

Studies of Electron Avalanche Behavior in Liquid Argon

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Abstract

Electron avalanching in liquid argon is being studied as a function of voltage, pressure, radiation intensity, and the concentrations of additives, especially xenon. The avalanches are produced in the intense electric field at the tip of a tungsten needle by ionization from a moveable gamma source. Photons from excited xenon atoms produce photomultiplier signals in coincidence with the current pulse from the needle. Although avalanches are observed in pure argon, the addition of even a small amount of xenon greatly stabilizes the performance. Similar attempts with (30%) neon have been unsuccessful. Typically the avalanche current (pulse height) spectrum is narrow and the width is relatively independent of voltage, pressure, and radiation intensity. Some conditions produce a second set of pulses that are larger, but very sensitive to pressure. We plan to test a practical wire chamber prototype, using microwires produced lithographically.

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The potential advantages of liquids over gases for particle detection have stimulated research on the noble liquids for several decades. The intrinsic spatial resolution in liquids is better, because the density of ions from charged particles is greater, and because the diffusion of drifting electrons is less. Avalanching in liquid xenon was observed at LBL thirty years ago by members of the Alvarez group [1], but experiments using more affordable liquid argon have been largely unsuccessful because the behavior of the detectors was unstable and pressure dependent. Although developments in microelectronics can insure better resolution with liquids, the signal-to-noise ratio and resolution will be improved if signals can first be amplified by electron avalanching.

The test apparatus includes a ~6 liter closed cryostat cooled by an open bath of mixed liquid argon and liquid nitrogen. The electric field is produced between a flat stainless steel wire mesh cathode, operated at 1kV to 3kV and a ground plane 6mm below. Protruding upward through a hole in the ground plane is an electrically isolated needle, also at dc ground. This conical tungsten anode is tapered from 0.25mm diameter to 0.5μm diameter near the rounded tip, which is spaced half way between the mesh and ground plane. With -1500V on the mesh, the field strength at the tip of the needle is estimated to be 6×10^6 V/cm. The detector is illuminated by 60keV gammas from a 0.1Ci Am²⁴¹ source that is moveable between 0.6cm and 15cm above the mostly transparent mesh. Also above the mesh is a UV transparent window of MgF₂, behind which is a photomultiplier [2] with a CsTe photocathode that records vacuum UV photons from the decay of excited xenon states. Using a similar geometry a CsI counter also was tested and showed good UV response.

DC currents from the mesh, needle, ground plane, and source holder are monitored and recorded using the LabView program [3]. Pulses are observed on an oscilloscope, and both avalanche rates and pulse heights are monitored and stored using an Oxford Instruments pulse height analyzer [4]. The signal from the needle is amplified first with an eV Products preamplifier [5], and then with an LBNL shaper amplifier (“TranLamp”), with 5μsec differentiation and integration time constants, yielding a total gain (preamp and TranLamp) of 11V/pC. Pulse heights between 0.2-3V have been observed, while the background noise level is approximately <20mV peak to peak.

We have explored the effects of xenon for eight concentrations in the range 10-50,000ppm (5%). Below are data from a run with ~100ppm. Figure 1 shows the rate and average height of avalanche pulses versus source position with -1600V on the mesh. As expected the rates are proportional to (distance)⁻². There are two sets of pulses, whose heights do not change significantly with distance; but, as shown in Fig. 2, the heights of the larger pulses are linearly dependent on pressure over the range 0-15psig, varied by adding He gas. The smaller pulses are independent of the He pressure. Assuming that the 60keV gammas release 2300 electrons in the liquid argon, the lower limit for the estimated avalanche gain for the smaller pulses in Fig. 1 is ~130, assuming no recombination.

For the data in Fig. 3 the source position is fixed at 3 inches and the He pressure at 5psig. The pulse height increases somewhat with voltage, but not with the exponential dependence seen in gas detectors. Fig. 4 shows a time spectrum (TDC), using the needle current pulse for ‘start’ and the PMT signal for ‘stop’. The decay curve is fit with a constant term and the sum of two exponentials. The time constant of the longer exponential ($\lambda_2 = 1.55^{+0.36}_{-0.55}$ μsec) is consistent with the 1.1μsec decay [6] of excited argon molecular states that subsequently transfer their energy to the xenon admixture. The sharper peak, whose slope is limited by the integration time of the electronics, is consistent with other observations of Ar-Xe mixtures [6]. With ~100nsec shaping times we have observed the fast component with a ~10nsec decay constant.

References

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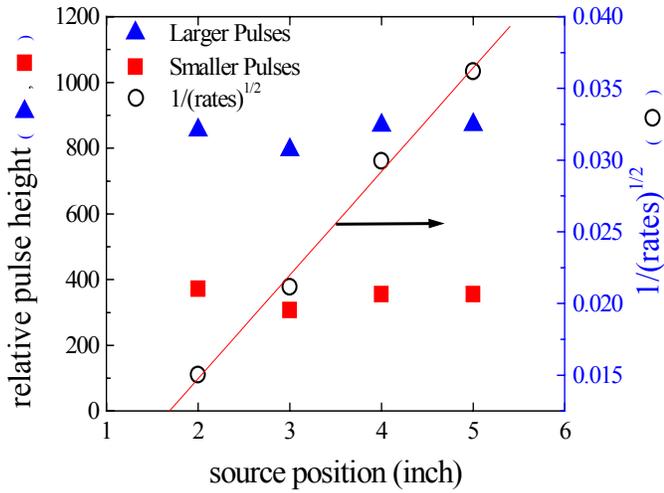


Fig. 1. Pulse height and $1/(\text{rate})^{1/2}$ versus source position. The rate is the sum of larger and smaller pulses (H.V. = 1600 V, Pressure = 5 psi).

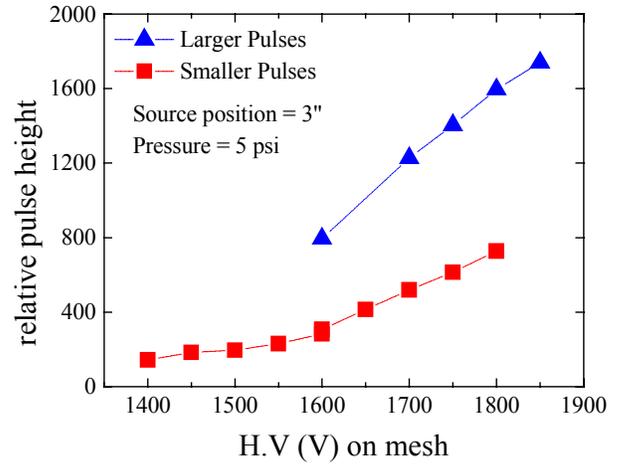


Fig. 2. Pulse height vs. H.V for larger and smaller pulses

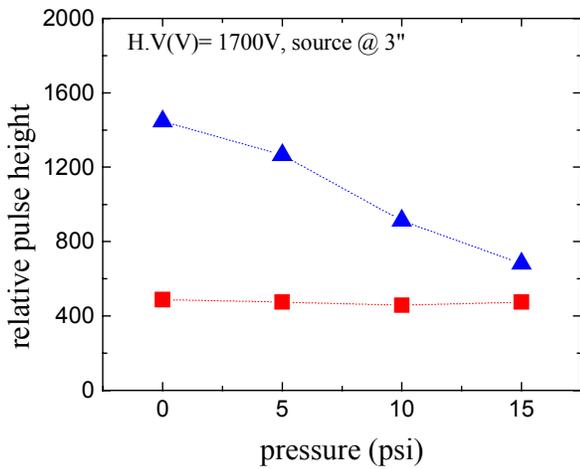


Fig. 3. Pulse height vs. pressure of He for larger and smaller pulses.

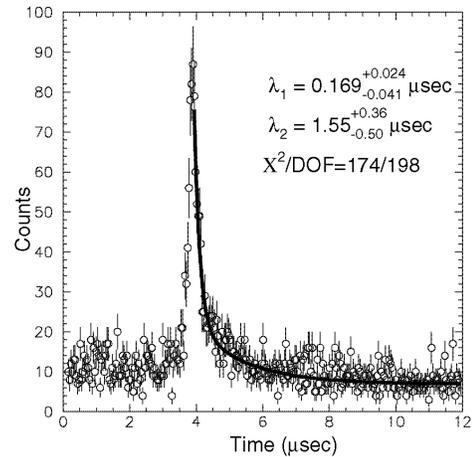


Fig 4. TDC distribution for coincidences between the needle and the PMT. The data is fit with a constant term and the sum of two exponentials, with decay constants as indicated. Fits with a constant term and a single exponential give a significantly worse fit; $\chi^2/\text{DOF} = 224/200$.