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Origins of the residual pulse height deficit in propane-filled gas ionization detectors

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Abstract

This work investigates the origins of the residual pulse height deficit in gas ionization detectors. It is motivated by the recent observation that the species dependence of gas detector response cannot be accounted for solely by considering the energy loss of the ions in the detector window and non-ionizing energy loss processes in the detector gas. It was found that the residual pulse height deficit is approximately proportional to the square of the ionization density. However, only a weak dependence of the residual deficit on gas pressure (in the range 70–120 mbar) was observed. It is hypothesized that the residual pulse height deficit in gas ionization detectors results from the effect of multiple ionization of individual gas molecules at high ionization densities on the energy required to create an electron–ion pair.

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Keywords: Gas ionization detector; Pulse height deficit; Ion beam analysis; Elastic recoil detection; Detector response

1. Introduction

Gas ionization detectors are extensively employed in nuclear physics and ion beam analysis for energy spectroscopy of heavy ions. Their pulse height–energy response is complicated, however, by the observation that heavier ions tend to produce lower pulse heights than lighter ions with

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the same energy, resulting in a pulse height deficit that increases with increasing ion atomic number [1–13].

Our recent measurements of gas detector response have led to the development of an empirical predictor of the pulse height deficit for propane gas [13], which was subsequently demonstrated to enable accurate energy spectroscopy using gas ionization detectors [14]. Although this correction proves adequate for the application of gas detectors, it still leaves questions as to the physical origins of the observed response.

Initially, it was expected that the non-linear response of gas detectors could be accounted for by the sum of the energy lost by the ions as they traverse the detector window and the energy lost in nuclear collisions in the detector gas [2–4]. Our earlier investigation revealed, however, that a large residual deficit of unknown origin remained even after these effects are taken into account. The physical origins of this residual deficit is the subject of the investigation presented here.

2. Experimental details

The experimental procedure employed for these new measurements was the same as that applied previously [13]. In brief, beams of ^{197}Au and ^{12}C ions were produced with the 14UD tandem Pelletron accelerator at the Australian National University. The incident energies of the ions were determined using an NMR probe to measure the field strength in the analyzing magnet of the accelerator, the uncertainty of which was better than 0.1% [15].

A parallel plate gas-ionization detector [16,17] was positioned in the beam such that ions were incident along its central axis. An ion count rate of typically 300 ions per second in the detector was used. This was achieved by first adjusting the beam current, measured in front of the detector with a Faraday cup, to 1 nA. The current was then further reduced by partially closing beam-limiting irises before and after the accelerator and switching off all quadrupole lenses so that the beam was not focused. The detector window was 12 mm in diameter and was made from a Mylar (PET) foil with a nominal thickness of 0.7 μm. A 2.5 mm diameter circular aperture was placed in front of the detector so that only the central region of the window was exposed to the ion beam.

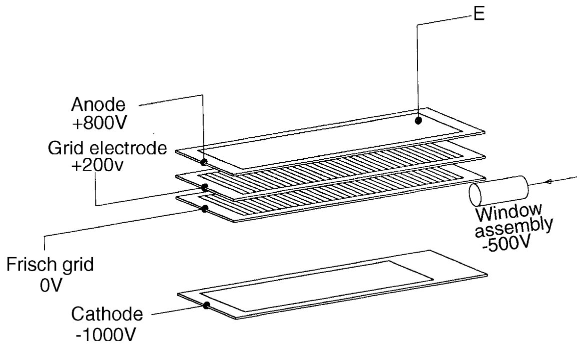

Fig. 1. A schematic of the electrode structure of the detector used in this study. The voltages used on each electrode are indicated. The total energy signal E was obtained from the anode.

Fig. 1 shows a schematic of the detector electrode structure as used in this study. It includes a cathode, a Frisch grid, a grid electrode, and an anode, separated by distances of 60 mm (cathode to Frisch grid), 10 mm (Frisch grid to grid), and 10 mm (grid to anode). A field strength of 167 V/cm was used, which is the same field strength used in the previous 120 mbar measurements [13]. To achieve this, voltages of -1000 V on the cathode, $+200$ V on the grid electrode, and $+800$ V on the anode were used. The Frisch grid was grounded. A bias of -500 V was applied to the window assembly to ensure that electrons produced in the entrance region of the detector were not lost to the window assembly [18]. Ion energy information was obtained from the anode signal. This signal was amplified using a preamplifier (Ortec model 142A) and a linear amplifier (Ortec model 572), and then digitized using a 1024 channel ADC.

The new measurements have been made at pressures of 70 and 95 mbar, in order to test if any pressure dependence of the residual pulse height deficit exists. This is compared with the data presented earlier at a detector gas pressure of 120 mbar [13]. For the lower pressure measurements, care was taken to ensure that the chosen ions were fully stopped within the 210 mm long active volume of the detector. Measurements were made only for ^{197}Au ions ($0.4 \leqslant E \leqslant 2.6$ MeV/u)