincidences per second were observed with 1500 V across both gaps, and with the discriminator thresholds set to the equivalent of $\sim 2 \times 10^3$ electrons per pulse.

The β pulses in solid argon lasted many hours without ever decaying away, and it was clear that the ionization from the β source was not sufficiently localized to cause poisoning. One curious feature of the β pulses was a hysteresis behaviour as the high voltage was raised and lowered. This was especially marked in the coincidence count rate when the voltage on plate 1 was varied (Fig. 5a). As the potential was increased from 0 to 800 V the coincidence rate increased rapidly. It then stayed at a plateau value until 2000 V, which was about the maximum that could be applied without breakdown on the leads. Then as the voltage was reduced the count rate decreased rapidly, so that at 800 V it was less than one fifth of what it had been at the same voltage as the voltage was increased. If the voltage was taken up to 800 V and left constant, the count rate dropped to about half its initial value over a period of about 10 minutes and then stabilized. If the voltage was brought down to 800 V from above and then left, the count rate rose over a period of about 10 minutes to the same stable value (Fig. 5b). At 1600 V, similar effects were observed, but the stabilized count rate was much closer to the plateau rate obtained on increasing voltage.

A detailed explanation of these effects will not be attempted here, but it should be noted that coincidences occur when electrons go straight across the first gap (plates 1 and 2) and stop in the second gap (plates 2 and 3). These electrons can be expected to give relatively small pulses (of $\leq 8 \times 10^3$ electrons) in the first gap, owing to their low ionization and short path. A reduction in the sensitivity of the gap will cause the pulses from these electrons to drop below threshold much more rapidly than those from electrons which stop, depositing their energy in the first gap, and do not give coincidences. It is therefore significant that the "hysteresis" effect is much more marked for the coincidence rate than it is for the singles rate in the first gap.

4.3 Pulse heights and rise-times

Measurements were made with simple equipment, shaping amplifier, and oscilloscope, so precise pulse height distributions and electron velocities cannot be given. The important features of the pulses were nevertheless quite clear and definite.

The α -particle pulse height, as mentioned above, decayed away over a period of about a minute. But its initial value, after "clearing" at reversed polarity, came very close to that observed in the liquid at the same voltage. In fact, as the clearing time was increased the initial pulse height came closer and closer to the value in liquid argon mentioned above (e.g. 1.8×10^4 electrons at 2.0 kV).

The pulse heights for β particles had a much broader spectrum than for α particles owing to fluctuations and to the wide variation of path lengths in the solid argon. No difference in this distribution was noticed between the solid and the liquid, and the maximum pulses were about the same size as the α -particle pulses.

The rise-time of β -particle pulses in the first gap was about 400 nsec (from 10% to 90%, as read from the oscilloscope). Both α particles and β particles in the second gap gave a rise-time of about 300 nsec, and the α -particle rise-time did not vary significantly, though the pulse height changed, as the voltage was switched from 500 to 1000 (i.e. 500 V/mm) and to 1500 V. These rise-times may have been lengthened by the electronics, of course, but it is clear that the electron velocity in solid argon is less than or of the order of 1 mm per 150 nsec. Previous workers have observed a saturation velocity of 1 mm per 70 nsec in solid argon and 1 mm per 200 nsec in liquid, at about 10^3 V/mm [5]. Our results are compatible with these velocities.

CONCLUSIONS

If argon is frozen slowly from below [4], it forms a clear solid. This had been used in an ionization chamber. Intense local irradiation due to an α source causes poisoning and loss of signal, but minimum ionizing particles from a β source can be observed for long periods with a stable pulse height. In any future application of these counters, the very rapid rise-time of the pulse should make it possible to use much thicker cells (e.g. two 6 mm gaps, one on either side of the HT plane) to give a larger charge pulse. This will be needed to compensate for the larger capacitance which would be associated with an ionization chamber of a practical size. The rise-time will still be less than 1 μ sec with such a cell thickness.

ACKNOWLEDGEMENTS

The advice and help of the following individuals was essential to the completion of these tests; W. Struczinski, W. Willis, H. Leutz, J. Tischhauser, G. Geydet, K. Ratz, G. Dubois-Dauphin, M. Firth and D. Rahm.

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Figure captions

- Fig. 1 : Cross-section through the centre of the double-gap ionization chamber and schematic diagram of the electronic connections.
- Fig. 2 : Photograph of the ionization chamber removed from its plexiglas beaker and stainless-steel dewar. One of the aluminium fins, attached to plate 2, which made thermal contact with the copper cooling loop is to be seen.
- Fig. 3 : The decay of the counting rate of α -particle signals above a fixed discriminator threshold. Each set of data was taken after a different length of clearing time with a reversed electric field.
- Fig. 4 : Coincidence delay curve taken for β -particle signals. These data were taken after leaving both gaps at a fixed HV of 1500 V for more than 30 minutes. The repeat point at -100 nsec was taken at the end of the sequence.
- Fig. 5a : β -particle coincidence rate as a function of the applied HV and the sense of the change of HV. The detailed shape of the curve changes according to the elapsed time between points.
- Fig. 5b : The stabilization of the β -particle coincidence rate as a function of the time at a fixed HV (800 V). Note that 800 V was approached from above more rapidly than for the data of Fig. 5a.

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