Nuclear Instruments and Methods in Physics Research A 606 (2009) 569–577

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Measurements of W-value, mobility and gas gain in electronegative gaseous CS_2 and CS_2 gas mixtures

Kirill Pushkin *, Daniel Snowden-Ifft

Department of Physics, Occidental College, 1600 Campus Road, Los Angeles, CA 90041, USA

ARTICLE INFO

Article history:
Received 26 November 2008
Received in revised form
17 April 2009
Accepted 23 April 2009
Available online 8 May 2009

Keywords:
W-value measurements
Ionization yield
Mobility measurements
Gas gain measurements
Proportional counter
Negative ion time projection chamber
Carbon disulfide
Carbon tetrafluoride
CS_2
CS_2–CF_4
CS_2–Ar
CS_2–Ne
CS_2–He

ABSTRACT

W-value, mobility and gas gain measurements have been carried out in electronegative gaseous CS_2 and CS_2 with a broad range of gas mixture additives at a pressure of 40 Torr making use of a single-electron proportional counter method. The experimental results have revealed that W-values obtained for CS_2 (40 Torr), CS_2–CF_4 (30–10 Torr), CS_2–CF_4 (20–20 Torr), CS_2–CF_4 (10–30 Torr), CS_2–Ne (35–5 Torr) and CS_2–He (35–5 Torr) gas mixtures are 24.9 ± 0.8, 25.2 ± 0.6, 29.2 ± 1.0, 33.0 ± 1.0, 23.1 ± 0.8 and 23.7 ± 0.8 eV, respectively. The average mobility was measured in all CS_2 gas mixtures and was found to be slightly greater than in pure CS_2. The gas gain was found to be significantly greater in CS_2 gas mixtures relatively to pure CS_2.

1. Introduction

Time projection chambers (TPCs) have been widely used in the last few decades. Image transport in TPCs is typically implemented with electrons with high drift velocities, ~1000 m/s, and large diffusion [1,2]. In a negative ion time projection chamber (NITPC) that has recently been proposed and developed [3], electrons are captured by electronegative gases, forming negative ions whose diffusion is substantially reduced. Carbon disulfide has a positive electron affinity of 0.5–1 eV and rapid electron attachment was found in CS_2 gas. [4]. It has been shown [5] that diffusion of negative ions in pure, electronegative CS_2 reduces to thermal levels, providing high spatial resolution in the detector though with very slow transport of negative ions ~50 m/s. The low diffusion in a NITPC is crucial in, for example, the search for dark matter in galaxies [6] or the search for neutrinoless double beta decay, where precise reconstruction of the events (3D tracks) is needed [7].

Directional recoil identification from tracks (DRIFT) detector based on electronegative, low-pressure carbon disulfide gas (CS_2) was the first NITPC proposed and used to search for dark matter [3–6]. This detector consists of two back-to-back TPCs each with multi-wire proportional counter (MWPC) readout, providing three measurements of the range components of the tracks (Δx, Δy, Δz). When electrons are captured on electronegative CS_2 molecules, negative ions are drifted to the anode wires of the MWPCs, where the high electric field there strips off the attached electrons, which then produce Townsend avalanches. The W-value, the average energy lost by the incident particle per ion pair, negative ion mobility and gas gain play an important role in the DRIFT experiment. For instance, measurements of W-value provide a precise estimation of ionization yield from 5.9 keV X-rays emitted from the calibration source ^{55}Fe and allow DRIFT to calculate the ionization yield from nuclear recoils [8]. Mobility values allow the time profile of event signals to be converted into measurements of the component of the track perpendicular to the MWPCs. Gas gain measurements allow for a quantitative comparison of various gas mixtures with an eye towards improving the signal to electronic noise. The ability of the DRIFT detector to run with different gas mixtures, already demonstrated with Ar and Xe, is a tremendous

---

* Corresponding author. Tel.: +1 323 259 2569.
E-mail address: kpushkin@bama.ua.edu (K. Pushkin).

0168-9002/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2009.04.045

advantage [3,5]. Carbon tetrafluoride (CF_4) is a prominent "cool" molecular gas [9,10] and its W-value, measured for the first time by Reinking et al. [11], was found to be ~34.3 eV. Moreover, it has recently been shown [12] that CF_4 can be used for detecting dark matter weakly interactive massive particles (WIMPs) via spin-dependent interactions. Its scintillating properties along with some noble gases Ar, Ne and He are of interest for future research as regards providing a start signal for events in the fiducial volume of a NITPC. In this work we explore CS_2–CF_4 gas mixtures, meanwhile exploring the properties of CS_2 with the above-mentioned noble gases, allowing us to optimize spin-dependent sensitivity while conserving the properties of NITPC, i.e. increasing of CF_4 concentration in electronegative CS_2 gas will be favorable to a better sensitivity of WIMP spin-dependent interactions but may decrease the probability of electron's attachment to CS_2 molecules. In this work we report on measurements of W-value, mobility and gas gain in CS_2 (40 Torr), CS_2–CF_4 (30–10 Torr), CS_2–CF_4 (20–20 Torr), CS_2–CF_4 (10–30 Torr), CS_2–Ar (35–5 Torr), CS_2–Ne (35–5 Torr) and CS_2–He (35–5 Torr) gaseous mixtures.

2. Method

2.1. Detector

A proportional counter was constructed to measure the W-value, mobility and gas gain in pure CS_2 and CS_2 gas mixtures. The tube, made out of copper, was 58 cm long with a diameter of 2.54 cm and a slit of about 0.6 cm, which ran along most of the length of the tube and allowed radiation to pass into the proportional counter. The central anode wire was 100 μm in diameter gold coated tungsten. All measurements were made with −1300 to −1600 V applied to the copper tube in pure CS_2 and CS_2 gas mixtures, respectively, while the anode wire was at ground. The proportional counter was placed within a stainless-steel chamber with an interior volume of ~270 l and filled with CS_2 or CS_2 gas mixtures. All measurements were made at 40 Torr of pressure. The ^{55}Fe source was placed in a holder with an automatic shutter, allowing operation of the source inside the chamber during the measurements. All electrical cables were connected to the detector and the source holder through BNC feedthroughs mounted on the stainless-steel chamber.

2.2. Gas system

Gas mixtures were prepared by introducing gases one by one into the evacuated stainless-steel vacuum vessel with the proportional counter. The initial purity of CS_2 liquid was ≥99.9% and ≥99.999% for all gas admixtures (CF_4, Ar, Ne and He), respectively. CS_2 vapor was evolved from a liquid source. All experiments were done at a pressure of 40 Torr. The chamber pressure was measured with a capacitance manometer (MKS, Baratron) providing an accurate (0.1 Torr) determination of pressure. Measurements taken before and during the experiment imply that the impurity of the gas was ≤0.1 Torr out of 40 Torr in all cases.

3. W-value measurements

3.1. Introduction

The method of W-value measurements with proportional counters was developed by Srdoc and co-workers [13–16] and used to measure W-values both in noble and molecular gases. It relies on the measurements of the average pulse heights (PHs) produced by single electrons (SEs) and by low-energy X-rays under the same experimental conditions. In this method, the ionization yield, N_{ion}, is calculated as a ratio of a pulse-height parameter $X_{^{55}\mathrm{Fe}}$, which is proportional to the total charge deposited on an anode wire from 5.9 keV X-rays emitted from an ^{55}Fe source to a similar pulse-height parameter X_{SE} from SEs:

$$N_{\mathrm{ion}} = \frac{X_{^{55}\mathrm{Fe}}}{X_{\mathrm{SE}}} \frac{G_{\mathrm{SE}}}{G_{^{55}\mathrm{Fe}}} \tag{1}$$

where G_{SE} and $G_{^{55}\mathrm{Fe}}$ are the electronic gains used in measuring X-rays from the ^{55}Fe source and SE events.

Having obtained N_{ion} the W-value can be found using

$$W = \frac{E_{^{55}\mathrm{Fe}}}{N_{\mathrm{ion}}} \tag{2}$$

3.2. Measurements of 5.9 keV X-rays from an ^{55}Fe source

A schematic of the experimental set-up and electronics for the measurements of 5.9 keV X-rays from the ^{55}Fe source is shown in Fig. 1. All data were taken using standard NIM electronics for trigger logic and event collection. As seen from the schematic, the anode charge was collected with a charge-sensitive preamplifier (Amptek-250) with a time constant of 300 μs. All signals were then sent to a linear shaping amplifier (Ortec-855) with a shaping time constant of 3 μs and gain of 5. The ionization signals were processed through a discriminator (Phillips 710) at different thresholds of ~25 and ~40 mV. Triggers were formed from the ionization signals using Quad Gate/Delay generator and then recorded to a data acquisition computer (DAQ). The rate of X-ray interactions in the proportional counter during the measurements was of the order of ~100–150 Hz to avoid pile-up of the events. The background data were taken and subtracted from the ^{55}Fe events. The charge-sensitive preamplifier was calibrated with a pulse generator and its thermal drift was less than 1%.

3.3. Measurements of single-electron events

The experimental set-up for the measurements of SE events is shown in Fig. 2. A xenon flashlamp (EG&G Optoelectronics, LS-1102) generated UV photons with high efficiency from 180 nm (air cutoff) to 400 nm. A small hole was drilled on the side of the xenon flashlamp cover, allowing a photodiode (PD) to see the flashes. The xenon flashlamp was operated with a pulse function generator at a frequency of 100 Hz. The UV photons traveled through several pieces of ~350–400 μm thick transparent polyethylene sheets used for attenuation, a 200 μm pinhole in a piece of aluminum for further attenuation and a 3 mm thick sapphire window for containment of the 40 Torr CS_2 gas and finally into the proportional counter itself. Single photoelectrons were predominantly generated on the copper cathode of the proportional counter chamber 1.27 cm away from the anode wire. As seen in Fig. 2 the signal from the PD was sent to a linear shaping amplifier (Ortec-855) with a shaping time constant of 3 μs, which was delayed through a Quad Gate/Delay generator with a time delay ~100 μs between the gate, whose width was ~300 μs, to coincide through a coincidence circuit (CC) with SE ionization signals. The SE ionization signals were sent to the charge-sensitive preamplifier and then to the linear shaping amplifier (Ortec-855) with a gain of 140. The SE signals were observed on an oscilloscope and stored in the DAQ computer. A typical PD signal recorded in coincidence with a SE ionization signal is shown in Fig. 3.

The generation of SE events in this experiment was governed by Poisson statistics [13–16], where the probability of observing n