Product Comparisons

Inorganic and Organic Scintillators Structural Differences

Inorganic Scintillators –

Inorganic Scintillators are crystals grown in high temperature furnaces and are typically Alkali Halides (i.e., NaI, CsI), Oxides (i.e., BGO) or Lanthium Halides (i.e., LaB, LaC). They have scintillation properties by virtue of their crystalline structure. This structure creates the energy bands between which electrons can jump — up to higher energy levels by excitation through ionizing radiation or down to lower energy levels by de-excitation through the emission of (visible) photons. The result is known as the scintillation effect.

Some crystals need activators to enable scintillation emission in the visible part of the spectrum. An example of such an activator is Thallium (Tl), which is used in the best known and most frequently used Inorganic Scintillator: NaI(Tl).

Organic Scintillators –

Organic Scintillators (plastics, liquids) on the contrary are composed of aromatic hydrocarbons. Plastic Scintillators are non-fluid solutions consisting of fluorescent organic compounds dissolved in a solidified polymer matrix. Liquid Scintillators are fluid solutions with similar fluorescent organic compounds.

Unlike Inorganic Scintillators, Organic Scintillators scintillate on a molecular level. No crystal structure is needed (just think of Liquid Scintillators ....). Basically each scintillator molecule can act as a scintillation center.

Interaction with Radiation

Apart from their structural differences, Inorganic and Organic Scintillators differ in their mode and level of interaction with ionizing radiation. For a typical X-ray/Gamma-ray energy range from 10 keV up to 1 MeV, the main interaction mechanisms involved are the Photoelectric effect and Compton scattering.

Inorganic Scintillators –

Inorganic Scintillators are usually made of high Z-elements and have a fairly high density. The high Z enhances the photoelectric interaction contribution, the high density increases the interaction efficiency. The photoelectric contribution enables spectroscopic measurements. NaI(Tl), because of its high Z components and its high light output, can be used for detection of X-rays as low as Fe-55 (5.9 keV).

Organic Scintillators –

In contrast, Organic Scintillators are made of low Z-elements and have a low density. Therefore, the main interaction mechanism is Compton scattering. The photoelectric effect is dominant only at low energies (typically below 20 keV). Because of the low density, more volume (thickness) is required to obtain a reasonable detection efficiency. However, the relatively low cost of Plastic Scintillators more than compensates for this when large area detectors are required.

The low intrinsic scintillation efficiency (read light output) of Organic Scintillators results in rather weak pulses for X-ray/Gamma-ray energies below 100 keV. Standard Plastic Scintillators, such as SGC BC-400, have a light output which is about a factor of 4 lower than that of NaI(Tl). Therefore, the main use of Plastic Scintillators for gamma detection is for gamma energies above 100 keV. The energy limit can be lowered by using a low noise Photomultiplier Tube, the common readout device of most scintillators. Plastic Scintillators are also very useful as charged particle or neutron detectors. More about that later.

Applications

Inorganic Scintillators –

Inorganic Scintillators are widely used in X-ray/Gamma-ray detection applications for which:

- spectroscopy is needed, and/or
- high detection efficiency is needed, and/or
- low energy radiation has to be detected.

Inorganic Scintillator based detectors are used in the Process Industry (Densitometry, Level Gauging, Thickness Monitoring of steel and other metals), Oil Exploration (Wireline Logging, MWD), Nuclear Medicine (Gamma Cameras, PET), Medical Imaging (CT scanners, PET scanners), Life Sciences (Radioimmunoassay, Osteoporosis, Thyroid Uptake etc.), Radioprotection, (Space) Science and Education.

Product Comparisons

Organic Scintillators –

As explained before, Plastic Scintillators are not very suitable for detection of lower energy X-rays and Gamma-rays and cannot be used for X-ray/Gamma-ray spectroscopy. However, they are useful for gross counting Gamma-rays with energies above 100 keV. Their relatively low cost and availability as large size sheets make them ideal for use in portal monitors and waste monitors. For such applications, a large detection area is required to increase sensitivity.

Large plastic scintillator sheets can be made in thicknesses of typically up to 15 cm. The choice of thickness will depend on:

- the energy range of interest,
- the required detection efficiency for this energy range,
- the mechanical constraints (as thickness increases, so do size and weight) or,
- the economical aspects (as thickness increases, so does cost).

Because of their ruggedness, Plastic Scintillators are also used in Gamma-ray detectors for the process industry (Densitometry, Level Gauging).

Other interesting aspects of Plastic Scintillators are their very short scintillation decay times (a few ns), they are very good charged particle and neutron detectors, and they have good spectroscopic properties for these kinds of ionizing radiation. It is because of these properties that they are widely used in high energy-, particle- and neutron-physics (calorimeters, time of flight {TOF} detectors) and in Radioprotection Equipment (i.e., alpha-, beta-, alpha/beta- and neutron probes).

Some Plastic Scintillators, such as SGC BC-444, are specially formulated to have a long decay time (>200ns). They are used in combination with normal, fast Plastic Scintillators to form Phoswich Detectors. Phoswich Detectors can be used for Particle Identification through Pulse Shape Discriminating (PSD) techniques. Some Liquid Scintillators have very good PSD properties for neutron-gamma separation; therefore, they are ideal for studying neutrons in a high gamma background.

Plastic and Liquid Scintillators can be loaded with elements such as Boron, Lithium and Gadolinium for increased thermal neutron sensitivity and Lead or Tin (the latter only in Liquid Scintillators) for increased X-ray and Gamma-ray sensitivity.

Other applications of Plastic Scintillators as (charged) particle detectors can be found in the process industry; i.e., in the paper or plastic foil industry for thickness control systems based upon beta absorption or backscattering.

Gas Flow Proportional Counters and Organic Scintillators

Both organic scintillators and gas flow proportional detectors are lightweight, low cost, and available with large surface areas; but there are significant, practical differences between them.

Interaction with Radiation –

Gas Flow Proportional Counters –

A gas flow proportional counter uses gas with a density of 1 to 2mg/cc as a detection medium. The active volume in the gas is defined by a region where an electric field is established in the gas. Incoming radiation will knock out an electron from an atom in this gas. The electron is pulled by the electric field toward a positively charged wire (anode). As it nears the wire, the electron picks up energy from the electric field and also bumps into the other atoms, knocking out more electrons. Each of these electrons is accelerated further and knocks out more electrons. The net result is that one electron is multiplied into as many as 10^3 electrons.
More than one electron is liberated by incoming particle radiation (such as a beta particle) and each will create 10^3 more. The initial number (and therefore the final number) of electrons is in proportion to the incident energy, giving rise to the name “proportional counter.”

Organic Scintillators –

A plastic scintillator is a solid material with a density near 1g/cc. Incoming radiation knocks out electrons from atoms in the plastic (a beta particle liberates many more electrons than a gamma ray photon), and scintillation light is emitted as the atoms return to their ground state.

This light is observed by a photomultiplier tube (PMT) which converts the light to electrons. The PMT then multiplies the number of electrons by about 10^6 times. The number of scintillation photons increases in proportion to the amount of incoming radiation, thus increasing the output of the PMT proportionally.

The following table lists parameters for both gas flow proportional and plastic scintillator radiation detectors:

Three important factors are:

1. Plastic has about 500 times more efficiency for gamma and X-ray photons than gas.
2. The gain of plastic detectors is about 10^3 times higher (higher signal-to-noise ratio). Therefore, gas flow proportional counters require more sophisticated electronics to achieve the same S:N ratio as plastic detectors.
3. Both detector types have the same efficiency for beta particles.

Product Comparisons

Upkeep and Maintenance –

Gas detectors need a continuous supply of gas flowing through the detector. The gas supply is typically changed about once a month. When the gas bottle is replaced, there is some downtime to purge any moisture that may have entered a gas system.

The gas flow in multiple gas flow proportional detector systems is in series. If one detector punctures or has other gas flow problems, it affects all those in the series behind it. When it is repaired or replaced, all of them have to be purged.

Plastic detectors require no regular maintenance. In addition, loss of one or more detectors doesn't necessarily disable the entire system. Unaffected detectors will remain on line. Detectors can be replaced quickly and easily with a spare while being repaired.

Product Comparisons

Type	Density (g/cc)	HV	Gain	Relative X and Gamma Efficiency	Relative Beta Efficiency
Gas	0.002	1000	10^3	1	1
Plastic	1.0	1000	10^6	500	1

Conclusions –

1. The best choice for X-Ray Spectroscopy is Inorganic crystals.
2. A plastic scintillation detector is 500 times more efficient for detecting photons than a gas detector.
3. A plastic scintillation detector has 10^3 times the signal output of a gas detector.
4. Plastic scintillators and gas detectors have about the same efficiency for beta particles or electronics.
5. Plastic scintillation detectors do not require the maintenance of gas detectors.
6. Plastic scintillation detectors require less downtime if one or more goes down.

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