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**Liquid Ionization Chambers with Electron Extraction
and Multiplication in the Gaseous Phase***

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Liquid Ionization Chambers with Electron Extraction and Multiplication in the Gaseous Phase

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Abstract

Electrons have been transferred from liquid to gaseous argon with an estimated efficiency of 100%. Electron extraction has also been accomplished in liquid 2,2,4,4-TMP with parallel plate amplification in the gas of over 10^3 .

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1. Introduction

A growing interest has been expressed in the use of large volumes of liquid argon as the detecting medium of Time Projection Chambers[1]. The major applications are for proton decay experiments and neutrino physics.

Even though the energy loss for particle tracks in liquids is much larger than in gases, the absence of charge multiplication leads to the use of expensive low noise amplifiers. There is also a limitation on the spatial accuracy due to limitations on cell segmentation and the electronic noise of such a high capacitance system.

In order to improve the detection ability of liquids, two-phase systems have been studied, where electrons are extracted from liquid argon (LAr)[2] and liquid xenon (LXe)[3] into the gas phase above the liquid. Before these measurements, the possibility of extracting electrons from these materials was not obvious since their conduction band energy (V_0), which is the energy of the excess electrons measured with respect to the vacuum, is negative. Thus, a substantial fraction of an electron volt must be given to the electrons to free them from the liquid into the gas.

There has also been a study where excess electrons have been extracted from liquid n-hexane into the gas phase[4]. Unlike LAr and LXe, this hydrocarbon has a $V_0 > 0$. Thus, it is easy to see how excess electrons can escape the liquid. This result was later verified[5], and in addition, electrons were extracted from isooctane (2,2,4-TMP) with a $V_0 = -0.24$ eV[6].

In our study, we started with a verification that the extraction of excess electrons from LAr held no hidden difficulties. The true object of our work, however, was to explore the possibility of extracting excess electrons from one of the warm liquids that are currently of interest for liquid ionization chambers[7-9]. We have therefore studied the extraction of electrons from the room temperature liquid 2,2,4,4-TMP (henceforth referred to as TMP).

2. LAr Cell

For our test of the extraction of electrons from LAr, a glass dewar with a 7.5 cm inside diameter was used. A 1 cm-wide strip of the silvering was removed to allow viewing of the liquid level. The dewar was also fitted with a drain so that the level of the LAr could be adjusted.

The cell consisted of a parallel plate ionization chamber, 25 mm in diameter, and with a 4 mm gap. The gap was positioned horizontally so that it could be partially filled with liquid. The lower electrode had an ^{241}Am alpha-particle source plated on it.

3. TMP Cell

The glass cell used in our work with TMP is shown in Fig. 1. It consisted of a test cell with two electrodes, and a reservoir for the excess liquid. The test cell and the reservoir were connected by a thin glass tube to allow the level of the TMP in the test cell to be adjusted. The electrodes were 15 mm in diameter and separated by a gap of 4 mm, with the lower electrode coated with an ^{241}Am alpha-particle source.

After purification, the TMP was placed in the baked-out glass cell and the cell was sealed off. In the second of two fillings, 80 torr of argon was also added to the cell. This was to increase the gas pressure above the liquid to improve electron amplification. The electron lifetime in the TMP of this filling was measured to be 7 μs demonstrating that the material's purity was not degraded by the addition of the argon.

4. Experimental Results - LAr

The extraction from the LAr of the electrons liberated by the 5.5 MeV alpha particles from the ^{241}Am proved to be very simple. One advantage of LAr is the large amount of charge liberated. At a typical operating voltage for the experiment of 800 V/mm, there were about 2×10^4 electrons liberated[10]. This produces a signal easy to detect.

The ionization gap was first filled with LAr and a pulse height spectrum was taken. At a voltage of 3200 V (800 V/mm) a clean pulse-height spectrum was obtained with an energy resolution of about 25% FWHM. The LAr level was then lowered so that the liquid filled only half of the gap. At the same voltage the pulse height was reduced by 6%, but otherwise had the same shape and energy resolution.

The electric field in the liquid of the partially filled gap was about 643 V/mm. One would anticipate that the pulse height would be about 25% lower than for the liquid-filled gap because of increased recombination at the lower electric field in the liquid[10]. The higher than expected pulse height is attributed to a small amount of amplification in the argon gas above the liquid.

Since the contribution to the signal is proportional to the fraction of the gap across which the electrons drift[10], the pulse height would have been down by a factor of 2 had the electrons not exited the liquid. This, along with the symmetric shape of the pulse-height spectrum, leads us to conclude that all of the electrons escaped the LAr and were collected, even at this low electric field. This result is consistent with earlier work.

The big disadvantage of LAr is that it is very difficult to maintain a constant pressure above the liquid in our small test system. Although it is easy to get charge amplification in the gas, the changing pressure made it impossible to maintain a stable gain. This proved not to be the case with TMP.

5. Experimental Results - TMP

The major disadvantage of warm liquids for the study of a two-phase detector is the small amount of charge that is liberated. Since we worked with typical electric fields of only about 400 V/mm in the liquid, fewer than 10^3 electrons are liberated by the alpha particles[11]. Thus, the signal for the full-gap measurement was smaller than could be measured with our electronic system. We therefore were not able to study the shape of the alpha peak until the electrons were extracted and amplified in the gas.

Our first tests were made with the cell filled with only TMP and its vapor. Because of TMP's low vapor pressure (about 14 torr and 40 torr at 20°C and 40°C, respectively[12]) amplification commenced at relatively low voltages. At room temperature we estimate our maximum charge gain to be about 10^3 at a potential of 1400 V. We increased the temperature of the system in order to increase the vapor pressure of the TMP. At 40°C we achieved a gain of about 7×10^3 at a potential of 2300 V. Unfortunately we had some sparking problems which eventually destroyed the TMP in this filling.

We did estimate that 100% of the electrons escaped the liquid and were collected in the gas. The general results for this test are qualitatively the same as the data discussed below.

The addition of 80 torr of argon to the second cell filling increased the stability of the system and allowed for higher gain. As expected, as the temperature of the TMP was increased a higher amplification could be achieved, but at a higher voltage. Figure 2 shows a typical pulse-height spectrum. This spectrum was taken with a charge gain of about 60. From the near symmetry of the peak, we feel that 100% of the electrons liberated by the alpha particles were extracted from the liquid. If there had been an inefficiency in the extraction of the electrons from the liquid, one would expect a low-energy tail on the pulse height distribution. The relatively poor energy resolution we attribute to the fact that, in the small diameter cell used, there was a large meniscus. Since the gap was not uniform, the charge gain would also vary across the cell.

The shoulder on the left in Fig. 2 seems real and was present in all of our data, though we are not able to account for its origin. Its pulse height was about 22% of the mean pulse height for the alpha peak. This is about a factor of three higher than what would be expected for the gamma rays from ^{241}Am [13]. We placed an intense ^{241}Am source exterior to the cell and were able to verify that the signals from the gamma rays fell approximately where we expected on the pulse-height spectrum.

Figure 3 shows the charge collected per alpha particle as a function of voltage across the gap, for a variety of temperatures. Figure 3 also shows the amount of charge liberated in the TMP[11]. In all cases, at a charge of a few times 10^6 electrons per alpha particle, the shape of the alpha peak became distorted, consistent with full amplification for a small part

of the events and reduced amplification the majority of events. This we believe to be due to the buildup of positive ions in the liquid, since with a charge collection of $3.5 \times 10^6 e^-/\alpha$, and a source intensity of 5700/s, the positive ion density in the liquid would be on the order of $10^7/\text{mm}$. Thus, areas with the greatest source intensity would have lower amplification because of electric field distortions.

6. Discussion

Our results confirm that electrons can be conveniently extracted from LAr. In large Time Projection Chambers where the detection medium is LAr, one can envisage a proper mixture of argon and methane, allowing the amplification of electrons in a parallel grid structure with all the inherent advantages of large pulses and greater readout flexibility connected with pulses induced by gaseous amplification. Our results also show that it is as easy to extract electrons from a warm liquid like TMP, widely considered for calorimetry in high-energy physics, with an easy and sizeable amplification of the extracted electrons in a parallel plate structure.

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Figure Captions

Figure 1 Schematic of glass cell.

Figure 2 Typical alpha-particle pulse-height spectrum.

Figure 3 Charge collected per alpha particle as a function of voltage across the gap for a variety of temperatures. The amount of charge liberated in the TMP as a function of voltage is also shown.

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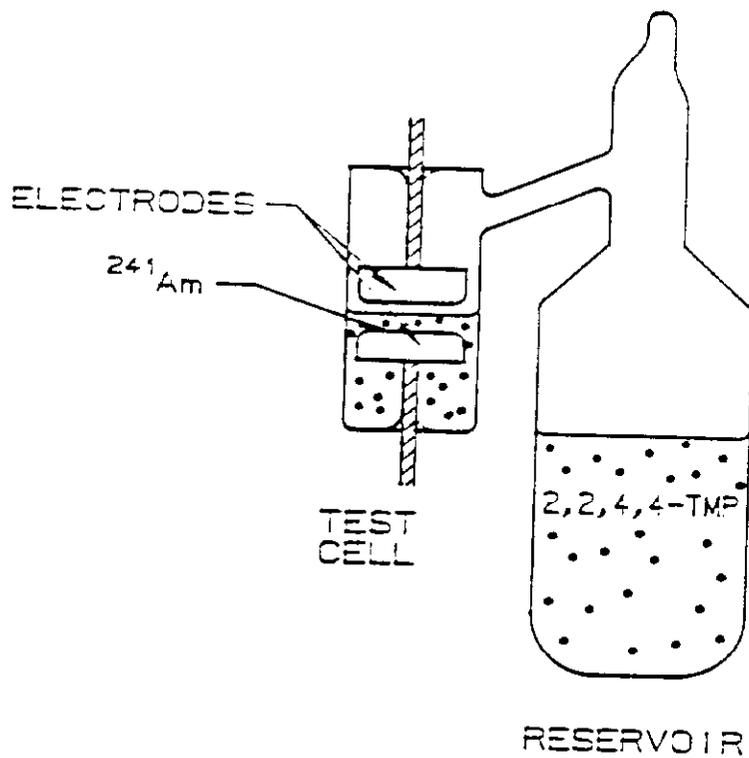


Figure 1 Schematic of glass cell.

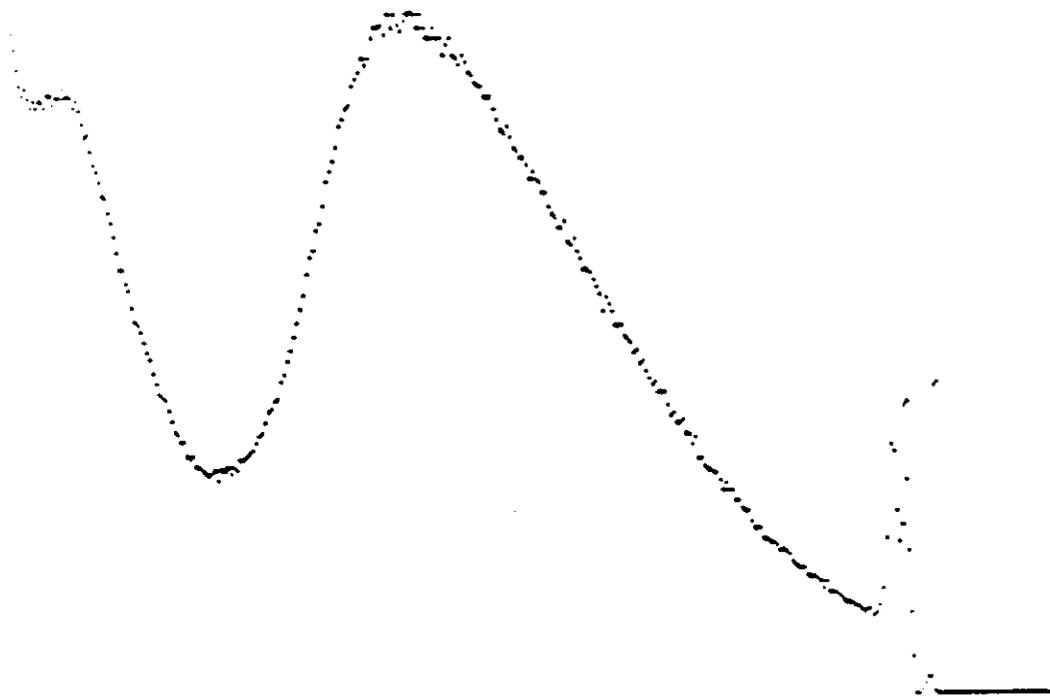


Figure 2 Typical alpha-particle pulse-height spectrum.

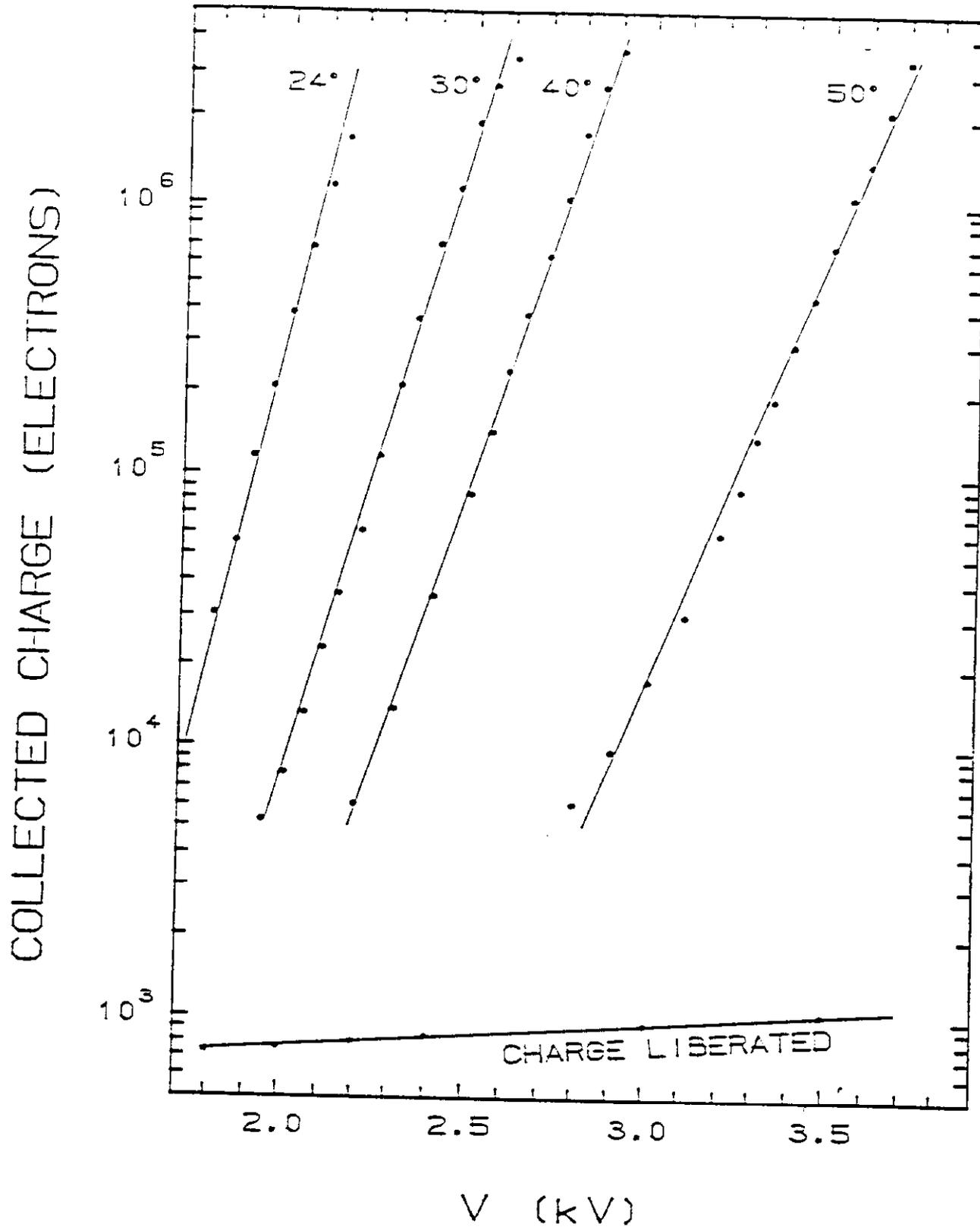


Figure 3 Charge collected per alpha particle as a function of voltage across the gap for a variety of temperatures. The amount of charge liberated in the TMP as a function of voltage is also shown.