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Detection of alpha particles with undoped poly (ethylene naphthalate)

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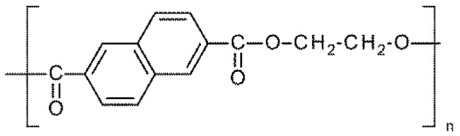
ABSTRACT

There has been recent interest in the use of undoped, aromatic-ring polymers as organic scintillation materials for radiation detectors. Here, we characterise the response of poly (ethylene naphthalate) (PEN) to alpha particles. The energy response to 5486 keV alpha particles emitted from ^{241}Am was 554 ± 45 keV electron equivalents (keVee), with an energy resolution of 11.2 ± 0.1%. The energy response to 6118 keV alpha particles emitted from ^{252}Cf was 618 ± 45 keVee, with a resolution of 8.8 ± 0.1%. It is also important to characterise the refractive index because it determines how efficiently light propagates in scintillation materials to the photodetector. By taking into account the PEN emission spectrum, it was revealed that its effective refractive index was 1.70. Overall, the results indicate that PEN has potential as a scintillation material for the detection of alpha particles.

1. Introduction

Aromatic ring polymers doped with various fluorescent guest molecules have been used for many years as organic scintillation materials in radiation detectors [1–3]. Doping is used to convert the radiation-induced ultra-violet emission of the polymers into more easily detectable visible light. Advanced photodetectors, however, now enable direct detection of short wavelength light from undoped polymers, and previously unknown optical properties of the polymers in this region are now being characterised for radiation detection purposes [4–6]. With better refining techniques available, there is now a considerable effort worldwide to identify polymers with increasingly favourable optical characteristics for use as pure base substrates in scintillation materials [7–9]. Thus, it needs to characterise the optical properties of these polymers in the context of radiation detection. The refractive index in particular is an important optical property that determines how efficiently light propagates in scintillation materials to the photodetector.

We recently demonstrated that undoped poly (ethylene naphthalate) (PEN) possesses optical properties that are suitable for radiation detection [10–12]. PEN has an emission maximum at 425 nm. With oxygen as a main component, it has a density of 1.33 g/cm^3, and is durable. These characteristics have attracted considerable attention for the potential application of PEN in radiation detectors. The repeat unit structure of PEN is:



Previous reports have examined the basic performance of PEN for the detection of beta particles, gamma-rays, and neutrons, but there have been few reports concerning detection of alpha particles [13–17]. Thus we have characterised its refractive index, the light yield, energy response and energy resolution for alpha particles. Overall, PEN has favourable characteristics for alpha particle detection.

2. Materials and methods

A 31 × 31 × 5 mm PEN plate (Teijin Ltd.) was prepared by injection molding. Refractive indices were determined with a refractometer (PR-2; Carl Zeiss, Jena, Germany) at the C line of a hydrogen lamp (656 nm), the D line of a sodium lamp (589 nm), the F line of a hydrogen lamp (486 nm), and the g line of a mercury lamp (436 nm). The experimental arrangement for measuring light yields is shown in Fig. 1. One 31 × 31 mm face was interfaced with a photomultiplier tube window (PMT, R878-SBA; Hamamatsu Photonics Co., Ltd.) *via* a very thin layer of optical grease (EJ-550;

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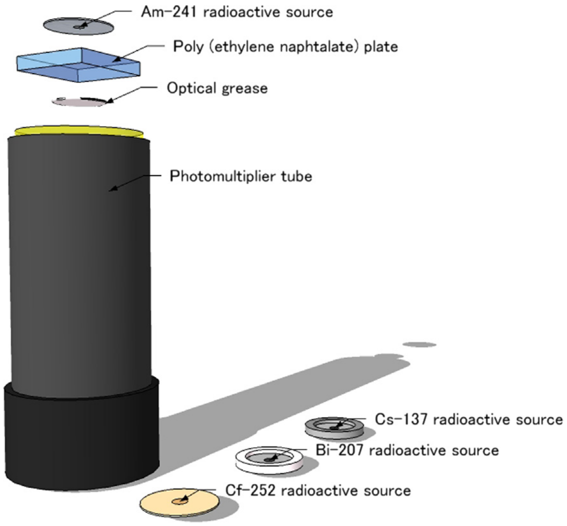

Fig. 1. Arrangement for measuring light yields in PEN.

Eljen Technology), while a radioactive source was positioned in the center of the opposite face. Output signals from the PMT were directly digitized with a charge-sensitive analogue-to-digital converter module (RPC022, REPIC Co.).

Two radioactive sources, ^{137}Cs and ^{207}Bi, both of which emit monoenergetic internal conversion electrons, were used to determine the relationship between the PEN light yield and the electron energy. The PEN light yield for alpha particles was then evaluated with ^{241}Am and ^{252}Cf radioactive sources that have no background beta particle or gamma-ray emission with energies near those energies at which the alpha responses were characterised. Because these alpha sources are simply vapour-deposited radioactive isotopes, the active regions can be directly positioned on the PEN face.

3. Results and discussion

The refractive index (N_D) of PEN at the 589-nm D line of the sodium lamp is 1.65. However, since PEN does not emit light in this region, refractive indices were obtained as a function of wavelength.

The results are plotted in Fig. 2 and follow the Sellmeier dispersion function [18]. We can then obtain an "effective" refractive index N_{eff}=1.70 by taking into account the emission spectrum, rather than using N_D=1.65 at 589 nm [4,17].

Fig. 3 shows the light yield distributions in PEN generated by the ^{137}Cs radioactive source, where the sharp peak corresponds to 624 keV conversion electrons. Counts in the low light-yield region derive from 514 keV beta particles and Compton recoil electrons generated by 662 keV gamma-rays. Similarly, Fig. 4 shows the light yield distributions generated by the ^{207}Bi radioactive source, where the sharp and small peaks correspond to 976 keV and 482 keV internal conversion electrons, respectively. Fig. 5 reveals the linear regression fit between the peak values in the two light yield distributions and the energies of the internal conversion electrons.

The relationship is then used to characterise alpha particles. For example, Fig. 6 plots the light yield distribution excited by the ^{241}Am radioactive source. The peak is generated by 5486 keV alpha particles, and the energy response (Fig. 5) was found to be 554 ± 45 keV electron equivalents (keVee). In addition, the energy resolution (σ) for the 5486 keV alpha particles was 11.2 ± 0.1%. Similarly, Fig. 7 plots the light yield distribution for the alpha particles emitted from the ^{252}Cf radioactive source. The peak is generated by 6118 keV alpha particles, and the energy response was 618 ± 45 keVee, with σ=8.8 ± 0.1%.

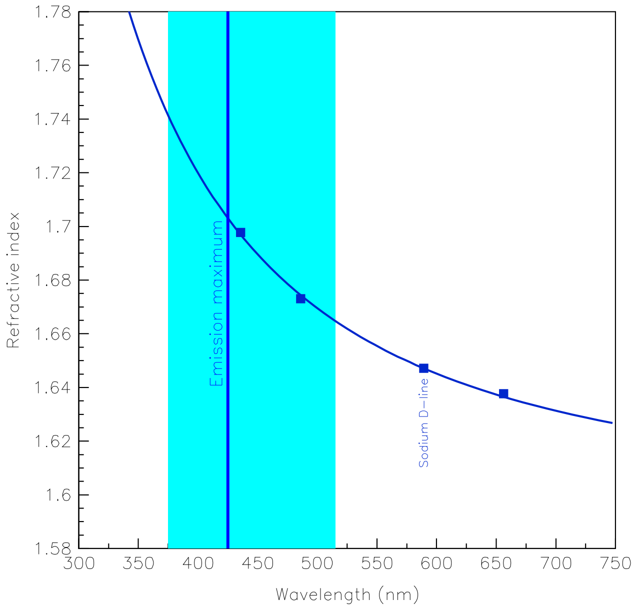

Fig. 2. Refractive indices of PEN at various wavelengths. The highlighted region (light blue) shows that the emission wavelengths of PEN dominate. The emission maximum is 425 m. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

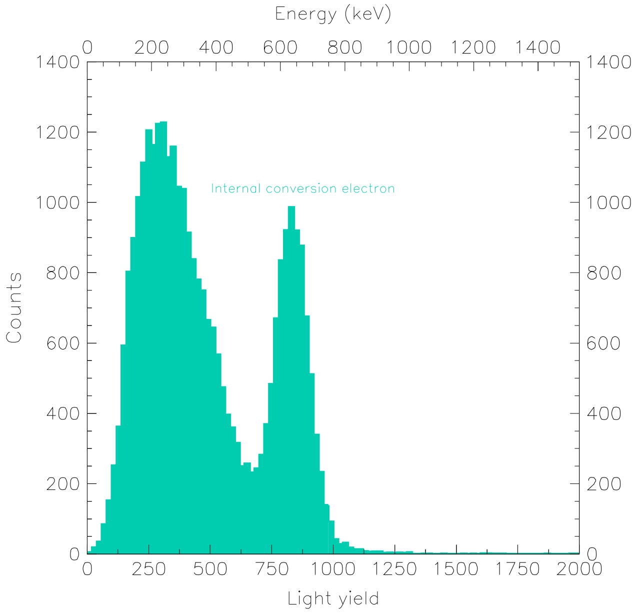

Fig. 3. Light-yield distribution from PEN when excited by radiation from a ^{137}Cs radioactive source. The peak in the distribution is from 624 keV internal conversion electrons. The counts for the low light-yield region are from 514 keV beta particles and Compton recoil electrons generated by 662 keV gamma-rays.

These results demonstrate that the light yield for alpha particles per unit energy was 1/9.9. The energy of most alpha particles emitted from radioisotopes is in the 4–6 MeV range, which coincides with the range for the PEN light yields presented here [1,2]. The data are summarised in Table 1 and demonstrate that PEN can be used for the detection of alpha particles.