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THE SECONDARY SCINTILLATION OF RARE GASES UNDER THE INFLUENCE OF MAGNETIC FIELDS

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Abstract

The influence of magnetic fields on the secondary scintillation of xenon and argon is studied. A small gas cell is used with excitation by alpha-particles and magnetic fields perpendicular to the direction of the electric fields. For reduced electric fields normally used in gas proportional scintillation counters the intensity of the secondary scintillation remains constant, within an accuracy of about ±1% for xenon and ±2% for argon, when the magnetic field intensity varied from 0 to 0.4 Tesla. A discussion and interpretation of the experimental data obtained is presented. It is concluded that gas proportional scintillation counters can be used in high magnetic field environments.

1. Introduction

Noble gases when excited by nuclear radiation emit light, the so-called primary scintillation. If an electric field is applied the primary electrons produced by the radiation in the gas may gain enough kinetic energy to excite (but not necessarily to ionize) the noble gas atoms which in the de-excitation processes produce light, the so-called secondary scintillation [1]. Its intensity may be a few orders of magnitude larger than that of the primary scintillation. This effect led to the development of a new type of detector: the gas proportional scintillation counter [1-2]. As a consequence of the large intensity of the secondary scintillation the energy resolution of a gas proportional scintillation counter it is quite good and can reach figures which for X-rays are a factor of two better than the ones for the standard proportional (ionization) counter [3], and can have areas as large as $100\ \mathrm{cm}^2$ [4]. These detectors arose a lot of interest in fields ranging from astrophysics (X-ray astronomy) to high energy physics [4-5].

The variation of the intensity of the secondary scintillation with the strength of the electric field has been already studied for xenon (the most used noble gas) and the experimental points [6] are fairly well fitted by a straight line that crosses the reduced electric field axis at $1\ \mathrm{V\,cm^{-1}\,Torr^{-1}}$.

The study of the influence of magnetic fields on the secondary scintillation intensity has not yet been reported in the scientific literature. However this study is essential if gas proportional scintillation counters are to be used in high magnetic field environments like the ones met in high energy physics.

The present work was done with the purpose of filling this gap.

2. Experimental Set-Up

The experimental system used for those measurements is shown in Fig. 1. A small gas cell filled with a noble gas is placed between the magnet polar pieces and is separated from the rest of the system by a quartz window.

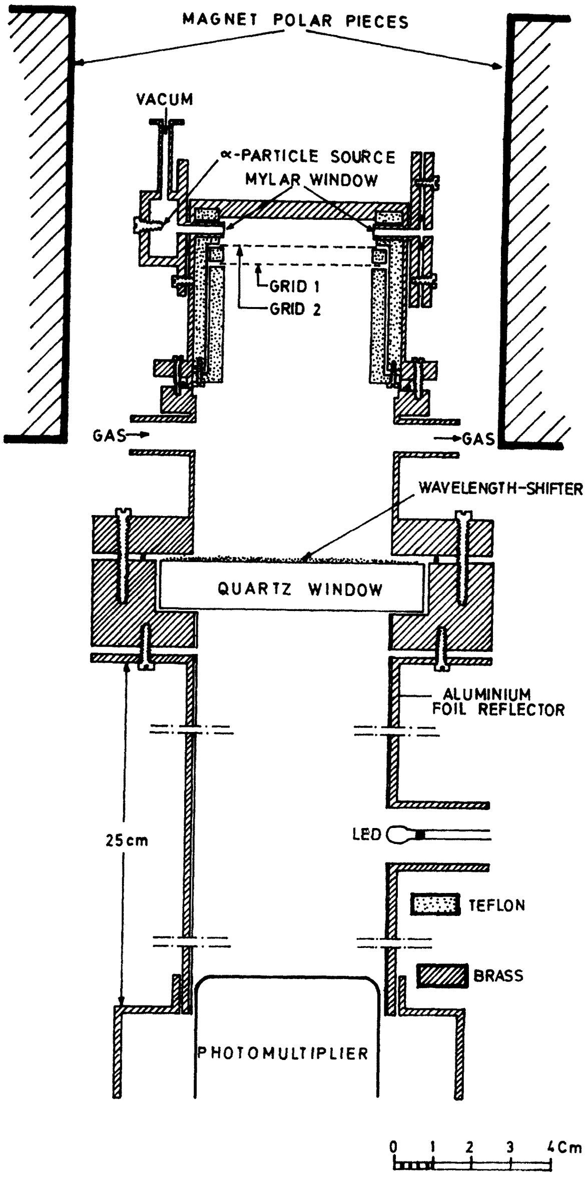

Fig. 1 - Experimental set-up

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A Th C - C' source injects alpha-particles into the gas cell through a Mylar window. The collimated alpha-particle beam being parallel to the magnetic field $\vec{B}$ is therefore not deflected. The primary ionization electrons drift towards grid 2 and once they reach the 6 mm wide region between this grid and grid 1 they meet a strong electric field $\vec{E}$ and a secondary scintillation is produced. As $\vec{B}$ is perpendicular to $\vec{E}$ the Lorentz force on the drifting electrons will be at a maximum and so any effect of $\vec{B}$ on the secondary scintillation intensity is expected to be enhanced. The 56 UVP photomultiplier was well shielded with high permeability magnetic materials and placed at the end of a tube, 25 cm away from the quartz window, in order to reduce the influence of the magnetic field on its gain. The mainly ultraviolet secondary scintillation light was shifted towards the sensitive region of the photomultiplier with a p-terphenyl wavelength shifter. The light collection efficiency was increased by lining the tube with aluminium foil reflector.

The efficiency of the magnetic shielding of the photomultiplier was tested with a pulsed GaP light emitting diode (LED) type EN 482 and the photomultiplier gain was found to shift by less than about 1% when the magnetic field intensity varied from 0 to 0.4 Tesla. A small amount of residual magnetization of the shielding materials seems to limit the accuracy of the measurement of the efficiency of the shielding.

The magnetic field intensity was uniform within about ± 2.5 % for the region between the two grids. The values quoted in Tesla are the ones measured in the central part.

The gas system was pumped down to 10^{-5} Torr before being filled with high purity gases. To keep the purity high a small pump circulated the gas through a calcium purifier similar to one described before [1].

3. Experimental Results

The secondary scintillation for xenon starts [6] at reduced electric fields of 1 V cm^{-1} $Torr^{-1}$ and it is useful for gas proportional scintillation counter work for fields up to at least 5 V cm^{-1} $Torr^{-1}$. Thus this is the region where the influence of magnetic fields should be studied. While the higher electric field region it is the most interesting one for gas proportional scintillation counter work, the lower field region it is the one where the influence of $\vec{B}$ on the secondary scintillation intensity it is expected to be stronger. For argon fields as high as those for xenon could not be reached.

The experimental measurement of the influence of magnetic fields on the intensity of the secondary scintillation was done by measuring the shifts of the highest energy peak of the alpha particle scintillation spectrum with a multichannel analyser. The electric field intensity remained constant while the magnetic field varied from 0 to 0.4 T. The LED was pulsed at a rate similar to that of the alpha-particle pulses and thus a real-time test of the influence of $\vec{B}$ on the photomultiplier gain could be carried out at the same time as the alpha-particle spectrum was taken.

The experimental results for xenon at a pressure of 1390 Torr are shown in Fig. 2 for reduced electric field intensities of 3.59, 2.87, 2.15 and 1.43 V cm^{-1} $Torr^{-1}$. These curves show that, within an experimental error of about ± 1%, magnetic fields up to 0.4 Tesla don't affect the xenon secondary scintillation intensity. The ±1% figure it is estimated and includes the statistical error (typical values are ± 0.25 %), the residual influence of $\vec{B}$ on the photomultiplier gain and the estimated instabilities of the photomultiplier (approximately ± 0.25 %).

The experimental results for argon at a pressure of 1610 Torr are shown in Fig. 3 for reduced electric fields of 2.48, 2.17, 1.87 and 1.24 V cm^{-1} $Torr^{-1}$. These curves show that within an estimated experimental error of ± 2% magnetic fields up to 0.4 Tesla don't affect the argon secondary scintillation intensity. The errors for argon are larger than those for xenon due to the statistics and to larger errors in measuring the residual influence of $\vec{B}$ on the photomultiplier gain.

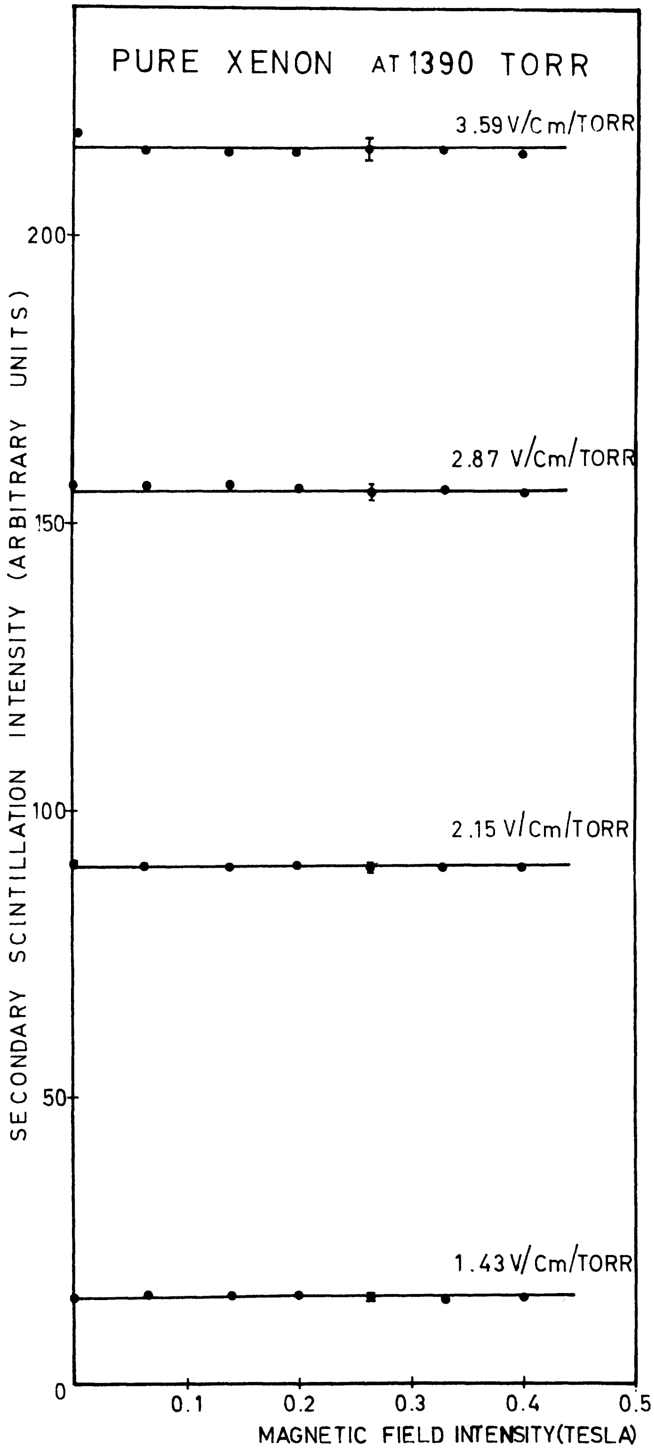

Fig. 2 - Variation of the secondary scintillation intensity of xenon with the magnetic field intensity.

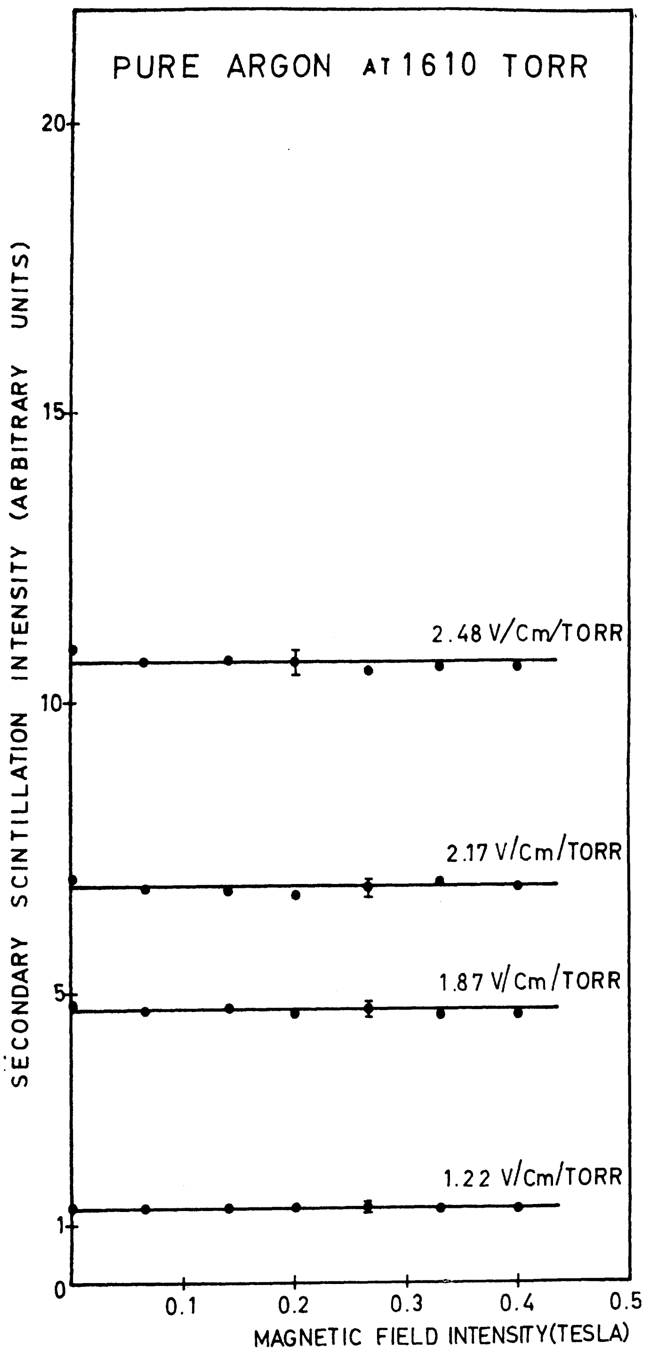

Fig. 3 - Variation of the secondary scintillation intensity of argon with the magnetic field intensity.

4. Discussion

The influence of magnetic fields on the drifting properties of electrons in gases has been the subject of both experimental and theoretical work, due to its importance in drift chamber experiments for high energy physics[7-9]. Those works led to the conclusion that, as a result of the Lorentz force, the electrons drift along a direction which makes an angle with the electric field vector that can reach values as large as 15° for standard drift chamber gas mixtures with $E/p \simeq 1\,\mathrm{V\,cm^{-1}\,Torr^{-1}}$. This is a consequence of the relatively low intensity of the electric fields in drift chambers, the low average electron kinetic energy (the gas mixtures used have molecules with low rotational and vibrational energy states),and the large electron mean free path as the electron approaches the Ramsauer minimum. Indeed the electron energy distribution function obeys a differential equation[9] that has a term with a factor due to the presence of a magnetic field which has the form

$$1 + \frac{e^2 B^2 l_e^2}{2 m \varepsilon}$$

where e is the electron charge, m its mass, ε its energy and l_e the electron mean free path. For the drift chamber working conditions the term

$$\frac{e^2 B^2 l_e^2}{2 m \varepsilon}$$

cannot be neglected due to the large values of l_e and low values of ε.

The situation for gas proportional scintillation counter work it is quite different due to the larger electric fields used, the larger electron kinetic energies involved (gas proportional scintillation counters generally use pure noble gases which have no rotational or vibrational states but only high energy electronic states around and above about 10 eV) and the larger cross-sections for elastic collision which, at energies near the ones for electronic excitation can be about two orders of magnitudes larger than those near the Ramsauer minimum, leading thus to much smaller l_e values. Although some of the approximations used for the calculation of the electron energy distribution function, $f(\varepsilon)$, in drift chambers are no longer valid for gas proportional scintillation counter work, it is reasonable to assume that if

$$\frac{e^2 B^2 l_e^2}{2 m \varepsilon} << 1 \qquad (1)$$

the distribution function, $f(\varepsilon)$, it is not much modified by the influence of $\vec{B}$. If $f(\varepsilon)$ doesn't change, the excitation rate and thus the intensity of the secondary scintillation shouldn't change as well. Let us take for ε the energy of the first excited states (8.3 eV for xenon and 11.6 eV for argon) and use the cross-sections for elastic scattering at those kinetic energies ($4 \times 10^{-15}\ \mathrm{cm}^2$ for xenon and $2 \times 10^{-15}\ \mathrm{cm}^2$ for argon); we obtain for the electron mean free path at the pressures we used the values $l_e = 0.055\ \mu\mathrm{m}$ for xenon and $l_e = 0.095\ \mu\mathrm{m}$ for argon. For the stronger magnetic field used, $B = 0.4\ \mathrm{T}$, inequality (1) takes the form

$5.1 \times 10^{-6} << 1$ for xenon
$10.9 \times 10^{-6} << 1$ for argon

which means that the secondary scintillation intensity should not change with the magnetic field. This agrees with the experimental results shown in Figs. 2 and 3. Even for magnetic fields as large as 2 Tesla, a field intensity typical of high energy physics work, inequality (1) is still verified.

5. Conclusions

The experimental results we presented and discussion we made of these results show that the secondary scintillation intensity of xenon and argon does not change with magnetic fields. Thus gas proportional scintillation counters can work in fairly high magnetic field environments provided care is taken in the following points:

i) Use light pipes to guide the light to well shielded photomultiplier tubes or use photoionization detectors[10].

ii) The influence of $\vec{B}$ on electrons moving in the weak electric field drifting region is corrected as in drift chambers[8-9].

Although the results we presented are for xenon and argon, there is every reason to believe that krypton and mixtures of noble gases have similar behaviour.

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References

1. C.A.N. Conde and A.J.P.L. Policarpo, Nucl. Instr. and Meth. 55 (1967) 105.
2. A.J.P.L. Policarpo, Space Sci. Instr. 3 (1977) 77.
3. M. Alice F. Alves, A.J.P.L. Policarpo and M. Salete S.C.P. Leite, IEEE Trans. Nucl. Sci. NS-22, nº 1 (1975) 109.
4. D.F. Anderson, W.H.-M. Ku, R. Novick and M. Scheckman, IEEE Trans. Nucl. Sci. NS-25, nº 1 (1978) 813.
5. G. Charpak, S. Majewski and F. Sauli, Nucl. Instr. and Meth. 126 (1975) 381.
6. C.A.N. Conde, L. Requicha Ferreira and M. Fátima A. Ferreira, IEEE Trans. Nucl. Sci. NS-24, nº 1 (1977) 221.
7. V. Palladino and B. Sadoulet, Nucl. Instr. and Meth. 128 (1975) 323.
8. F. Sauli - "Principles of operation of multiwire proportional and drift chambers", 1977, Report CERN 77-09.
9. G. Schultz, Thesis - "Etude d'un détecteur de particules a très haute précision spatiale (chambre à drift)", Université L. Pasteur de Strasbourg, (1976); also CERN EP Internal Report 76-19 (1976).
10. A.J.P.L. Policarpo, Nucl. Instr. and Meth. 153(1978) 389.