Nuclear Instruments and Methods in Physics Research A256 (1987) 521-524
North-Holland, Amsterdam



# LIGHT-PARTICLE DETECTION WITH A CsI(Tl) SCINTILLATOR COUPLED TO A DOUBLE PHOTODIODE READOUT SYSTEM

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Received 27 October 1986 and in revised form 29 January 1987

The properties of a detector consisting of a CsI(Tl) scintillator coupled to a double photodiode readout system were investigated for protons and $\alpha$-particles over a wide energy range. A nearly linear response combined with a relatively good energy resolution was found, resulting in a compact and cheap detector for use in nuclear reaction studies at intermediate energies.

## 1. Introduction

In heavy-ion reactions at intermediate energies, light particles with high energies (protons and $\alpha$-particles with energies up to a few hundred MeV) are observed with large cross sections and high multiplicities. Various reaction models have been proposed to describe the production process (see e.g. refs. [1,2]) however, the presently available experimental data are not sensitive to the differences in these models.

Large ($4\pi$) multidetector systems [3] are needed to fully understand the underlying reaction processes. A multidetector system that is limited in size, yet able to stop and identify light particles, easy to operate (especially with respect to the energy calibration procedure), and if possible cheap, would have many advantages. The detector, as discussed in this article, was built with the knowledge gathered during the development of such a multidetector system.

Highly energetic light charged particles are difficult to detect with conventional silicon detector telescopes. Individual detectors are too thin to stop them, and detector stacks are expensive and quite sensitive to radiation damage. This article describes the construction and performance of a light-particle detector based on a CsI(Tl) scintillator with a double photodiode readout system.

The design of the CsI light-particle detector is presented in section 2, details of the experimental setup and the off-line analysis are given in sections 3 and 4, respectively. Results on the energy resolution are described in section 5, and concluding remarks can be found in section 6.

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## 2. Design of the CsI(Tl) light-particle detector

Several authors [4,5] have already noted the advantages of a light charged-particle detector consisting of an inorganic crystal scintillator and a photodiode. Moreover, the emission wavelength of 580 nm and the relatively large light output (95% of Antracene and 40% of NaI(Tl)) makes the CsI scintillator especially well-suited for the Hamamatsu S1723-04 photodiode. An estimation based on these numbers and the quantum efficiency curve of the photodiode shows that a CsI-photodiode combination produces a factor of 4 more charge than a BGO-photodiode combination. The specific density of CsI(Tl) ($\rho = 4.51$ g/cm$^3$) is a good compromise between the requirements of stopping high-energy particles in a reasonably small detector and circumventing the extreme sensitivity of the light output, at high crystal densities and low particle energies, to surface defects. Furthermore, CsI(Tl) is available at low cost in various sizes, it is rugged and nearly nonhydroscopic, and it is easy to machine. For high counting-rate applications, however, the rather long decay time of 7 $\mu$s of the slowest scintillation component may affect its performance.

The salient properties of the photodiodes are listed in table 1. The quantum efficiency of the diodes for the scintillation light of CsI(Tl) is about 0.6. For the higher light intensities the linearity and resolution of the photodiodes are known to be better than for photomultipliers [6].

The crystal, delivered by the Harshaw company, has a dimension of $3 \times 3 \times 1$ cm (see fig. 1). Two photodiodes are coupled to one end with transparent silicone grease. The photodiodes were soldered on a printed circuit board, and the mechanical construction of the detector housing was such that the diodes exerted a

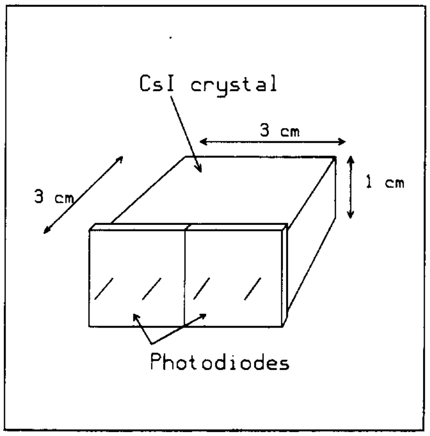


Fig. 1. Sketch of the CsI(TL) photodiode light-particle detector.

Table 1
Properties of the Hamamatsu S1723-04 photodiodes

| | |
|---|---|
| Sensitive surface | 1 $cm^2$ |
| Capacitance | 100 pF |
| Rise time | < 15 ns |
| Spectral response between | 200–1150 nm |

slight pressure on the crystal. The crystal was wrapped in aluminum foil to ensure an optimal light collection, and the whole detector was housed in a 1 mm thick brass holder.

## 3. The experimental setup

The CsI scintillator was used as the final element of a telescope in a $^{20}Ne + ^{27}Al$ experiment at 20 MeV/nucleon using the KVI cyclotron in Groningen. The telescope consisted of two ion-implanted silicon $\Delta E$ detectors ($\Delta E_1$, $\Delta E_2$), manufactured by Schlumberger, and the scintillation detector. The $\Delta E_1$ detector was position sensitive with a thickness of 300 $\mu$m. The $\Delta E_2$ detector had a thickness of 500 $\mu$m. The telescope was placed at a distance of 167 mm from the target at a mean angle of 14°. In this geometry it covered an in-plane angular range between 10.2° and 17.8°, determined by a 1 cm thick lead collimator. The whole system was cooled to a temperature of −5° C, which is important to reduce the noise of the silicon detectors and leads to a well stabilized system. The Faraday cup was placed 50 cm from the target and approximately 30 cm from the telescope. In this geometry no disturbances due to $\gamma$-radiation were observed.

The signals of the silicon detectors were amplified by standard Ortec 121 charge-sensitive preamplifiers and Ortec 472 main amplifiers. Canberra 2003BT charge-sensitive preamplifiers were connected to the photodiodes with 40 cm coaxial cables. The signals of the preamplifiers were further amplified with Ortec 452 main amplifiers with a shaping time of 6 $\mu$s. The main amplifier outputs were connected to an Ortec AD811 ADC. The data were stored event by event on magnetic tape.

## 4. The off-line analysis

In the off-line analysis the measured photodiode pulse heights were corrected for offsets and differences in the amplification chains. The thicknesses of the $\Delta E_1$ and $\Delta E_2$ detectors were determined by comparing the punch-through energies with the calculations of an energy-loss program that uses the stopping powers tabulated by Andersen and Ziegler [7]. Both thicknesses agreed within 20 $\mu$m with the values (300 and 500 $\mu$m) supplied by the manufacturer.

Fig. 2 shows the summed energy loss in $\Delta E_1$ and $\Delta E_2$ as a function of the summed photodiode response for the light particles produced in the investigated reaction. All isotopes of the light elements through Li are clearly separated, indicating that the isotope separation is not limited by the energy resolution of the CsI detector.

The dependence of the summed photodiodes responses on the position of the particle in the crystal, for $\alpha$-particles with a total energy loss between 15.0 and 15.5 MeV in $\Delta E_1$ and $\Delta E_2$, is given in fig. 3. The position information was deduced from the position-sensitive $\Delta E_1$ detector. It is important to note that the

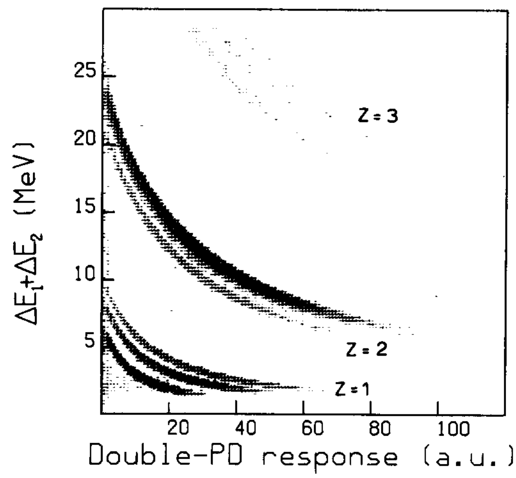


Fig. 2. The correlation between the total energy loss in $\Delta E_1 + \Delta E_2$ and the sum of the responses of the two photodiodes for light particles produced in the 20 MeV/nucleon $^{20}Ne + ^{27}Al$ reaction.

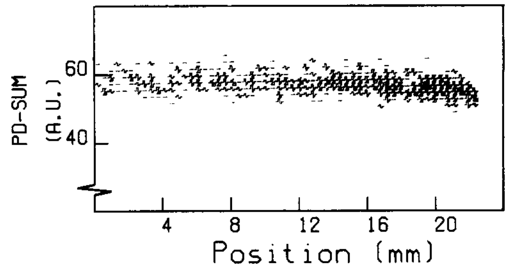


Fig. 3. The summed responses as a function of the position of the particle in the crystal, for $\alpha$-particles with a total energy loss between 15.0 and 15.5 MeV in $\Delta E_1 + \Delta E_2$.

response of the two photodiodes is independent of the position.

The incident kinetic energy of a particle was calculated from the energy losses in both $\Delta E_1$ and $\Delta E_2$. The energies of the different particles (p, d, t, $^3$He and $\alpha$) were obtained by interpolating between values in tables that contain the calculated energy losses in both the $\Delta E_1$ and the $\Delta E_2$ detectors as a function of increasing incident energy. The step size for the incident energy was always smaller than 0.5 MeV. The method was tested using the calibrated data from a three-element silicon detector telescope, which was also used in the same experiment.

The scintillator response from the energy deposited by $\alpha$-particles up to 160 MeV and by protons up to 50 MeV is shown in fig. 4a and 4b, respectively. The cutoff at the lowest energies is due to the aluminum reflector foil at the entrance of the crystal. A linear dependence over the whole energy range is observed for $\alpha$-particles. The nonlinear behaviour for protons for energies above 20 MeV can be attributed to nuclear collision effects and to the light collection efficiency at larger penetration depths. The energy loss due to nuclear inelastic interactions at energies above ~ 40 MeV/nucleon becomes considerable [5]. This velocity dependence explains the different behaviour of protons and $\alpha$-particles in the studied range. Moreover, the light output for protons is greater than for $\alpha$-particles at energies below 40 MeV (see also fig. 5). This is a well-known effect for crystals [8,9]. The scintillation efficiency decreases at higher differential energy losses $dE/dx$; therefore, at higher ionization densities ($\alpha$-particles) the relative light output will be smaller. The apparent decrease of energy resolution at higher energies is mainly an artifact of the energy-loss procedure used, resulting from the fact that the calculated particle energy is a much stronger varying function of the energy losses at the higher energies than at the lower energies. Uncertainties in the energy loss due to straggling and noise, therefore, results in the larger errors in the energy determination for the highest energies. To

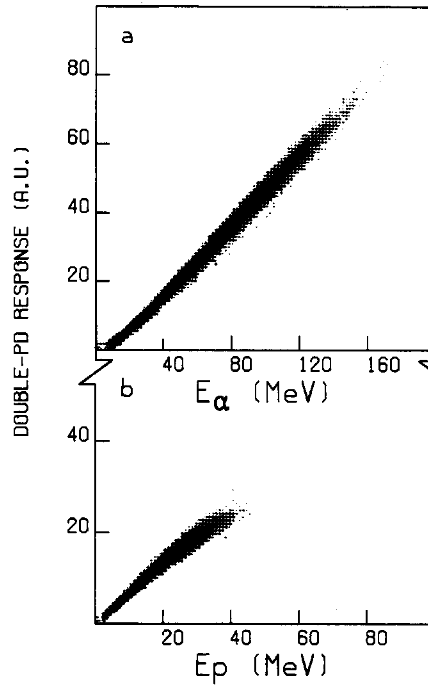


Fig. 4. Scintillator response to (a) $\alpha$-particles and (b) protons of different energies.

circumvent this problem, the energy of the particle as a function of photodiode response was fit with a polynomial. In this way the energy deposited in the crystal could be calculated directly from the photodiode response. The results of these fits for the different elements and isotopes are summarized in fig. 5.

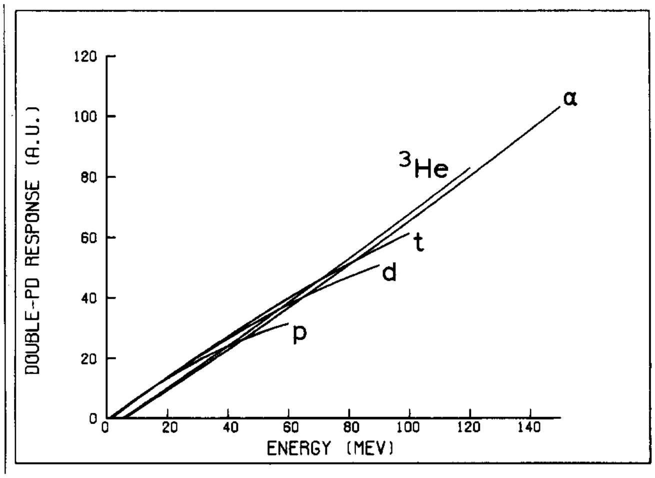


Fig. 5. The fitted detector response for the various light particles as a function of their energy.

## 5. The resolution

From the procedure described above, no precise information can be obtained on the energy resolution of the CsI crystal. Therefore, the energy resolution for 10 MeV protons, accelerated by the 6 MV EN tandem in Utrecht, was measured. The detector was placed in the focal plane of an Enge-split pole spectrograph. The energy resolution for 10 MeV protons was found to be 500 keV, and is completely determined by the electronic noise of the photodiodes. Although this is certainly worse than the resolution of a typical silicon detector, it is normally more than sufficient to measure the light-particle energy distributions in heavy-ion reactions at intermediate energies. Compared to the results presented in table 4 of ref. [10], we see that this resolution is a factor of two better than the resolution obtained with a BGO or a NE102 plastic scintillator coupled to the photodiode. This is a direct consequence of the higher light output of CsI and the operation of the photodiode at a wavelength near its maximum efficiency.

The position dependence of the energy signal was also measured at $E_p = 10$ MeV. Even at this low energy the sum of the photodiode responses was position independent.

## 6. Conclusions

A compact and cheap detector with a linear response over a wide range of energies and with a relative high resolution for low- and high-energy light particles was constructed from a CsI(Tl) crystal with a double photodiode readout system. With standard nuclear electronics this system performed successfully under experimental conditions.

## Acknowledgements

This work was performed as part of the research program of the "Stichting voor Fundamenteel Onderzoek der Materie" (FOM) with financial support from the "Nederlandse Organisatie voor Zuiver-Wetenschappelijk Onderzoek" (ZWO).

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