FURTHER OBSERVATION OF IONIZATION ELECTRONS
DRIFTING IN LIQUID ARGON

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Measurements using a ^{137}Cs internal conversion source demonstrate that ionization electrons will drift at least 35 cm in liquid argon in electric fields of a few kV-cm^{-1}.

I. Introduction

Liquid argon ionization detector technology is advancing at a rapid pace following the recent efforts of Willis[1] and others.[2,3] The initial design of such detectors made use of inert inserts within the liquid argon, both as electrodes and as converters for electromagnetic and/or hadronic cascades. It was recognized early that these inserts degrade the energy resolution of such calorimeters. The first liquid argon shower counters were made with many thin converter sheets in order to minimize this effect. Eventually, the suggestion was made that inert converters should not be used at low energies to achieve optimal energy resolution, and wire planes were introduced as electrodes.[4] Such detectors have totally sensitive volumes and, if sufficient spacial resolution could be achieved, these detectors would have unique capabilities and could be favorably compared with bubble chambers.

This was recognized, and such a detector was proposed to Fermilab for a four Fermion leptonic scattering experiment.[5] However, it was clear that spacial resolution of a few millimeters with closely spaced wire planes led to technical as well as financial difficulties. Thus, the idea of drifting ionization electrons over large distances in liquid argon and collecting the induced charge as a function of time[6] was introduced and actively discussed.

The capability to drift electrons over large distances in liquid argon is basic to the feasibility of this idea. Information from detectors which collected ionization electrons over distances of a few millimeters, was encouraging.[7] It is well known that electronegative impurities, especially oxygen, must be at very low levels. Typically, oxygen levels of a few parts per million in argon[8] can be tolerated in the shower counters. However, as yet undetermined impurities can seriously affect the performance of such detectors.[9] Thus, there is significant uncertainty as to whether ionization electrons will drift over distances of tens of centimeters even if oxygen is reduced to the appropriate levels, since such distances are at least an order of magnitude greater than had been attempted.

II. Detector Details

A detector, schematically shown in Fig. 1, was designed to focus on the question of free ionization electron drift distance, λ_D,[8] in liquid argon. The materials used in the construction of this detector were glass, ceramics and stainless steel to insure cleanliness. Bellows were used to allow for rapid adjustment of the drift distance which is constrained to be less than about 75 mm. This is approximately an order of magnitude greater than had been attempted

before. Argon gas purification/handling and cryogenic systems are shown in Fig. 2. Argon gas is purified by the sequence: (a) Hydrox purifier;[10] (b) molecular sieve, 13X,[11] at 293° K; (c) molecular sieve, 4A,[11] at 196° K. Oxygen impurity is measured with a trace oxygen analyzer[12] which has a rated sensitivity to O_2 concentration at the level of 0.1 ppm.

The liquid argon detector is kept cold by immersing it in a bath of liquid nitrogen. The nitrogen is pressurized to 30-40 psig in order not to freeze argon.
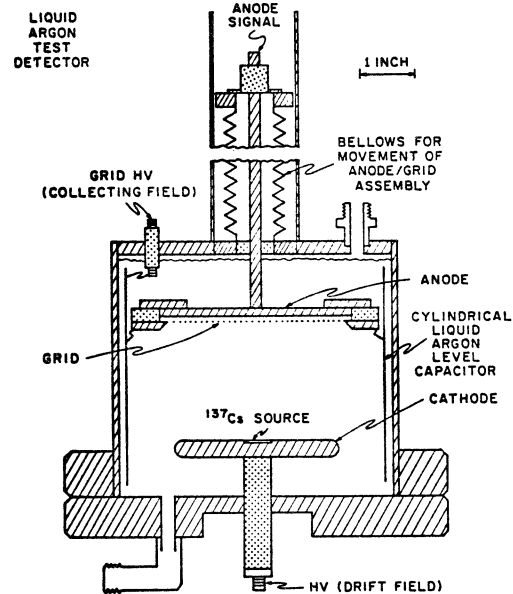

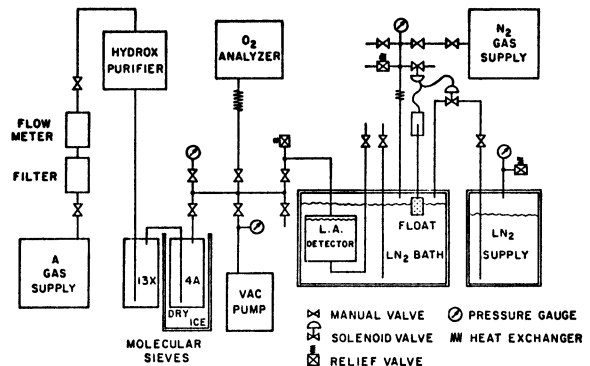Figure 1. Schematic of detector for measuring ionization electron drift distance in liquid argon.

Figure 2. Schematic of argon gas purification/handling and cryogenics systems. The liquid nitrogen bath is pressurized to 30-40 psig in order not to freeze argon.

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The sequence for purifying and liquifying argon is as follows:

(1) degas molecular sieves by baking in a 20μm vacuum for several hours, also degas detector simultaneously,

(2) flush out detector by a sequence of 3 to 5 pump and fill cycles,

(3) condense purified argon gas inside detector by filling the liquid nitrogen bath.

Oxygen concentration in the purified argon gas is typcially below the 0.1 ppm rated sensitivity of the oxygen monitor. However, an occasional gas leak within the system does degrade the purity of the argon, thereby giving a measurable oxygen concentration.

An initial study without the grid was carried out with an alpha source in the liquid argon. This indicated that ionization electrons could drift over the 75 mm distance without significant attenuation.[13] However, due to the relatively high ionization density of alphas in the liquid argon and its concomitant recombination effects, these observations provided encouragement rather than quantitative results.

The present study with the grid[14] is carried out using a 0.2 μCi ^{137}Cs internal conversion source (624 KeV monoenergetic electrons). The number of ion pairs produced in liquid argon per unit energy loss has been measured to be around 25 eV per ion pair.[15] Using this value for the 624 keV internal conversion electron, we expect a charge of 4.0 fC of each sign to be liberated within about 2 mm (the range of the 624 keV electron in liquid argon) of the cathode. The ionization electrons drift to the anode through the grid under the influence of the applied electric field in the region between the cathode and the grid, $\vec{E}_{drift}$. Between the grid and the anode, these electrons drift in a collecting field, $\vec{E}_{collect}$. The total collected charge at the anode, therefore, depends upon:

(1) the total liberated charge

(2) recombination with Ar^+ ions[16]

(3) capture by residual electronegative impurities in drifting through liquid argon.

(4) transmission through the grid.[17]

The total liberated charge, item (1), is fixed by using the 624 keV internal conversion source. Recombination with Ar^+ ions, item (2), is a weak function of $\vec{E}_{drift}$.[16] Transmission through the grid, item (4), depends on the ratio of $\vec{E}_{collect}$ to $\vec{E}_{drift}$.[17] If $\vec{E}_{drift}$ and $\vec{E}_{collect}$ are held constant, then items (2) and (4) do not affect the total collected charge. Therefore, only residual electronegative impurities, item (3), can affect the total collected charge as a function of drift distance.

III. Data Collection and Analysis

A typical pulse height spectrum observed at the anode of the liquid argon detector with the ^{137}Cs source is shown in Fig. 3. The 624 keV internal conversion peak stands out well above the lower energy beta and Compton electron continuum. Including the uncertainties associated with the charge measurement, the total collected charge in the peak is about 3.6 fC, which is a little lower than the 4.0 fC

liberated in the liquid argon. The collected charge increases with higher drift field, therefore, recombination is occurring. This can be separately studied, but the absolute position of this peak, as discussed above, is not important to the measurement of electron drift distance.
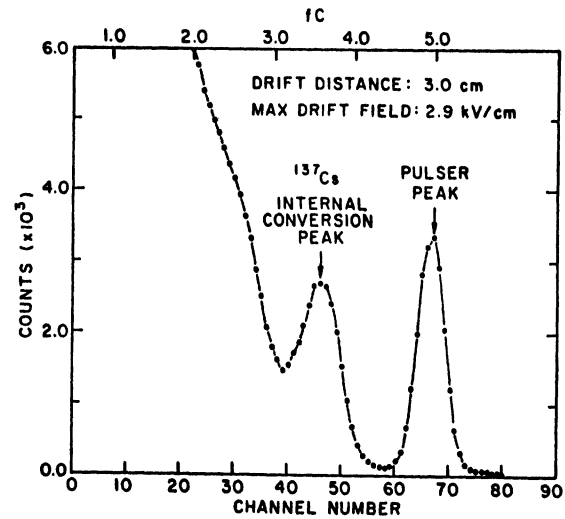

Figure 3. A typical pulse height spectrum of the ^{137}Cs source as observed in the liquid argon detector.

Additional confirmation that this peak is due to internal conversion comes from a comparison of the absolute rate of events in the peak. This is possible since the source intensity is known, i.e., about 0.2 μCi, 93.5% beta branching ratio, and K/γ ratio of 9.3%. A calibration pulser producing signals, 3 ms apart, at 5.0 fC gives a calibration peak with a similar rate and spectral width. The pulser peak is also shown in Fig. 3. These observations are independent of the drift distance. From the calibration peak, the noise level in the electronics[18] is estimated to be 0.4 fC (FWHM).

The present data comes from a pure argon sample with less than 0.1 ppm oxygen, the rated sensitivity of the trace oxygen analyzer, and consists of ^{137}Cs spectra which were collected at six cathode/grid distances (0.78, 1.73, 3.00, 4.27, 5.54 and 6.81 cm) with cathode voltages ranging to -19 kV.

Analysis of this data to extract λ_D is complicated by inhomogeneity of the drift field which is cause by the finite cathode size. There are two effects. The first effect is a possible anode electron collection loss due to electric field lines terminating outside the grid area. This effect arises due to the finite source size, and increases as the cathode/grid distance increases. Its overall consequence is expected to be small. By ignoring corrections for this effect, our analysis will be conservative, and will provide a lower limit to λ_D. The second effect arises from growth of the electric field near the source (cathode) above the average field as the cathode/grid distance increases. The higher local field decreases Ar^+, e^- recombination, thereby increasing the collected charge.[19] By using the (higher) local field as the drift field, $\vec{E}_{drift}^{max}$, our analysis will again be conservative.[20]

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Figure 4 shows the internal conversion peak position as a function of $\vec{E}_{drift}^{max}$. There is a noticeable decrease of the collected charge with an increase in drift distance at fixed $\vec{E}_{drift}^{max}$. This data indicates that λ_D is greater than 35 (50) cm with $\vec{E}_{drift}^{max}$ at 2 (4) kV-cm^{-1}.
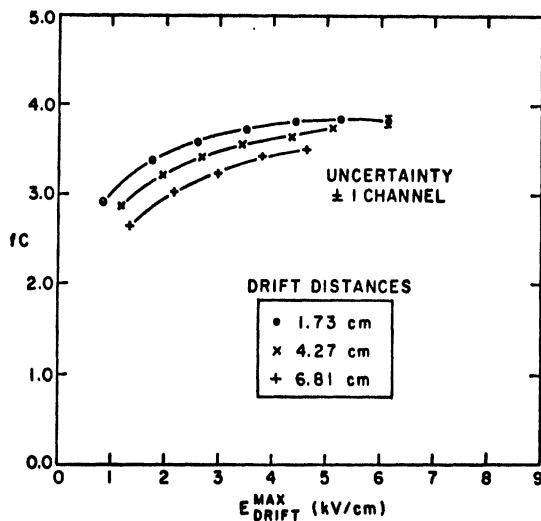

Figure 4. The ^{137}Cs internal conversion peak position versus $\vec{E}_{drift}^{max}$. (See text for a discussion). The collecting field used is 10.6 kV-cm^{-1}. Data from several drift distances are shown. The decrease in the collected charge with distance at fixed $\vec{E}_{drift}^{max}$ indicates that λ_D, the electron drift distance, in at least 35 (50) cm with $\vec{E}_{drift}^{max}$ at 2 (4) kV-cm^{-1}.

IV. Additional Observations and Plans

We have started to address questions relating to materials, i.e. whether the materials used in liquid argon shower counters, e.g. G10, Teflon, etc., can be used in a liquid argon drift detector. Such materials may introduce electronegative impurities, and stop the drifting of ionization electrons over tens of centimeters. Both G10 and Teflon have been inserted in our test detector, and these were observed to have a significant effect in decreasing λ_D. Also, we have observed a large decrease in λ_D after the occurrence of severe high voltage breakdown inside the test detector (across a Teflon insulator, we believe).

Present plans for the test detector include additional studies of:

(1) materials

(2) Ar$^+$, e$^-$ recombination

(3) grid signals

(4) alternate purification methods

(5) O_2, N_2 contamination, etc.

A larger liquid argon test detector is under construction at Caltech.[21] It will be possible to attempt drifting electrons up to distances of about 50 cm. Plans for this detector include several of the above as well as measurements of:

(1) electron drift velocity

(2) multiple grid signals

(3) electron diffusion, etc.

The above information will be essential for the design, construction, and operation of a several ton prototype liquid argon drift detector presently planned at Fermilab. This prorotype will have an adequate volume to totally contain electromagnetic showers, and it will be used to address questions such as:

(1) energy resolution

(2) spacial resolution

(3) angular resolution

(4) gamma, electron and hadronic cascade identification, etc.

These studies will be carried out in a collaborative effort between UCI, Caltech and Fermilab.

V. Conclusion

The present measurements have demonstrated that ionization electrons will drift over a distance of at least 35 cm in liquid argon in an electric field of a few kV-cm^{-1}. It is now clear that, for high spacial resolution in liquid argon, the multitudes of closely spaced wire planes can be replaced by a few wire planes which read out charge as a function of drift time.

VI. Acknowledgements

We wish to acknowledge useful discussions about the possibilities of a detector based upon drifting electrons long distances in liquid argon with the following: R. R. Burns, P. E. Condon (UCI); B. C. Barish, F. J. Sciulli (Caltech); D. Hitlin (SLAC); S. E. Derenzo (LBL); and W. J. Willis (CERN). We also acknowledge assistance with the equipment from A. A. Hruschka.

[1] W. J. Willis and V. Radeka, Nucl. Instru. and Meth. 120 (1974) 221.

[2] J. Engler, B. Friend, W. Hofman, H. Keim, R. Nickson, W. Schmidt-Parzefall, A. Segar, M. Tyrrell, D. Wegener, T. Willard and K. Winter, Nucl. Instru. and Meth. 120 (1974) 157.

[3] S. E. Derenzo, A. R. Kirschbaum, P. H. Eberhard, R. R. Ross, and F. T. Solmitz, Nucl. Instr. and Meth. 122 (1974) 319.

[4] A. Eisner, G. Hanson, D. Hitlin, U. Koetz, M. Marshak, T. Mast, J. Matthews, C. Peck, and D. Young, 1975 PEP Summer Study p. 94, PEP-193.

[5] H. H. Chen, P. E. Condon, B. C. Barish and F. J. Sciulli, FNAL proposal P-496, 1976.

[6] Application of this idea in gas was introduced by G. Charpak, et al., Nucl. Instr. and Meth. 80, (1970) 13, and pursued by D. Nygren, 1974 PEP Summer Study p. 58, PEP-144; 1975 PEP Summer Study p. 126, PEP-198. Such a detector has been named the "Time Project Chamber" (TPC) by D. Nygren.

[7] D. W. Swan, Proc. Phys. Soc. $\underline{83}$ (1964) 659; W. Hofman, U. Klein, M. Schulz, J. Spengler and D. Wagener, Nucl. Instr. and Meth. $\underline{135}$ (1976) 151; J. H. Marshall, Rev. Sci. Instr. $\underline{25}$ (1954) 232.

[8] The electron drift distance λ_D, is the distance over which the total ionization electron charge decreases by a factor e^{-1}. λ_D is inversely proportional to electronegative impurity concentration, and is also a function of the applied electric field. See reference 7 for further details. These measurements indicated that λ_D is about 1 cm in liquid argon with 1 ppm oxygen and a 10 kV-cm^{-1} drift field.

[9] W. J. Willis (CERN) private communication; S. E. Derenzo (LBL) private communication.

[10] Matheson Gas Products, Hydrox purifier model 8301.

[11] Union Carbide Corp. Linde Molecular sieves 13X and 4A.

[12] Matheson Gas Products, Oxygen Monitor model 8440.

[13] H. H. Chen and J. F. Lathrop, reported at the Fermilab Neutrino Workshop, April, 1977.

[14] The grid consists of 25 μm stainless steel wires spaced 280 μm apart located 2 mm from the anode.

[15] M. Miyajima, T. Takahashi, S. Konno, T. Hamada, S. Kubota, E. Shibamura, and T. Koke, Phys. Rev. $\underline{A9}$ (1974) 1438; $\underline{A10}$ (1974) 1452, gives 23.6 ± 0.3 eV per ion pair for 1 MeV electrons. Earlier references are contained here.

[16] E. Shibamura, A. Hitachi, T. Doke, T. Takahashi, S. Kubota, and M. Miyajima, Nucl. Instr. and Meth. $\underline{131}$ (1975) 249.

[17] O. Bunemann, T. E. Cranshaw, and J. A. Harvey, Can. J. Res. $\underline{A27}$ (1949) 191.

[18] Standard commercial electronics is used. In particular we collected data with the following: Canberra Industries, Inc., Model 2001A preamplifier, and Model 2010 amplifier with 1 μs Gaussian pulse shaping.

[19] We thank M. Shaevitz (Caltech) for discussion on this point.

[20] We used electric fields calculated from a simple model, i.e. a right cylindrical can of radius R_1 with walls and one end at ground potential; the other end at a fixed potential to radius R_0, and ground potential between R_0 and R_1. We thank G. Brooks for carrying out these numerical calculations.

[21] F. J. Sciulli, M. Shaevitz (Caltech) private communication.