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THE PROPORTIONAL CHAMBER GAMMA CAMERA

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Abstract

The theoretical and experimental design of a proportional chamber gamma camera using the high-density drift space principle is outlined, for photon energies greater than 100 keV. Detection efficiencies of 50% or more are possible, using two converters, combined with a spatial resolution of 1 mm. Energy resolution is, however, poor.

Experimental results of imaging are given.

Introduction

In previous publications^{1,2)}, the addition of a high-density drift space to a proportional chamber has been shown to provide new possibilities for photon imaging. Such a drift space consists of a solid block perforated with a large number of small holes, close together. By making the block thick enough, a photon will have a high conversion probability. With a correct choice of hole size and spacing, the resulting conversion electron will have a high probability of escaping to a hole, but a low probability of propagating to a second hole. The application of an electric field will drift the electrons produced by ionization out of the holes for subsequent detection by a proportional chamber. If the hole axis is parallel to the direction of the impinging photons, the two dimensions perpendicular to this direction may be resolved to an accuracy determined by the hole size. Here the problem of optimising the converter for photon energies of interest for medical imaging is considered. Only energies greater than 100 keV will be considered: at lower energies a proportional chamber gamma camera has already been demonstrated³⁾, using xenon gas under pressure as the converter.

Converter Design

Calculation of detection efficiency

The theoretical calculation of the converter efficiency has been developed in reference 1, and shown to fit closely to experimental results. Here it is used to optimise the converter geometry and material for various photon energies.

Some refinements have been added to the basic theoretical model:

1. Square holes have been replaced by round ones, packed on a hexagonal pattern.
2. The restriction that the conversion electron only escapes to the nearest hole has been removed. The electron has a probability $P(x)$ of escaping to the hole on one side of the bar, and $P(b-x)$ of escaping to the hole on the other side; b is the bar thickness. The total probability of escape is then $P(x) + P(b-x) - P(x) \cdot P(b-x)$.

3. The experimental electron scattering data of Seliger⁴⁾ has been treated by a minimisation program to obtain best values for the scattering parameters p and A of equation (3) in reference 1.

4. For calculating the Compton contribution to detection efficiency, the detailed form of the conversion electron energy spectrum⁵⁾ has been used, rather than the flat approximation.

5. The escape-peak contribution is not included in the total efficiency since it represents a contribution to the background, rather than the signal.

6. Numerical integration by computer, was used, instead of the analytic solution in reference 1.

7. The thickness of the converter is assumed to be always at least 3 to 4 photon interaction lengths, i.e. the photon conversion probability is close to unity.

8. All sizes are density independent (gm cm^{-2}) to give a clear picture of the effect of the atomic number of the converter material.

Some results of these calculations are now presented.

Converter material

The best photon conversion process for imaging is the photoelectric. This gives a higher energy electron than the Compton effect, and there is no scattered photon that may degrade the spatial resolution by being detected at a distance from the original event.

Fig. 1a

The photoelectric interaction cross-section increases with atomic number, so a material with a high atomic number is desirable for the converter. However, the reason for the increasing photoelectric cross-section, the increasing K-shell energy, implies that the energy of the photoelectron and thus its escape probability decreases with increasing atomic number. In addition, the background from the de-excitation of the K-shell (escape-peak) will be worse for a high atomic number. Thus an optimum choice of converter material exists that minimises Compton and escape peak efficiencies and maximises the photoelectric efficiency. Figure 1a illustrates this clearly for 140 keV photons, where the optimum atomic number is around 50. For an energy of 360 keV (fig. 1b) the optimum atomic number has risen to around 80, whilst for 500 keV (fig. 1c) the optimum is not reached, since it would be at about 150!

Geometrical considerations

For any given hole pitch, an optimum hole size exists: thin bars are desirable to maximise the electron escape probability, but thick bars will stop more photons. Figure 2 illustrates this situation for different pitches, for 360 keV photons stopping in lead (atomic number 82). Obviously the smaller the pitch is, the better. The lower limit to the hole size is mainly a practical problem; and it must be big enough to ensure sufficient ionization for detection. Generally a detection efficiency of around 25% may be obtained with one converter. By using two or more converters, efficiencies greater than 50% should be possible.

Spatial resolution

Obtaining a good spatial resolution is primarily concerned with the operation of the proportional chamber. It has already been shown^{1,2} that a spatial resolution equal to the hole pitch results, provided that photoelectric conversion dominates in the converter. If the hole size is made small, to improve the

detection efficiency, then the limitation is the chamber wire spacing and the readout electronics. In general, it is not difficult to obtain a resolution, at all photon energies, of 1mm: a value much better than the scintillation camera.

Energy resolution

The poor energy resolution of the converter is clearly a disadvantage. Some resolution may be "designed in": efficiency falls at low energies, due to the low energy of the photo-electron; and if the converter thickness is reduced it may be made relatively transparent to higher energy photons. Further discrimination may come from analysing the pulses from the readout system. Amplifier-per-wire readout, with pulse-height information⁶⁾ would be advantageous here. Computational methods of data smoothing and filtering⁷⁾ which already are used for improving scintillation camera images might be particularly beneficial in this case.

Practical considerations

The success of making a good camera depends on the careful design of the converter according to the principles described in the preceding sections. Two general methods of practically realising the converter have been described in reference 1. The first is to use a solid block of slightly electrically conductive material, and the second is to make a sandwich of alternating conducting and insulating sheets. For either of these constructions, many material possibilities exist: metal alloys or compounds, powders and foams, doped plastics, resins or glasses, and wires and meshes. For making the holes, spark-erosion machining, chemical etching and mechanical drilling methods have been used. The most economical technique was drilling with a numerically-controlled printed-circuit drill. Chemical etching gives very accurate results, but is more expensive as each plate must be treated separately. Two experimental chambers are now described.

Experimental Chambers

The channel-plate converter

Advantage has been taken of channel-plate technology⁸⁾. The end-product of this technology is just the type of structure required for this work: a matrix of very small, slightly electrically conductive tubes. The tubes are usually of lead oxide glass and the electrical conductivity is created by heating the tubes in an atmosphere of hydrogen at about 350°C, when a surface layer of lead oxide is reduced to lead.⁹⁾ A 1cm thick converter of this nature, made of 10% lead-oxide doped glass was investigated. See fig. 3. Its hole size was 0.2 mms. on a 0.25 mm pitch. For a drift voltage greater than 500 volts the converter started to discharge, presumably due to the rough surface of lead grains on the glass. Even at this comparatively low voltage, however, efficient electron drifting through the very small holes was obtained. Figure 4 shows encouraging preliminary imaging results for 60 keV photons. At 140 keV the escape peak background from the lead K-shell was severe, as fig. 1a predicts. Further investigations of this converter are planned.

Fig. 3

Fig. 4

Position imaging

Work, to date, had concentrated on chambers designed for positron imaging, i.e. the detection of 500 keV photons. Figure 5 shows one of two 10 x 10 cm. chambers now in operation. "Sandwich" type converters are used. Each is made of 75 lead-bismuth plates, 0.25 mm thick, interleaved with 0.1 mm thick glass-fibre epoxy resin sheets. The hole size is 0.8 mm and the pitch 1 mm. Holes were chemically cut in the lead-bismuth sheets and drilled in the epoxy. Two converters are used in each chamber; they are offset so that the bars of the one are behind the holes of the other. Readout is the digital centre-of-gravity method¹⁰⁾.

Fig. 5

For 660 keV photons from ^{137}Cs the detection efficiency is 15% and the spatial resolution is 1 mm (fig. 6a), as expected. It is interesting to note (fig. 6b) that good spatial resolution is still obtained at 1.25 MeV, despite the predominance of Compton scattering. Since the detection efficiency is 30% at this energy, the chamber could have applications for non-destructive material testing¹¹⁾. Finally, fig. 7 shows the image of a 1 mm slit in a lead block 5 cms. thick. Good linearity is evident.

Fig. 6a

Fig. 6b

Fig. 7

Conclusion

The main interest of this camera is for higher photon energies, where energy resolution is not so important. Its first application will be as a tool for solid state physics research: the measurement of the angular correlation of positron annihilation radiation¹²⁾. The good spatial resolution of the chamber over a relatively large area will provide a significant experimental advance. At lower energies the camera offers cost, size and spatial resolution advantages over the scintillation camera. A further advantage may accrue from the combination of the collimation and detection possibilities of the converter. It may be possible to optimise such an "active-collimator" to better the overall imaging efficiency of the usual collimator-sodium iodide scintillation camera.

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Figure Captions

Fig. 1. The effect of the converter material on the detection efficiency.

a) 140 keV b) 360 keV c) 500 keV

Fig. 2. The effect of the hole size and pitch of the converter on the detection efficiency.

Fig. 3. A view through the 0.2 mm diameter holes of the channel-plate converter. The channel-plate is 10 cms in diameter.

Fig. 4. Preliminary imaging of a lead stencil with 60 keV gamma rays. The smallest holes visible (sector bottom left) are 1.5 mm diameter on a 3 mm pitch.

Fig. 5. A general view of a chamber constructed for positron imaging. Two converters are used, one each side of the wire planes.

Fig. 6. Spatial resolution obtained from gamma rays collimated by a 0.5 mm slit. Tick marks every 3 mm.
a) 660 keV b) 1.25 Mev.

Fig. 7. The image of a 1 mm slit in a 5 cm thick lead block, from 660 keV gamma rays. The vertical lines are the anode wires of the chamber, spaced at 1.7 mm.