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# A NANODOSIMETER BASED ON SINGLE ION COUNTING

S. Shchemelinin, A. Breskin, R. Chechik and A. Pansky
*Department of Particle Physics, Weizmann Institute of Science, Rehovot 76100, Israel*

P. Colautti
*INFN Laboratori Nazionali di Legnaro, Via Romea, 4, I-35020 Legnaro, Italy*

**Abstract**

An approach, which permits to overcome certain fundamental limitations in spatial resolution in nanodosimetry is been developed. It is based on counting the number of radiation-induced single ions, extracted from a wall-less sensitive region, filled with gas. The extracted ions are accelerated in vacuum into an electron multiplier.

Such development requires the knowledge of the ion diffusion within the detector. As the gases of interest for nanodosimetry have multi-atomic molecules, the transport picture is rather complicated and involves a variety of mechanisms, resulting in series of ion species produced in the track, and their subsequent transformations during the diffusion process. The diffusion parameters, which should actually take into account all these mechanisms, are not available for most of the gases of interest.

A special setup for measuring ion transport parameters has been built, in which first measurements for propane were performed. Calculations, based on the obtained data, show that in an ion counting nanodosimeter a closed wall-less sensitive volume of about 0.2 $nm$ to 1 $nm$ across can be formed. Due to the absence of electron avalanche (like in electron counting devices), the choice of working gas is not restricted. This permits the use of various gases for simulation of the chemical composition of living cell fine subsystems.

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## 1 INTRODUCTION

According to microdosimetry, a biologically significant radiation damage distribution should be related to a living cell size or to that of its subsystems: $\sim 10\ nm$ for the nucleosomes and $\sim 2\ nm$ for the double-helix of the DNA. Some biological models[7] indicate that the maximum radiobiological damage is related to the coincidence of two ionization clusters, each having a size of a few nanometers and being a few tens of nanometers apart. Therefore, it is desirable to develop experimental methods enabling measurement of ionization statistics within volumes of a nanometer across as well as measurement of spatial correlations between such two separated damage sites.

There is an approach according to which a small tissue-equivalent sensitive volume is simulated by a low-pressure (a few $Torr$) tissue-equivalent gas (TEG); the number of ionizations in this volume is measured by counting the number of deposited electrons.[7] Electron diffusion limits the resolution of this method to about 10 nanometers.

We proposed a new approach[7] based on counting single deposited ions, which permits to reach significantly better spatial resolution. The development of such ion counting nanodosimeter requires the knowledge of ion diffusion parameters in TEG, which are not available. In this work a method for measuring such parameters was developed and applied to propane. The data enable us to calculate the expected performance of a nanodosimeter based on the proposed approach.

## 2. MEASUREMENT OF ION TRANSPORT PARAMETERS

The experimental setup built for our measurements (Figure 1 *a*) consists of two main sections. The first is filled with the gas under study (typically a few tenths of a $Torr$) and contains a movable ion source and a drift column with a narrow slit ($0.1 \times 10\ mm$) centered at its bottom end. This slit connects the first section to another one containing a vacuum operated microsphere plate electron multiplier (MSP)[7] used as a single ion detector. It requires ion acceleration up to $\sim 4\ keV$, which necessitates the second section to be maintained at a few $10^{-5}\ Torr$.

In the ion source, $\alpha$-particles from an $^{241}Am$ source pass 20 $mm$ of gas in the direction perpendicular to the figure plan, form a "linear" ion cloud (trail), and hit a PIN diode. This diode provides the "*start*" signal for measuring the ion drift time. Under an electric field the ion cloud drifts towards the slit, spreading in three dimensions. Some of the ions, that pass the narrow slit, are counted by the ion detector. The whole source unit can be moved perpendicular to the drift column axis. Examples of arrival time spectra corresponding to various ion source displacements are shown in Figure 1*b*. The distribution of the transverse displacement of the ions during their drift is obtained by integration of such spectra over the time.

It should be noted that in multiatomic gases (of interest for nanodosimetry), a multitude of ion species can be produced, each having a different diffusion coefficient and mobility. Moreover, various ion-molecule reactions are possible, which lead to subsequent transformations of the ions during the diffusion process. Therefore, the data required for our nanodosimeter development should be averaged over the spectrum of the initially produced ion species and over

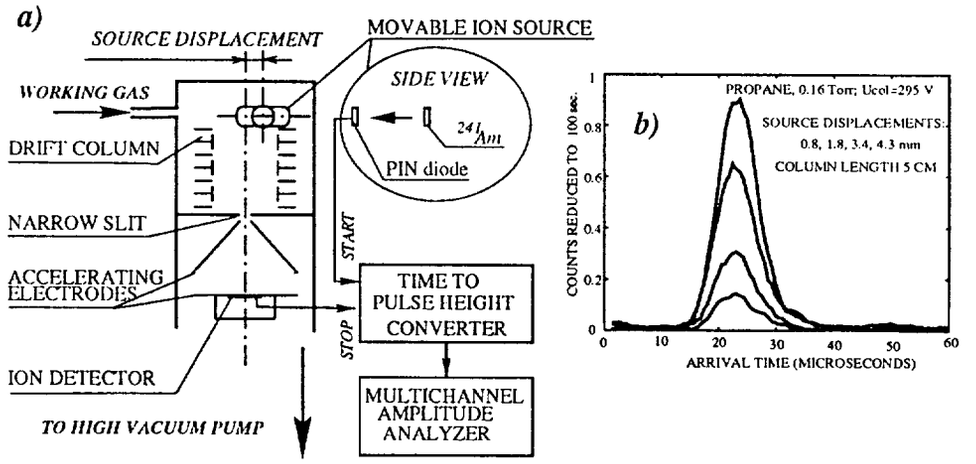


**Figure 1** *Measurements of arrival time spectra and transverse diffusion*

various "transport channels", connected to various transformations during the diffusion. In our experiment, where no selection of ions exists, such averaging naturally occurs. However the same feature of our technique hinders the comparison of our data with data of other experiments. For testing our method we measured mobilities of the ions induced by $\alpha$-particles in argon and drifting in the same gas, as some data for an indirect comparison ($Ar^+$ and $Ar_2^+$ ions in argon gas) are available in literature[7]. Such comparison shows reasonable agreement, which gives confidence in the technique.

Series of measurements were made in propane, in a reduced electric field range of 10 to 300 $Vcm^{-1}Torr^{-1}$. In Table 1 examples of measured transverse diffusion-induced RMS displacement of the ions in propane are compared with corresponding values for electrons in the same gas. The latter are obtained by computer simulations according to our previous work,[7] for an initial energy of 10 $eV$, which is typical for electrons induced in ionization tracks. One can see that ion transverse displacement is about five times lower than that of the electrons. This is connected to the fact that the mean free path of the electrons induced in an ionization track in living tissue is more than 1 $nm$, and many such lengths are required to reach equilibrium

**Table 1** *Comparison of ion RMS transverse displacements (from present measurements) and those of electrons (computer simulations ) in propane. Centimeters are used for gas and nanometers – for simulated tissue.*

| | Pressure | Electric field | Drift length | | RMS displacement | |
|---|---|---|---|---|---|---|
| | $Torr$ | $V/cm$ | $cm$ | $nm$ | $cm$ | $nm$ |
| Ions induced | 0.15 | 50 | 1.5 | 5.4 | 0.13 | 0.5 |
| by $\alpha$-particles | 0.15 | 5 | 1.5 | 5.4 | 0.17 | 0.6 |
| Electrons (initial | 0.15 | 50 | 1.5 | 5.4 | 0.55 | 2.1 |
| energy of 10 $eV$) | 0.15 | 5 | 1.5 | 5.4 | 0.95 | 3.4 |

conditions. Consequently, in a gas, quasi-ballistic electron transport dominates at corresponding simulated distances and causes high diffusion. This sets limits on the space resolution of methods based on electron counting. The induced ions have low initial energies and effectively exchange it with the gas molecules. Furthermore, moderate drift velocities of ions (in comparison to those of electrons) enable additional simple selection of the sensitive volume size using delayed time gating.

## 3. AN ION COUNTING NANODOSIMETER

A concept of the proposed device in shown in Figure 2*a*. An energetic charged particle traverses a low-pressure gas ionization cell. It induces ionizations directly and through the mediation of $\delta$-rays. Radiation-induced ions drift under an electric field $E_1$. Those ions which start from a certain sensitive volume, schematically shown in Figure 2*a*, pass through a small aperture and are counted by an ion detector. The electric field configuration, the size and

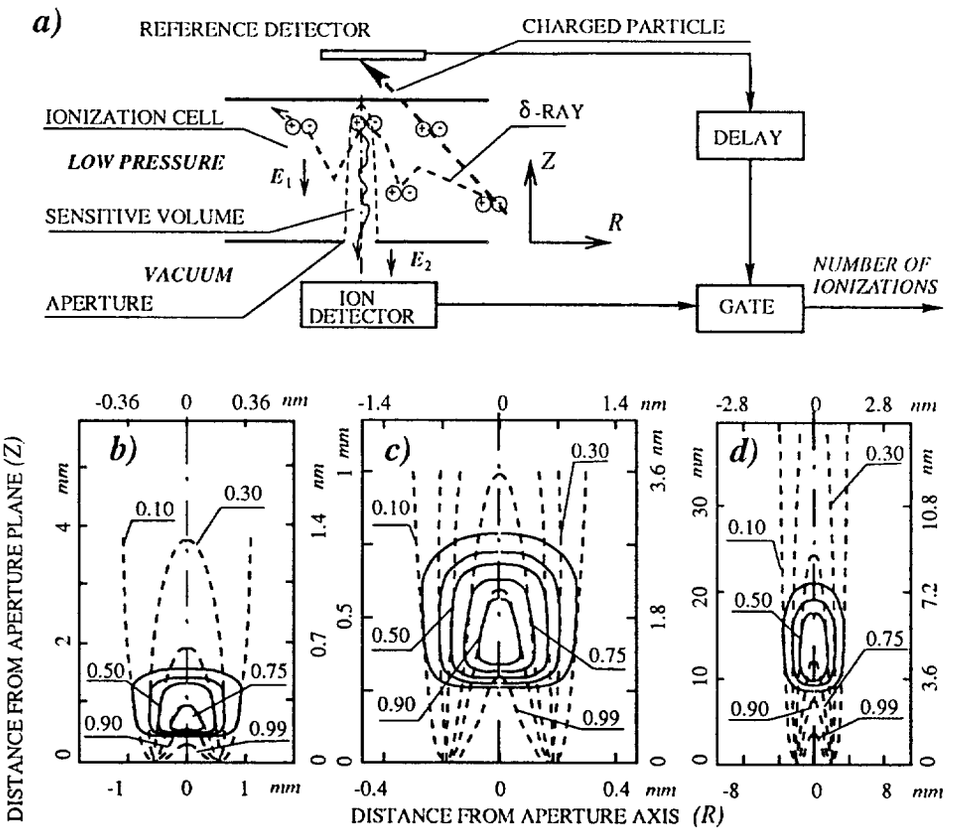


**Figure 2** *Conceptual diagram of an ion counting nanodosimeter (a) and calculated sensitive volume configurations for propane (b - d). The contours correspond to the marked efficiency levels for collecting ions with time gating (solid) and without it (dashed).*
*b) 0.15 Torr, $E_1$ = 50 V/cm, 1.12 mm aperture diameter; c) 1.5 Torr, $E_1$ = 500 V/cm, 0.35 mm aperture diameter; d) 0.15 Torr, $E_1$ = 50 V/cm, 4.0 mm aperture diameter.*

geometry of the aperture, and ion diffusion, define the sensitive volume. An additional selection of the sensitive volume along $E_1$ is provided by time gating, triggered by pulses from the reference detector. Ions are accelerated (under $E_2$) to an ion counter operating in high vacuum, which requires an appropriate differential pumping system (not shown).

Based on results of our measurements and a known diffusion model[7] we calculated the sensitive volume configurations for a number of cases (Figure 2 *b* - *d*). The vacuum conditions in cases *b* and *c* are achievable with the technique used in our present measurements. One can see that sensitive volumes of about 0.2 *nm* and 1 *nm* across, respectively, are already possible. Case *d* indicates another way of affecting the sensitive volume size and configuration, by enlarging the aperture size.

To conclude, the proposed ion counting nanodosimeter should enable subnanometer level spatial resolution. This permits good definition of *completely closed wall-less* sensitive volumes. Due to the absence of electron avalanche (like in electron counting devices), the choice of working gas is not restricted. This permits the use of various gases for simulation of the chemical composition of living cell fine subsystems.

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