Field Effects on Ionic and Excitonic Quenching for Heavy Ions in Liquid Ar

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ABSTRACT

An increase in scintillation of up to 17% has been observed in liquid argon with the application of low electric fields (< 6 kV/cm) for ^1H , ^4He , ^{18}O and ^{36}Ar ions of energy 1–35 MeV/u. This increase occurs at a field much lower than that required for the proportional region (10^6 V/cm). The observed phenomenon is attributed to the recovery of quenching in the high excitation density region of the particle track by the external field.

1 INTRODUCTION

LIQUID rare gases such as Ar, Kr and Xe are suitable materials for many types of detectors [1,2]. Liquids have ideal properties such as high density and practically no limit in size for making the large detectors required for γ rays and high-energy particles. Both charge and scintillation signals can be used depending on the kind of particle, energy, and of course, the purpose. The electron has a high mobility $475\text{--}2000\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ [3] in liquefied rare gases, but high fields are required to collect it because of the high excitation density in the particle track and the short thermalization length compared to the gas phase. Scintillation signals can readily be used for high linear energy transfer (LET) particles. Scintillation in liquid rare gases occurs in the VUV region and can be converted to the visible light with a wavelength shifter such as sodium salicylate or dimethyl-POPOP. Liquid rare gas scintillators are expected to have less quenching effects than other scintillators [4], e.g., liquid argon has a linear response for relativistic Ne to La ions [5]. Furthermore, a proper summation of charge and scintillation signals gives a linear response for particles from electrons to relativistic La ions with corresponding LET of 1 to about $10^4\text{ MeV g}^{-1}\text{cm}^2$ [5]. Scintillation yields q_o , the amount of light output per energy deposited, for heavy ions with low velocity are less than those for relativistic heavy ions because of quenching

at high excitation density. The value of q_o for Po-210 α particles is 0.71 of that for relativistic ions.

Both the charge and scintillation signals have been measured for ^1H , ^4He , ^{18}O and ^{36}Ar ions of energy 1–35 MeV/u in liquid argon with an applied external electric field. Normally, the charge and scintillation signals are complementary to each other, the scintillation decreases and the charge increases with increasing field. However, in this work an increase in scintillation and collected charge are observed with the application of the external field. This increase occurs at a low field of a few kV/cm, which is much lower than that for the proportional region (10^6 V/cm). A similar phenomenon was first observed for α particles in liquid argon; however, the increase observed was only 2.5% [6].

2 EXPERIMENTAL

^1H and ^4He beams were obtained from the FN Tandem Van de Graaff at University of Notre Dame Nuclear Structure Laboratory. ^{18}O and ^{36}Ar ions were obtained using the K1200 cyclotron at the Michigan State University National Superconducting Cyclotron Laboratory. The apparatus is basically a gridded ionization chamber with a Pyrex window for the observation of the scintillation and has been described elsewhere [7]. The ion beams passed first through a 3.6 mg/cm^2 Ti foil and into the liquid ar-

gon through the cathode, which consisted of a Havar foil window of 18.6 mg/cm². The detection area was 26 mm in diameter. The beam direction was parallel to the applied electric field. A Po-210 α source was deposited on the cathode to give a standard for the scintillation yields. The preamplifier for the charge measurements was calibrated using a Po-210 α source and a SSD. Experiments were performed with ^1H and ^4He ions of energy 2–20 MeV and ^{18}O and ^{36}Ar ions of about 35 MeV/u. All ions were in their equilibrium charge state after passing through the window materials. The amount of charge and scintillation were measured for single ions using a pulse method. The shaping time constants of the main amplifiers were set at 6 μs and 3–12 μs for the scintillation and charge signals, respectively. The intensity of the beams was 10 to 300 particles/s. The distance between the cathode and the grid was set at 2.7–6.8 mm depending on the range of the ions in liquid argon. The VUV emission from the excited dimer was converted to visible light with a sodium salicylate wavelength shifter coated on the Pyrex window and observed by a photomultiplier. A ground potential grid was inserted between the collector and the photomultiplier in order to avoid the influence of the high voltage applied to the photomultiplier.

3 RESULTS AND DISCUSSION

The variation of the scintillation yields relative to that at zero field, S/S_0 , are shown as a function of the applied electric field in Figure 1 for 5 and 15 MeV ^1H , 5.5 and 15.4 MeV ^4He , and 603 MeV ^{18}O . For almost all of the ions examined, the scintillation initially increases with an applied field and then decreases at higher fields. The scintillation yields for 15 MeV ^1H ions and the ^{18}O ions are virtually constant up to about 1.5 and 0.2 kV/cm, respectively. The values then decrease for the protons and increase for the oxygen ions with increasing field. It appears that the scintillation yield for ^{18}O ions may be reaching a maximum at about 3 kV/cm [8]. A further in-

Figure 1. Ratio of scintillation with external electric field to scintillation without the field for ^1H , ^4He and ^{18}O ions as a function of the field.

Figure 2. The maximum scintillation increase, $\Delta S_{\text{max}}/S_0$, as a function of LET for ^1H , ^4He , ^{18}O and ^{36}Ar ions in liquid argon.

crease in field should lead to the expected decrease in scintillation with increasing electric field.

The maximum scintillation increase, $\Delta S_{\text{max}}/S_0$, is shown as a function of the track average LET in Fig. 2 for ^1H , ^4He , ^{18}O and ^{36}Ar ions. With increasing LET, the values of $\Delta S_{\text{max}}/S_0$ increase for 1.9–15 MeV ^1H ions and decrease for ^4He ions of 5.5–20 MeV. An increase in scintillation with an applied electric field has only been observed for those particles that exhibit quenching. In these cases, the scintillation is less than expected from the amount of energy deposited. Quenching seems to occur in the dense tracks of some high LET particles. The scintillation efficiencies, q_0 , for ^4He , ^{18}O and ^{36}Ar ions are about 0.45–0.75 of that for relativistic particles. ^1H ions also show considerable quenching in spite of their relatively low LET. Relativistic ions such as Fe and Kr have larger LET than α -particles, but they do not exhibit quenching effects or an increase in scintillation with the electric field. Relativistic Au ions [9] and fission fragments [6] have very high LET and show quenching, but no increase in scintillation with the electric field has been observed. The excitation densities in the tracks of these particles are probably so high that the field can not penetrate into the track core.

It can be seen in Figure 2 that with increasing LET there is an increase in the maximum scintillation enhancement with ^1H ions and a decrease with ^4He ions. For the experimental configuration used in these experiments, a maximum occurs at 30–60 eV/nm. The decrease with LET for ^4He ions can be explained by the denser track core for higher LET; the track core radii for He ions are small and decrease with increasing LET. At high LET the applied fields can not overcome the high track density. On the other hand, the ~ 35 MeV/u ^{18}O and ^{36}Ar ions have high velocities with large track core radii that can be penetrated by the applied field. Further experiments with higher energy ^4He , ^{18}O , and ^{36}Ar ions will help clarify the

proposed mechanism. For ^1H ions, the existence of considerable quenching for such low LET particles is surprising and certainly requires further investigation.

The increase in scintillation has only been observed at low fields (<4 kV/cm). The application of higher fields does not lead to a further increase [6]. Quenching should affect both excitons and ionic species, but ordinary fields do not seem to lead to the complete recovery of both. The electric field required to give the observed recovery of quenching in liquid argon was a few kV/cm, which gives only an order of 10^{-4} V over the distance of the nanometer size of the track core radius. It is surprising that such a low field can affect the high excitation density quenching, which was once thought to be caused by an ion explosion mechanism.

The increase in scintillation with the application of an external field has only been observed in liquid argon; however, it is possible that such a phenomenon will be found in other materials. The simultaneous measurements of both scintillation and ionization as a function of the external field strength has so far been restricted to liquefied rare gases.

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