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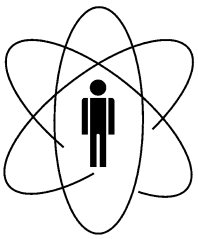

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Propagation Speed of γ-Radiation (Rγ) in Water with/without Flux

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Abstract - propagation speed of ^{22}Na-isotope γ-radiation 511 keV was measured in water, with and without flux.

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

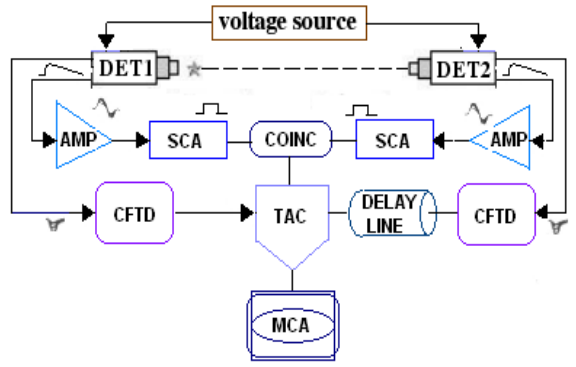
1) Introduction - The propagation speed (**PS**) of visible light -a short frequency range in the large frame of electromagnetic radiations (**ER**)- in air was measured, during the last hundred years[(1)], using a great deal of different methods, with high precision results being achieved. Presently, a conventionally accepted value is **c= 299,792.458 m/s**[(2)] (**c** reporting to the latin word *celeritas*: "speed swiftness"). The value of **ER**'s **PS** in a gas, air here included, is approximately the same when compared to such number in vacuum, because of the very small **ER** dispersion in gases. Therefore, as usually accepted, we may admit that **ER**'s **PS** in air and vacuum have the same value.

Further improvements of detection and electronic measuring systems allowed to determine such parameters as **PS** by using **Rγ**[(3,4,5,6,7,8)] -order of magnitude values comparable to those measured for visible ligth-, with an advantage that such experiments could also be measured in a larger variety of propagation media. In this context, to compare with our already performed measurements in air[(8)], we extended such measurements in water as a propagation media.

As already well settled[(3-8)], to perform such 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**, energy **511 keV** each, both emitted simultaneously in opposite directions.

2) Experimental – The measuring setup [**MS** (**Fig. 1; Photo 9**)] 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)]. A previous measurement of **PS** in air resulted in **c= 301,817.077 m/s**[(11)], **0.67354 %** larger than the **CODATA** value. The experiments consisted in the measurements of the transit-time differences -water tube interposed or not- of the two oppositely emitted **Rγ** originating from a **~ 7 μCi/^{22}Na γ-emmiter**, as far as they appeared as coincidence spectra displayed in a **Multi-Channel**. In order to calibrate the **MS** five spectra were measured in air in such a way that the distance difference between them was **0.40 m**, a distance that avoided their interference upon the measurements due to MS time resolution. All the so measured coincidence spectra were fitted with "gaussian function", as founded in the **ORIGIN** software[(12)] (**Eq. 1**).

Fig. 1: Measuring Setup (MS)



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

Eq. 1 - gaussian function

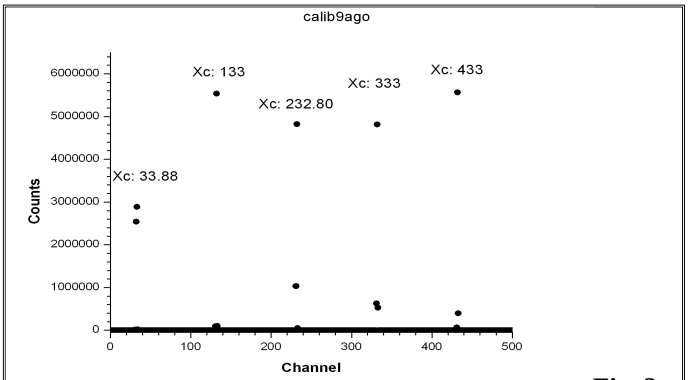


Fig. 2 - Time-Calibrator output spectrum

As a first step of the experiments, it was measured the *time calibration* of the **MS** by using a Time Calibrator (**TC**), range **0.08µs**-period **0.01µs**, which produces two pulses with highly precise variable delays between their outputs; which, by their way, were directed to the **TAC** whose amplitude outputs is related to those delays (**Table I** - ***cali9ago***). Finally, the average ***time calibration*** displayed by the **MS** was **0.1002204 ns/ch**, a result extracted from fitting (**Fig. 2**).

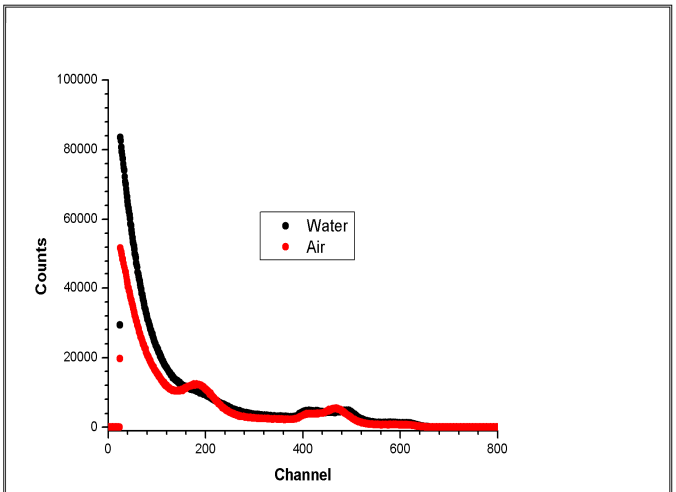


Fig 3 - ^{22}Na emission spectra: red (in air); black (in water)

All the next **PS** experiments, beside **Exp. 1,** were performed with the **511 keV Rγ** detected by **DET2** propagating in water; therefore, it was fundamental to know if it was not completely attenuated during this propagation and still appeared in the **DET2**: a comparison between the ^{22}**Na** emission spectra in air and after propagating across water, in both situations crossing a distance of **1.40 m** is displayed in **Fig.(3)**, where the **511 keV** in the crossing-water spectrum, even attenuated, appears reasonably well defined.

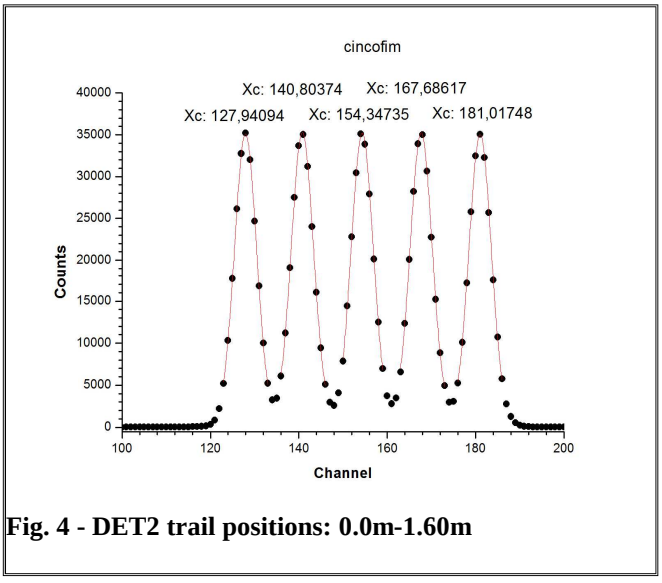


Fig. 4 - DET2 trail positions: 0.0m-1.60m

Experiment 1 (Exp. 1): in this experiment, in air, which can be seen as a test experiment, the five coincidence spectra were recorded **0.40 m** each one apart from the other (**Fig. 4**). The difference between both extreme spectra's fitted centers channels, corresponding to **1.60 m**, was estimated: **181.01748 ch – 127.94094 ch = 53.07654 ch**; taking into account the time interval related to this difference, **5.319352207 ns**, the PS $\mathbf{c_{air}}$**= 1.60 m/5.31935221 ns= 300,788.505 m/s → 100.332 %** of the standard accepted **CODATA** value.

The "zero" channel, central fitted point of the coincidence spectrum measured with both detectors at the minimum distance **5 cm** from the ^{22}**Na** source, was the **127.94094 ch**, used as "zero" in all the next experiments.

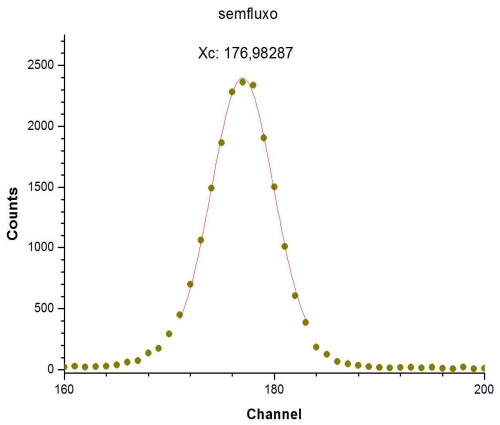


Fig. 5 – water without flux

Experiment 2 (**Exp. 2**): in this experiment coincidence spectra were recorded with the **511 keV Rγ** detected by **DET2** after propagating in fluxless water kept in a **1.40 m** long glass tube,. The difference between both extreme spectra's fitted centers channels, was estimated: **176.98287 – 127.04794= 49.93493 ch**; taking into account the time interval related to this difference, **5.00449866 ns**, the **PS** C_{water} = **1.40 m/5.00449866 ns= 279,748.301 m/s → 93.313 % of CODATA** air value.

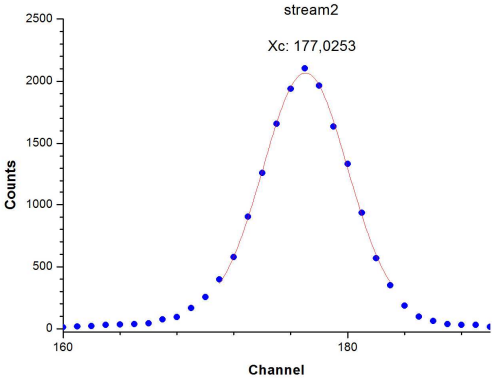


Fig. 6 - water flux direction: right to left

Experiment 3 (Exp. 3): in this experiment the measured of the water tube was made like the **Exp. 2** but with flux, the stream direction was right to left, in opposite of **Rγ**,. The difference between both extreme spectra's was estimated: **177.0253 – 127.04794= 49.97736 ch**; taking into account the time interval related to this difference, **5.00875101 ns**, the **PS** c_{water}**= 279,510.799 m/s → 93.234 %** of **CODATA** air value.

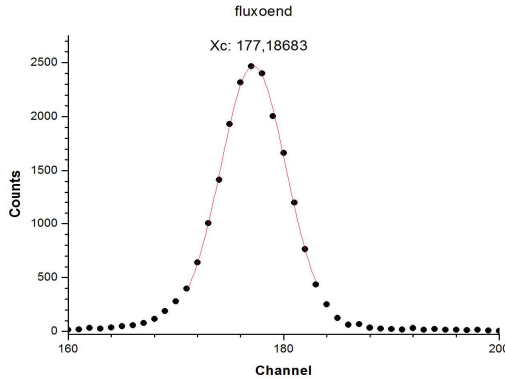


Fig. 7 – water flux direction: left to right

Experiment 4 (Exp. 4): in this experiment the measured of the water flux was made in the same direction of **Rγ**. The difference between both extreme spectra's fitted centers channels, was estimated as: **177.18683 – 127.04794= 50.13889 ch**; taking into account the time interval related to this difference, **5.02493961 ns**, the **PS** C_{water}**= 278,610.313 m/s → 92.934 %** of **CODATA** air value.

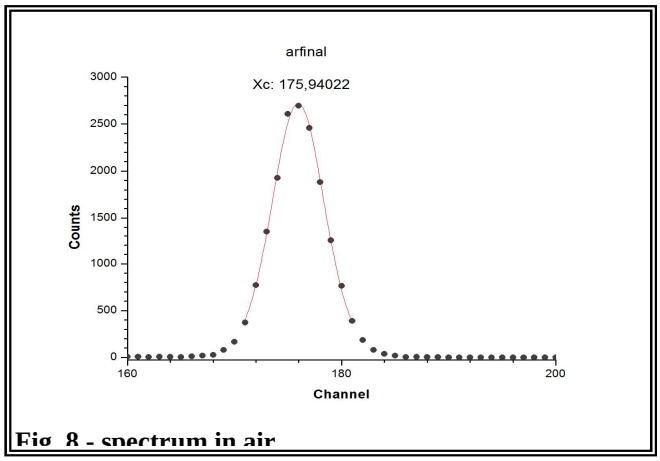


Fig. 8 - spectrum in air

Experiment in air (final): in this experiment, as a comparison with the preceding ones, the measured coincidence spectrum displayed the **175.94022** channel as the fitted central one, almost two channels before the fitted with the interposition of water; in a clear display of a time shortening of the **511keV PS** in air when compared to **PS** in water.

Table I – Measured Parameters

experimental conditions	archives	Δ-channels
water flux (opposing Rγ propagation)	***stream2***	**177.0253 – 127.04794= 49.97736 → 5.008751 ns**
fluxless water	***semfluxo***	**176.98287 – 127.04794= 49.93493 → 5.004498 ns**
water flux (direction Rγ propagation)	***fluxoend***	**177.18683 – 127.04794= 50.13889 → 5.024939 ns**
fluxless water	***quitefim***	**177.3383 – 127.04794= 50.29036 → 5.040119 ns**
coincidence spectrum in air	***arfinal***	**175.94022 – 127.04794= 48.89228 → 4.90000 ns**
emission spectrum/water interposed	***aguafull***	
emission spectrum in air	***ar28fim***	
calibration with coincidence	***cali9ago***	**33.88-133-232.80-333-433**

3) Concluding Remarks –

a) the electronic **γ-γ** coincidence method showed to be a valuable method to measure **PS** of electromagnetic radiation in air and water, 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) irrespectively the water flux direction **PS**, as expected, showed to be smaller in water than in air.
e) possibility of measuring such **PS** in material media non-transparent to visible light, a topic that the LCA/CBPF Laboratory is presently extending to plastics and metals.

4) References:

(1) "The Speed of Light" - J.H. Rush; Scientific American, August 1955.
(2) "CODATA" – The Committee on Data for Science and Technology.
(3) "The velocity of γ-Rays in Air" - M.R. Cleland & P.S. Jastram; Physical Review 84/2(1951)271.
(4) "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.
(5) "Speed of Pair Annihilation Gamma-Rays" - Dept. Physics, Middlebury College; e-mail: physics@middlebury.edu.
(6) "Speed of Light Measurements Using BaF_2 Scintillation Detectors" - L. Chow et al.; Eur. J. Physics 15(1994)49.
(7) "Measuring Speed of Light in Laboratory Using Na-22 Source and $LaBr_3$ Detector" - A Thirunavukarasu; Tata Inst. Fund. Research, Mumbai; 29/03/2010.
(8) "Propagation Speed of γ-Radiation (Rγ) in air" - Osmar F.S.L. Neto, Marcelo A.V. Macedo Jr., Jose T.P.D. Cavalcante, Henrique Saitovitch.
(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

Fig. 8 - MS photo - LCA/CBPF

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