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"THE SECONDARY SCINTILLATION OUTPUT OF XENON IN A UNIFORM FIELD GAS PROPORTIONAL SCINTILLATION COUNTER"

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Abstract

Data on the xenon uniform field gas proportional scintillation counter is presented. The energy resolution obtained for 8.1 MeV α-particles was 1.2%.

Measurements for pressures from 600 to 1500 Torr showed that the "reduced light output", i. e. the number of photons produced by a single electron travelling the unit of distance, divided by the gas pressure, depends only on the reduced electric field but not on the gas pressure. An empirical equation for this quantity is given. The role played by different mechanisms is discussed.

1. Introduction

The gas proportional scintillation counter, a scintillation counter where the light is produced by the primary ionization electrons while drifting through a fairly strong electric field (strong enough for excitation but not for ionization of the gas molecules) has been the subject of recent researches due to the good energy resolutions obtained (for a survey see Policarpo's article[1]).

After the initial work with cylindrical field geometries[2] followed by the work with a spherical anode[3], emphasis is being put recently on the two grid uniform field gas proportional scintillation counter[4-9]. This geometry seems to offer advantages over the others for nuclear counting experiments and on the other hand allows the study of the dependence of the secondary scintillation upon the electric field intensity, the gas composition and pressure. The results obtained for the cylindrical and spherical non-uniform field geometries do not allow that study, and very little results have been published for uniform fields.

The best energy resolution so far obtained for charged particles was 1.6% for 8.1 MeV α-particles with an uniform field argon filled counter[8]. As xenon is known to give more light than argon a further improvement in the energy resolution seems possible.

These reasons led us to carry out the study of the xenon filled uniform field gas proportional scintillation counter.

2. Experimental Set-up

The experimental system used is essentially the same as the one described before [4,6,8] but with a 1200 $\mu g/cm^2$ p-terphenyl wavelength-shifter deposit and filled with xenon at pressure from 600 to 1500 Torr. Due to the large amount of light produced in xenon, to avoid saturation and to increase the stability of the EMI 9656 QR photomultiplier[10] only the first four dynodes were connected and fifth one was used as anode.

3. Experimental Results

a) Energy resolutions

Fig.1 shows a spectrum for 8.1 MeV α-particles with an energy resolution of 1.2%. This figure is the experimentally obtained one and includes the fluctuations of the phototube gain and the straggling in the 1.616 mg/cm^2 Melinex window. The straggling contribution was measured to be 0.84% using a high resolution silicon detector. Therefore the intrinsic resolution of the counter is below the 1% figure. This means that even for charged particles the gas proportionalscintillation counter can become competitive with other counters.

The energy resolution obtained for the 21.988--22.163 keV X-ray group from a ^{109}Cd source was 7.6% for xenon at 1431 Torr and for voltages of grid 1, V_1=4 kV, and of grid 2, V_2=1.2 kV. This figure is worse than the one obtained by Policarpo et al.[3] (4.5%) due to the fact that a single photomultiplier with no reflector was used.

b) The secondary scintillation output

The variation of the intensity of the secondary scintillation as a function of the voltage difference, V_1-V_2, for a constant distance of 6mm between the grids, was measured for pure xenon at pressures, p, of 600, 900, 1200 and 1500 Torr. The maximum voltages used were limited by sparking. The amplitude of the secondary scintillation pulses were normalized to the ones from a NaI (Tl) crystal excited by 0.661 MeV γ-rays. As the number of photons produced in the crystal is roughly equal to 5000, a rough figure for the number of photons reaching the photomultiplier can be estimated. For 8.1 MeV α-particles in xenon at 600 Torr and V_1-V_2=3000 V that figure becomes 2.9×10^6 photons. If we take into account the fact that there is no reflector in the counter inner walls, at most, only half (or even less, due to the wavelength--shifter effect) of the total light reaches the photomultiplier which means that the total number of photons produced is about 6×10^6. As an 8.1 MeV α-particle produces 3.86×10^5 electrons in xenon the total number of photons, n, produced by a single electron travelling between the grids is around 16. Since these figures do not take into account the variation of the photocathode efficiency with wavelength nor with the reflectivity of the walls, they are estimates and should be used only as a guide.

Rather than plotting the variation of n with the electric field intensity, we plot in Fig.2 the "reduced secondary light output" γ (defined as the number of photons produced by a single electron travelling the unit of distance, x, divided by the gas pressure, p): $\gamma=\frac{1}{p}\frac{dn}{dx}$ (expressed in photons/electron $cm^{-1}Torr^{-1}$) as a function of the reduced electric field: E/p (Volt cm^{-1} $Torr^{-1}$).

The results obtained show that, even for fields well above 1 Volt cm^{-1} $Torr^{-1}$ there is no dependence of the reduced light output on the gas pressure[11,13]. The empirical equation $\frac{1}{p}\frac{dn}{dx}=(-0.0074 + 0.0066\ \frac{E}{p})\pm 0.002$ photons/electron cm^{-1} $Torr^{-1}$ describes fairly well the behaviour of the secondary scintillation. It shows that for reduced fields lower than about 1 Volt cm^{-1} $Torr^{-1}$ there is practically no secondary light produced; above this threshold the variation is a linear one. Although, as it was referred to before, the absolute number of photons is subject to appreciable errors, the relative figures are fairly accurate; the relative error of $\pm$ 0.002 is estimated.

4. Discussion of the Experimental Results

The above empirical equation can be used to estimate the light output and so the energy resolution of new designs of gas proportional scintillation counters with any electric field geometry, at any pressure. For uniform field counters with grids at a distance of x centimeters and voltages V_1 and V_2, that equation leads to

$$n=-0.0074\ px + 0.0066(V_1-V_2) \quad \text{photons}$$

which means that for fields of a few kilovolt n can be sufficiently large so that for each electron there are 3 or 4 photoelectrons released from the photomultiplier cathode. Thus, the contribution of the photomultiplier statistics to the energy resolution can be made smaller than the contribution of the statistical fluctuations in the average number, $\bar{N}$, of the primary electrons, which is equal to $(2.36F\bar{N})^{\frac{1}{2}}$ where F, the Fano factor, is 0.17 for xenon. Thus, the limiting energy resolution of a gas proportional scintillation counter is equal to the one of a noiseless ionization chamber and it can be approched when the condition

$$n\gg 1$$

is verified.

As it has been discussed before[3,12], due to the fact that noise can be neglected in a gas proportional scintillation counter and that there is very little or no charge multiplication, the energy resolution of this counter is better than the one of a standard proportional counter.

If the distance between the grids is increased by Δx (cm) keeping the voltage and the gas pressure constant, the number of photons is increased by:

$$\Delta n=-0.0074\ p\ \Delta x$$

Therefore, if the grids are not exactly parallel and their average distance, x, has fluctuations of the order of Δx, the contribution of these to the energy resolution is of the order of:

$$\frac{\Delta n}{n} \approx \frac{\frac{\Delta x}{x}}{1-\frac{0.0066(V_1-V_2)}{0.0074\ px}}$$

which means that for the conditions of the spectrum of Fig.1, if for example the fluctuations of the distance are of the order of 2.5% the energy resolution is deteriorated by 1%. For the cases where the numerical values are such that $V_1-V_2 \approx px$, instead of having a decreased contribution we have an increased one: the 2.5% fluctuations lead to a deterioration of the order of 25%.

The reduced light output, γ, as defined before should be in principle equal to the photon production coefficient of Massey[14], α_{ph}, divided by the gas pressure, p. However as α_{ph} doesn't take into account the wavelength-shifter photon conversion, we must write:

$$\gamma=\alpha_{sc}\frac{\alpha_{ph}}{p}$$

where α_{sc} is the efficiency coefficient for photon conversion.

Let us assume that the photon production is due to the two body electron-atom collisions (the three and more body processes being absent). Then, as the energy acquired between two collisions depends only on E/p, and the number of photons depends only on the number of collisions (for the same energy acquired between collisions) the reduced secondary light output as a function of the reduced electric field should be independent on the gas pressure[11]. As said before our experimental results (Fig. 2) confirm this prediction. This is in disagreement with Szymanski and Herman's results[13]. The discrepancy might result from the fact that in their experiments the nuclear radiation interacted with the gas in the light production region. Thus primary electrons produced at different points travelled along different distances and produced different amounts of light; as the gas pressure is increased, the radiation is more absorbed and the electron paths get longer. Our experimental set-up doesn't have this inconvenient.

The referred to above independence on the gas pressure shows that indeed the excitation of xenon atoms by electrons is due mainly to two body processes. But as the mean free path of electrons in xenon at atmospheric pressure is at least 1.6 x 10^{-4} cm (the maximum of the total cross-section is around 5 x 10^{-16} cm^2) and the threshold for secondary light production is around 800 V/cm, an electron acquires between collisions at least an energy of 0.13 eV. This implies a very low probability for an electron to reach, in a single step process, the energy of the first metastable state of xenon at around 8 eV. However, a lower cross-section and the fact that an electron loses very little energy in elastic collisions, make possible the direct excitation of xenon atoms by electrons. Let us now consider other theories for the production of secondary light. As it has been shown before[4] due to the fact that the secondary scintillation is indeed produced between the grids, the theory of Braglia et al.[15] doesn't seem to explain it for the electric field intensities used in gas proportional scintillation counters. The bremsstrahlung theories (for a discussion see reference [11]) cannot be ruled out. However they might have difficulty in explaining the threshold for light production at about 1 Volt cm^{-1} $Torr^{-1}$.

The fact that an electron needs to travel across a difference of potential of 200 Volts to produce one photon, means that the efficiency for conversion of electrical into optical energy it is of the order of 2 or 3% for the reduced fields used. This figure is of significance for laser work.

As the energy resolution of gas proportional scintillation counters is improved the scope for applications increases. Besides the ones described before: low energy X-ray spectrometry, fast coincidence experiments with X-rays, internal gas counting (e.g. carbon-14, tritium and alpha particles), etc., applications to low energy proton spectrometry seem practicable.

Acknowledgements

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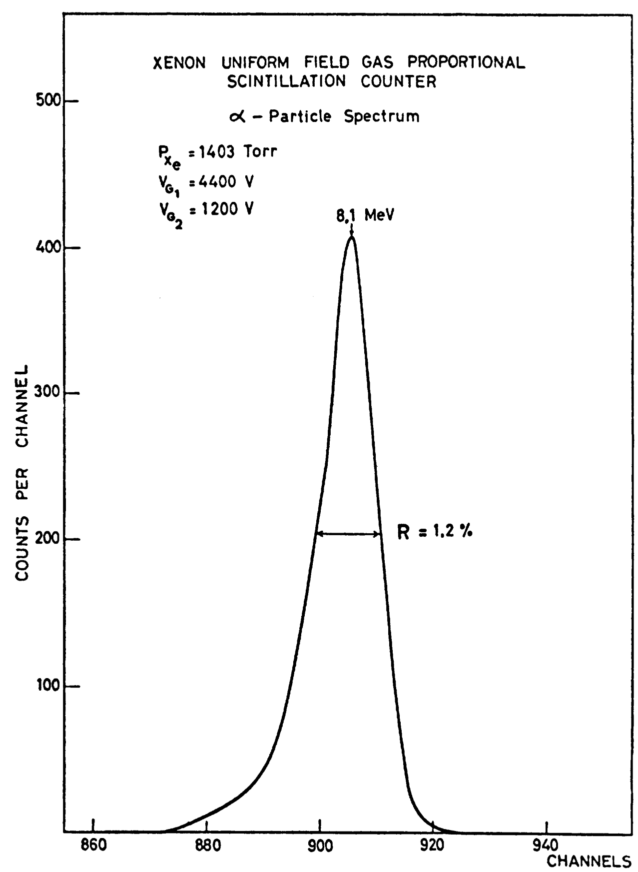

Fig. 1 — Alpha particle spectrum for a xenon uniform field gas proportional scintillation counter.

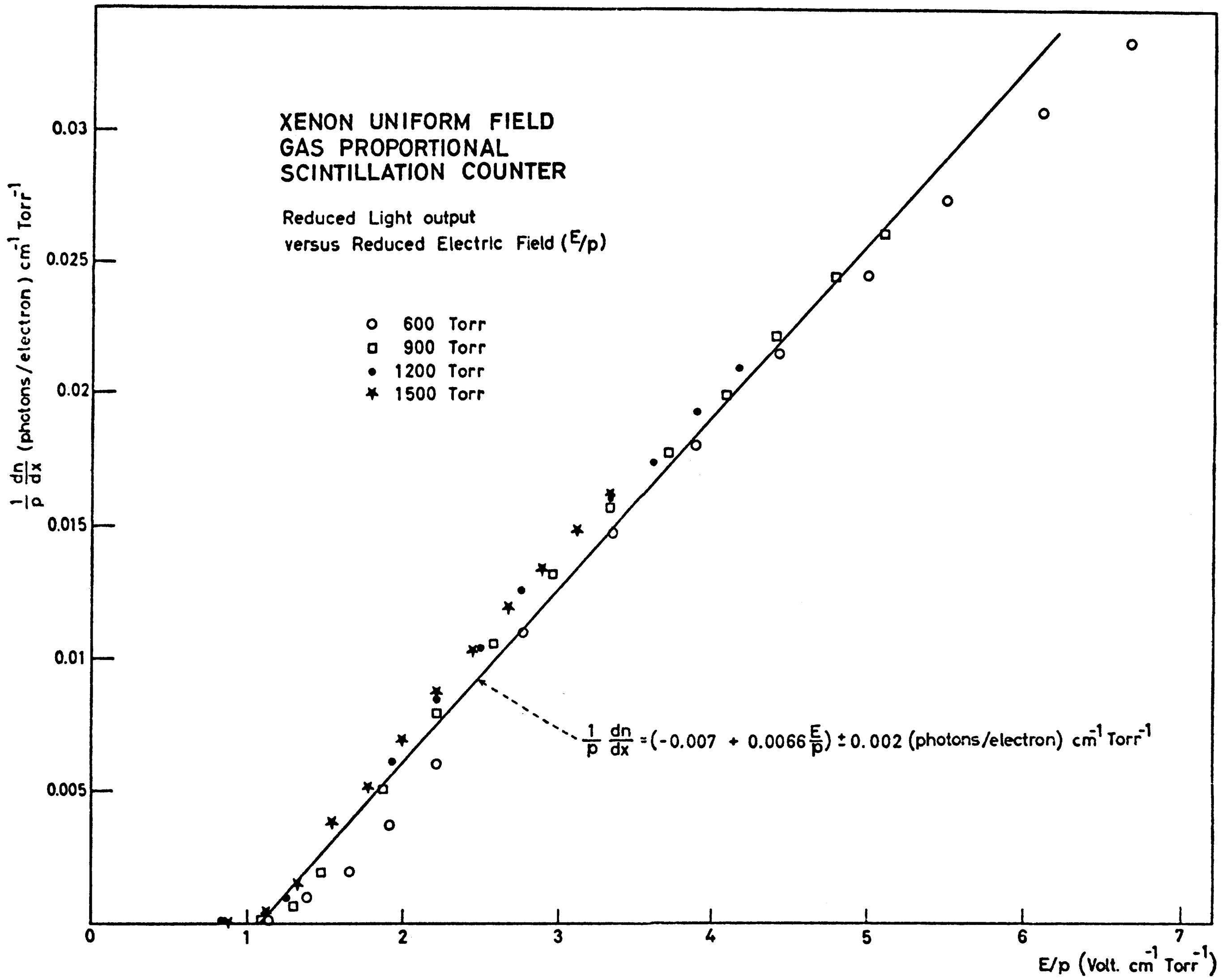

Fig. 2 — Reduced secondary light output for a xenon uniform field gas proportional scintillation counter with p-terphenyl wavelength-shifter.