ISSN 0029-3865

CBPF - CENTRO BRASILEIRO DE PESQUISAS FÍSICAS
Rio de Janeiro

Notas de Física

CBPF-NF-010/12
May 2012

Propagation Speed of R$\gamma-$511 keV in Plastics

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Raios Cósmicos
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Ministério da
Ciência, Tecnologia
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Propagation Speed of Rγ-511 keV in Plastics

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Abstract: fitted central peaks of the coincidence spectra resulting from measuring the propagation speed (PS) of ^{22}Na-isotope γ-radiation 511 keV in plastics

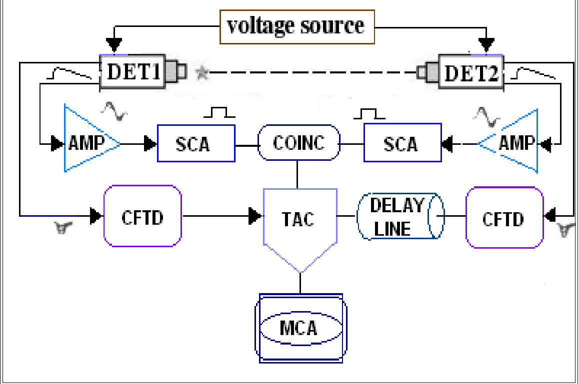
Key Words: **propagation speed, ^{22}Na-isotope, electronic coincidence method, plastics**

1) Introduction - The propagation speed (**PS**) of visible light -a small frequency range in the large frame of electromagnetic radiations (**ER**)- in air was measured, during the last hundred years(1), using a great deal of different methods, with high precision results being achieved.

Further improvements of detection and electronic measuring systems allowed to determine such parameters as **PS** by using **Rγ**(2,3,4,5,6,7) with an advantage that such experiments could also be performed in a larger variety of propagation media non-transparent to visible light. In this context, beside our already performed measurements in air(7), in a good extent comparable to the CODATA value(8), we extended such measurements in plastics as a propagation media. As already well settled(2-7), to perform such **PS** measurements the availability of a **Rγ** source in which two **Rγ** are emitted simultaneously in opposite directions turns out to be essential to the feasibility of the experiment, as far as no reflection techniques could be used. Such suitable source, in all cases, was the positron emitter **^{22}Na** placed in a metal container in which the positrons are stopped and annihilated when reacting with the medium electrons, in such way originating -as it is very well established from momentum/energy conservation laws(9)- two **Rγ-511 keV** each, both emitted simultaneously in opposite directions.

2) Experimental – The measuring setup [**MS** (**Fig21/photo**)] included two **Rγ** detectors, **DET1** (photomultiplier XP-2020Q + BaF$_2$ scintillator) and **DET2** (photomultiplier XP-2020 + CsF scintillator), each of them connected to an electronic fast-slow coincidence circuit [slow branch: amplifier (**AMP**), timing single channel (**SCA**), universal coincidence (**COINC**); fast branch: constant fraction timing discriminator (**CFTD**); time to pulse amplitude converter (**TAC**). Finally, the slow-fast coincidences were recorded on an analog-digital- converter/multi-channel (**MCA**). More detailed explanations about construction and performance of such an **MS** can be found elsewhere(10,11). The experiments consisted in the measurements of the eventual shifts of the fitted coincidence spectra peaks when different plastic rods were interposed. The two oppositely emitted **Rγ** originated from a ~ **30 μCi/^{22}Na γ-emmiter**, as far as they appeared as coincidence spectra displayed in a **Multi-Channel (MC)**.

Fig1: Measuring Setup (MS)



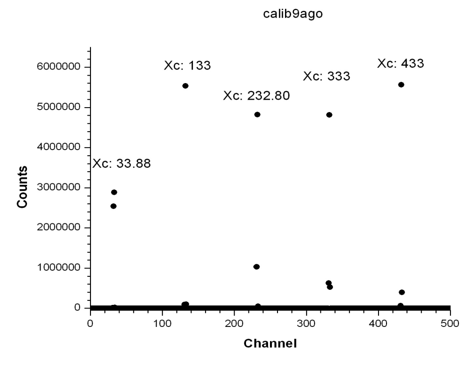


Fig2 - Time-Calibrator output spectrum

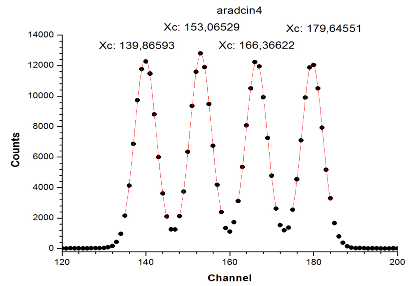


Fig3 - PS in air (ADC adcin condition)

As a first step of the experiments, it was measured the *time calibration* of the **MS** by using a Time Calibrator (**TC**), range **0.08 μs**-period **0.01 μs**, which produces two pulses with highly precise variable delays between their outputs; which, by their way, were directed to the **TAC** whose amplitude outputs isrelated to those delays (**Table I**). Finally, the average ***time calibration***

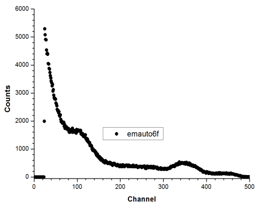


Fig4–emission across 0.50m length teflon rod: DET2

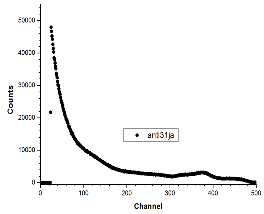


Fig5-emission across 1.0m length teflon rod: DET2

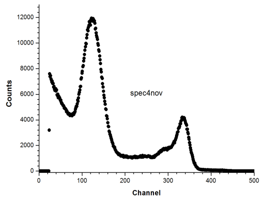


Fig6-emission in air

displayed by the **MS** was **0.1002204 ns/ch**, a result extracted from fitting (**Fig2**). As beginning coincidence experiments, in order to fix standards spectra and time-energy calibration in real measurement conditions of the **MS**, **PS-adcin** in air was performed **(Fig3)** with an estimation: **PS= 300,998.90 km/s (1.20 m →179.64551ch–139.86593ch= 39.77958 ch → 3.9867254 ns – 1.20x10^{-3} km/3.9867254x10^{-9} s= 300,998.90 km/s)**. The following **PS** experiments were performed with the **Rγ-511 keV**, detected by **DET2**, after propagating in **1,0 m** and **0,50 m** plastic rods with **25 mm** diameter; the two experiments with each plastic road in the two multiple double dimensions were performed in order to get the time-standards relative to well known propagating distances. Also, in order to make sure that the **Rγ-511 keV** would be still present in **DET2** after it's propagation through the plastic rods, emission spectra are displayed in (**Figs4-5**): a comparison between the ^{22}**Na** emission spectra in air and after propagating across the most dense plastic, teflon, used in the following experiments; compaired to air (**Fig6**), it may be realized from the displays that the **Rγ-511 keV** is certainly attenuated but, even so, still visible. As the next steps, coincidence experiments were performed and the fitted peak's centers of the measured spectra were determined (**Tables I-II**). All the measured coincidence spectra were fitted with "**gaussian function**" (eq.1), as founded in the **ORIGIN** software$^{(12)}$.

$$y=y_0+\frac{A}{\sqrt{2\pi}\,\sigma}\exp[-\frac{(x-\mu)^2}{2\sigma^2}]$$

eq.1 - gaussian function

Table I: One-Meter (1 m) Interposed Plastic Rods

interposed 1m plastic rods	**archives**	**central fitted channel**
acetal	***ace26jan***	**168.58222 (fig7)**
acrílico	***acr15fim***	**170.20413 (fig8)**
celeron	***cel03fim***	**169.78821 (fig9)**
polipropileno	***ppn09fim***	**170.00488 (fig10)**
polietileno	***pe25jan***	**168.43552 (fig11)**
uhmw	***uhmw19ja***	**168.49768 (fig12)**
teflon	***tef1mfim***	**170.45959 (fig13)**
nylon1	***ny18jan***	**168.47672 (fig14)**
nylon2	***ny1m24fe***	**168.73331 (fig15)**
air spectra	***aradcin4***	**139.86593-153.06529-166.36622-179.64551**
emission – 1m teflon interposed	***anti31ja***	**fig6**
emission in air	***emadinco***	**fig7**

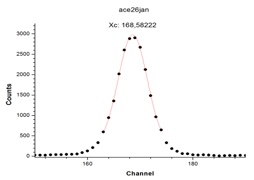


Fig7-ace26jan

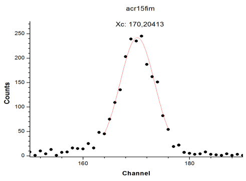


Fig8-acr15fim

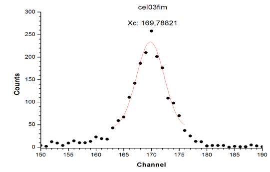


Fig9-cel03fim

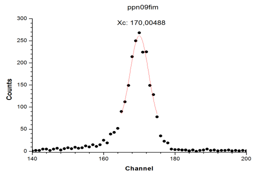


Fig10-ppn09fim

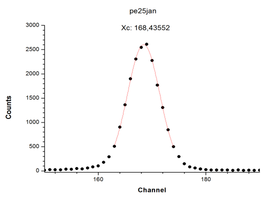


Fig11-pe25jan

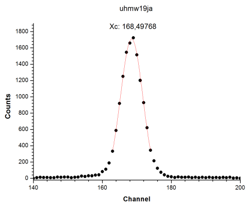


Fig12-uhmw19ja

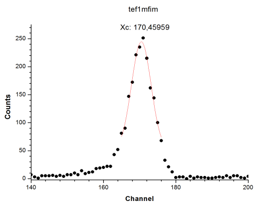


Fig13-tef1mfim

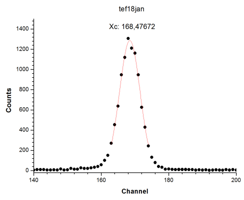


Fig14-ny18jan

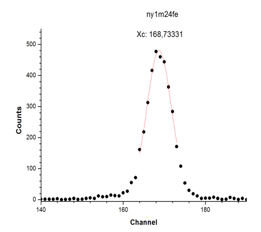


Fig15-ny1m24fe

The full-half-width (**fhwm**) of the so fitted coincidence spectra displayed 7-8 channels, **0.7015428ns-0.8017632ns**, according the **MS** calibration; reasonable high values when compaired to the time differences between the coincidence spectra fitted central peaks. Even so only the coincidence spectra fitted central peaks, without error bars or **fhwm**, were considered in the present **PS** estimations.

Table II: Half-Meter (0,50 m) Interposed Plastic Rods

interposed 0.50 m plastic rods	archives	central fitted channel
acetal	***aceadc21***	**150.54677 (fig16)**
acrílico	***acradc12***	**150.65962 (fig17)**
celeron	***cel10adc***	**150.63215 (fig18)**
polipropileno	***ppnadc13***	**150.11976 (fig19)**
polietileno	***penadc14***	**150.28886 (fig20)**
uhmw	***uhmwadin***	**150.09526 (fig21)**
teflon	***tefadcin***	**150.60433 (fig22)**
nylon	***nyfadcin***	**150.60433 (fig23)**
emission – 0,50m teflon interposed	***emauto6f***	**fig6**

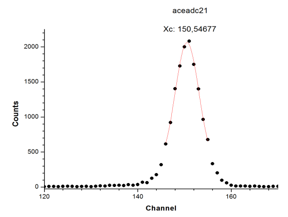


Fig16-acadc21

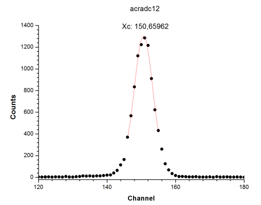


Fig17-acradc12

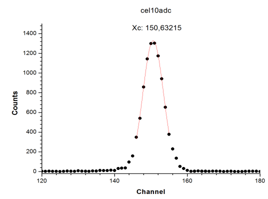


Fig18-cel10adc

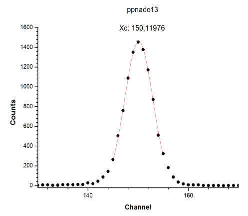


Fig19-ppnadc13

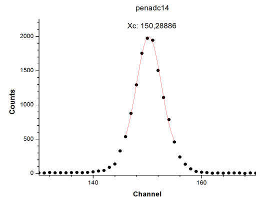


Fig20-penadc14

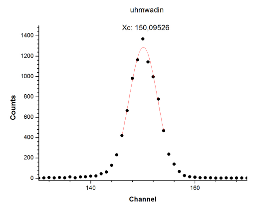


Fig21-uhmwadin

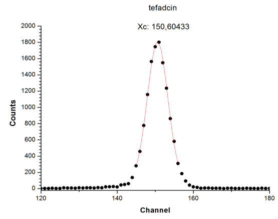


Fig22-tefadcin

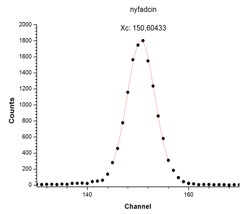


Fig23-nyfadcin

Table III: Time Channel Relationships – PS Parameters

Plastic Rods Interposed	Time/Channels Relations (Δt/ch)– 0,50m Plastics	Propagation Speed – PS (km/s)
polipropileno (δ= 0.91)	**170.00488 – 150.11976= 19.88512 ch → 1.9928946 ns**	**250,891.34**
uhmw (δ= 0.93)	**168.49768 – 150.09526= 18.40242 ch → 1.8442978 ns**	**271,105.89**
polietileno (δ= 0.95)	**168.43552 – 150.28886= 18.14666 ch → 1.8186655 ns**	**274,926.86**
nylon1 (δ= 1.13)	**168.47672 – 150.60433= 17.87239 ch → 1.791178 ns**	**279,145.90**
nylon2	**168.73331 – 150.60433= 18.12898 ch → 1.8168936 ns**	**275,194.98**
acrílico (δ= 1.25)	**170.20413 – 150.65962= 19.54451 ch → 1.9587586 ns**	**255,263.71**
acetal (δ= 1.42)	**168.58222 – 150.54677= 18.03553 ch → 1.807528 ns**	**276,620.88**
celeron (δ= 1.45)	**169.78821 – 150.63215= 19.15606 ch → 1.9198279 ns**	**260,440.01**
teflon (δ= 2.2)	**170.45959 – 150.60433= 19.85526 ch → 1.989902 ns**	**251,268.65**

3) Concluding Remarks –

a) the electronic **γ-γ** coincidence method showed to be a valuable method to measure **PS** of electromagnetic radiation in plastics, even when measured in very short distances.
b) in the above estimations it was taken into account only the **fitted peak's centers** of the coincidence spectra, neglecting any deviation concerned these values as done, for instance, by the **fwhm** of those spectra.
c) the **PS** final results are closely related to the **MS** calibration conditions due to crystal scintillator's shapes and sizes, as well as detectors distances to emmiting source.
d) at a first glance to the refractive indexes it would be difficult to associate **PS** changes to the materials densities in a regular way; different from what expected, lower densities may be related to lower **PS**
e) going on with the possibility of measuring such **PS** in material media non-transparent to visible light, a topic that the **LCA/CBPF** is presently extending to metals.

4) References -

(1) "The Speed of Light" - J.H. Rush; Scientific American, August 1955.
(2) "The velocity of γ-Rays in Air" - M.R. Cleland & P.S. Jastram; Physical Review 84/2(1951)271.
(3) "Measure of the Speed of Gamma-Rays as a Test of Performance of a Fast Timing Coincidence System" - M. Lo Savio et al.; NIM in Physics Research A355(1995)537.
(4) "Speed of Pair Annihilation Gamma-Rays" - Dept. Physics, Middlebury College; e-mail: physics@middlebury.edu.
(5) "Speed of Light Measurements Using BaF_2 Scintillation Detectors" - L. Chow et al.; Eur. J. Physics 15(1994)49.
(6) "Measuring Speed of Light in Laboratory Using Na-22 Source and $LaBr_3$ Detector" - A Thirunavukarasu; Tata Inst. Fund. Research, Mumbai; 29/03/2010.
(7) "Propagation Speed of γ-Radiation (Rγ) in air" - Osmar F.S.L. Neto, Marcelo A.V. Macedo Jr., José T.P.D. Cavalcante, Henrique Saitovitch.
(8) "CODATA" – The Committee on Data for Science and Technology.
(9) "Física Moderna para Iniciados, Interessados e Aficionados" - I.S. Oliveira, Cap. IX; Ed. Livraria da Física, 2005.
(10) "Espectroscopia de Radiação-Gama" - H. Saitovitch et al.; LCA/EXP/CBPF; Monografia/CBPF-MO-001/07; março/2007; attached references about instrumentation.
(11) "Radiation Detection and Measurements" - Glenn F. Knoll; J. Wiley&Sons, eds. 1979-1989.
(12) www.originlab.com – equation parameters:

y= maximum height
y_0= initial height
A= amplitude
σ = average half-width
μ = central channel

Fig24 - MS photo: LCA/CBPF

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