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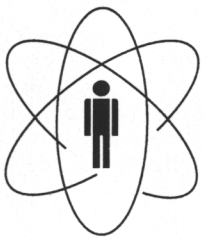

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Propagation Speed of γ-Radiation in Brass

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Ministério da Ciência e Tecnologia

BRASIL UM PAÍS DE TODOS GOVERNO FEDERAL

Propagation Speed of γ-Radiation in Brass

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1) Introduction - The propagation speed (PS) of visible light -represented by a short frequency range in the large frame of electromagnetic radiations (ER) frequencies- in air was measured, during the last century[(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 propagating MM density playing an important role.
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 a 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, $\mathbf{c_{\gamma(air)}}$**= 298,300.15 Km/s**[(3)]; a method that went on with later 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[(4,5)] 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 a suitable source was the positron emitter ^{22}Na placed in a thin wall 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[(6)]- two γ-rays, energy 511 KeV each, both emitted simultaneously in opposite directions. In all the previous experiments were used photomultiplier detectors coupled to NaI(Tl) crystal scintillators, which have a good energy resolution but a deficient time resolution for such purposes. Presently, as an innovative improvement, were used BaF_2 and CsF crystal scintillators which display a much better time resolution. Incidentally, the use of γ-rays would allow a determination of ER propagation values in non-transparent MM, nontransparent for visible light; and in such a way better sketching their structural -or of other nature- properties that may interfere with this propagation.

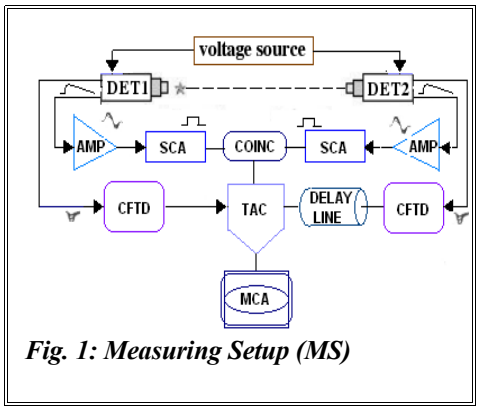


Fig. 1: Measuring Setup (MS)

2) Experimental – The measuring setup (MS) (Fig. 1) was 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 a MS can be found elsewhere[(7,8)]. To perform the experiments two photomultiplier tubes, XP-2020Q and XP-2020, were coupled to crystal scintillators BaF_2 and CsF, detectors DET1 and DET2 respectively. Both scintillators, in their sides facing the source, were shielded with lead covers -8 mm thick, 10 mm diameter central hole- in order to better centrally collimate the γ-rays. In all of the experiments the detectors 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, by displaying the positions of the coincidence spectra built-up by the counts, displayed in a Multi-Channel, as results of the electronically detected coincidences between those emitted γ-rays according the different distances, on air and with interposed brass rods, DET2 assumed on the trail. The "zero position" was at 5 cm of both detectors concerning the ^{22}Na source.
As a first step of the experiments, it was measured the time calibration of the MS fast branch (TAC/MCA) by using a Time Calibrator: **0.05435 ns/ch**[(9)].

It should be stressed that in all the present PS estimations were taken into account only the so fitted peak's centers amplitudes of the coincidence spectra, neglecting the fitting shifts represented by the *wfm* of those spectra that, concerning experimental conditions, can be noticeably different; therefore, mainly when the experiments are performed with other MM than air, standards should be fixed from the comparison of results extracted from the propagation in different lengths of the same MM.

2a) Propagation Speed in Air: a MS Calibration Measured by Electronic Coincidence Spectra - this experiment[9] was performed immediately before the present "brass experiments", in two steps: in a first one 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 peak's center channels, corresponding to 1.60 m was estimated as: 243.4537658 ch - 145.3565498 ch= 98.0972160 ch; taking into account the MS time calibration, the time interval related to this 1.60 m difference, **5.33158369ns**, estimates a propagation speed $\mathbf{c_{air}}$**= 300,098.450 Km/s → 100.102%** of CODATA value. Fig. 3 displays the coincidence spectra shifted 0.20 m between them. All the measured coincidence spectra were fitted with "gaussian function" as founded in the QTIPLOT software[10].

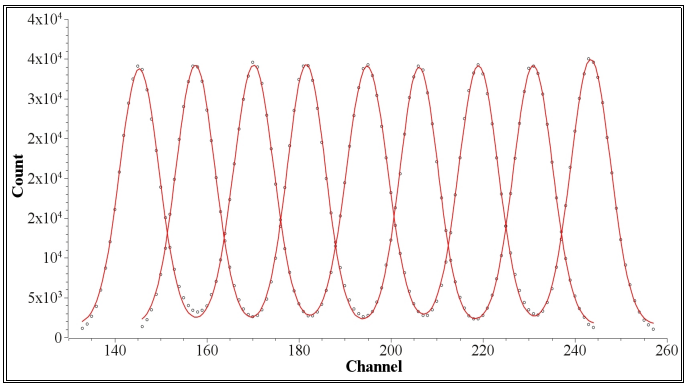
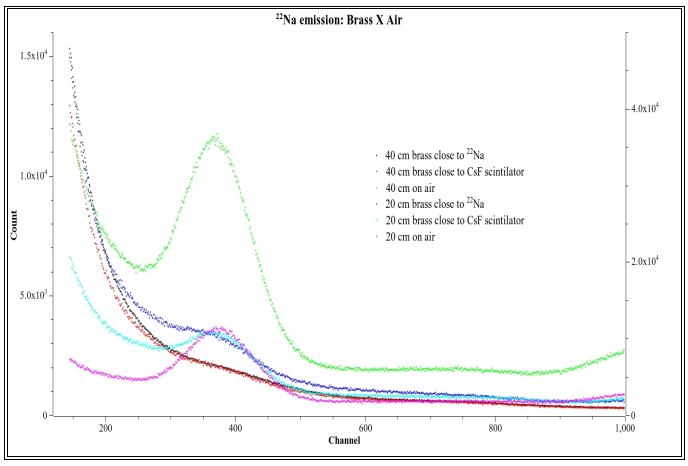


Table I: Fitted Parameters of the MS Calibration

peak center – n (ch)	amplitude	width (ch)	[(n+1) – n] (ch)	Δn x calibration (ns)
145.35654986	32,245	8.53849559	12.19505402	0.66280118
157.55160388	32,983	8.44913136	12.66615218	0.68840537
170.21775606	32447	8.67196794	11.43024142	0.62123362
181.64799748	32,479	8.24922619	13.20901479	0.71790995
194.85701227	32,502	8.88229777	11.28310206	0.61323660
206.14011433	32,129	8.24063147	12.91098403	0.70171198
219.05109836	32,558	8.54666409	11.89296232	0.64638250
230.94406068	32,548	8.50714968	12.50970518	0.67990247
243.45376586	33,433	8.63378924		

Brass Experiments - Concerned with the eventual deformation of the spectra shapes resulted from the **γ**-rays interactions in metals and how it could interfere in the final results, some other complementary tests were also performed. It is well known that **γ**-rays strongly interact with the MM they are crossing. In this way, taking into account: the long extensions of the Brass rods, it's high density (~ 8.5 g/cm^3), the energies of **γ**-rays emitted by ^{22}Na, it would be expected a high rate of Compton-scattering with a consequent decreasing of those original energies when detected by DET2; and so masking the electronic measured coincidence rate DET1(511 KeV)/[DET2(511 KeV)?]. To make better sure about which **γ**-rays energies would "still exist and come out" after crossing the brass rods, such results of the DET2 recorded emission spectra are displayed in Fig. 3, same measuring times in all cases: the two peaks emitted by the source, 511 KeV and 1,274 KeV, after Brass crossing appear coincidently with their equivalents in air, even with a higher electronic noise and a lower counting rate, certainly due to the **γ**-rays interactions in the metal. Even so, as far as the relevant ^{22}Na **γ**-rays appear



non-shifted in the above emission spectra, such displays make better sure that the coincidence **γ**-rays partners which arrive from DET2 to participate in the electronic coincidences with the DET1 511 KeV **γ**-rays are, with good chance, the DET2 511 KeV´s.
In order to extract inner standards of the present set of results, six experiments were performed, here included new "in air" experiments for comparison with the brass rods results; the recordings are referred to the so fitted central peak's channels.
The difference between both extreme peak's center channels in air, corresponding to 0.20 m was estimated as: 169.87983122 ch – 157.76787714 ch= 12.11195407 ch; taking into account the MS time calibration, the time interval related to this difference, **0.65828470 ns**, estimates a PS $\mathbf{c_{air}}$**= 303,819.912 Km/s** → **101.343%** of CODATA value.

Table II: Fitted Parameters of the Measurements in Brass Rods		
position of DET2	**position of brass rod**	**peak center channel**
0.40 m in air	no brass (fig. 4)	169.87983122
0.40 m	brass touching CsF (fig. 5)	170.12497152
0.40 m	brass touching source (fig. 6)	169.99150369
0.20 m in air	no brass (fig. 7)	157.76787715
0.20 m	brass touching CsF (fig. 8)	157.86498680
0.20 m	brass touching source (fig. 9)	158.02495773

Concerning the present brass PS measurements (Table II – Figs. 4 to 9), all of them in two configurations -brass rods touching CsF scintillator and source- on 0.40 m/0.20 m long x 10 mm diameter brass rods:
1) brass rod touching CsF → 170.12497152 ch - 157.86498680 ch= 12.25998472 ch; the time interval related to this difference, **0.666330169 ns**, estimates a PS $\mathbf{c_{brass}}$**= 300,151.500 Km/s**, 98.792% of the PS in air.
2) brass rod touching source → 169.99150369 ch – 158.02495773 ch= 11.96654596 ch; the time interval related to this difference, **0.65038177 ns**, estimates a PS $\mathbf{c_{brass}}$**= 307,511.694 Km/s**, 101.215% of the PS in air.
From the both above results it seems that in the case of the "brass rod touching CsF" the eventual deviations due to source/brass interactions may be smaller when compared to the "brass rod touching source" configuration results, as far as in the first case it's PS result is smaller than the "in air" result, as it should be because of the **γ**-rays interactions in the brass rod. In the second configuration, probabely it occurs some distortion due to the larger solid angle when the brass rod is so near as to touch the ^{22}Na source.

Fig. 4: DET2 at 0.40 m in air

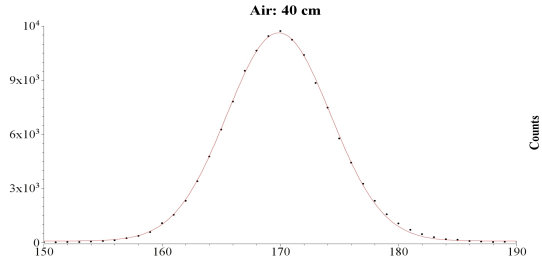
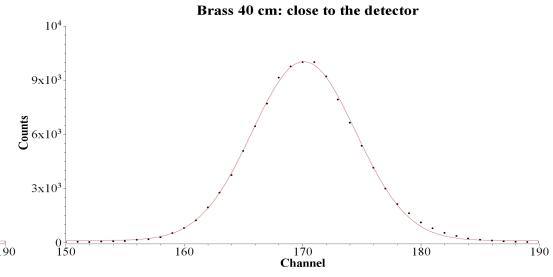


Fig. 5: 0.40 m brass touching CsF



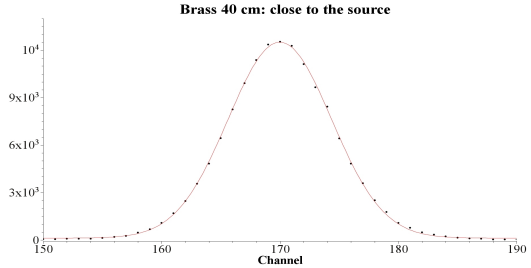


Fig. 6: 0.40 m brass rod touching the source

Fig. 7: DET2 at 0.20 m in air

Fig. 8: 0.20 m brass rod touching CsF

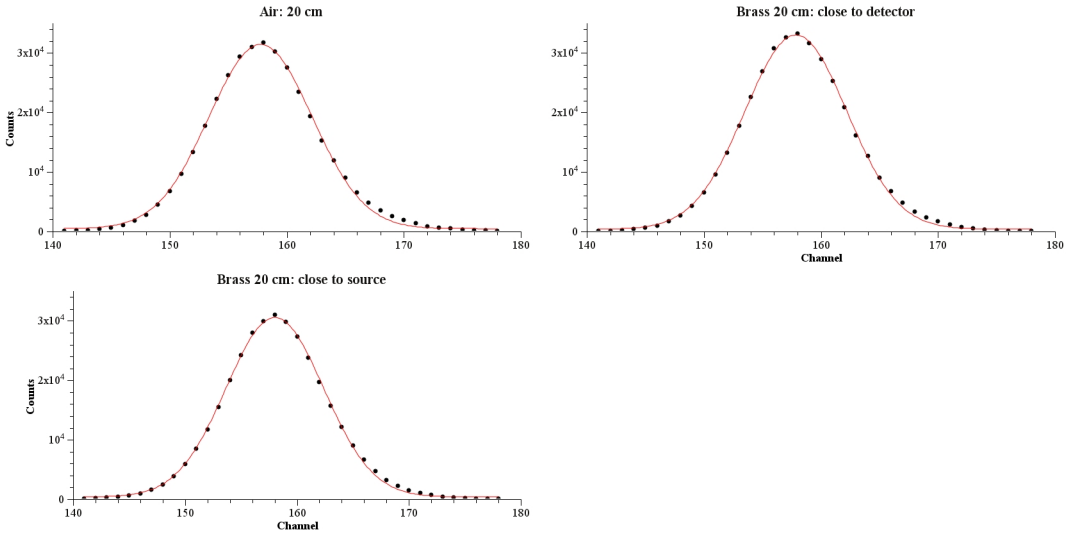


Fig. 9: 0.20 m brass rod touching the source

3) Concluding Remarks –

a) the electronic **γ-γ** coincidence method showed to be a valuable method to measure PS of ER in a MM. Remarkable advantages of it are the short distances needed for this kind of process as well as the possibility of measuring such propagation speeds in a MM non-transparent to visible light, a topic that our Lab is presently extending to plastics and metals;
b) a comparison of the results related to closeness of the MM, brass in the present case, to the scintillator and source seems to display a higher negative interference in the second case.
c) it should be reminded that in the above estimations it was taken into account only the fitted peak's centers of the coincidence spectra, neglecting the uncertainties shown by their *wfm*; in this sense, mainly when the experiments are performed with other MM than air, standards should be settled from the comparison of results extracted from the propagation in different lengths of the same MM.
d) a very recent MS calibration estimated a value **0.0549147 ns/ch**; if taking into account this value with the previous one used in all the present estimations, **0.05435 ns/ch**, all the present PS values had to be multiplied by a factor **0.989006**. In this case the present PS in air (2a-page2) would be $\mathbf{c_{air}}$**= 296,799.267 Km/s → 99.0016 %** of CODATA value.

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