

Fast light of CsI(Na) crystals^{*}

SUN Xi-Lei(孙希磊)^{1,1)} LÜ Jun-Guang(吕军光)¹ HU Tao(胡涛)¹ ZHOU Li(周莉)¹
 CAO Jun(曹俊)¹ WANG Yi-Fang(王贻芳)¹ ZHAN Liang(占亮)¹ YU Bo-Xiang(俞伯祥)¹
 CAI Xiao(蔡啸)¹ FANG Jian(方建)¹ XIE Yu-Guang(谢宇广)¹ AN Zheng-Hua(安正华)¹
 WANG Zhi-Gang(王志刚)¹ XUE Zhen(薛镇)¹ ZHANG Ai-Wu(章爱武)¹ LÜ Qi-Wen(吕绮雯)²
 NING Fei-Peng(宁飞鹏)¹ GE Yong-Shuai(葛永帅)¹ LIU Ying-Biao(刘颖彪)¹

¹ Institute of High Energy Physics, CAS, Beijing 100049, China

² Shanxi University, Taiyuan 030006, China

Abstract: The responses of different common alkali halide crystals to alpha-rays and gamma-rays are tested in this research. It is found that only CsI(Na) crystals have significantly different waveforms between alpha and gamma scintillations, while others do not exhibit this phenomena. The rise time of the fast light is about 5 ns and the decay time is 17 ± 12 ns. It is suggested that the fast light of CsI(Na) crystals arises from the recombination of free electrons with self-trapped holes of the host crystal CsI. Self-absorption limits the emission of fast light of CsI(Tl) and NaI(Tl) crystals.

Key words: CsI(Na), waveform, ionization, scintillation, exciton, self-absorption

PACS: 29.40.Mc **DOI:** 10.1088/1674-1137/35/12/009

1 Introduction

CsI(Na) crystals are important scintillators for electromagnetic calorimetry in experimental particle physics. According to the catalogues of main scintillation crystals producers (Saint-Gobain, AMCRYS-H et al.), the decay time of γ -scintillations in CsI(Na) amounts to approximately 630 ns with a peak wavelength of 420 nm. In fact, our previous paper reveals that there are fast components hidden in the slow γ -scintillations of CsI(Na) crystals [1].

In this paper, we report the test results of some common alkali halide crystals responding to alpha-rays and gamma-rays. The luminescence processes of common alkali halide crystals are discussed in detail.

2 Experimental set-up

The schematic of the experimental set-up is illustrated in Fig. 1. Two R8778 PMTs are directly attached to the top and bottom surfaces of the crystal. The PMT signals are sent to the oscilloscope and discriminators (NIM CAEN N840) via a fan-out mod-

ule (NIM CAEN N625). The discriminator thresholds are set to be equivalent to 0.5 single photoelectrons, which are calibrated by a pulsed LED light source. The noises of PMT, which is mainly caused by Cherenkov light, can then be effectively suppressed to 0.055 Hz by the coincidence of two discriminator signals with a width of 200 ns. The oscilloscope is a TDS3054C with a sampling frequency of 5 GS/s and a memory depth of 2 μ s (10000 points, 0.2 ns/channel) for each of 4 channels. The high-speed sampling rate is a necessary condition for fast waveform analysis.

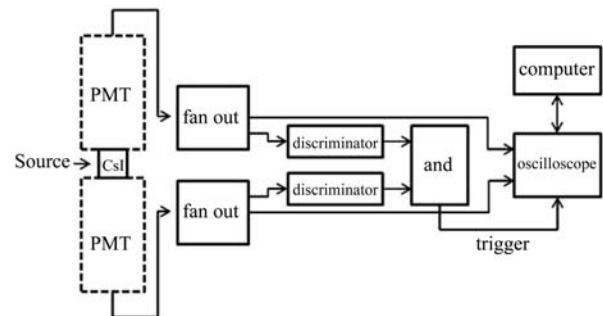


Fig. 1. Experimental set-up for the test of the crystals.

Received 14 March 2011, Revised 27 April 2011

^{*} Supported by Technological Innovation Project of Institute of High Energy Physics

1) E-mail: sunxl@ihep.ac.cn

©2011 Chinese Physical Society and the Institute of High Energy Physics of the Chinese Academy of Sciences and the Institute of Modern Physics of the Chinese Academy of Sciences and IOP Publishing Ltd

The crystals tested in this study are CsI(Na), CsI(Tl), NaI(Tl) and pure CsI. Their detailed properties are listed in Table 1. Gamma-rays from a 0.5 micro-Curie ^{137}Cs source and alpha-rays from a 5 micro-Curie ^{239}Pu source are used to excite the crystals.

Table 1. The crystals tested in the research.

crystals	CsI(Na)	CsI(Tl)	NaI(Tl)	CsI
doping	Na	Tl	Tl	-
mole%	~ 0.02	~ 0.2	~ 0.2	-
size/cm	$2.5 \times 2.5 \times 2.5$	$\Phi 2.5 \times 2.5$	$2 \times 2 \times 2$	$\Phi 2.5 \times 2.5$

3 Results and discussion

The measured waveform profile histograms of γ -scintillations and α -scintillations from different crystals are shown respectively below. Here we choose the waveforms of full energy deposition to build the histograms, which are 661.7 keV for gamma and 5.2 MeV for alpha. The values of the rise time are read from amplification plots of the leading edge directly, and those of the decay time are gotten from an exponential fitting of the trailing edge. The decay time is defined as the time after which the amplitude of scintillations is smaller by $1/e$.

3.1 Waveforms of CsI(Na)

The waveform profile histograms of γ -scintillations (661.7 keV) and α -scintillations (5.2 MeV) from CsI(Na) crystals are shown in Fig. 2. The waveforms of γ -scintillations have a rise time of ~ 40 ns and a decay time of ~ 670 ns. In comparison, the waveforms of α -scintillations with “old” or “new” surfaces have significant fast components. The decay time is only ~ 17 ns and the rise time is ~ 5 ns. The decay time of slow components of α -scintillations is shorter than that of γ -scintillations, which is ~ 490 ns. Here, the old surface is the surface layer of CsI(Na) crystals with sodium ion loss caused by the moisture absorption of sodium; the new surface is obtained by grinding off the old layer. Thallium-doped crystals do not exhibit this phenomenon.

3.2 Waveforms of CsI(Tl)

The waveform profile histograms of γ -scintillations (661.7 keV) and α -scintillations (5.2 MeV) from CsI(Tl) crystals are shown in Fig. 3. The rise time of α -scintillations is ~ 35 ns and the decay time is ~ 670 ns. There is no fast light. Similarly, the waveforms of γ -scintillations have a rise time of ~ 50 ns and a longer decay time ~ 1080 ns. Although the different

decay time can be used for alpha-gamma separation, the performance is much worse than that of CsI(Na) crystals using fast light.

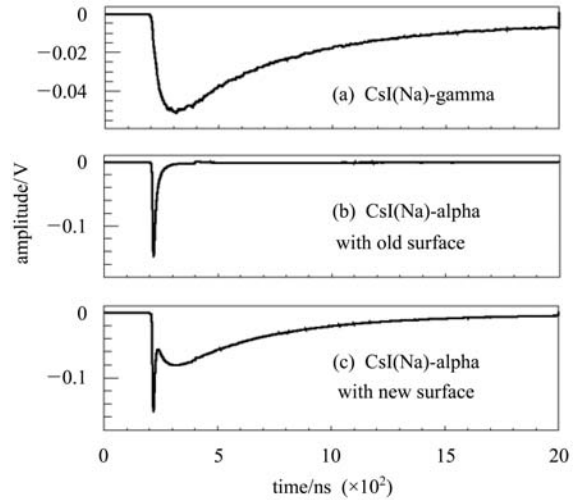


Fig. 2. The waveform profile histograms from CsI(Na) crystals. (a) γ -scintillations of 661.7 keV (b) α -scintillations of 5.2 MeV with an old surface (c) α -scintillations of 5.2 MeV with a new surface.

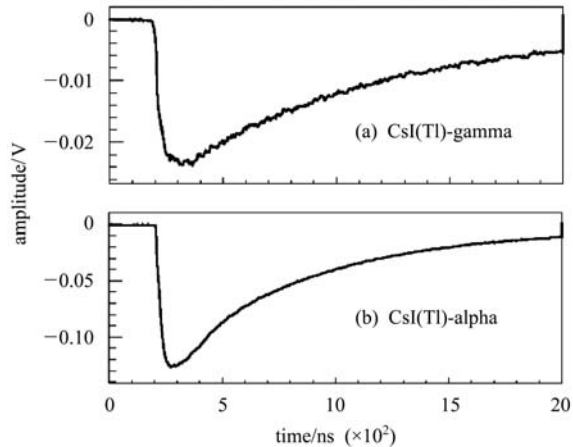


Fig. 3. The waveform profile histograms from CsI(Tl) crystals. (a) γ -scintillations of 661.7 keV (b) α -scintillations of 5.2 MeV.

3.3 Waveforms of NaI(Tl)

The waveform profile histograms of γ -scintillations (661.7 keV) and α -scintillations (5.2 MeV) from NaI(Tl) crystals are shown in Fig. 4. The rise time of α -scintillations is ~ 10 ns and the decay time is ~ 170 ns. Similarly, the waveforms of γ -scintillations have a rise time of ~ 20 ns and a slightly longer decay time of ~ 250 ns. It is difficult to separate alpha and gamma by the decay time.

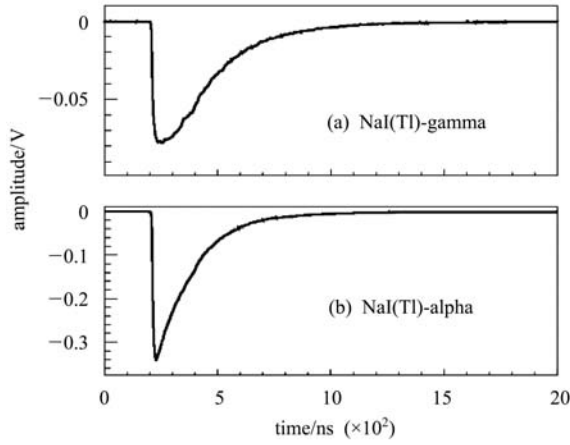


Fig. 4. The waveform profile histograms from NaI(Tl) crystals (a) γ -scintillations of 661.7 keV (b) α -scintillations of 5.2 MeV.

3.4 Waveforms of pure CsI

Finally, the waveform profile histograms of γ -scintillations (661.7 keV) and α -scintillations (5.2 MeV) from pure CsI crystals are shown in Fig. 5. The rise time of α -scintillations is ~ 5 ns and the decay time is ~ 15 ns. Similarly, the waveforms of γ -scintillations have a rise time of ~ 5 ns and a decay time of ~ 22 ns.

The measured waveform parameters are listed in Table 2. The present measurements of waveforms

lead to two facts: (1) The fast light of CsI(Na) crystals can be significantly excited by alpha-rays, while they cannot be excited by gamma-rays. (2) The luminescences of gamma and alpha from other common alkali halide crystals are not significantly different. Thus, it appears from these two facts that the luminescence mechanism of CsI(Na) crystals is different to that of CsI(Tl) and NaI(Tl) crystals.

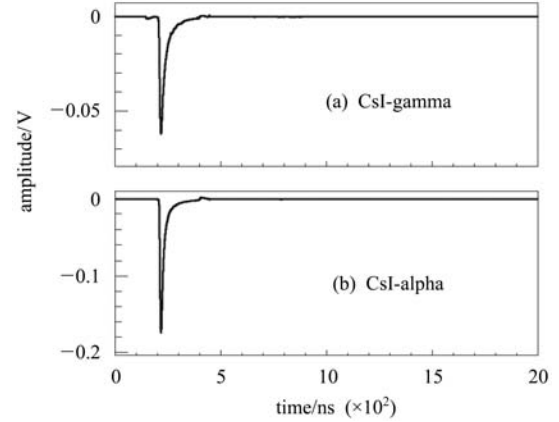


Fig. 5. The waveform profile histograms from pure CsI crystals. (a) γ -scintillations of 661.7 keV (b) α -scintillations of 5.2 MeV.

Table 2. Summary of the waveform parameters.

crystals source	CsI(Na)		CsI(Tl)		NaI(Tl)		CsI	
	γ	α	γ	α	γ	α	γ	α
rise time/ns	40	5	50	35	20	10	5	5
decay time/ns	673 \pm 131	17 \pm 12 _{fast} 493 \pm 46 _{slow}	1080 \pm 325	671 \pm 58	253 \pm 72	170 \pm 17	22 \pm 23	15 \pm 9

3.5 Discussion

The scintillation process in common alkali halide crystals has been discussed by Stephen E. Derenzo and Marvin J. Weber in Ref. [2], and can be described in several steps:

1) Ionization

Ionization occurs when the particles are injected into the crystals, and the average energy needed to produce an electron-hole pair is about 20 eV for CsI and NaI crystals.

2) Relaxation of electrons and holes

The electrons and the holes resulting from the ionization process form separated charge carriers that cause the surrounding atoms to rearrange themselves. In CsI and NaI crystals, the self-trapped hole takes the form of a so-called V_k center, where two iodine

atoms share the hole by pulling together and forming a covalent bond.

3) Carrier diffusion

In CsI and NaI crystals, the valance bands are filled and an excess electron is spatially diffused in an essentially empty conduction band. On the other hand, the holes are generally localized and will only diffuse if thermal vibrations are able to move the hole from one trapping site to another.

4) Formation of different excitons

A diffuse electron can be trapped by an activator atom and then a self-trapped hole can also be captured by it through thermal migration. The result is an activator-trapped-exciton. A diffuse electron may also be trapped immediately by a self-trapped hole resulting in a self-trapped-exciton. The probability that a given electron will recombine with a self-

trapped hole rather than suffer capture at an activator atom site will be an increasing function of the density of self-trapped holes, hence, an increasing function of ionization density, while a decreasing function of concentration of activator atoms.

5) Radiative emission

The de-excitation of two different kinds of excitons results in two different scintillations. Thermal quenching is a common non-radiative process and occurs if thermal vibrations can deform an exciton to ground state. Self-absorption is another constraint of scintillations if the emission band overlaps with the absorption band.

Based on the above process, it is noted that fast scintillations with a decay time of about 20 ns and a wavelength of about 310 nm from pure CsI or NaI crystals are dominated by self-trapped-excitons for both gamma and alpha particles. The fast light of α -scintillations from CsI(Na) crystals arises from self-trapped-excitons, while slow components of both alpha and gamma scintillations are dominated by activator-trapped-excitons. Fortunately, the absorption bands of CsI(Na) are all below 300 nm [3], thus, fast light can be propagated through crystals.

CsI(Tl) and NaI(Tl) crystals have the same mechanism of scintillation, while, one discrepancy is that the emission bands of fast light overlaps with the absorption bands [4, 5], thus, the fast light of high ionization density particles cannot be significantly observed. UV self-absorption of CsI(Tl) and NaI(Tl) crystals may be due to the presence of Tl atom, which can be excited by UV light.

The transmittance of different crystals measured by a DH-2000-BAL Deuterium-Halogen Light Source and a QE65000 Scientific-grade Spectrometer is shown in Fig. 6. It can clearly be seen that a wavelength of light of less than 320 nm is strongly absorbed for CsI(Tl) crystals. The decay length of

310 nm light is ~ 33 cm for CsI(Na) crystals according to measurements.

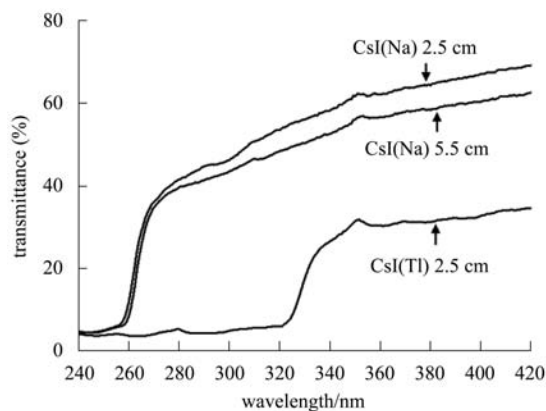


Fig. 6. Transmittance of different crystals.

4 Conclusions

Different alkali halide crystals are tested. Only the fast components of α -scintillations are significantly found from CsI(Na) crystals. Self-absorption limits the emission of fast light from CsI(Tl) and NaI(Tl) crystals. Hence, CsI(Na) is unique among common alkali halide crystals, which can be used to carry out particle identification by different kinds of luminescence mechanisms.

The fast light of CsI(Na) crystals can be significantly excited by particles with a high ionization density, like alphas rather than electrons. As a result, the high dE/dx particles can be easily distinguished from gamma-rays and electrons. Therefore, CsI(Na) crystals are suitable materials for neutron detection and dark matter detection.

We are grateful to WEN Liang-Jian for his support.

References

- 1 SUN X L et al. Nucl. Instrum. Methods A, 2011, doi:10.1016/j.nima.2011.03.062
- 2 Stephen E D, Marvin J W. Nucl. Instrum. Methods A, 1999, **422**: 111–118
- 3 Olive L H. Phys. Rev. B, 1977, **15**: 5821–5833
- 4 Gwin R, Murray R B. Phys Rev., 1963, **131**: 508–512
- 5 Eiichi M J. Phys. Soc. Jpn., 1967, **22**: 819–830