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Propagation Speed of γ-Radiation in Air

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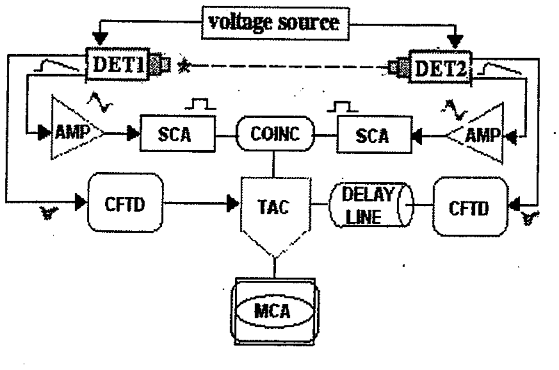
1) Introduction - The propagation speed (PS) of visible light -a short frequency range in the large frame of electromagnetic radiations (ER)- in air was measured, during the last hundred years(1), using a great deal of different methods, with high precision results being achieved . Presently, a well accepted value, with very small uncertainty, is **c= 299,792.458 Km/s**(2) (**c** reporting to the latin word *celeritas*: "speed swiftness"). When propagating in denser material media (MM), such value is always lower when compared to the air value, with the specific MM density playing an important role. The ratio between both the PS is called *refractive index*, $\mathbf{n= c/c_{MM}}$, of this MM relatively the propagating wavelength. 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. In most cases, therefore, we may admit that ER's PS in air and vacuum have the same value, and so far to consider the air index refraction $\mathbf{n_{air}= 1}$. But this is a specific feature, far of being a general situation: in the case of yellow- Na light, wavelength $\boldsymbol{\lambda \sim 6.0\times10^{-5}}$ **cm**, when propagating in water, $\mathbf{n_w= 1.333}$(3).

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 MM. A first incursion in this subject dealing with γ-rays was performed using an electronic coincidence counting system, when the value of it's PS was measured in air, $\mathbf{c_\gamma}$**= 298,300.15 Km/s**(4); a method that went on with electronic improvements, always in air.

To perform such measurements the availability of a γ-radiation source in which two γ-rays are emitted simultaneously in opposite directions -as already used(5,6) as well as applied in the present case- turns out to be essential to the feasibility of the experiment, as far as no reflection techniques could be used. Such suitable source 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(7)- two γ-rays, energy 511 KeV each, both emitted simultaneously in opposite directions. In all these previous experiments were used photomultiplier detectors coupled to NaI(Tl) crystal scintillators, which have a good energy resolution but a defficient time resolution for such purposes. Presently, as an innovatively improvement, were used BaF_2 and CsF crystal scintillators which display a much better time resolution.

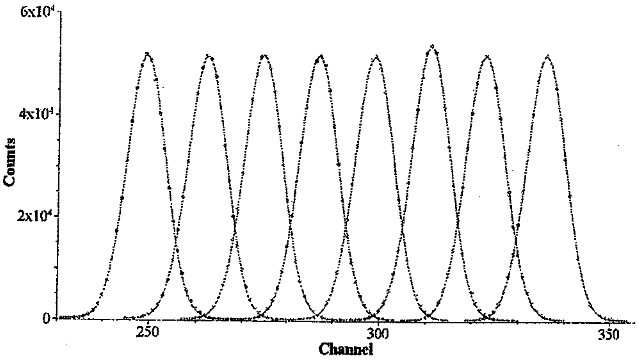
Fig. 1: Measuring Setup (MS)



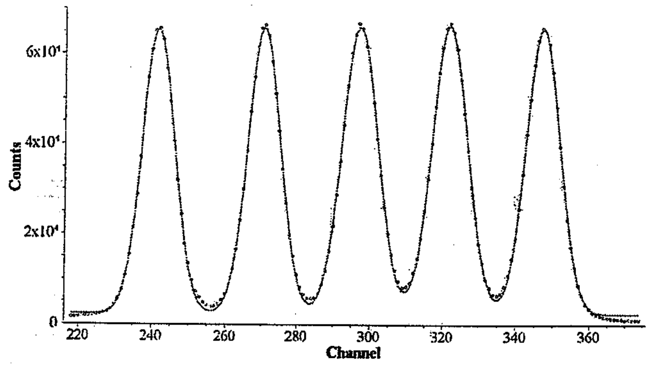
2) Experimental – The measuring setup (MS) (Fig. 1) included two detectors (photomultiplier + scintillator), DET1 and DET2, each of them connected to an electronic fast-slow coincidence circuit [slow branch: amplifier (AMP), timing single channel (SCA), universal coincidence (COINC); fast branch: constant 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(8,9). A total number of six 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 ~ 30 μCi/^{22}Na γ-radiator. The experiments consisted in the measurements of the transit-time differences of the two oppositely emitted γ-rays, as far as they appeared as coincidence spectra displayed in a Multi-Channel, according the different distances DET2 assumed on the trail. Several arrangements of the detector/scintillator part of the MS were tried in order to display how far it may interfiere in the final results; these details will be mentioned in the description of each experiment. All the measured coincidence spectra were fitted with "gaussian function" as founded in the QTIPLOT software(10). The so obtained fitted parameters are in Table II.

value.

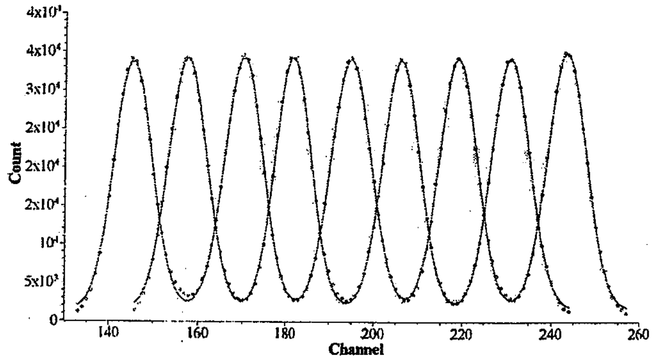
- **Experiment 4 (Exp. 4)**: in this experiment were used conically truncated 40 mm-Ø x 40 mm-height BaF_2 scintillators coupled to XP-2020Q photomultipliers. The eight coincidence measured spectra were recorded individually 0.20 m each one apart from the other, and then computationally overlaped. The difference between both extreme spectra's fitted centers channels, corresponding to 1.40 m, was estimated as: 335.92201535 ch - 249.15540500 ch= 86.76661035 ch; taking into account the time interval related to this difference, **4.70577667 ns**, the PS $\mathbf{c_{air}}$= **297,507.681 Km/s →** **99.238 %** of CODATA value.



- **Experiment 5 (Exp. 5)**: in this experiment were used conically truncated 40 mm-Ø x 40 mm-height BaF_2 scintillators coupled to XP-2020Q photomultipliers. The five coincidence spectra were recorded individually 0.40 m each one apart from the other, with both the scintillators touching the emmiting source in the first position measurement, and with the DET1 remaining in this configuration for all the measurements. The difference between both extreme spectra's fitted centers channels, corresponding to 1.40 m, was estimated as: 347.34609370 ch - 241.70179056 ch= 105.64430314 ch; taking into account the time interval related to this difference, **5.74176671 ns**, the PS $\mathbf{c_{air}}$= **278,659.877 Km/s → 92.951 %** of CODATA value. Neglecting the first spectrum, the present difference between both extreme spectra's fitted centers channels, corresponding to 1.20 m, was estimated as: 347.34609370 ch - 270.76683181 ch= 76.57926189 ch, and taking into account the time interval related to this difference, **4.16208172 ns**, the present PS $\mathbf{c_{air}}$= **288,317.180 Km/s → 96.172 % of** CODATA value. Focusing only the difference between pos4-pos3 (0.80 m to 1.20 m): 321.89481454 ch – 297.29970648 ch= 24.59510806 ch, with it's related time interval, **1.33674412 ns**, the PS in this case would be estimated $\mathbf{c_{air}}$= **299,234.531 Km/s → 99.814 %** of CODATA value.



- **Experiment 6 (Exp. 6)**: in this experiment, performed in two steps, were used2" x 2" BaF_2 and CsF scintillators coupled to XP-2020Q and XP-2020 photomultipliers, respectively. In order to better avoid detection of dispersed γ-rays around the strict horizontal emission, shielding plates of lead -5 mm thick, central hole with 10 mm-Ø- were put just in front the scintillators-. In a first step were measured successively five coincidence spectra, here included the first and the last ones, 0.40 m each one apart from the other; in a second step were measured four coincidence spectra, also successively and 0.40 m apart one from the other, and in such way with each spectrum virtually interposed 0.20 m between the first five spectra set. The final overlap was done by computation. The difference between both extreme spectra's fitted centers channels, corresponding to 1.60 m, was estimated: 243.45376586 ch - 145.35654986 ch= 98.09721600 ch; taking into account the time interval related to this difference, **5.33158367 ns**, the PS $\mathbf{c_{air}}$= **300,098.450 Km/s → 100.102%** of CODATA value.



		Exp. 4		
249.15540500	52,005 (88.041)	8.28200742	13.10027657	0.71200003
262.255681569	52,062 (87.353)	8.44150096	12.35350171	0.67141282
274.60918328	52,642 (87.407)	8.54316563	12.13116565	0.65932885
286.73299845	52,313 (87.932)	8.37772141	12.03314838	0.65400161
298.76614683	52,122 (87.808)	8.37206749	12.22128813	0.65383892
310.98743496	54,285 (89.255)	8.43679983	11.92462937	0.64810360
322.91206433	52,339 (87.313)	8.50406249	13.00995102	0.70709084
335.92201535	52,259 (87.967)	8.35806147		
		Exp. 5		
241.70179056	62,524 (99.472)	8.72606345	29.06504125	1.57968499
270.76683181	62,623 (100.508)	9.07726668	26.53287467	1.44206174
297.29970648	62,550 (99.639)	9.58710141	24.59510806	1.33674412
321.89481454	62,890 (99.331)	9.70024226	25.45127916	1.38327702
347.34609370	62,984 (98.133)	9.04783091		
		Exp. 6		
145.35654986	32,245 (69.816)	8.53849559	12.19505402	0.66280118
157.55160388	32,983 (71.250)	8.44913136	12.66615218	0.68840537
170.21775606	32447 (72.778)	8.67196794	11.43024142	0.62123362
181.64799748	32,479 (74.711)	8.24922619	13.20901479	0.71790995
194.85701227	32,502 (72.979)	8.88229777	11.28310206	0.61323660
206.14011433	32,129 (74.372)	8.24063147	12.91098403	0.70171198
219.05109836	32,558 (73.630)	8.54666409	11.89296232	0.64638250
230.94406068	32,548 (70.635)	8.50714968	12.50970518	0.67990247
243.45376586	33,433 (70.798)	8.63378924		

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