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MULTITON GASEOUS DETECTORS

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ABSTRACT

Large volumes of compressed air or any cheap gas used as multiton detectors are being envisaged. The collection of slow positive or negative ions would permit the detection of minimum ionizing particles without any gas amplification, at sufficiently high pressures. Some preliminary measurements of charges liberated in air by α particles show that a good energy resolution can be expected with such gases.

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1. INTRODUCTION

Several physical problems of great interest require heavy detectors, with stringent requirements as regards particle resolution, decay pattern recognition capability, and energy resolution. The two main fields where such detectors are needed are neutrino physics and baryon stability studies.

In a recent approach to this problem, a Moscow group¹⁾ has demonstrated the possibility of a high-pressure argon drift detector where 100 tons of sensitive gaseous volume could be envisaged. Two imperative requirements have to be met for such a detector to work:

- an extremely high purity of argon, to permit the drift of electrons over paths of the order of several metres, at a pressure of several hundred bar, without being captured;
- a complex gas composition, including a small fraction of xenon which appears necessary to permit electron amplification around the wires. The cost of even 1% xenon addition is such that it would appear unrealistic to extrapolate such a detector to sizes 100 times larger, as is required for baryon stability studies which triggered our investigation. We decided to limit this investigation to the possibility of the cheapest gas, namely air, as a detector.

The fact that the electrons are immediately captured means that we have to deal with slow ions and obtain from them all the information we need: position, pattern, energy loss. Since amplification is excluded in any convenient way, we have to investigate the conditions under which the operation in the ionization chamber mode would give us this information.

2. PULSES IN AN AIR CHAMBER

To restrict ourselves to inexpensive electronics we considered that a noise of 10^3 electrons (r.m.s.) could easily be obtained with a simple amplifier. And, indeed, good results were obtained with an amplifier with the following characteristics:

- Noise: 2×10^{-16} C (r.m.s.).
- Sensitivity: 20 V/pC.
- Rise-time: 50 μ s. Decay time: 2.5 ms.
- Cost of components: SF 40.

We fixed as our goal the necessity to detect minimum ionizing particles. The energy loss in air is 1.8 MeV/(g/cm²); this means, at 20 °C, with a pressure of 300 bar, an energy loss of about 0.65 MeV per cm, i.e. about 26,000 ion pairs, far above noise.

The scheme of the detector is given in Fig. 1. The positive ions and the negative ions migrate in opposite directions. They are detected on strips or pads (after traversal of a Frisch grid). The time difference in the induced pulses gives the vertical position; the pulses induced on the strips or pads give the lateral position and the energy loss distribution. In order to find if the available electronics is suitable for the collection of the ions liberated in compressed air by a minimum ionizing particle, we simulated almost the same energy loss, in an air chamber at atmospheric pressure with α particles whose energy loss is close to 1 MeV/cm.

A series of measurements were undertaken in air, with 5.5 MeV α 's from ^{241}Am , with the amplifier quoted above. The main obstacle for the detection of ionization pulses appeared to be the production of microphonic noise. This was finally suppressed by suspending the chamber schematized in Fig. 2 from the ceiling, with elastic strings. It then appeared simple to collect the ions, positive or negative, and to obtain a good energy resolution.

An encouraging fact is that for energy losses of the order of several hundred MeV, as generated in proton decay modes, one can expect an energy resolution strictly limited by the systematic errors and dream reasonably of 1%, since there are no sources of ion losses other than columnar recombination -- all the electrons having been captured at the track itself -- and no amplification fluctuations.

3. GASEOUS CALORIMETERS

Table 1 gives some properties of the cheapest gas, air, and of another gas which has interesting properties, namely freon 13 B1, which in a liquid form was one of the filling fluids of Gargamelle.

Unfortunately the radiation length in air is large, 1.1 m at 300 atm at room temperature and 0.5 m at -133°C . Only large tanks of at least 25 m diameter can be envisaged for the confinement of isotropic showers. The situation is more attractive for physics problems where the showers are in the direction of a beam, since a few metres of lateral dimensions are acceptable and a tube of great length permits a target with a high mass of air.

Freon is clearly more advantageous for electromagnetic showers. Under the manageable conditions of 28 bar at 50°C , the density is 269 kg/m^3 and the radiation length 60 cm. For some problems in neutrino physics, such as electron scattering, it may be attractive.

4. DRIFT VELOCITIES OF IONS

The mobility of ions varies with their mass M_i and the mass M_g of the gaseous molecules in which they drift. The mobility is roughly proportional to $(1 + M_i/M_g)^{1/2}$.

Table 1

Some properties of air and freon

AIR		
Radiation length 36 g/cm ² , dE/dx = 1.82 MeV/(g/cm ²)		
Pressure (bar)	Density at 17 °C (kg/m ³)	Density at -133 °C (kg/m ³)
100	121.9	573
200	234.7	668
300	326.8	718
CF ₃ Br FREON 13 B1		
Radiation length 16.5 g/cm ² , dE/dx = 1.52 MeV/(g/cm ²)		
Molar mass 148.9		
Critical point 67 °C, 39.8 bar, density 744.8 kg/m ³		
Pressure (in equilibrium with liquid) (bar)	Temperature (°C)	Density (kg/m ³)
12.66	15	102
28.28	50	269

Figure 3 shows the mobility of various ions in nitrogen. We see that a reasonable value for the mobility of ions produced in air is about 3 (cm/s)/(V/cm), while the mobility of freon would be 2 (cm/s)/(V/cm).

High voltages will have to be applied to drift the ions over large distances. Neglecting the technological problems for the time being, let us assume that we can apply 5 kV/cm over the drifting distance. This leads to velocities of 1.5×10^4 cm/s for the air and 0.5×10^4 cm/s for the freon in freon at 1 atm. For 1 m of drift at 300 atm we thus have occupation times of the order of 2 s. The maximum rates that can be tolerated are determined by the granularity of the charge collecting system. This granularity is determined by the noise of the amplifier which controls the minimum length of detector required to detect a minimum ionizing particle, if the sensitivity has to be at this level.

The distance between the shielding grid and the collecting electrodes has to be small compared with the size of the collecting strips or pads.

5. ENERGY RESOLUTION

The test performed with an air gap of 6 cm, where the maximum energy deposited by the α particles of ^{241}Am was 5 MeV, is very encouraging. Figure 4 shows that the pulses are far above noise. With a total energy loss of 1 GeV, averaged

over a large number of collecting pads, say 1000, we may expect an improvement of $\sqrt{1000}$ on the energy resolution and aim reasonably at 1%, which would be an enormous asset in a search for rare events.

The problems are however formidable for a detector of 10^4 tons. We could imagine a tube lying on the ground deep in the ocean to give shielding and pressure equilibrium. We would then have a detector with the size of a submarine and maybe a comparable cost to pay for the large quantity of charge-collecting channels with a continuous monitoring of the charge arrival at the anode and cathode.

Owing to the great interest of the physics problems which could be studied with such a detector, we thought it worth presenting these rather unrealistic ideas to the community for comments, suggestions, and criticisms.

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REFERENCE

- 1) V.K. Chernyatin et al., A pressurized gas detector for high energy neutrinos, Proceedings of the Second IFCA Workshop, Les Diablerets, Switzerland, 4-10 October 1979 (Ed. U. Amaldi) (CERN, Geneva, 1980), p. 320.

Fig. 1 Schematics of a slow-ion three-dimensional chamber. The filling gas is air or any electronegative gas. The collection of the ions of opposite polarities gives the coordinate along the field lines without requiring a zero time trigger. The charges collected in pads or strips give the orthogonal coordinates and the total energy loss.

Fig. 2 Test ionization chamber. The 5.5 MeV α particles from ^{241}Am are stopped in air at atmospheric pressure and the charges collected and amplified.

Fig. 3 Mobility in nitrogen of various ions as a function of mass at 1 atm pressure.
 [From J.H. Mitchell and K.E.W. Ridler, Proc. Royal Soc. (London) A146, 911 (1934).]

Fig. 4 Pulses from α particles in air. Horizontal scale: 0.5 ms/div. Vertical scale: 50 mV/div. Amplifier sensitivity: 20 V/pC. The α 's of an ^{241}Am source stop in the air in the chamber. The charges are collected by a field of 500 V/cm over a drift length of 6 cm. The noise is only a few per cent of the signal.