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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Development of a pulse shape discrimination circuit

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A pulse shape discrimination circuit was designed and used in an experiment measuring double-differential cross sections of (n, charged particle) reaction; to identify p, α and γ. The performance of the circuit was tested. With this circuit, excellent identification of p, α and γ was obtained.

1. Introduction

In nuclear reaction experiments often the discrimination of a specific type of emitted charged particles among other types of radiation is required. For solving this problem various methods are available. One of the main methods is pulse shape discrimination (PSD), which has become increasingly popular as a means of identifying particles. It is based on the fact that for some organic or inorganic scintillators the time dependence of the scintillation is a function of the type of incoming particles. In this case an analysis of the pulse shapes of the scintillation events can be used to discriminate different low charged particles and γ-rays. This method is most used to discriminate neutrons and γ-rays [1–8]. In the present work a pulse shape discrimination circuit for a CsI(Tl) scintillator is described. This arrangement has been used in experiments measuring double-differential cross sections of protons from the ^{93}Nb(n, xp) reaction. With this circuit, the protons can be discriminated from α-particles and γ-rays with a low energy threshold.

2. The circuit design

The scintillation pulses decay of CsI(Tl) crystal is a combination of exponents of different time constants:

$$L(t) = L_f \exp(-t/\tau_f) + L_s \exp(-t/\tau_s), \quad (1)$$

where $L(t)$ is the total light amplitude which was emitted at time t, and L_f and L_s are the light amplitudes corresponding to the fast and slow components. τ_f and τ_s are the decay time constants of the fast and slow components. Discrimination among particles is then possible because (1) the amplitude ratio of fast and slow components L_f/L_s varies with particles type, and (2) τ_f is the function of the ionization density.

In the experiment measuring cross sections of the (n, charged particle) reaction, a multitelescope system was designed, it consists of two ΔE detectors and an E energy detector [4]. A CsI(Tl) scintillator coupled to a photomultiplier was chosen as the energy detector and was installed in the center of the cylindrical multiwire proportional chamber (MWPC). The block diagram of the electronics for the pulse shape discrimination circuit is shown in Fig. 1. It consists of three parts: the strobe circuit (SC) which serves as a discriminator and a trigger, the zero crossing time discrimination (ZCD) circuit and the constant fraction discrimination (CFD) circuit.

When the particle received by CsI(Tl) scintillator, the current pulses generated at the last dynode of the photomultiplier was first converted in a voltage pulse $u_1(t)$ by means of a simple RC-integrating network. This voltage signal, then, produced a bipolar pulse $u_2(t)$ by means of a RC-differentiation network. $u_1(t)$ and $u_2(t)$ are given by

$$c_1\, du_1(t)/dt + u_1(t)/R_1 = I_0\, e^{(-t/\tau)}, \quad (2)$$

$$c_2\, du_2(t)/dt + u_2(t)/R_2 = c_2\, du_1(t)/\, dt. \quad (3)$$

The decay time constants of α, p and γ are about 0.43 μs, 0.60 μs and 0.70 μs respectively. Solving differential equations (2) and (3) we can obtain the solution of the zero crossing time T_0 and $dT_0/d\tau$ which depend on the kinds of particles. To discriminate the particles, the time-constant must be selected enabling the difference in T_0 for different particles to be as large as

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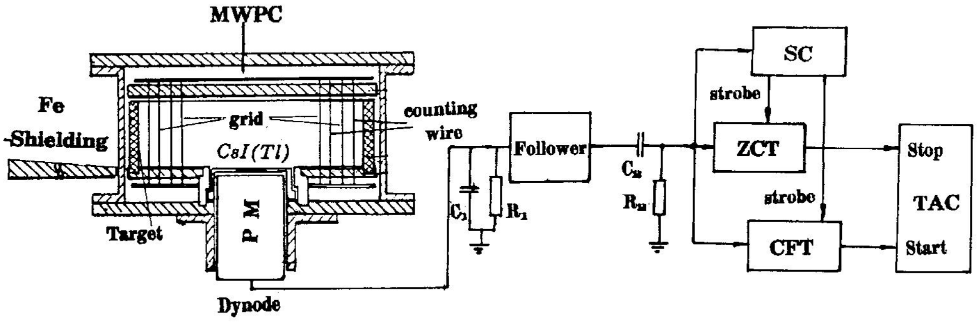

Fig. 1. The block diagram of the PSD circuit.

possible and opposite for $dT_0/d\tau$. After consideration of various factors, we select $T_1 = 1.0$ μs and $T_2 = 5.0$ μs [5].

Fig. 2 shows the electronics circuit in detail. The high speed comparator (AM687) and IC ECL#10k series are used in this circuit. The main advantage of the circuit is large band width and high speed which increase the precision of timing and time resolution remarkably.

3. The experimental results

To describe the specific property of pulse shape of CsI(Tl) crystal to identify particles, a PSD figure of

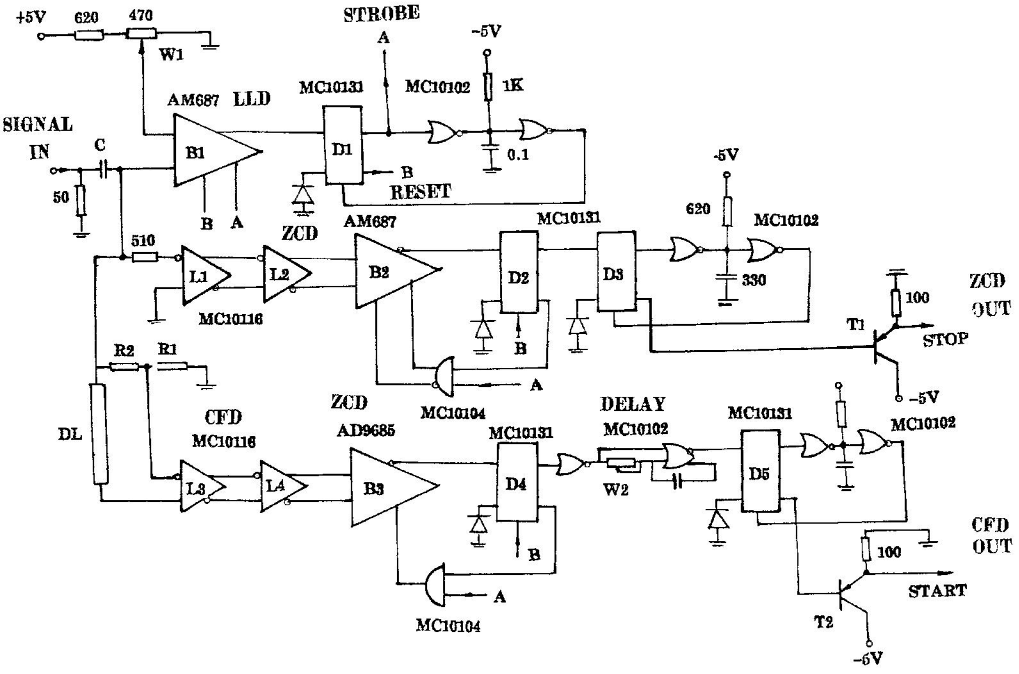

Fig. 2. Circuit diagram of the PSD system.

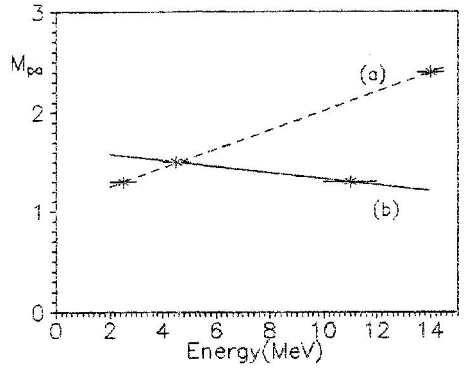

Fig. 3. $M_{p,\alpha}$ value varies with the energy of particles.

merit M was defined by Winyard [6] as follows:

$$M_{a,b} = T/(t_a + t_b), \quad (4)$$

where t_a and t_b are the respective FWHMs of the pulse shape distribution spectra and T is the separation between peaks.

The CsI(Tl) crystal was directly coupled to the photomultiplier with silicone oil. The photomultiplier GDB50-L was chosen and the operation condition was adjusted carefully. For the peak corresponding to the 4.7 MeV α-particles of a ^{241}Am source (about 0.8 eV energy is lost in the gas of the MWPC), a resolution of 0.28 MeV (FWHM) or $\Delta E/E = 6.0\%$ was achieved.

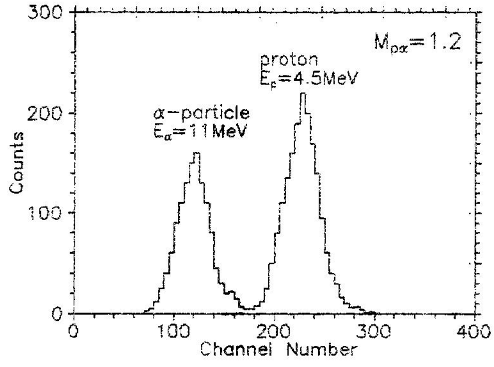

Fig. 4. A PSD spectrum of protons and α-particles.

3.1. The discrimination of protons and α-particles

Protons were produced by bombarding polyethylene foil with 14 MeV neutrons and by the ^{6}Li(d, p)^{7}Li reaction (with 150 keV deuterium beam). Some α-particles were produced by the ^{6}Li(d, α)^{4}He reaction with the same energy deuterium beam and others come from ^{241}Am and ^{239}Pu sources. Fig. 3 shows $M_{p,\alpha}$ values varying with the energy of the particles. Line (a) in Fig. 3 shows $M_{p,\alpha}$ varying with proton energy while the α-particle energy is about 4.5 MeV. When the proton energy is changed from 14 MeV to 2 MeV, $M_{p,\alpha}$ is reduced from 2.5 to 1.2. Fig. 3, line (b) shows $M_{p,\alpha}$ values varying with α-particle energy, while the proton

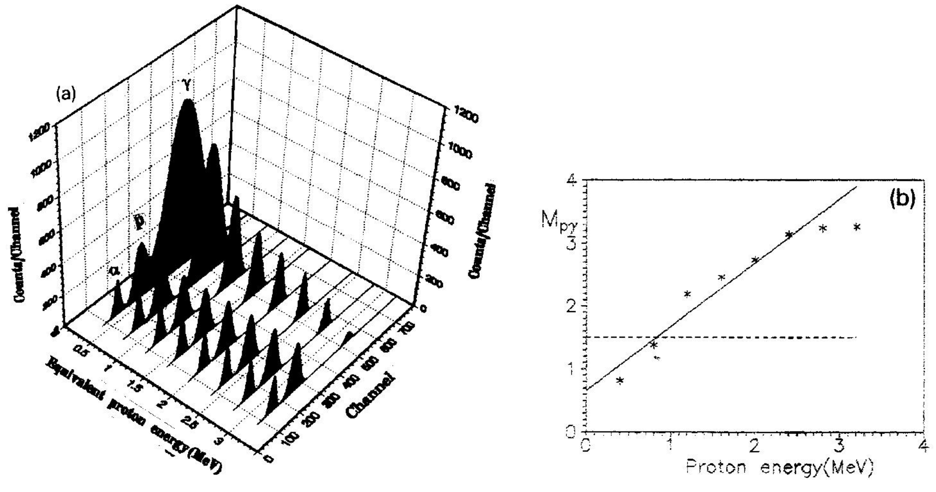

Fig. 5. The Discrimination of protons α-particles and γ-rays with different thresholds. (a) PSD spectra with different thresholds. (b) $M_{p,\gamma}$ varies with thresholds.

energy is about 3 MeV. When the energy of the α-particles increases from 2 MeV to 12 MeV, the $M_{p,\alpha}$ value was only marginally reduced from 1.7 to 1.2. Fig. 4 shows a PSD spectrum in which protons may well be identified from α-particles with this method.

3.2. The discrimination of protons and γ-rays with different thresholds

In the experiment of measuring the cross sections for the (n, charged particle) reaction, the background event rate is very high and consists mainly of γ-rays which are produced in the detector materials and its surrounding in (n, n′γ) and (n, γ) reactions. The background events are much more abundant than the true events (by about a factor of 10^3–10^6), so it is very important to test the performance of this system to discriminate protons against γ-rays with different thresholds. Fig. 5a shows the PSD spectra of α, p and γ with different thresholds and Fig. 5b is corresponding to $M_{p,\gamma}$ values. In Fig. 5, it is illustrated that protons and γ-rays are well separated even at the low threshold of the equivalent proton energy $E = 1$ MeV. As is seen, the whole system has been adjusted for an optimum discrimination of protons against γ-rays.

3.3. The discrimination of proton and γ-rays with different neutrons fluxes

In the experiment of measuring the cross sections for the (n, charged particle) reaction, the true event rate is low because of low charged particle produced cross sections. It is also very important to use a neutron strength as high as possible. The neutron strength was limited because of: 1) the space-charge effect of positive ions in the MWPC, 2) the pulse pile-up effect in the electronics system, and 3) the discrimination property of the PSD is bad. For this aim, we have measured the discrimination property of the PSD with different neutron strengths and the results are showed in Fig. 6. Fig. 6a shows the PSD spectra with different neutron strengths and Fig. 6b shows the corresponding $M_{p,\gamma}$ values. It shows that $M_{p,\gamma}$ values are almost not varied when the neutron strength increases from 0.6×10^9/s to 3.0×10^9/s (with a distance of 44 cm from the CsI(Tl) crystal to the neutron source). When the neutron strength is 1.8×10^9/s, the space-charge effect of positive ions in the MWPC has caused a count-rate of loss about 2%, so the PSD circuit used in this experiment is not limited for the neutron strength.

4. Summary

The performance of a PSD circuit which was used in an experiment measuring (n, charged particle) reactions has been studied. The pulse shape signal allows a good particle identification at a low threshold of 1 MeV equivalent proton energy and with a neutron strength 3.0×10^9/s. Using this circuit, all α-particles and γ-rays were deleted well in the ^{93}Nb(n, xp) reac-

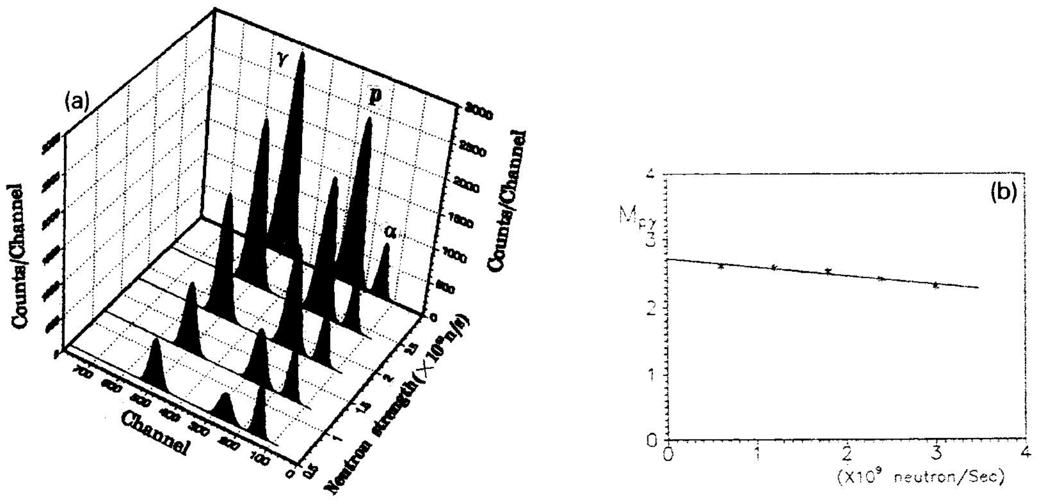

Fig. 6. The discrimination of protons, α-particles and γ-rays with different neutron strengths. (a) PSD spectra in different neutron strengths. (b) $M_{p,\gamma}$ values with different neutron strengths.

tion. The double-differential cross sections of protons from the ^{93}Nb(n, xp) reaction has been measured well [7].

Acknowledgements

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