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ELECTRON LIFETIME DETECTOR FOR LIQUID ARGON

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ABSTRACT

A method has been developed for a fast and reproducible measurement of the electronegative contamination of liquid argon. The method is based on the transport of electrons extracted by a UV laser beam from a metallic photocathode. The transit time of the electrons from the emitting surface to a collecting plate depends on the applied electric field and ranges from a few tens of microseconds to milliseconds. The measurement of the purity is based on the ratio of collected to emitted charges. The operation can be performed in a few minutes and gives values of the electron lifetime with a typical error of a few percent. Filling and emptying the vessel can be done in less than an hour.

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1. INTRODUCTION

The possibility and interest of using liquid rare gases in detectors of ionizing radiation has grown in the last ten years. The study of processes like proton decay [1], solar neutrino [2], double beta decay [3], neutrino interaction [4], extraterrestrial low-energy gamma rays [5] and gamma detection in nuclear reactions requires the construction of detectors of large volume, completely sensitive, of high density and good energy and spatial resolution. The use of a Time Projection Chamber (TPC) is suitable for these requirements [6 - 10]. In order to operate such devices a large amount of experimental work has been carried out on different aspects of the technique, such as: liquid purification methods, electrons X-Y read-out, electron mobility, impurity monitoring, scintillation light and front-end electronics.

Here we present a rapid and simple way to monitor the electronegative impurity of cryogenic liquids. We have operated our detector with liquid argon.

The motivation for this development was born in the context of the *ICARUS* [11]. The goal of this project was to build a large volume (several kilotons) liquid argon TPC where rare events processes could be studied. The use of noble liquids (Argon, Xenon) allow a good electron transport because of their very low electronegativity. In these liquids the electron attenuation length can be very long, in the meter range, depending on the concentration of the impurities. Current ways of checking the purity of the liquids are based on the absorption mechanism of the electron and depend on the measurement of the ratio between the collected (Q) and the emitted (Q_0) charge over a given drift field.

This ratio measures the fraction of e^- lost via attachment:

$$Q = Q_0 e^{-t_d/\tau} \quad (1)$$

where t_d is the electron drift time and τ is the electron lifetime in the liquid.

Normally the electrons are produced by radioactive sources [12] or cosmic rays [13]. The disadvantages of these instruments are: a long measuring time for the determination of the electron lifetime (a few hours), a small amount of electrons hence poor resolution, the need for a careful calibration and stability of the read-out electronics, the fact that the number of free electrons generated in this way depends on the electric field.

In our monitoring device the electron generation from the cathode (Q_0) is obtained via photoelectric effect and the light source is provided by a UV laser beam sent onto the cathode through a quartz-fiber optical system.

The drift distance (d) could be limited to a few centimeters because the large number of electrons released in the liquid (in the picocoulomb region)

allows a precise measurement of the absorption in the liquid. At low values of the electric field the drift time of the electrons is of the order of milliseconds, comparable with the time of interest in highly purified liquids.

For the specific configuration of our chamber formula (1) takes the form:

$$Q = Q_0 \frac{t_c}{t_a} \frac{\left[1 - e^{-\frac{t_a}{\tau}}\right]}{\left[e^{-\frac{t_a}{\tau}} - 1\right]} e^{-\frac{t_d}{\tau}} \quad \text{or} \quad Q_0 e^{-\frac{\left(t_d + \frac{t_a + t_c}{2}\right)}{\tau}} \quad \text{if } t_a \text{ and } t_c < t_d \quad (2)$$

which takes into account the different transit times of the electrons over the distances anode-grid 1 (t_a) and grid 2-cathode (t_c).

The laser repetition rate being capable of reaching the Hertz region our device can determine the electron lifetime very quickly.

2. EXPERIMENTAL TECHNIQUE

2.1. The chamber

A cross section of the chamber is shown in fig. 1. The vessel has been designed to contain a small volume of liquid ($\sim 180 \text{ cm}^3$) so as to allow fast filling and emptying. The anode was a stainless steel disk 35 mm in diameter. The photocathode was an aluminium disk 20 mm in diameter whose surface had been previously treated in a solution of sulphuric acid. The two grids consisted of copper electro-formed meshes of 25 wires per inch, with 0.00128" wire dimension and 88% geometrical transparency. The distance between cathode and anode was 60 mm; the cathode-to-grid1 and grid2-to-anode distance was 5 mm. The grid1-grid2 region contained a series of four field-shaping stainless steel rings each 3 mm thick, separated by 7 mm and supported by *Macor* insulators [14]. Each ring was connected to the next by a 10 M Ω carbon resistor. The anode, cathode and two grids were electrically accessible from the outside via four cryogenic feed-throughs. The latter were needed in order to apply the suitable electric-field ratio between the three drifting regions. The field ratios were fixed at $E_{g1-g2} = 2E_{c-g1}$, $E_{g2-a} = 4E_{c-g1}$. In these conditions the transparency was almost 100% [13].

The chamber body was a stainless steel vessel 100 mm long with a flange (DN-63 *CONFLAT* [15]) on the upper part of which were also located the cryogenics feed-throughs and the pipe (14 mm diameter) for evacuating and filling the chamber. Before filling, the chamber was evacuated during 12

hours but not baked¹. A vacuum-leak test was done before liquefaction both at room temperature and after cooling to liquid argon temperature. The leak-rate test was performed with a sensitivity of 3×10^{-9} mbar l s⁻¹. A rough estimate of the outgassing rate gave values of 10^{-12} mbar l s⁻¹ cm⁻², as expected on the basis of the published values for stainless steel [16].

The procedure for cleaning the components of the chamber was the same standard operation performed at CERN [17] already described in detail in ref. [13].

The fiber-optics feed-through is shown in detail in fig. 2. It consisted of a bulk copper O-ring (DN16) specifically manufactured for this purpose, with the fiber soldered over the external side with a special silver-tin alloy. Before the soldering operation the plastic protective sheath of the fiber had been removed. The quartz fiber was made of pure fused-silica core-doped and fused-silica clad for operation at wavelengths down to 180 nm. The core-clad fiber diameter was ~ 1000 μ m and over one meter it had a numerical aperture of 0.22. In these condition the fiber was expected to transmit 90% of the input light for a wavelength of 226 nm [18].

2.2. The experimental set-up

A schematic diagram of the experimental set-up and read-out system is shown in fig.3.

A *ND-YAG* laser [19] was used as UV light source. The laser beam characteristics were: 266 nm wavelength, 30 Hz maximum repetition rate, 10 mJ maximum energy available at this wavelength with a light pulse width of 8 ns. The energy at the entrance of the fiber was held at the milliJoule level because at higher energies a degradation of the fiber was noticed over long periods of operation (months). In these conditions the light intensity was of the order of $3.5 \cdot 10^{15}$ photons per pulse; the electrons extracted were in the picoCoulomb range ($\approx 10^6$ electrons).

A summary of the parameters of the set-up is given in Table 1. The chamber was placed in an open dewar of liquid argon for easy refilling. The trigger of the laser pulse and the cathode and anode signals read-out was provided by a pulse generator with a rate of a few Hz.

The signals induced on the cathode and on the anode by the photoelectrons were fed into the charge amplifier through a 100 cm long commercial *RG-58* coaxial cable (100 pF per meter). The charge amplifiers were of the Q-A type used by the UA1 collaboration at CERN for the read-out of the TMP calorimeter [20]. They had an integration time of 300 μ s, a rise time of 10 ns, a dynamic range from a few fC up to 4pC and very low noise level. A test pulse was injected through a 1 pF capacitor to determine the

¹ The optical fiber feed-through would have melted.

calibration factor of the Q-A's. This calibration was used as off-line correction for the different responses of the two amplifiers for the same injected charge.

The output signals of the Q-A's were sent to two Camac Peak-Sensing ADC's (*LeCroy* mod. 2249a) which digitized the signals when a gate signal (5 μ s NIM width) was in coincidence with the cathode (or anode) signal. The gate signals were provided by two separate NIM timing units (*CAEN* mod. 2255) triggered by the pulse generator and set manually to match the appropriate start and arrival time of the electrons from the cathode to the anode. The signals, after the 11 bit ADC conversion, were collected and processed on a *Hewlett-Packard* computer (mod. HP-87) via a GPIB Camac module.

The typical induced signals from the cathode and the anode are shown in fig. 4 for two different argon gas sources. The data in fig. 4a refer to argon directly liquefied from a commercial "*argon-60*" bottle [21] with a guaranteed impurity content of ≤ 0.1 ppm of oxygen; the data in fig. 4b were obtained with the same "*argon-60*" bottle after filtering the gas through an *OXISORB* cartridge [22].

The time between the minimum of the cathode signal and the leading edge of the anode signal measures the electron drift time in the region between grids (5 cm).

3. RESULTS

The electron drift velocity in liquid argon was measured and compared with earlier results. Fig. 5 shows that our values are in very good agreement with those obtained with other techniques. Notice that, differently from the latter, our apparatus is able to scan over a much larger range of electric field.

In order to test the reliability of our detector, we have repeatedly liquefied the following gases:

- a) *argon 60* (impurity content ≤ 0.1 ppm of oxygen equivalent);
- b) *argon 60* filtered through an *OXISORB* cartridge (which is expected to lower the impurity content down to ≈ 10 ppb).

Results from two typical runs are given in figs. 6 to 8. The distributions in figs 6a and b demonstrate the stability of the measurement (charge ratio as a function of time). The spectra in figs 7a and b show the charge ratios. Those in figs 8a and b are those for the measured lifetimes as calculated via eq. (2). These measurements were repeated and found to give consistent results within the errors.

It can be seen that the electron lifetime is increased by a factor 10 when the gas is filtered through the *OXISORB* cartridge. This result is in agreement with the expected value of the impurity concentration (100 ppb for "*argon-60*" and 10 ppb for "*argon-60*" + *OXISORB*) because the electron lifetime is inversely proportional to the impurity concentration as expected from ref. [13]:

$$\tau (\mu\text{sec}) \sim \frac{300}{\rho [\text{ppb}]}$$

Further measurements are in progress and will be presented in a subsequent paper.

4. CONCLUSION

The method shows a high degree of reproducibility. We have observed charge generation and collection with the correct drift time. The purity measured via the charge ratios (Q/Q_0) for "*argon-60*" and "*argon-60*" filtered by *OXISORB* have been found to be in agreement with the expectation.

We are presently testing this device for different applications. In particular our instrument is in the process of being used for: (a) determining the purifier efficiency for different kinds of filters (*OXISORB*, *SORBAL*, "*gettering*" material, molecular sieves) and for different gases (Ar, Xe, CH₄, Ar+CH₄,...), (b) detecting the electron evaporation through the liquid-gas interface, (c) measuring the mobilities of liquids, (d) establishing the electron-phonon coupling and its cross section, (e) studying the electron attachment coefficient for different contaminating materials and with different electric fields.

The instrument needs improvements to make it suitable for a practical rugged use, in particular a better high-voltage decoupling to reduce the noise on the cathode charge-amplifier.

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FIGURE CAPTIONS

Fig. 1. - A cross-section through the chamber.

Fig. 2. - Fiber-optics feed-through (CF16).

Fig. 3. - Experimental set-up with electronics and read-out system.

Fig. 4. - Typical induced signals of the drifting electrons of the cathode and anode as seen on the oscilloscope.

a) *argon 60* ($V.B_{cat.}=200$ mV/cm, $V.B_{an.}=20$ mV/cm, $T.B.=10$ μ sec/cm, $EG1-G2=400$ V/cm);

(b) *argon 60 + OXISORB* ($V.B.=100$ mV/cm, $T.B.=10$ μ sec/cm, $EG1-G2=400$ V/cm).

Fig. 5. - The electron drift velocity v_d in cm/s as a function of the electric field E in V/cm (■ Swan, Proc. Phys. Soc. 83, 659 (1964), ○ Miller et al., Phys. Rev. 166, 871 (1968), ▲ W. Schmidt et al. Phys. Rev. 14A, 438 (1976), □ Halpern et al., Phys. Rev. 156, 351 (1967), Δ E. Buckley, submitted to NIM A.)

Fig. 6. - Charge ratio (Q_a/Q_c) as a function of time at $E=384$ V/cm for:

(a) *argon 60*,

(b) *argon 60 + OXISORB*.

Fig. 7. - Spectra of the charge ratio (Q_a/Q_c) (400 events) at $E=384$ V/cm for:

(a) *argon 60*,

(b) *argon 60 + OXISORB*.

Fig. 8. - Electron lifetime $\tau(\mu s)$ at $E=384$ V/cm (400 events) $t_d=38.2$ μ sec for:

(a) *argon 60*,

(b) *argon 60 + OXISORB*.

TABLE 1

PARAMETERS OF THE DETECTOR

Volume of the cell	180 cm ³
Anode to cathode distance	60 mm
Cathode to first grid distance	5 mm
Second grid to anode distance	5 mm
Maximum electric field	1000 V/cm
Angle between anode and fiber	11 deg
Quartz fiber diameter	1 mm
Fiber length	1.5 m
Laser wavelength	266 nm
Laser repetition rate (max)	30 Hz
Energy at the input of the fiber (average)	1.5 mJ
Laser pulse width (FWHM)	8 ns.

FIG. 1

FIG. 2

FIG. 3

Argon 60

Cathode

$$V_{\text{cat}} = 516,7 \text{ mV}$$

Anode

$$V_{\text{an}} = 17,5 \text{ mV}$$

FIG. 4 a

Argon 60 + OXISORB

Cathode

$$V_{\text{cat}} = 350 \text{ mV}$$

Anode

$$V_{\text{an}} = 233 \text{ mV}$$

FIG. 4 b

Fig. 5

FIG. 6 a

FIG. 6 b

FIG. 7 a

FIG. 7 b

FIG. 8 a

FIG. 8 b