Ionization of Liquid Tetramethyl Germanium by ^{60}Co-γ-Radiation

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Z. Naturforsch. **45a**, 832–834 (1990);
received March 30, 1990

The ionization current produced in liquid tetramethyl germanium by ^{60}Co-γ-radiation was measured with a guard ring type, parallel plate ionization chamber. The yield of ion pairs as a function of the applied electric field strength was determined and the free ion yield without applied electric field was obtained to be $G_{\mathrm{fi}}(0) = 0.68 \pm 0.10$.

The study of the radiation induced conductivity of non-polar liquids provides important information on the elementary process of ionization in the condensed phase [1, 2]. The apparent ionization yield is determined by the initial yield and by the processes of electron thermalization and electron-positive ion recombination. Measurements of the ionization yield as a function of electric field can shed light on these processes.

The discovery of high mobility excess electrons in non-polar liquids opened a new field of research for detectors of ionizing radiation. Initially, the application of such kind of liquids as detection media in ionization chambers with electronic read-out was restricted to liquid argon and liquid xenon because of the purity required. Recently, improved purification techniques have opened the door for the application of room temperature liquids such as tetramethylsilane [3] or tetramethylpentane [4].

Liquid hydrocarbons and related compounds comprised of spherical molecules incorporating methyl groups have shown high yields of radiation induced carriers as compared to straight chain molecules (see [1]). For some applications in high energy physics or medical physics it would be desirable to have a room temperature liquid with high electron density and high electron mobility [5]. Tetramethyl germanium (TMGe) is such a liquid. It has a density of $d_{20} = 0.97\ \mathrm{g\,cm^{-3}}$, and a boiling point of $t_b = 43\,°\mathrm{C}$. The electron mobility has been measured to be $\mu_{\mathrm{el}} = 90\ \mathrm{cm^2\,V^{-1}\,s^{-1}}$ [6]. In this communication we wish to report on the yield of ion pairs produced by ^{60}Co-γ-radiation in this liquid.

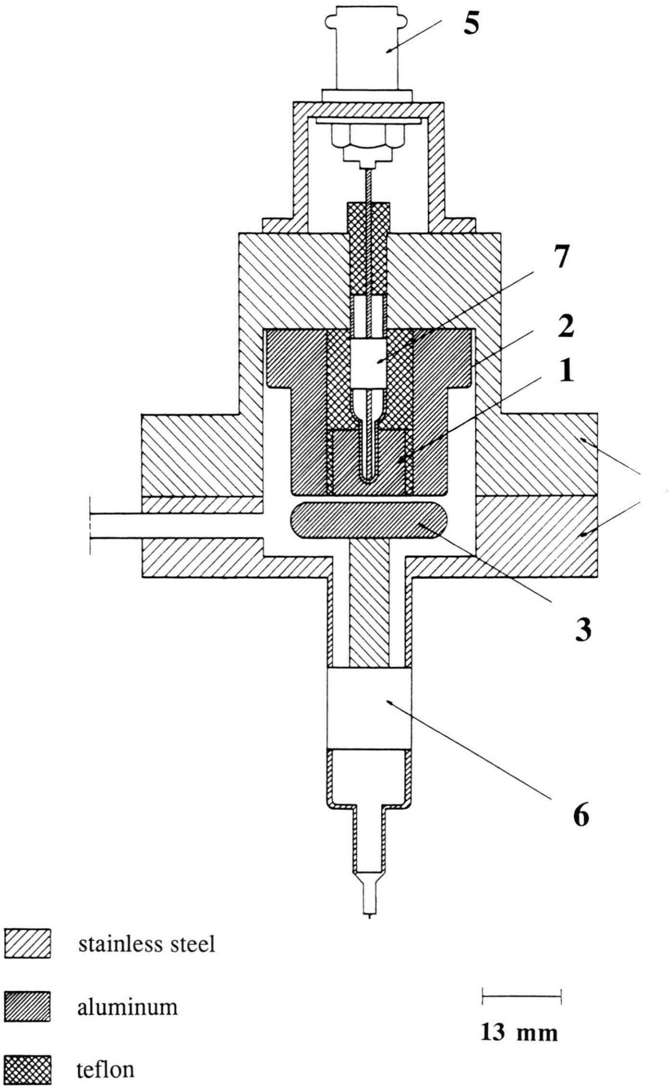

Fig. 1. Schematic drawing of the conductivity cell; 1 measurement electrode; 2 guard ring electrode; 3 high voltage electrode; 4 UHV-flange; 5 BNC jack; 6 high voltage feed through; 7 feedthrough.

The measurements were carried out with a parallel plate guard ring type ionization chamber. A schematic drawing of the chamber is shown in Figure 1. The

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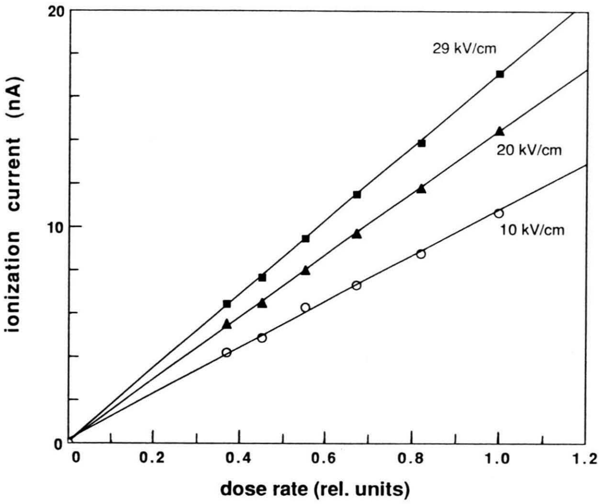

Fig. 2. The radiation induced current as a function of dose rate with the electric field strength as a parameter.

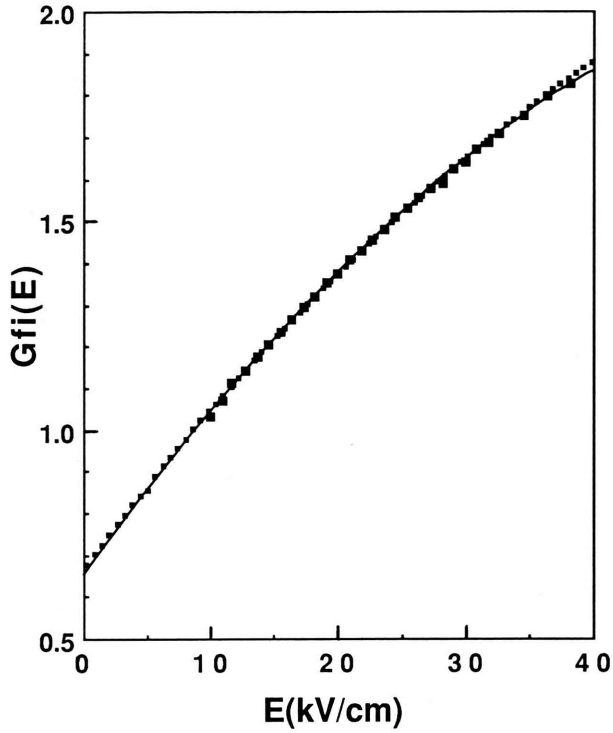

Fig. 3. The free ion yield in liquid tetramethyl germanium as a function of the electric field strength; ■ measured data points; ▪ calculated points after Eq. (3) with $G_{tot} = 4.4$ and $b = 147$ Å.

body of the cell was made of stainless steel UHV elements. The electrodes and the guard ring were made of aluminum which has the same absorption properties with respect to γ-rays as the liquid itself. The diameter of the high voltage electrode and collector electrode were 2.6 cm and 1.2 cm, respectively. The spacing between the electrodes was 0.11 ± 0.01 cm. The high voltage was supplied by a well regulated power supply (Nucletron Mod. NU 315A) and the ionization current was measured with a pico-ammeter (Keithley Mod. 610C). For the irradiation, a panorama type ^{60}Co-γ-source was employed. The measurement cell was placed at a distance of approximately 1 m in a cage made of lead bricks of 10 cm thickness. A small, opening in this cage admitted the γ-rays. This way homogeneous irradiation of the test cell was assured. Attenuation of the γ-rays was affected by lead absorber plates of different thickness. Relative dosimetry was carried out by filling the test cell with neopentane, for which the radiation induced ion yield has been measured previously [7].

Tetramethyl germanium (Alpha Products, electronic grade, 99.999% metal contents) was subjected to several freeze-pump-thaw cycles before it was introduced into the cell through a 2 µm stainless steel frit (NUPRO 4TF). The liquid in the test cell exhibited a self conductivity of $10^{-15}\,\Omega^{-1}\,\text{cm}^{-1}$, which was less than 2% of the radiation induced conductivity at the lowest dose rate and the maximum field applied. The measurements were carried out at (20 ± 2)°C.

Measurements of the ionization current in TMGe were carried out at six different dose rates in the field strength range of 9 kV/cm to 38 kV/cm. Typical results are shown in Figure 2. Taking into account the measurements with neopentane, absolute ion-pair yields as a function of electric field strength were obtained. The results are shown in Figure 3.

The data of Fig. 3 may be analyzed in terms of the Onsager model in which the escape of a single ion pair under the combined influence of temperature, externally applied field and Coulomb attraction was calculated [8]. Application of this model to the radiation induced ion-pair yield gives,

$$G_{\text{fi}}(E) = G_{\text{tot}} \int_0^\infty F(r)\, P(r, E)\, \mathrm{d}r, \tag{1}$$

where G_{tot} is the total number of electron-ion-pairs generated per 100 eV of absorbed energy. $F(r)\,\mathrm{d}r$ is the fraction of electrons that is thermalized between r and $r + \mathrm{d}r$ from its parent positive ion. $P(r, E)$ is the probability that electron-ion pairs of separation distance r will escape geminate recombination in the presence of an externally applied field E. For $F(r)$ the Gaussian function provides a good approximation [1],

$$F(r)\frac{4r^2}{\sqrt{\pi b^3}}\exp(-(r/b)^2). \tag{2}$$

Equation (1) and (2) were fitted to the experimental data with G_{tot} and b as adjustable parameters. The best fit was obtained with $G_{tot}=4.4\pm0.2$ and $b=147$ Å. With these parameters the ion yield at $E=0$ can be calculated from (1). A value of $G_{fi}=0.68\pm0.08$ was obtained which agrees with the value obtained from the extrapolation of the experimental curve to $E=0$.

Acknowledgement

Financial support by “Stiftung Volkswagenwerk” is gratefully acknowledged.

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