A NEW TECHNIQUE FOR STUDYING THE FANO FACTOR AND THE MEAN ENERGY PER ION PAIR IN COUNTING GASES

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ABSTRACT

A new method is presented for deriving the Fano factor and the mean energy per ion pair in the ultrasoft x-ray energy range. It is based on counting electrons deposited by a photon in a low-pressure gas, and is applicable for all counting gases. The energy dependence of these parameters for several hydrocarbons and gas mixtures is presented.

A fundamental topic in radiation physics and dosimetry deals with the number of ion pairs generated in matter and its fluctuation, following the passage of an ionizing particle or the absorption of an energy quantum. In the latter, the dissipation of energy released by a soft x-ray photon involves the photoelectric effect and its related processes: the Auger/Coster-Kronig transitions, fluorescence , electron shake-up and electron shake-off, as well as further gas ionization by the photo/Auger electrons. The x-ray energy absorption can be described by two energy-dependent parameters: the mean energy per ion pair (W_i) and the Fano factor (F). The mean energy per ion pair is defined by W_i=E/$\bar{n}$ where E is the deposited energy and $\bar{n}$ is the mean number of induced electrons, while F characterizes the ionization fluctuation given by : $\sigma_{\bar{n}} = \sqrt{F\bar{n}}$.

The mean energy per ion pair was extensively studied both theoretically and experimentally [1], mainly for charged particles. However, only small number of measurements of F exist [2,3], mainly due to a lack of accurate experimental tools.

We report here on a new accurate experimental method for determination of F and W_i in the ultrasoft x-ray energy range. The method is applicable for all counting gases and their mixtures with noble gases. A complete description of this technique is presented elsewhere [4].

Ultrasoft x-rays are produced by a Particle-Induced X-ray Emission (PIXE) and are detected using an Electron Counting (EC) technique [5]. The electron swarms induced in a low-pressure gas are expanded while drifting under very low electric field towards a multiplication element. Electrons reach the multiplier in sequence and are therefore individually amplified. They are counted with very high efficiency and their number is proportional to the initial photon's energy. An example of a fluorine-K (676 eV) induced electron pulse-trail is shown in fig.1. A contour plot of the number of counted electron versus the electron trail length is shown in fig.2 for Be, C and Al lines. The additional time information helps resolving close lines.

In order to extract F and W_i we used a Monte-Carlo simulation, which accurately simulates all phenomena involved in the photoabsorption and electron transport multiplication and counting. A typical simulated electron pulse-trail is shown in fig.1b. By correlating the experimental distributions of the number of counted electrons with the simulated ones, one can extract F and W_i. This is done by varying the simulation input parameters and testing the the degree of agreement (χ^2 test) between the experimental and simulated counted electron distributions. An example of the good agreement between such experimental and simulated distributions is shown in fig.3.

Our results of F and W_i as a function of the photon energy for several gases and mixtures are presented in table.1. In all gases, a tendency of decrease in F and W_i with increasing x-ray energy is observed. An increase of these parameters above the argon L-shell ($\approx$ 250 eV) can be seen in the argon mixtures. An example of such behavior can be seen in fig.4 for i-C_4H_{10} and its mixture with argon. The increase of the W_i value above the argon L-shell energy is a result of the additional energy required to release an argon LMM-Auger electron compared to a M-electron. The increase in the F value is due to an opening of additional electron thermalization paths.

With its good accuracy, the method provides an excellent tool to study both the energy dependence of both parameters (F and W_i), as well as possible Penning and shell structure effects. We are currently investigating a new electron multiplier, based on a low-pressure microstrip amplification element [6], which will improve the accuracy of the method. We are currently studying F and W_i values in a large number of counting gases.

References

[1] International Comission on Radiation Units and Measurements, *Average Energy Required to Produce an Ion Pair,* ICRU Report No. 31, Washington, DC, 1979).

[2] D. Srdoc, B. Obelic, and I. Krajcar Bronic. *J.Phys B*, 20 (1987) 4473.

[3] T. H. V. T. Dias et al. *Nucl. Instr. and Meth.*, A307 (1991) 341.

[4] A. Pansky A. Breskin, R. Chechik A new technique for studying the Fano factor and the mean energy per ion pair in counting gases. *to be published in the J. Appl. Phys, June 1996 issue.*

[5] A. Pansky A. Breskin, R. Chechik, and G. Malamud. *Nucl. Instr. and Meth.*, A330 (1993) 150.

[6] A. Breskin, E. Shefer, R. Chechik and A. Pansky. *Nucl. Instr. and Meth.*, A345 (1994) 205.

Figure captions

1. Typical 676 eV, Fluorine x-ray events: (a) a digitized experimental electron trail, (b) a simulated electron trail. Electron pulses recognized are circled in (a) and (b). Ar/C_2H_6(20:80) at 20 Torr.
2. Contour plots of the counted number of electrons as a function of the pulse-trail length for Al-K, C-K and Be-K x-rays.
3. Distributions of experimental (squares) and simulation (lines) counted number of electrons. x-ray energy 1486 eV, Ar/C_2H_6 (20:80) at 20 Torr. Note that the simulation remarkably reproduces the experimental data.
4. Extracted W_i and F values as function of x-ray energy for Ar/C_4H_{10} (20:80) and C_4H_{10}.

x-ray energy (eV)		108.5	183.5	277	676	1253	1486
C_2H_6	W_i	27.4(6)	28.0(4)	27.6(3)	27.2(5)		24.9(6)
	F	0.270(7)	0.280(7)	0.278(7)	0.260(10)		0.250(10)
Ar/C_2H_6(20:80)	W_i	27.4(6)	28.0(4)	27.6(3)	27.2(5)		24.9(6)
	F	0.270(7)	0.280(7)	0.278(7)	0.260(10)		0.250(10)
C_4H_{10}	W_i	28.0(4)	27.4(3)	27.9(3)	27.0(3)	25.6(3)	
	F	0.300(10)	0.285(9)	0.280(6)	0.265(9)	0.255(9)	
Ar/C_4H_{10}(20:80)	W_i	25.5(6)	26.3(4)	26.9(3)	26.4(5)	25.0(6)	
	F	0.275(15)	0.253(8)	0.265(7)	0.250(10)	0.250(10)	
DME-$(CH_3)_2O$	W_i	28.6(5)	28.5(4)	28.6(3)	28.4(4)	27.7(4)	
	F	0.340(15)	0.320(10)	0.315(10)	0.330(20)	0.285(20)	
Ar/DME (20:80)	W_i	26.8(5)	26.9(3)	27.7(3)	26.4(3)	26.8(5)	
	F	0.340(15)	0.300(10)	0.310(6)	0.330(10)	0.315(15)	

Table 1. Results of the mean energy per ion pair (W_i) and the Fano factor (F) extracted for various gases and gas mixtures by the electron counting technique. Errors are quoted in parenthesis.

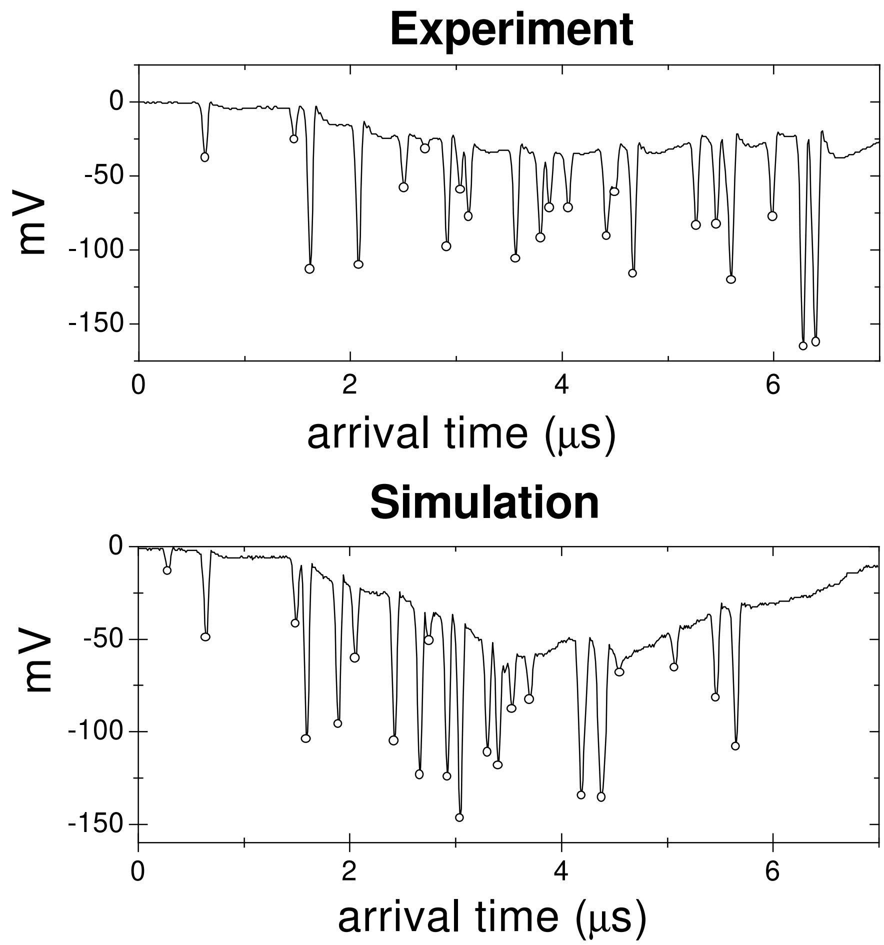
Experiment
0
-50
-100
-150
mV
0
2
4
6
arrival time (μs)
Simulation
0
-50
-100
-150
mV
0
2
4
6
arrival time (μs)

fig.1

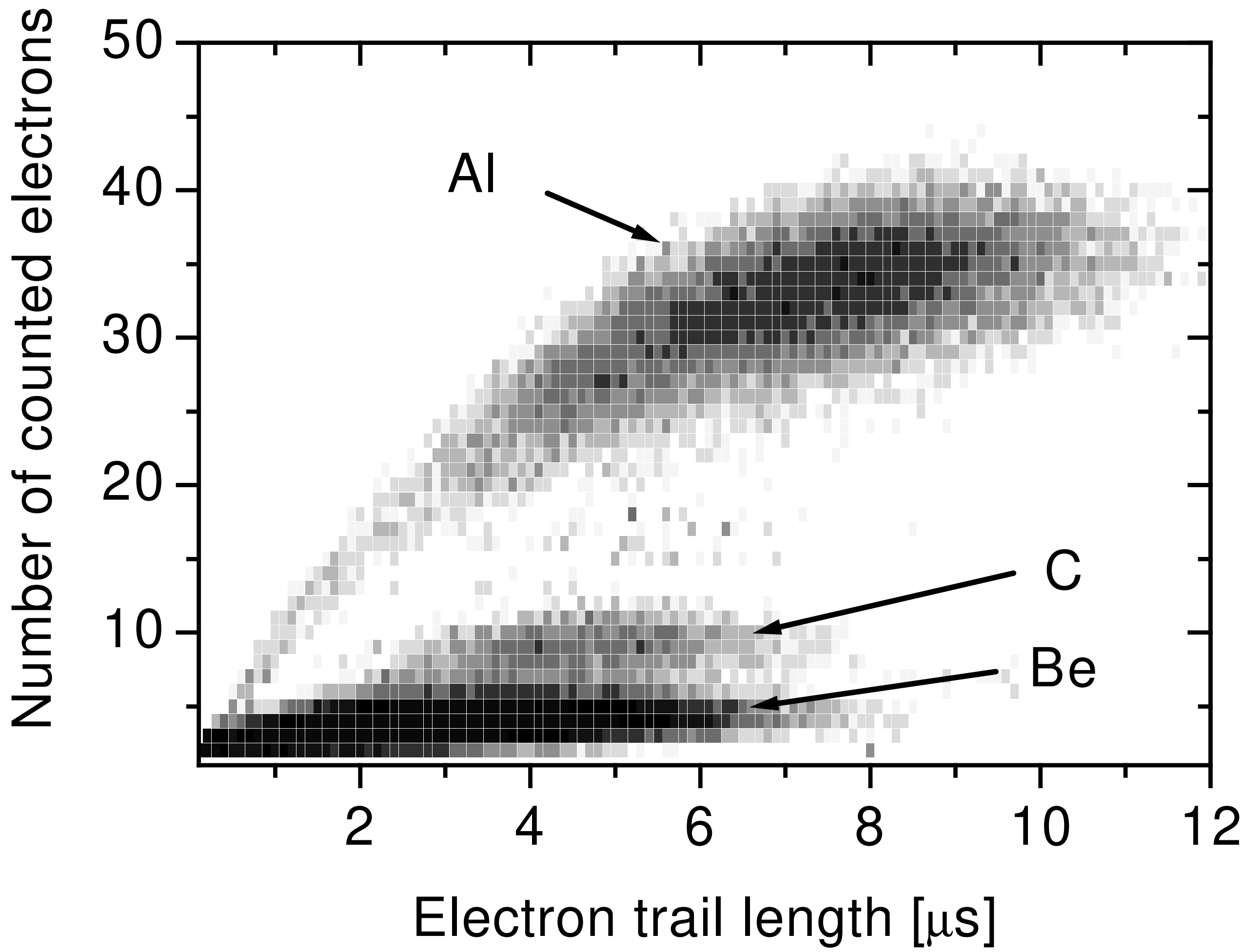
Al
C
Be
Number of counted electrons
Electron trail length [μs]
50
40
30
20
10
2
4
6
8
10
12

fig.2

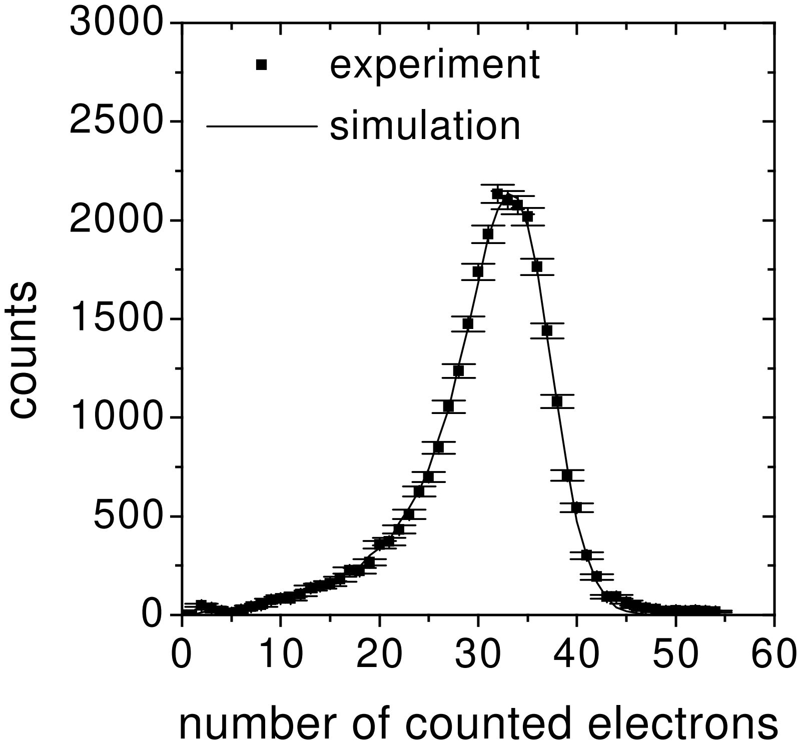
experiment
simulation
counts
number of counted electrons
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60

fig.3

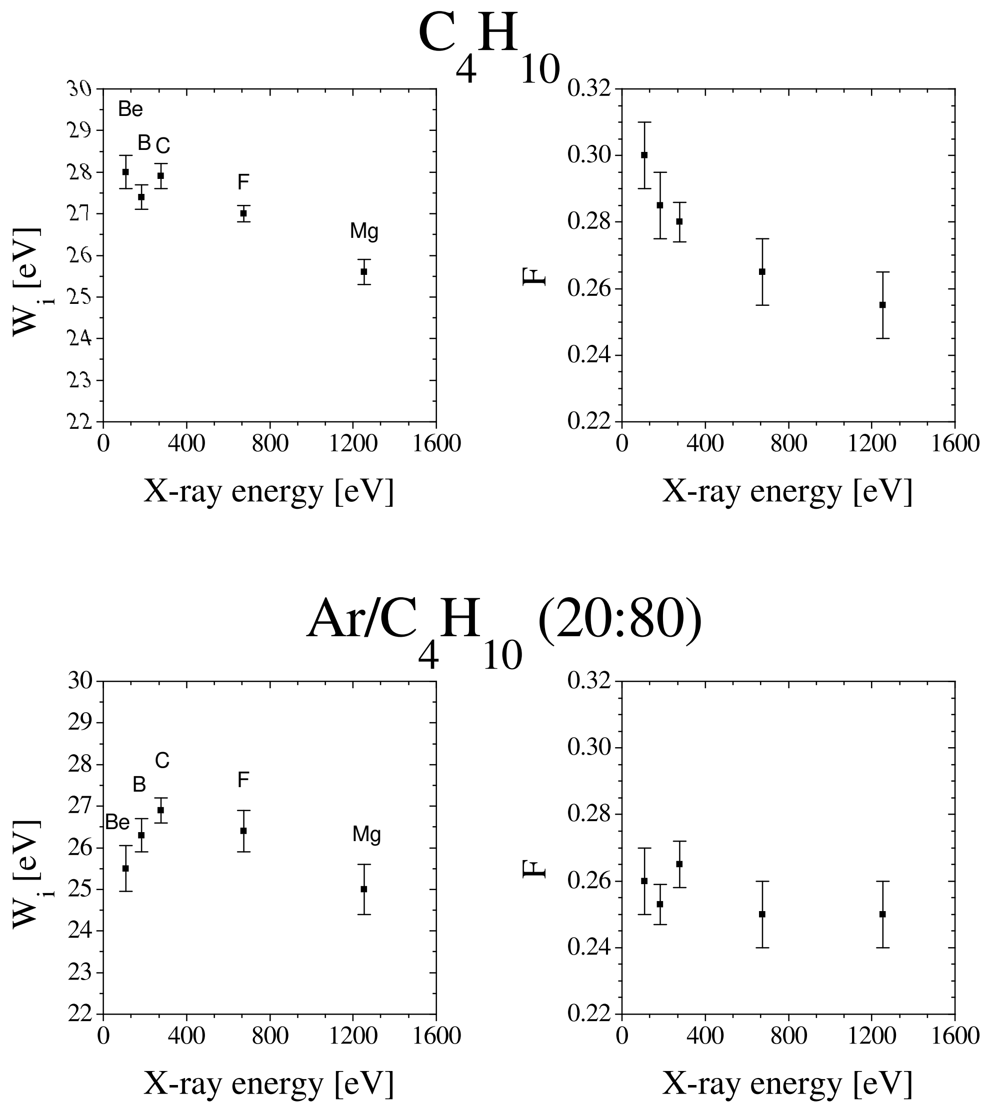

fig.4