12/III-84

объединенный
институт
ядерных
исследований
дубна

E4-83-849

V.G.Nikolenko

RELATIONS BETWEEN VARIOUS METRIZATION STANDARDS

Submitted to Conference on Precision
Electromagnetic Measurements
(Delft, The Netherlands, August 20-24, 1984)

1983

In view of a new official definition of the metre [1] let us consider three operational methods of metrization: 1) by rigid bodies (b -metrization), 2) by using the interference of electromagnetic waves (EMW) (i -metrization), and 3) on the basis of the time of flight of a closed measured trajectory by a standard EM signal γ (c -metrization); and the way they are related to each other. Symbols "b, i, c" mark quantities and units of these methods.

1. The γ-signal is an EMW superposition in a standard frequency region. Its shape must be unchanged in the course of propagation. The observation of flushes from pulsars restricts the relative difference of "velocities" for a visible light by 10^{-16}. Therefore, the EMW of a visible light can be taken as a standard EMW (SW). Below SW is considered only (for non-standard EMW, see [2]).

A) If such an SW and γ propagate between points at rest, the SW phases measured at these points at the moments of γ arrival are equal to each other. The use of clocks and γ may accomplish the space and time metrization [2]: If events a and b occur at different points at rest, an experimental connection between them and a given clock C can be established only with the help of signals. This connection is characterized by two C-clock readings $\tau_a^-(C), \tau_b^-(C)$ at instants of γ-signal departures from the C-clock towards the event-points a and b, and by two C-clock readings $\tau_a^+(C), \tau_b^+(C)$ at instants of the arrival of these γ-signals (being reflected from the event-points a and b) at the C-clock point. The usual time interval $t_{ab} = (\tau_{ab}^+ + \tau_{ab}^-)/2$, $\tau_{ab}^{\pm} = \tau_b^{\pm} - \tau_a^{\pm}$. The distance r_{ab} is determined by the γ-flight time τ of a closed trajectory (round-trip or forward and back), is expressed in seconds, and is measured by clocks at a and b: $2r = \tau = (\tau_{ab}^+ - \tau_{ab}^-)$.
There is no sense to speak both about a one-way (no closed trajectory) γ-velocity c_c, as $\tau^{\pm}$ -measurements require the closed γ way, and about a two-way (round-trip) velocity $\bar{c}_c$, because the trivial ratio $2r_c/\tau = \tau/\tau = 1$ does not characterize the motion of γ.

As will be seen below, the new metre definition should correspond to the c -metrization (the new metre is c -metre). However, the new official metre is groundless-interpreted as a path covered by EMW during c^{-1} seconds, i.e., here the traditional one-way γ-velocity definition B) $c = r/t$ is used. But in the b-metrization (B) is based on the operational two-way γ-velocity definition C) $\bar{c}_b = 2r_b/\tau$ (r_b and τ are determined by different measuring operations) and on two conventions: D) $t = \tau/2$ (the so-called one-way flight time) and E) $c_b = \bar{c}_b$ (light-velocity isotropy). However, in the c-metrization (B) loses the only actual base, (C), that occurs in the b- and i-metrizations. Below, to reveal more easily the actual grounds of metrizations, the (D) and (E) conventions are not used. That this is possible is demonstrated by the operational approach to kinematics [2].

2. Let us define the wavelength λ without (D) and (E). Directly from (A) or expressing the conventional t and c through the measured $\tau^{\pm}$ ($t_{12} = (\tau^+_{12} + \tau^-_{12})/2$, $x_{12}/c = (\tau^+_{12} - \tau^-_{12})/2$) we can obtain a more simple relation for the difference (between events 1 and 2) of EMW phases ϕ_{12}. For instance, for a plane SW propagating from the event-point 1 towards 2 we have $\phi_{12} = 2\pi \cdot \tau^-_{12}(C)/T$ instead of $\phi_{12} = 2\pi(t_{12}/T - x_{12}/cT)$. Thus, ϕ_{12} does not need both c and t and the conventional λ defined as a product of the SW one-way velocity c and period T.

An operational λ can be defined on a closed trajectory only. It is essential that the krypton standard of λ is just realized by a two-way propagation of SW. In similar cases the phase difference between the oscillations of SW at a point C (where the phase increases by $2\pi\tau(C)/T$ during $\tau(C) - \tau^+_\gamma \ \tau^-_\gamma$) and of SW having returned along a closed trajectory of length ℓ (according to (A) the SW phase at instant τ^-_γ equals that at instant τ^+_γ) is $2\pi\tau(C)/T$. Equating the latter to $2\ell/\lambda$ (according to the usual operational λ-definition) we have: F) $\ell/\lambda = \tau/T$. Within the i/b-metrization the λ-definition (F) results in $\lambda_i(i-m) = \bar{c}_i T$ (because $\ell_i(i-m) = \tau\bar{c}_i$) (i-m is i-metre) and within the c-metrization in $\lambda_c(s) = T$ (because $\ell_s(s) = \tau$). Thus, the nonconventional λ-definition cannot imply the one-way γ-velocity.

3. The b- and c-metrizations are essentially different. For instance, on a rotating disk (or in a gravitational field) the ratio $r_b(b-m)/r_c(s) = r_b/\tau = \bar{c}_b$ of these metrizations depends on the orientation and site of a measured segment. We stress that the $\bar{c}_b$ velocity (on a closed trajectory) is also the ratio of different metrizations.

Using (F) let us now consider the ratio of i- and c-metrizations:

$$\frac{r_i(i-m)}{r_c(s)} = \frac{2r_i}{\tau} = \bar{c}_i = \frac{\lambda_i}{T} = \frac{\lambda_i(i-m)}{\lambda_c(s)}. \qquad (1)$$

Despite different measuring operations for quantities λ_i and λ_c in (1) and provided that the ratio $\bar{c}_i$ (contrary to $\bar{c}_b$) is a true constant, we get λ_i to be equivalent to λ_c. Indeed, for the standard Kr transition the i-metre definition fixes the λ_i(Kr) value, and λ_c(Kr) is determined by measuring T(Kr)/T(Cs) (T(Cs) is fixed by the definition of Cs second). Constancy of the latter ratio under different conditions is a necessary requirement for a possible use of the atomic transitions as a base of standard clock. Therefore, one must consider $\bar{c}_i$ as the true constant. It means that in the length measurements the i- and c-metrizations are equivalent in their basis. Therefore, $\bar{c}_i$ can be interpreted as the conversion factor between the equivalent (but defined independently) units: the i-metre and second. As a matter of fact, in (1) both the members in each ratio represent the same quantity expressed in different units. From such a viewpoint there is no sense to use the c-metre/second dimension. Thus, since accepting the i-metre standard the two equivalent units can be used for expressing both time and distance, however, usually they are considered as essentially different units. (Earlier a doubt has appeared concerning the possibility to make two independent standards using the spectral lines [3]). Strictly speaking, there are no grounds to interpret $\bar{c}_i = \lambda_i/\lambda_c$ as a characteristic of the rapidity of γ-motion and call it the velocity of light. This name may be used only in a nonstrict sense, by analogy with other physical movements, where in the ratio $2r_i/\tau = v$ quantities $2r_i$ and τ are different.

4. About a decade ago the accuracy of $\bar{c}_i$ (measured by T(s) and λ (i-m)) has been restricted by the reproducibility of the Kr i-metre that cannot be improved, and it is more poor than the accuracy of the Cs second. This has made it necessary to fix a value of c_f within deviations of the measured various $\bar{c}_i$ values (the recommendation of the Committee Consultatif pour la Definition du Metre). A similar fixing of $\bar{c}_i$ (contrary to $\bar{c}_b$) was justified above in item 3. Fixing $\bar{c}_i$ means in fact the transition to the c-metrization. This leads to the following: 1) In kinematics a clock (frequency standard) becomes the only primary standard providing the time and space metrizations; 2) The new unit of length, c-metre, reduces to the second (contrary to the i- and b-metre); 3) Getting the status of the conversion factor c_f loses the status of the velocity of light (r_c and τ are not measured independently contrary to r_b and τ or r_i and τ); 4) There is no sense to use the c-metre/second dimension just as the metre/foot or hour/second dimension. Thus, the length expressed in terms of seconds or c-metres can be measured by a) the time of γ flight of a closed trajectory or b) the SW interference band numbers **N** and **T**

together ($r = NT$). Usually, the accuracy of the latter method is better than of the first one, but the first method provides also the time coordination ($r^{\pm}$) of events.

REFERENCES

1. Giacomo P. Metrologia, 1983, 19, No.2, p.77.
2. Nikolenko V.G. JINR, E4-80-845, E4-81-357, Dubna, 1981; E4-82-273, Dubna, 1982.
3. Brillouin L. Relativity Reexamined. Academic Press. New-York-London, 1970.

Received by Publishing Department
on December 15, 1982.

Николенко В.Г. E4-83-849

Отношения между различными стандартами метризации

В связи с новым официальным определением метра рассматриваются теоретические основы измерений длины и временной координаты удаленных событий с помощью сигналов и часов. Эта метризация сравнивается с метризациями, использующими твердые тела и интерференцию электромагнитных волн. Связь различных стандартов метра и стандарта секунды и их отношения к скорости света анализируются в нетрадиционном духе.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1983

Nikolenko V.G. E4-83-849

Relations between Various Metrization Standards

In view of a new standard of the metre, theoretical foundations are considered of measurements of the length and time coordinates of remote events by using the standard signals and clock. This metrization is compared with the ones which make use of rigid bodies and interference of electromagnetic waves. A nontraditional analysis is given for the connection of various standards of the metre with that of the second and for their relation to the light velocity.

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1983