Experimental Determination of Volume Density of Ionization in NaI:Tl scintillator

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The value of the specific ionization loss -dE/dx is an important characteristic of the theory of the scintillation process [1]. Namely with dE/dx increasing with decreasing of electron energy the non-proportionality of photon (or electron) response is associated. It is known that duration of the scintillation pulse is shorter for excitation by particles with high specific energy loss, such as alpha-particles than electrons. It is also known that the decay time decreases with decreasing energy of gamma-rays [2, 3] , especially near the L-absorption edge of iodine. It is believed that dE/dx for low-energy electron is higher than that of fast. Because of the creation of the large number of slow δ-electrons a track tail is slowly different from the other parts of track. Simulation of the track structure shows that the energy losses are distributed un-uniformly and are concentrated in areas of high density ionization [4]. In this sense, the linear energy loss is un-informative, and it is necessary to know the bulk density of electron-hole pairs -dE/dV.

In this paper we propose a simple phenomenological model for the evaluation of the ionization density in the birthplace of the photoelectron. We used known data on concentration dependence of the light output for the experimental determination of dE/dV.

Schematically, the process in question is shown in Fig. 1. It is known that after knocking out an electron from K- or L- shell of iodine the photoelectron photoelectron (with energy $E_e = h\nu - E_b$, where E_b – binding energy) creates a track, at the end of which path there is a Bragg peak of ionization. When a vacancy in the inner shell of the atom is filling the characteristic X-rays arise or instead it the Auger electrons are emitted. According to the model of cascade filling [5] for sodium and cesium iodides the Auger process is dominant, and the energy of emitted electron is ~ 1 keV.

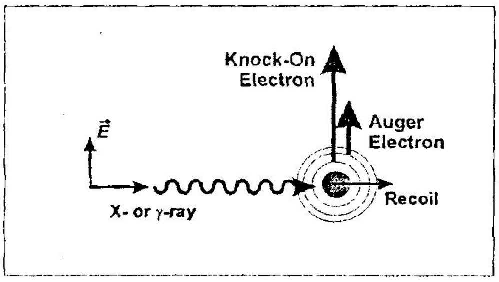

Fig. 1. Schematically presentation of the process of photo- or Auger electron creation as a result of photo-interaction

By reducing the photon energy when the $h\nu$ only slightly more E_b, there comes a time when the range of photoelectron coincides with that of the Auger electron and the ionization regions of two particles are overlap. This situation is schematically depicted in Fig. 2. By analogy with the Bragg peak at the end of the electron range, the peak formed by the Auger electrons in the place of birth (beginning of the primary electron range) we denoted as anti

Bragg peak. It is clear seen from the data of this figure that on the basis of the model proposed it is easily to explain the increase in dE/dV twice or even three times (when the two are born Auger electron).

In paper [6] it has been shown that the maximum light yield in NaI:Tl crystal (for photons with E_γ = 662 keV) is reached at a concentration of thallium $C_{Tl} \geq 2.2\cdot10^{18}$ cm^{-3}, followed by a plateau, where the output is constant. According to the theory (Murray and Meyer) on the adequacy of the number of luminescence centers to given ionization density [1], it means that the indicated concentration corresponds to dE/dV for the Bragg peak (case "a" in Fig. 2).

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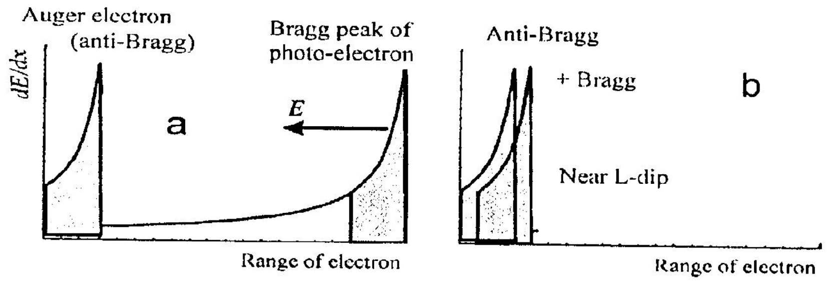

Fig. 2 – Schematic imagination of ionization areas overlapping which are created by photo- and Auger electrons

It is also known that maximum light yield for photons with an energy of 5.9 keV is achieved at activator concentration $C_{Tl} \geq 7.3\cdot10^{18}$ cm^{-3} (case "b" in Fig. 2) when $E_e \leq 1$ keV, see also data of the table. Comparison of two concentrations (7.3 / 2.2 ≈ 3) shows that the volume density of electron-hole pairs is three times more for the events near L- edge of iodine absorption. In our opinion it is this fact explains the reason for reducing the duration of the scintillation pulse for photons with energy of 5.9 keV.

Table. The concentration of the activator, which is sufficient to achieve maximum light yield at various types of excitation in NaI:Tl

Type of excitation	Energy [keV]	C_{Tl}, cm^{-3}
Gamma- rays	662	$2.2\cdot10^{18}$
X-rays	5.9	$7.3\cdot10^{18}$
Alpha-particles	5150	$13\cdot10^{18}$

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