CERN 73-11
Laboratory I
Nuclear Physics Division
24 September 1973

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

HIGH-ACCURACY MEASUREMENTS OF THE CENTRE OF GRAVITY OF AVALANCHES IN PROPORTIONAL CHAMBERS

G. Charpak, A. Jeavons, F. Sauli and R. Stubbs

GENEVA

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CERN - Service d'Information scientifique - H/546 - 2200 - septembre 1973

ABSTRACT

By measuring the centre of gravity of the pulses induced in the cathodes of a multiwire chamber, the position of the avalanche can be determined with a high accuracy.

The inherent accuracy of the method is at least of the order of 15 microns. The accuracy is determined only by the spatial extension of the avalanches. With X-rays of 6 kV, the accuracy is at least $\sigma = 150$ μm along the wire. The conditions for interpolation between the wires are discussed.

CONTENTS

In a multiwire proportional chamber[1] the avalanches occur close to the anode wires. The motion of the positive ions in the large electric fields at the vicinity of the wires induces fast-rising positive pulses on the surrounding electrodes. If one cathode is made of wires perpendicular to the sense wires, a distribution of induced pulses can be observed on the cathode wires, with the maximum centred at the position of the avalanche[2]. This feature is essential for the detection of low-energy neutral particles, X-rays or neutrons, since the two coordinates have to be extracted from a single gap, the secondary particles being usually of too low energy to cross several successive chambers.

Different methods have been developed in order to determine the position of the centre of the avalanches. The most common of these in the field of X-ray detection are the delay-line method of the Perez-Mendez group[3], the rise-time method of Borkowski and Kopp[4], and the digital read-out of strips in the cathode planes.

In the method we describe, the centre of gravity of the pulse distribution is measured directly. It seems to lead to an accuracy which is limited only by the stability of the spatial distribution of the avalanches generated by the process being measured.

1. METHOD

The dimensions of the chamber are 10 × 10 cm^2. The anode sense wires are made of gold-plated tungsten of 10 μm diameter, with a spacing of 1 mm; the gap between the sense wires and the cathode is 3 mm. The cathode is made of wires of 50 μm diameter, spaced by 0.5 mm. The wires in one cathode plane are parallel to the sense wires, and in the other they are orthogonal to the sense wires. The sense wires are not used for position measurements; they are connected together to a discriminator selecting the events accepted in the system according to their energy loss. The gas used in all our measurements is a mixture of 70% argon, 25% isobutane, and 5% methylal.

The cathode wires are coupled together in groups of six. We measure the pulse height induced by an avalanche on each band of 3 mm (Fig. 1).

An amplifier connects such a band to a digitizing amplitude converter[*] and to a PDP11 computer. The amplifier has a voltage gain of 10, with an input impedance of 2000 Ω and an output impedance of 50 Ω.

The computer determines the centre of gravity of the distribution. This method is an improvement on our previous measurements of the centre of gravity by the indirect method of pulse-height comparison on two successive strips[5]. The two-dimensional positions of an avalanche can be displayed on a Tektronix 4010 Display Screen.

2. ACCURACY OF THE METHOD

In order to measure the intrinsic accuracy, we send a positive generator pulse on one sense wire, inducing positive pulses on the cathode strips of approximately the same pulse shape as those induced by radiation.

Figure 2 shows the distribution of the centre of gravity. It corresponds to $\sigma = 15$ μm and, according to our observation, is introduced by the noise in our amplifiers.

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[*] Le Croy Multi ADC, sensitivity 1 pC/channel.

By varying the pulse height by 6 dB we observe a shift corresponding to 50 μm. This is introduced by the defects in the linearity of our amplifiers, which have a 2% linearity over the range we use. These factors could be improved. We can expect that any important deviation from this sort of accuracy results from the fluctuation in the spatial distribution of the charge distribution.

3. ACCURACY IN THE DIRECTION PARALLEL TO THE SENSE WIRES

We have used a ^{55}Fe source of 5.9 keV X-rays collimated to a slice of about 100 μm. Figure 3 shows the position of the centre of gravity. The FWHM of 300 μm corresponds to what can be expected from the range of the photoelectrons and from the collimation. It is slightly reduced when argon is replaced by krypton in the gas filling. It gives, however, an upper limit to the spatial distribution of the avalanches from this source of photoelectrons, which plays an important role in discussing the accuracy in the orthogonal direction.

4. ACCURACY IN THE DIRECTION ORTHOGONAL TO THE SENSE WIRES

If we irradiate this chamber with a uniform distribution of 5.9 keV X-rays, we observe that the centre of gravity positions are distributed either in narrow peaks corresponding to the position of the wires or into a continuous distribution (Fig. 4a). Using the 0.1 mm collimated source we have investigated the variation of the centre of gravity position as a function of the position of the source.

Figures 4b to 4i show the distribution of the centre of gravity as a function of the distance from the wire.

The distributions suggest two conclusions:

i) Some energy sharing might occur between two wires. It is compatible with an over-all size of the photoelectron cluster resulting from 5.9 keV X-ray absorption of about 500 μm, as can be deduced from the relative surface of the peak distribution and the continuous distribution shown in Fig. 4.

ii) When the source is centred close to one wire no sharing occurs, but a clear right-left effect appears.

Figure 5 shows the peaks obtained at the positions -50 μm and +100 μm. Taking into account the intrinsic resolution of the source, the right-left effect is remarkably clear, as was already mentioned in Ref. 4.

5. INTERPOLATION OF POSITION BETWEEN WIRES

The right-left effect and the energy sharing may have some importance for further progress in the direction of high-accuracy trajectory localization.

With tracks inclined with respect to the chamber, there always exists an energy sharing among adjacent wires, and the centre-of-gravity method may lead to an accuracy better than the wire spacing.

With X-rays one may wonder whether this would lead to an improvement in resolution.

We have irradiated the chamber with X-rays of different energies: 5.9 keV (Fig. 3), 8.5 keV, 14 keV, 23 keV, 34 keV, and 54 keV (Fig. 6).

We see that the energy sharing becomes more and more pronounced, and that at 25 keV nearly all the photoelectrons have such an extension that the electrons liberated in the gas are shared among several wires.

With a source of 14 keV, well collimated on the middle of two wires, we do not observe a peak. We may thus say that with our gas and this energy the spatial resolution is not governed by wire spacing but by the range of the photoelectrons. The situation is clearly different for each gas. High density gases are of great advantage.

6. TWO-DIMENSIONAL MAPPINGS OF SOFT X-RAYS

We have equipped a small fraction of the chamber (3.5 cm × 3.5 cm) with the equipment necessary for the two-dimensional read-out of the centre of gravity of the avalanches produced by 5.9 keV X-rays. This is within a range of energy which is interesting in some applications such as X-ray diffraction studies.

Figure 7 shows the display obtained with a source of 5 mm diameter at a distance of 30 cm with several objects placed against the chamber.

Figure 7a shows a strong non-linearity in the position of the sense wires. There are two reasons for this:

i) any difference in the electronic amplification, from channel to channel; this has been shown to have only a small effect;

ii) the most important cause is due to the following. In order to register an event, the sense wires covering the area of interest were connected in parallel to an amplifier of input impedance $\sim 2\ \mathrm{k\Omega}$, and used as a trigger. Consequently, a negative pulse on one sense wire caused by an avalanche is automatically fed to all the other sense wires. This negative excursion couples to all the cathode strips, which for one strip far from the initial avalanche produces a negative signal greatly in excess of the positive induced pulse. The effect could be removed by coupling all the sense wires to ground with an impedance of a few ohms.

7. ADVANTAGES OF THE METHOD

The interest of this method as compared to the other analog methods relies on several facts.

- It does not require any special circuits apart from the amplifiers. Standard commercial CAMAC modules are used.
- There is no loss in the signal size irrespective of the chamber size. This can be decisive for small wire spacing. Methods in which a small fraction of the induced signal is used, such as in the delay-line method with external coupling, require a higher amplification from the wire.
- This method relies on a local measurement and is to a large extent independent of the chamber size. For problems in which a single particle has to be measured, an adequate grouping of the pick-up cathode electrodes may result in a quite economical solution. For the focal plane of spectrometers this should be seriously considered. In this case the tracks are usually inclined with respect to the planes, and energy sharing should provide a space resolution much smaller than the wire spacing.

- In the case of multitrack detection, the method leads to an easy way of resolving the ambiguities. The pulse heights on the two orthogonal pick-up electrodes are strictly correlated in size and may offer an immediate rejection of ambiguities resulting in the combination of avalanches of different sizes. The situation is very similar in this respect to the rejection of ambiguities using the strict time correlation of the pulses induced on two orthogonal cathode wire systems[2)].

- In applications such as X-ray diffraction studies it is possible to tolerate a very high local rate such as the one observed in the central spot. A fast coincidence between the bands corresponding to this spot make it possible to detect the photons in this spot, to count them for monitoring purposes, and to prevent the digitizing system from wasting time over these unwanted events. This is much more difficult in an analog method, which has to accept at one end all the events occurring in any part of the chamber.

It is clear that more work is required on this method in order to find out the ultimate limits that can be reached in the accuracy for charged particle trajectories. It seemed worth while to us at this stage to attract attention to it as a potential tool for some applications.

We wish to thank Messrs. H. Verweij and C. Engster for their support in the design and construction of the electronics for this experiment.

We are greatly indebited to the NP Technical Assistance group, and in particular to Mr. R.E. Benoit whose ingenuity and enthusiastic support has allowed us to do our work with perfectly constructed prototypes.

* * *

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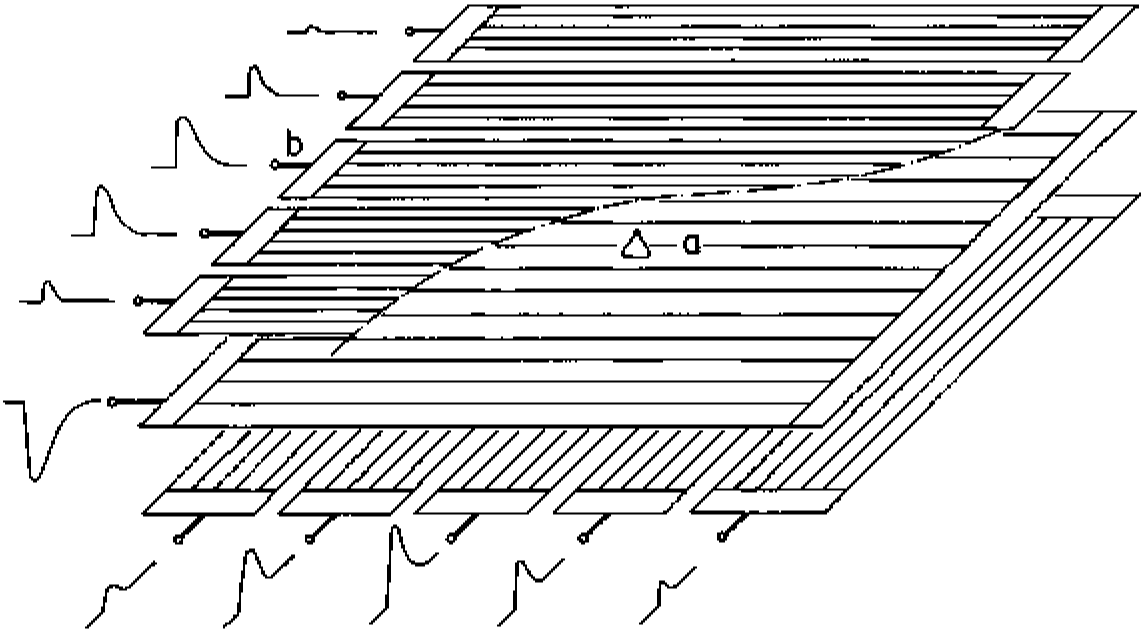


Fig. 1 Principle of the method.

The avalanches surrounding a wire a induce a positive pulse on the cathode strips b. The pulse height of the induced pulse is measured and stored and the centre of gravity of the pulse-height distribution is compared and gives the position of the avalanche. The two cathode planes are equipped with strips parallel and orthogonal to the wires; coordinate x parallel to the sense wires, coordinate y orthogonal to the wires.

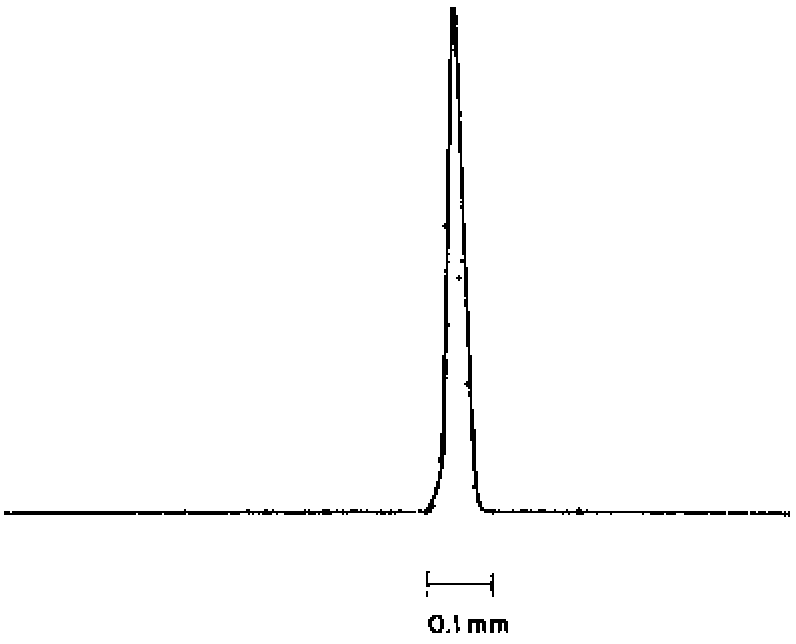


Fig. 2 Intrinsic resolution of the method.

By sending a positive pulse on the sense wire the distribution of the centre of gravity in the y-direction shows a width of 30 μm due to the noise in the amplifiers. By changing the gain by 6 dB the peak shifts by the equivalent of 0.1 mm.

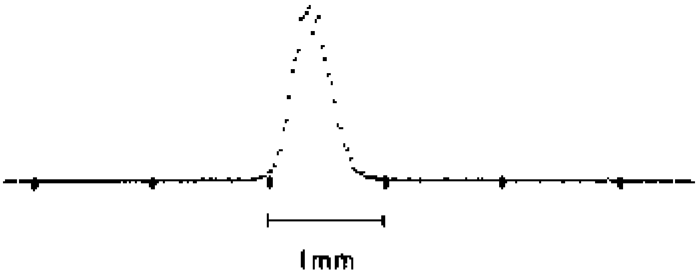


Fig. 3 Accuracy in the direction parallel to the wire.

The figure shows the centre of gravity distribution along the wire. ^{55}Fe X-ray source of 5.9 keV, collimated to 0.1 mm. The width is accounted for by the collimation, the range of the electrons, and the non-linear response of the amplifiers.

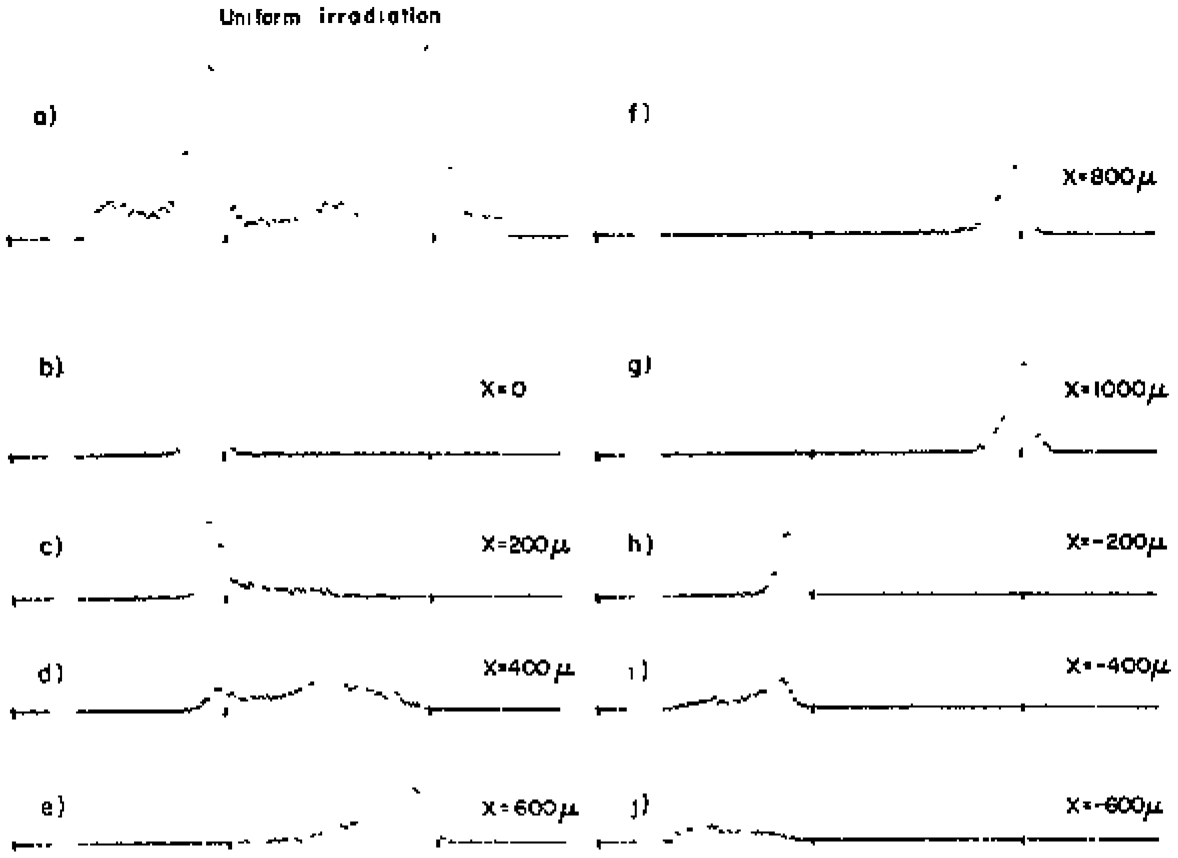


Fig. 4 Accuracy in the direction orthogonal to the wires.

Collimated source of 5.9 keV X-rays, 0.1 mm wide. Three central sense wires trigger the system.

a) Uniform irradiation
b) Beam centred approximately on a sense wire: $y = 0$
c) $y = +0.2$ mm
d) $y = +0.4$ mm
e) $y = +0.6$ mm
f) $y = +0.8$ mm
g) $y = +1.0$ mm
h) $y = -0.2$ mm
i) $y = -0.4$ mm
j) $y = -0.6$ mm.

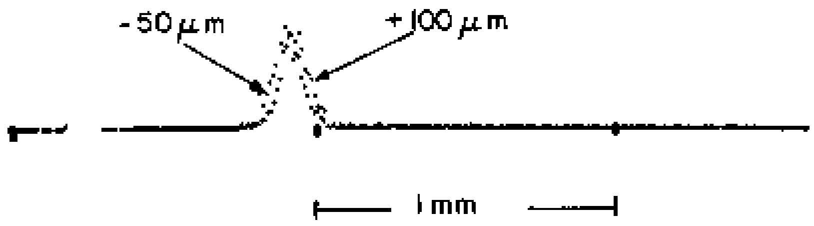


Fig. 5 Right-left effect.

Superposition of the distributions at $x = -50$ μm and $x = +100$ μm.

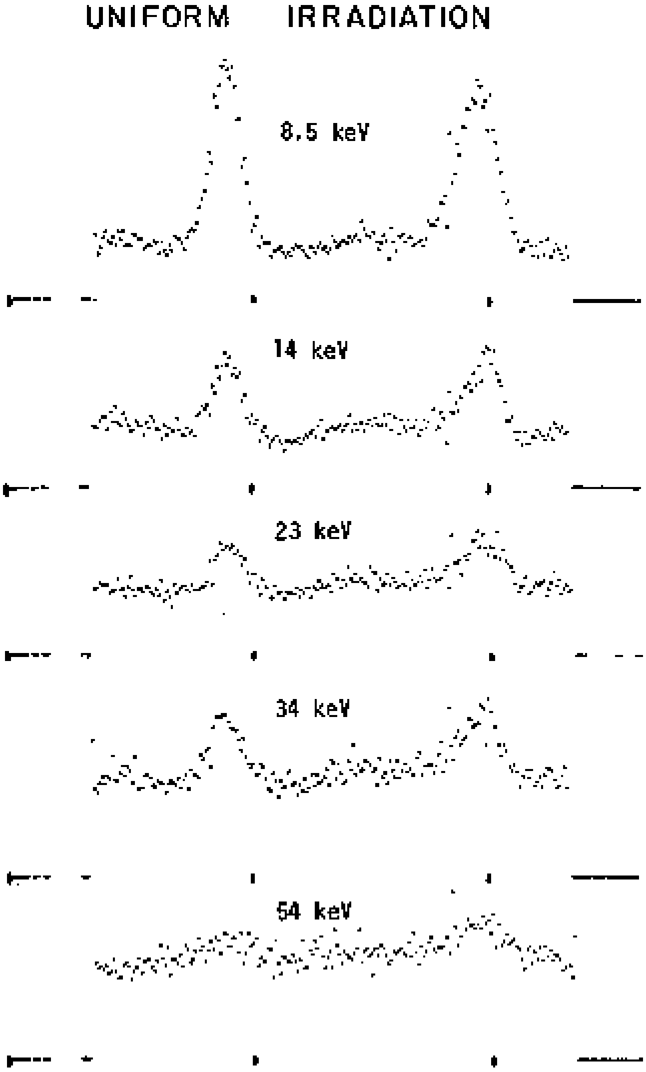
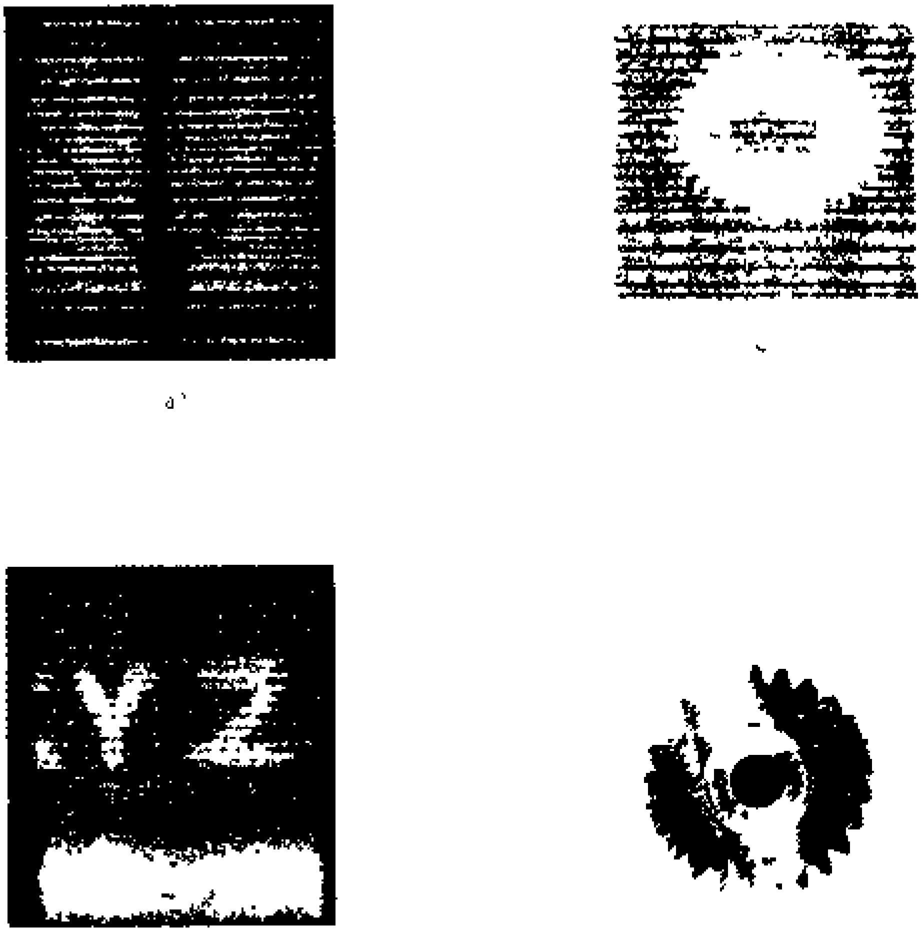


Fig. 6 Localization as a function of X-ray energy.

Response to uniform irradiation with X-rays of different energies. The disappearance of the peaks at higher X-ray energy indicating that the size of the electron cloud liberated by a photoelectron is extending over several wires.

a) 8.5 keV
b) 14 keV
c) 23 keV
d) 34 keV
e) 54 keV.



(a)

(c) (d)

Fig. 7 [illegible] plasma

[illegible]

(a) [illegible] connected [illegible] impedance line [illegible]

(b) [illegible]

(c) [illegible]

(d) [illegible]