Propagation Speed of γ-Radiation (Rγ) in Air

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Abstract - propagation speed of ^{22}Na-isotope γ-radiation 511 keV was measured in air, in different propagation distances variation of 0.10m; final results comparable to CODATA value.

Key words: propagation speed in air, ^{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 usual, we may admit that **ER's PS** in air and vacuum have the same value.

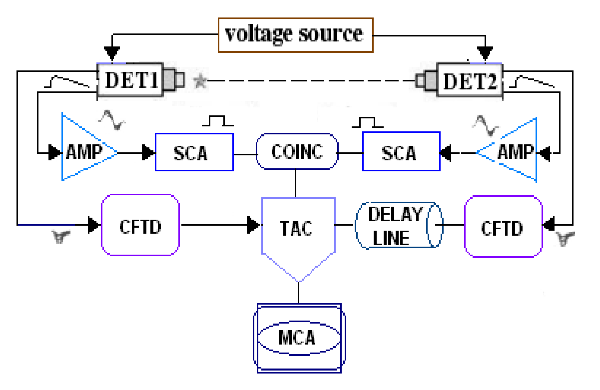
Until present, such studies focusing propagation speeds, refractive indexes, dispersions were specially related to visible light, or to **ER** in wavelengths ranges close to it, and with transparent material media (**MM**). A first incursion in this subject dealing with **Rγ** was performed using an "electronic coincidence counting measuring system"(3). This method went on to be applied, with improvements concerning newer electronic modules and scintillation crystals for **Rγ** detection in order to get better time resolution measuring setups (**MS**)(4,5,6,7). 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(8)- two **Rγ**, energy **511 keV** each, both emitted simultaneously in opposite directions.

Presently, the same method of measuring electronic coincidences related to ^{22}Na **Rγ** emission was applied; as a temptative innovation step, the **Rγ** detection system time resolution was improved when compared to the until present equivalent equipment used.

2) Experimental

– The **MS** (Fig. 1; Fig. 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(9,10). A total number of seventeen experiments on air were performed and in all of them **DET1** and **DET2** were attached to a 2 m iron trail, on opposite sides of a ~ **5 µCi/^{22}Na γ-emmiter**. The experiments consisted in the measurements of the transit-time differences of the two oppositely emitted **Rγ**, as far as they appeared as coincidence spectra displayed in a **Multi-Channel**, according the different distances, each of them 0.10m appart from the other, **DET2** assumed on the trail. Operationally, the seventeen spectra were divided in one set with five spectra and three sets with four spectra measured in such a way that the distance difference

Fig. 1: Measuring Setup (MS)



between them, in each set, was 0.40m, a distance that avoided their interference upon the measurements due to MS time resolution. Finally, all the seventeen measured spectra of the four sets were intercalated computationally. All the so measured coincidence spectra were fitted with "gaussian function", as founded in the **ORIGIN** software[11] $y=y_0+\frac{A}{\sqrt{2\pi}\sigma}\exp[-\frac{(x-\mu)^2}{2\sigma^2}]$, and the so obtained fitted parameters are in **Table II**.

As a first step of the experiments, it was measured the *time calibration* of the **MS** by using a Time Calibrator (**TC**) 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. Finally, the average *time calibration* displayed by the **MS** was **0.0999186 ns/ch**, a result extracted from fitting (Figs. 2-3).

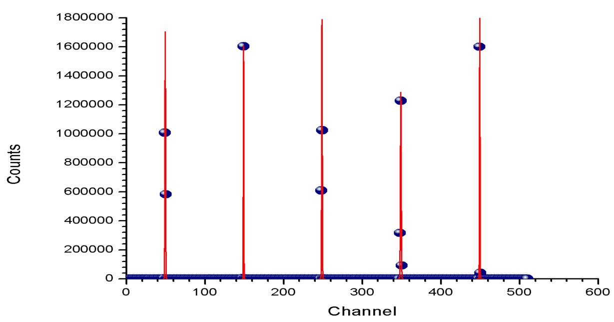


Fig. 2 - Time-Calibrator Output Spectra

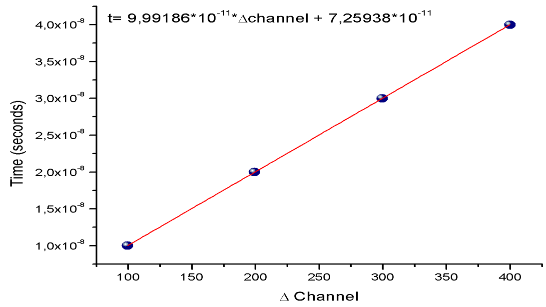


Fig. 3 - Time-Calibration Line

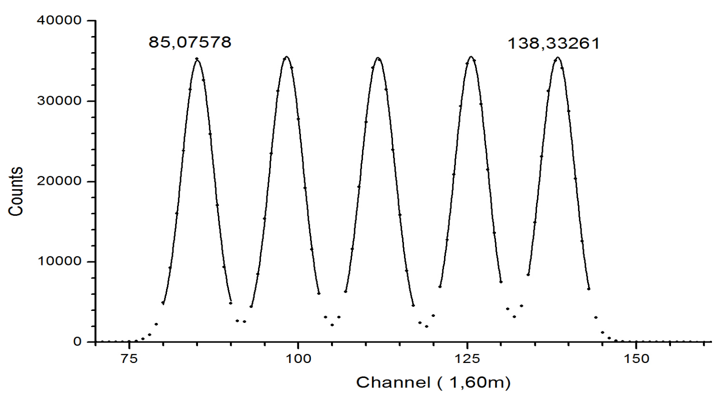


Fig. 4 - DET2 Trail Positions: 0.0m-1.60m

Experiment 1 (Exp. 1): in this experiment the five coincidence spectra were recorded 0.40 m each one apart from the other. The difference between both extreme spectra's fitted centers channels, corresponding to 1.60 m, was estimated: 138.33261 ch – 85.07578 ch = 53.25683 ch; taking into account the time interval related to this difference, **5.3213478 ns**, the PS $\mathbf{c_{air}}$= **1.60 m/5.3213478 ns= 300,675,705 m/s** → **100.294 %** of CODATA value.

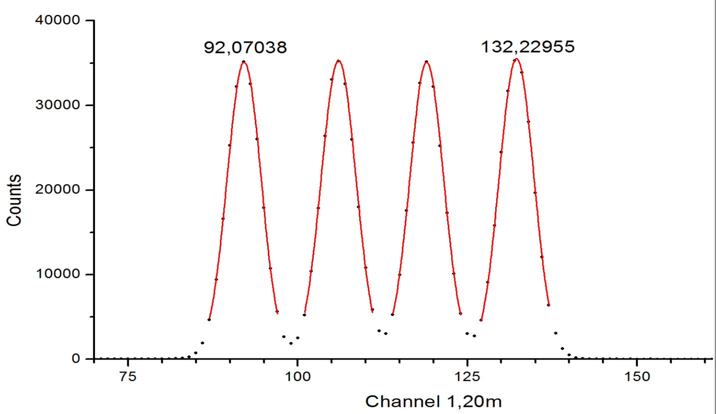


Fig. 5 - DET2 Trail Positions: 0.20m-1.40m

Experiment 2 (Exp. 2): in this experiment the four coincidence spectra were recorded 0,40 m each one apart from the other. The difference between both extreme spectra's fitted centers channels, corresponding to 1.20 m, was estimated: 132.22955 ch – 92.07038 ch = 40.15917 ch; taking into account the time interval related to this difference, **4.012648 ns**, the PS $\mathbf{c_{air}}$ = **1.20 m/4.012648 ns = 299,054,390 m/s** → **99.753 %** of CODATA value.

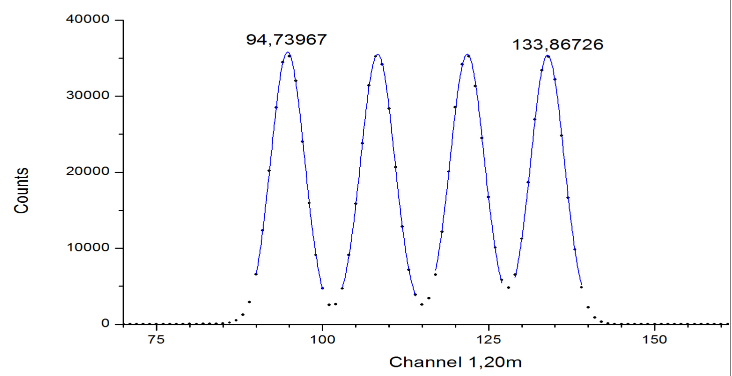


Fig. 6 – DET2 Trail Positions: 0.30m-1.50m

Experiment 3 (Exp. 3): in this experiment the four coincidence spectra were recorded individually 0.40 m each one apart from the other. The difference between both extreme spectra's fitted centers channels, corresponding to 1.20 m, was estimated: 133.86726 ch – 94.73967 ch = 39.12759 ch; taking into account the time interval related to this difference, **3,909574 ns**, the PS $\mathbf{c_{air}}$**= 306,938,812 m/s** → **102.384 %** of CODATA value.

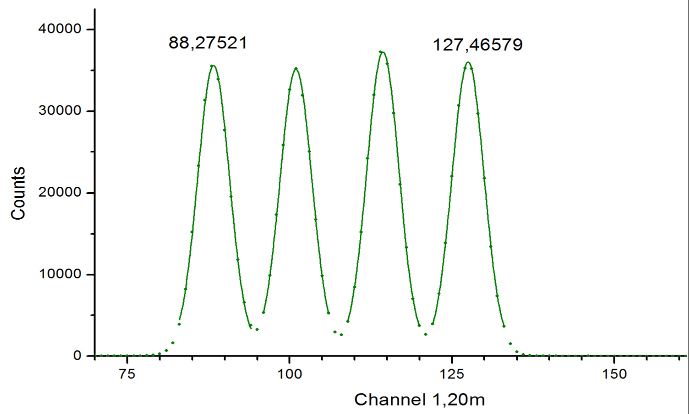


Fig. 7 – DET2 Trail Positions: 0.10m-1.30m

Experiment 4 (Exp. 4): in this experiment the four coincidence measured spectra were recorded individually 0.40 m each one apart from the other. The difference between both extreme spectra's fitted centers channels, corresponding to 1.20 m, was estimated as: 127.46579 ch – 88.27521 ch = 39.19058 ch; taking into account the time interval related to this difference, **3.915868 ns**, the PS $\mathbf{c_{air}}$**= 306,445,468 m/s** → **102.219 %** of CODATA value.

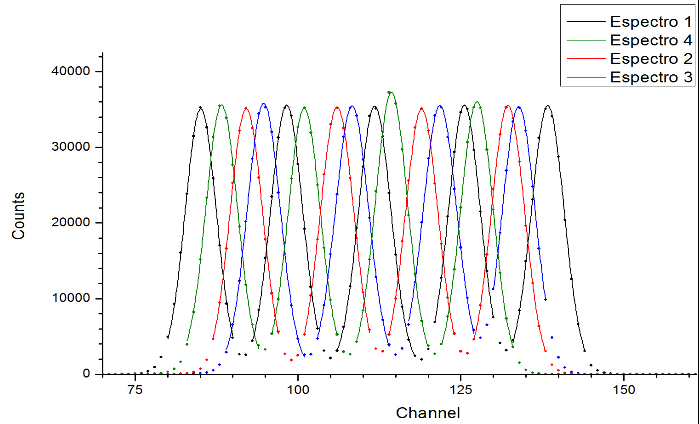


Fig. 8 - Composition of Overlapped Spectra

Experiment 5 (Exp. 5): this "experiment" is a computationally composition of the previous four sets of experiments in the sense that their measured spectra were intercalatedly overlapped, totalizing a distance of 1.60m between first and last spectra, always according their positions in the abcissa/time coordinate. The difference between each spectra's fitted centers channels corresponds to 0.10 m.

It would be expected that the mid-points fitted peaks would keep between them the same distances. But, as it can be seen in Fig. 8, this is not the case; the differences, even very small if we consider the 0.10 m value in time, are probabely due to very small variations of the TC output pulses concerning their time-amplitude.

The average of propagation speed of **Rγ** in air was estimated by the sum of the values and divided for sixteen intervals: the **PS** in air is **4,829,073.219/16** → $\mathbf{c_{air}}$**= 301,817,077 m/s** → **0,67534 %** larger than the CODATA value, a very good approach.

3) Concluding Remarks –

a) the electronic γ-γ coincidence method showed to be a valuable method to measure **PS** of electromagnetic radiation in air, 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) possibility of measuring such **PS** in material media non-transparent to visible light, a topic that our Lab. is presently extending to plastics and metals.

4) References:

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(11) www.originlab.com

Table II (a): Fitted Parameters

spectra channels fitted centers – Xc (μ)	fitted spectra centers amplitudes (H)	fwhm (ch)	ΔXc: [(n+1) – n] (ch)	ΔXc x calibration (ns)
		Exp. 1		
85.07578	33,800.83426	5.56222	13.17442	1.3163696
98.2502	34,682.62815	5.75097	13.52723	1.3516218
111.77743	34,625.55813	5.83249	13.76462	1.3753415
125.54205	34,314.3219	5.65958	12.79056	1.2780148
138.33261	35,291.63243	5.95692		
		Exp. 2		
88.27521	34,314.74801	5.69391	12.68515	1.2674824
100.96036	33,923.63439	5.70971	13.38526	1.3374364
114.34562	36,156.91773	5.76202	13.12017	1.310949
127.46579	35,196.89021	5.80689		
		Exp. 3		
92.07038	34,687.91838	5.88706	13.93098	1.391964
106.00136	35,005.53313	6.02555	12.98331	1.2972741
118.98467	34,223.79334	5.82542	13.24488	1.3234098
132.22955	35,207.43916	5.97914		
		Exp. 4		
94.73967	35,265.53973	5.95937	13.55848	1.3547443
108.29815	34,531.89479	5.97243	13.48298	1.3472004
121.78113	34,184.77778	5.95514	12.08613	1.2076291
133.86726	34,301.73914	5.86167		

Table II (b): PS Estimation on each 0.10m Adding

	"Exp. 5"	
distance (m) → ΔXc: [(n+1) – n] (ch)	**ΔXc x calibration (ns)**	**Propagation Speed (PS) of γ-Radiation in Air**
0.10m: 88.27521 – 85.07578= 3.19943	0.3196825	312,810,366 m/s
0.20m: 92.07038 – 85.07578= 6.9946	0.6988906	286,167,821 m/s
0.30m: 94.73967 – 85.07578= 9.66389	0.9656023	310,686,915 m/s
0.40m: 98.2502 – 85.07578= 13.17442	1.3163696	303,866,027 m/s
0.50m: 100.96036 – 85.07578= 15.88458	1.5871649	315,027,128 m/s
0.60m: 106.00136 – 85.07578= 20.92558	2.0908546	286,964,000 m/s
0.70m: 108.29815 – 85.07578= 23.22237	2.3203466	301,679,068 m/s
0.80m: 111.77743 – 85.07578= 26.70165	2.6679914	299,851,042 m/s
0.90m: 114.34562 – 85.07578= 29.26984	2.9246014	307,734,244 m/s
1.00m: 118.98467 – 85.07578= 33.90889	3.3881288	295,148,165 m/s
1.10m: 121.78113 – 85.07578= 36.70535	3.6675471	299,927,982 m/s
1.20m: 125.54205 – 85.07578= 40.46627	4.043333	296,784,855 m/s
1.30m: 127.46579 – 85.07578= 42.39001	4.2355504	306,925,872 m/s
1.40m: 132.22955 – 85.07578= 47.15377	4.7115386	297,142,848 m/s
1.50m: 133.86726 – 85.07578= 48.79148	4.8751763	307,681,181 m/s
1.60m: 138.33261 – 85.07578= 53.25683	5.3213478	300,675,705 m/s

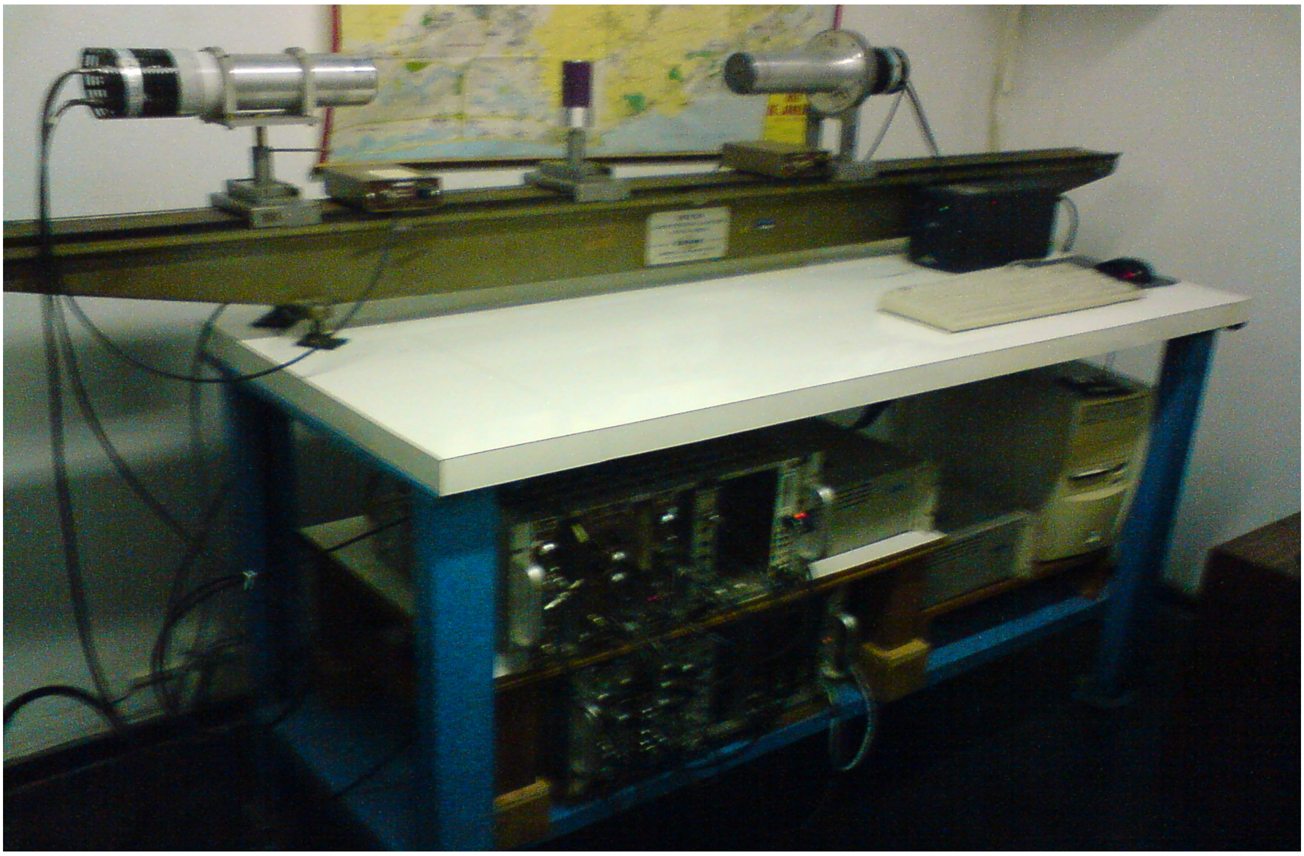

Fig. 9 - MS photo