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An educational PET camera model

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Physical principles

In 1925-26 Heisenberg, Dirac, Schrödinger and others had established a non-relativistic quantum mechanical theory for matter on the atomic scale. In 1928 Dirac published a paper [1] that unified quantum mechanics and relativity theory in a relativistic wave equation including the spin of the electron. The negative energy solutions were interpreted as signalling a new kind of matter, antiparticles [2]. When an electron interacts with its antiparticle, the positron, they will annihilate and their masses will be converted into energy, normally appearing as two antiparallel photons. These two simultaneously emitted photons can easily be detected, and with a sufficient number of annihilations and detectors the distribution of annihilation points can be accurately determined. This is the principal of the PET (Positron Emission Tomography) camera introduced in the 1970's.

The PET camera model in Stockholm House of Science [3] is used to explain the principles of positron emission tomography for school pupils in the Einstein theme [4] project and in several project oriented activities. It was built by the Nuclear Physics division of the Physics Department at Stockholm University which produced one of the first PET cameras for medical use in co-operation with Karolinska Hospital in Stockholm [5].

Experimental details

The educational PET camera is a compact, easy-to-handle and transportable device, showing in a pedagogical way the principles of imaging by positron annihilation. For positron annihilation resulting in two annihilation gamma quanta of each 511 keV emitted back to back (180 degrees), a coincident signal in two gamma-ray detectors means that the annihilation took place somewhere on the line joining the two detectors.

The educational camera comprises two pairs of gamma-ray detectors, each pair mounted on a common moveable arm, as shown in the schematic drawing (Fig. 1) and on the photograph (Fig. 2). All detectors are in the same (horizontal) plane. The distance between the two detectors in a pair is 10 cm. The arm of the pair slides along rails. The pair can be moved approximately 10 cm along the straight line defined by the rails, by moving the holder of one of the detectors. The two pairs are moved in perpendicular directions. An area of 10×10 cm^2 between the detectors, in the detector plane, can therefore be scanned for positron emission activities. Coincident signals in both pairs of detectors imply that there are annihilations taking place at the intersection point of the two lines joining the detector pairs (Fig. 2).

In order to have the possibility to check that the annihilation photons are emitted back to back, one of the detectors can be rotated through 20 degrees to either side (Fig. 1). The source is fixed, normally hidden under a cylindrical cover. The location of the source is found by moving the detector arms until maximum counting rate is achieved.

Each gamma-ray detector consists of a scintillator crystal (in this case made of barium fluoride, BaF_2) of surface area 5×5 mm^2 and length 30 mm coupled by optical grease to a photomultiplier (PM) tube. The PM tube transforms the scintillation light created by the gamma-ray in the crystal to an electric current. The integrated current, the charge, is ideally proportional to the energy that the gamma ray deposits in the scintillator crystal. Using Hamamatsu R647-01 PM tubes, that have a 13 mm diameter standard glass window, one does not utilize the fast component of the emission spectrum of the scintillation light in BaF_2 .This does, however, not affect the performance of the camera in any significant way. The positron-emission activities used are in general very low so there is no need for very short time windows in the coincidence conditions. The major part of the light generated in the scintillator belongs to the long wave-length part of the spectrum, giving a reasonable energy resolution. No specific energy cuts have to be made as the gamma ray background from other sources than the annihilation process is low. If better time and/or energy resolution are required, the PM tube Hamamatsu R647-04, with exactly the same dimensions and pin configuration, but with a window of fused silica, is an alternative in order to collect more of the scintillation light. The detector assembly, with a layer of mu metal around the PM tube to protect from the influence of magnetic fields, is robustly mounted in a cover consisting of a black plastic cylinder in the front and a brass cylinder attached to the box holding the voltage divider (Fig. 2).

The electronics consists of both standard commercial and home-built modules. The anode signal of each detector is fed to a leading edge discriminator, the purpose of which is to discriminate against small anode signals, mainly noise, from the PM tube, and to generate a standard output signal with a length of 50 ns indicating that the detector is hit by an annihilation quantum of 511 keV. The discriminator level is chosen as low as possible to obtain maximum efficiency. The two pairs of 50 ns long output signals are each fed to a coincidence unit. In case of a coincidence the output signal is fed to a module which generates a sound of a frequency, different for the two detector pairs. It is also fed to a light emitting diod attached to each detector assembly of the pair, the light emitting diodes emitting red light for one pair and blue light for the other pair.

As a positron emitter the nuclide ^{68}Ge with a half-life of 288 days is used. It decays by electron capture to ^{68}Ga which in turn decays to 90% by positron emission to ^{68}Zn. The activity of ^{68}Ge is deposited in a small cavity at the top of a Teflon pin, and covered by a sealed copper cylinder with a diameter of 8 mm and a wall thickness of 1 mm. In the copper cylinder the emitted positrons are decelerated to rest and annihilate. The main advantage of using ^{68}Ge is the very small probability (approximately 3%) of gamma rays appearing due to de-excitations of excited states in either of the two the daughter nuclei.

Medical imaging theme

One of the themes of modern science in House of Science is medical imaging. Upper secondary school and high school classes are given short demonstrations of the PET camera as a part of a visiting program and as an example of physical research resulting in an application used in many hospitals all over the world. The students are fascinated by the blinking LEDs and the loudspeaker signals announcing particle annihilations in the hidden source (Fig. 3). The experiment can easily be run with two or three hidden radioactive sources to make the detective work to localise them more challenging.

The curriculum in Swedish high schools requires students to carry out one larger project of about 100 hours of work. In these activities a more realistic PET camera at the physics department of KTH with 48 detectors is used (Fig. 4). These detectors are coupled to a computer to produce images of the annihilation point. With the simple PET camera in House of Science the students learn the principles of scanning tomography and can then continue with the KTH experiment at AlbaNova to get images. The project sometimes ends with a visit to an X-ray department of a larger hospital to learn about PET cameras in use.

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Figure captions
Fig. 1 Schematic drawing of the PET camera model, showing the photomultiplier arrangement and the possibilities for translation and rotation.

Fig. 2 The PET camera model.

Fig. 3 The PET camera model arrangement with the electronics.

Fig. 4 Students exploring the 48 detector PET camera.