MONASH University

School of Physics

Supplement 1: Electronics for Nuclear Counting

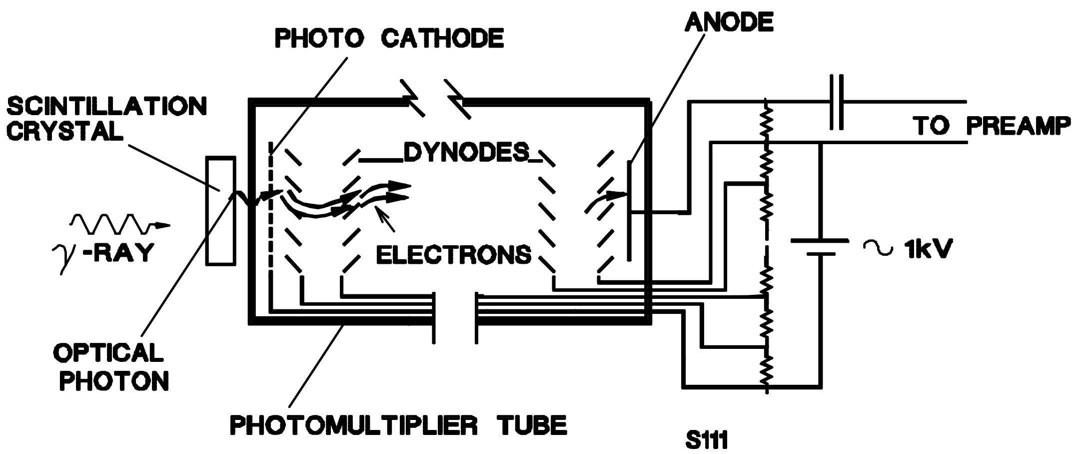
These notes are intended to serve as a brief introduction to the electronics used in nuclear counting experiments such as the Mössbauer effect and angular correlation experiments. They are not intended to describe the detailed electronics but merely to explain the function(s) of the various parts with a brief hand-waving description of the technique so that they are not completely "black boxes".

1. Detector

The detector of the incoming radiation is either a scintillation counter or a proportional counter, both of which produce an electrical pulse for each particle detected. The charge in the electrical pulse is proportional to the energy of the incoming particle. Both require a high voltage power supply.

(a) Scintillation Counter

This consists of a scintillation crystal in optical contact with the photo cathode of a photomultiplier. A charged particle moving through the scintillator (usually an organic crystal or a doped alkali halide such as NaI(Tl) produces excited states in the crystal, which de-excite by emitting photons in the visible region. A burst of photons is thus produced, the number of which is proportional to the energy deposited in the crystal by the charged particle. A scintillator detects γ rays indirectly via the electrons (Compton - scattered, or photoelectrons) produced in or near the crystal by the γ rays.



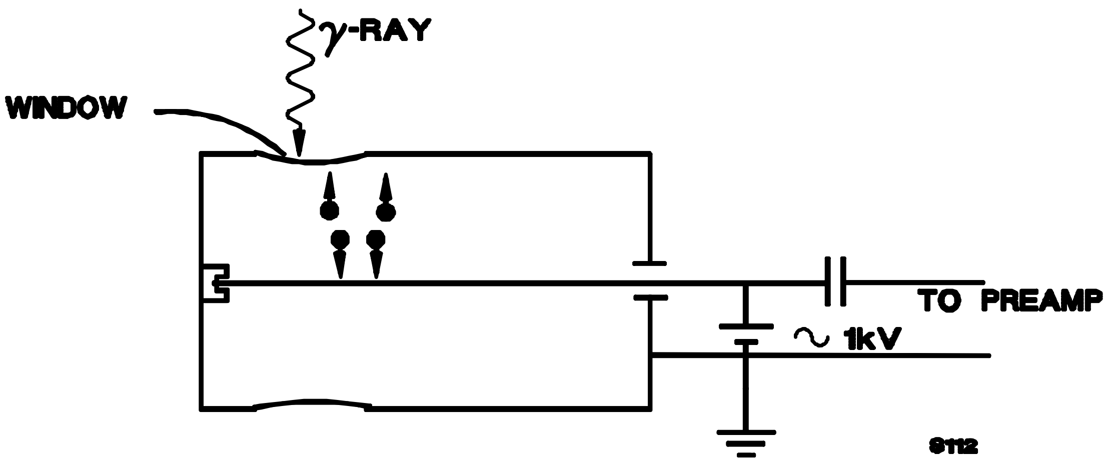
A calculable fraction of the photons from the scintillator fall on the photo cathode of the photomultiplier, which emits electrons via the photoelectric effect. Note that the photocathode is sensitive to visible radiation - it does NOT detect γ ray photons directly.

Each photoelectron is accelerated to the next electrode (called the first dynode) which it hits with sufficient energy to eject 3-4 more (slow) electrons. This process continues at each stage down a chain of 10-15 dynodes, each at a potential of ~ +100V with respect to the one preceding. The electric fields are arranged so as to produce focusing of the electrons towards the next dynode. By the last electrode (anode) there has been a total amplification of $\sim 10^6$.

If the incoming radiation is already of optical wavelengths the scintillation crystal may be dispensed with.

(b) Proportional Counter

Ionization detectors may be operated in three different ways called (in order of increasing applied voltage) an ionization chamber (100-200V), proportional counter (1000-2500V) and Geiger counter (~ 2500V). Only the proportional counter provides energy resolution.



The potential difference is applied between an axial wire and the outer metal cylinder, and the intervening space filled with an inert gas/organic gas mixture - here Kr/3% CH_4. The incoming radiation ionizes some of the gas and the ions and electrons are accelerated to their respective electrodes, creating more ionization by collisions on the way. The collection of all these particles (~ 10^6) constitutes the output pulse signalling detection of the radiation. In practice, the ions travel so slowly that they recombine with electrons before reaching the cathode, so all the pulse is from the primary and secondary electrons.

2. Pre-Amplifier

Although a gain of $\sim 10^6$ in the detector sounds very good it still only produces a charge of $\sim 10^{-13}$ Coulomb. The pre-amp converts this to a voltage pulse and since for fixed pulse shape the peak voltage is proportional to the charge, its output pulse has a peak voltage proportional to the energy of the incoming radiation. The pre-amp is usually placed as near as possible to the detector to minimize loss of signal in the connecting lead. The pulse has a very sharp rise time (positive or negative) of ~ 10 ns and a slow decay of ~300 μs.

3. Amplifier

This provides further amplification and pulse shaping to facilitate analysis by the following electronics. It differentiates the incoming pulse to obtain the energy information even in the presence of possibly several overlapping pulses. The smoother shape of the output pulses may be varied for particular applications.

4. Single Channel Analyzer (Discriminator)

Most radioactive sources emit radiation of more than one energy and it is not usually desired to count them all together. Since the amplifier puts out pulses whose voltage is proportional to energy we can count the radiation in a particular energy range by only allowing through pulses within certain voltage limits (once we have determined the energy-voltage conversion). The S.C.A. sets these upper and lower voltages and then produces a pulse of fixed voltage every time it receives a pulse within its set limits.

The S.C.A. has two modes. In NORMAL mode the two helipots set the lower and upper levels of the allowed range and are reasonably calibrated in volts (0-10). In WINDOW mode, the upper helipot sets an adjustable window of 0-1 which sits on lower level setting.

5. Multi Channel Analyzer

An M.C.A. has a number of memory units (at least 512) each capable of accumulating counts like a scaler. M.C.A.'s can be either "hard-wired" or computer based, or can be a microcomputer interfaced to act as an M.C.A. They can usually be run in either of two modes:

(a) Pulse Height Analysis Mode (P.H.A.) using an A.D.C.

This mode sorts pulses into channels depending on their voltage. Thus if the pulses direct from the amplifier are recorded this way we obtain a spectrum of the number of counts against energy.

The method of sorting is by an analog to digital converter (ADC) which records the maximum height of the incoming voltage (analog) pulse on a capacitor, then measures it by counting how many increments of a fixed voltage size are required to make up the same voltage. This number of increments (digital) is then the channel number into which the pulse is sorted. From the method it can be seen that the sorting time increases with channel number and is typically $(4 + 0.01N)$ μs where the constant 0.01 depends on the frequency of the A.D.C. (typically 100 MHz).

This mode is used to determine the energy spectrum of the radiation produced by a source to enable selection of a particular γ ray (eg. in the angular correlation and Mössbauer effect experiments) or in the determination of nuclear energy levels and transition probabilities or for the chemical or isotopic analysis of a sample by neutron activation analysis.

(b) Multi-Channel Scaler Mode (MCS)

In this mode the MCA steps through its channels in equal intervals of time and any incoming pulse is recorded in the particular channel which is open at that time independent of the height of the pulse (provided it is within the capabilities of the analyzer).

A single cycle through the channels can be carried out or repetitive cycles which may be in phase with some external periodic apparatus. This mode can be used for studies of the time dependence of nuclear or electronic properties following some initial perturbation (e.g. β-decay or a nucleus or a pulse or NMR or similar radiation) or in the case of the Mössbauer effect, recording counts as a function of velocity when this velocity has a definite periodic time dependence in synchronism with the sweep through the multi-scaler channels.

6. Coincidence Unit

A coincidence unit only responds to events in which signals are received "simultaneously" at each of its inputs. "Simultaneously" in this context means within the resolving time of the counter. The first pulse to arrive opens an electronic gate which remains open for a (usually adjustable) resolving time. If the other input receives a pulse during this time then a fixed voltage output pulse is produced. If the second input pulse is not received in the required time no output is produced.

In anti-coincidence mode the unit only passes when it does <u>not</u> receive the two pulses at once.

Delayed coincidence can be used when two incoming pulses have a fixed time difference between them - e.g. in a nuclear decay chain. Two succeeding decays will then be separated by a time ranging from zero up to many times the half-life of the intermediate level. The unit analyses this type of signal by sending the first pulse down an adjustable delay line before reaching the prompt coincidence unit.

In most experiments the coincidence unit is used with two detectors and preamp/amp/SCA units to detect radiation emanating from the same nucleus or nuclear event. There will also be some chance coincidences which depend on the individual count rates and the resolving time of the detector.

The coincidence input on a M.C.A. can also be used to set up an S.C.A. window in P.H.A. mode. This is achieved by putting the pulses from the amplifier into the A.D.C. input to give a pulse height spectrum and then putting the S.C.A. output into the COINC input. Then all the pulses going into the ADC input will be blocked except those which coincide with a pulse from the SCA unit - i.e. those of the right height to pass through the SCA window. Thus one observes a display of the PHA spectrum of the pulses passing through the S.C.A. window.