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Section A

Letter to the Editor

The energy linearity of gaseous xenon radiation detectors for X-rays with energies between 2 and 60 keV: Experimental results

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The energy linearity of gaseous xenon radiation detectors for X-rays in the 2 to 60 keV energy range has been shown experimentally to have a noticeable discontinuous decrease of 92 ± 10 eV near the 4.8 keV L shell threshold. Apart from this discontinuity the behaviour is practically linear. A discussion of the results is presented.

The average number of primary electrons, N, produced by ionizing electromagnetic radiation in a gas has been, until recently, assumed to vary linearly with the photon energy [1–5] which implies a constant value for w, the average energy to produce an ion pair. For other kinds of radiation like heavy charged particles and electrons nonlinearity effects have already been described in the literature [6–8].

However, for X-rays, recent results [9–11] have shown that, for the case of xenon and energies near the L and M shells of this atom, nonlinearity effects do occur, the clearest one being near the L_{III} subshell threshold where a discontinuity was measured. While some authors have measured an increase in N to the right of the L_{III} discontinuity [10], recent calculations [12] predict a decrease. Effects near the K shell threshold have not yet been reported nor calculated. To clarify this situation we have carried out the present work.

While the linearity problem is important for both gas proportional scintillation counters (GPSC) and standard proportional counters, due to the superior energy resolution of the first type of detector, nonlinearity effects are easier to measure with them. Therefore we carried out experiments with one of these detectors [13], filled with pure xenon at 1200 mbar, which has a 4 cm drift region and an energy resolution of 8.0% for 5.9 keV X-rays. The X-ray lines available were the K_α ones for a few elements, some excited with a ^{244}Cm X-ray source (Si, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn and the W and Pb L_α lines) and others with a ^{244}Cm alpha source (Sb, I, Ba, La, Dy, Tm, Ta, W and the backscattered Pu L_β line). Although only relative values of N can be measured, close to absolute values were obtained assuming a value for w equal to 22.4 eV for 5.9 keV [12] (see fig. 1) and 21.7 eV for 25 keV [12] (see fig. 2).

The experimental results obtained are plotted in figs. 1 and 2 and show indeed a decrease of N of about 4.1 ± 0.5 electrons (which corresponds to a jump in the energy linearity of 92 ± 10 eV) to the right of the 4.8 keV L threshold (fig. 1), in agreement with the calculated results of ref. [12] (a partial decrease of 65 eV at the L_{III} subshell, of 15 eV at the L_{III} subshell and of 15 eV at the L_I subshell) rather than with the experimental ones presented in ref. [10] (an increase of about 50 eV at the L_{III} subshell). The magnitude of the discontinuity we measured at the L shell is also in agreement with the sum of discontinuities at the three subshells (L_{III} 59 eV, L_{II} 22 eV and L_I 5 eV) presented in ref. [11] and measured using synchroton radiation, but it is not clear in this work if what was measured is an energy increase or a decrease. As shown the N value for the V K_α line is slightly above the straight line fitting to the ones for the Cr, Mn, Fe, Ni, Cu and Zn K_α lines, and the W and Pb L_α lines, in agreement with fig. 1b of ref. [12], for energies between the L_{III} and L_{II} edges.

The results for X-ray energies around the K edge of Xe (34.6 keV) obtained with the elements we had available, are shown in fig. 2. In this case the slight discontinuity shown is within the experimental errors (about 10 electrons, corresponding to about 200 eV). However more accurate results are needed to detect any eventual anomaly which requires the use of detectors with longer absorption regions and K_α lines of the rare earth elements nearer the 34.6 keV energy such as Ce, Pr and Nd.

Besides the experimental study, the linearity problem can also be approached in a different way: from

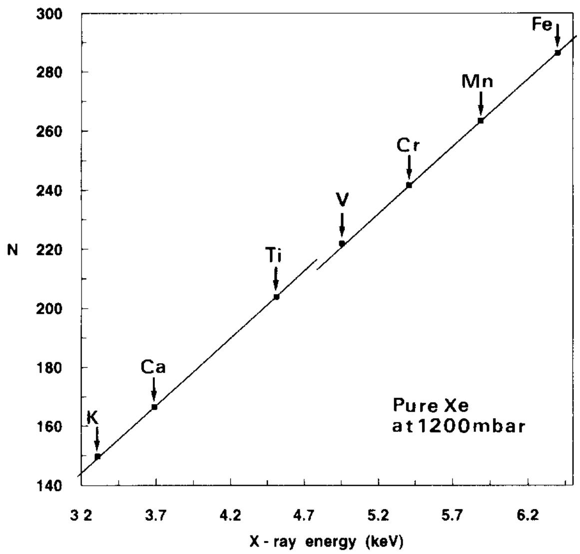

Fig. 1. Average number of primary electrons, N, produced in a xenon GPSC [13], as a function of the X-ray energy for the K_α lines of K, Ca, Ti, V, Cr, Mn, and Fe targets, excited with a ^{244}Cm X-ray source. The solid straight lines correspond to the best linear fit to the experimental points of each side of the edge (Si, S, Cl, K, Ca, Ti K_α lines for the left side, and Cr, Mn, Fe, Ni, Cu, Zn K_α lines and W and Pb L_α lines for the right side). These values were obtained from the MCA calibration assuming a value of $w = 22.4$ eV (the average energy to produce an ion pair) at 5.9 keV [12].

the calculated w values for xenon [12] other nonlinearity effects can be predicted since, within the shells, w decreases as E increases. Indeed the calculated variation of w (in eV) with the energy E (in keV) (fig. 3 of ref. [12]) can be fitted with a series of powers of $\ln(E)$. From these fittings the variation of N with the energy can be calculated:

$$N = (10^3 \times E)(23.171 - 1.3072 \ln(E) + 0.45727 \ln^2(E) - 6.9387 \times 10^{-2} \ln^3(E))^{-1} \quad (1)$$

for energies between 1.2 and 4.7 keV, and with the expression

$$N = (10^3 \times E)(26.044 - 3.4517 \ln(E) + 0.94533 \ln^2(E) - 9.0769 \times 10^{-2} \ln^3(E))^{-1} \quad (2)$$

for energies between 5.5 and about 34 keV.

Eq. (1) when approximated by a Taylor series leads to

$$N = -2.787 + 45.721\ E + 0.111\ E^2 - 7.660 \times 10^{-3}\ E^3, \quad (3)$$

while a Taylor series for eq. (2) is

$$N = -12.503 + 46.855\ E + 1.792 \times 10^{-2}\ E^2 - 2.780 \times 10^{-4}\ E^3. \quad (4)$$

As can be seen only the constant and the linear terms of eqs. (3) and (4) are significant, leading to results which differ by less than 0.7% from those obtained by eqs. (1) and (2), respectively, for the energy range considered. This means that although the continuous variation of w with E cannot be neglected its effect on N is small and so, apart from the discontinuities near the subshells thresholds, N varies almost linearly with the energy.

A better linear approximation for N is then obtained using a linear fitting to the values of E/w calculated by the Monte Carlo method [12]:

$$N = 46.1\ E - 3.2 \quad (5)$$

for the 1.2 to 4.7 keV energy range, and

$$N = 4.66\ E - 10.7 \quad (6)$$

for the 5.5 to 34 keV energy range; both fittings are within 0.3% of the respective values [12], and the difference between the two at 4.78 keV shows a decrease of N of about 5 electrons. Again, although the linear approximation is quite good, the slopes and offsets for the two energy ranges are slightly different.

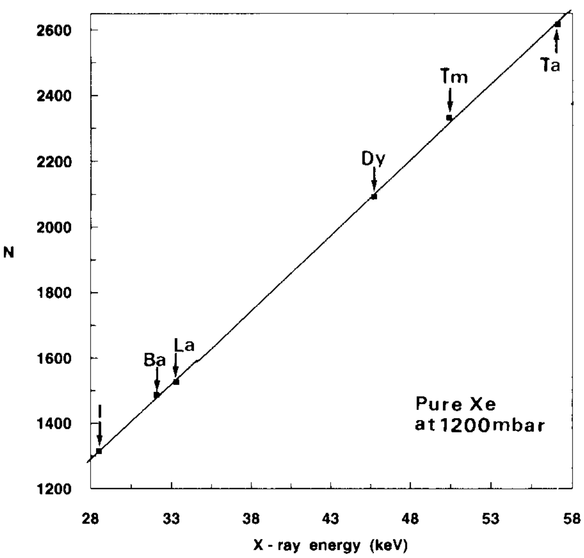

Fig. 2. Average number of primary electrons, N, produced in a xenon GPSC [13], as a function of the X-ray energy for the K_α lines of I, Ba, La, Dy, Tm, Ta targets excited with a ^{244}Cm alpha source. The solid straight lines correspond to the best linear fit to the experimental points of each side of the edge (Sb, I, Ba, La K_α lines and the backscattered Pu L_β line for the left side, and Dy, Tm, Ta, and W K_α lines for the right side). These values were obtained from the MCA calibration assuming a value of $w = 21.7$ eV (the average energy to produce an ion pair) at 25 keV [12].

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