Quantum Nonlocality with Single Detector and Superluminal Transfer of Information

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We suggest a few experiments using Young's interference, Fraunhofer diffraction, and parametric down conversion to be able to manifest considerable quantum nonlocalities of a new type. Their most characteristic feature is the usage of merely one detector. An inequality defining Einsteinian locality and suitable for violating via a statistical procedure is formulated. It should be pointed out that our method is entirely distinct and independent of Bell inequalities. We demonstrate that proposed devices can be used to transfer information with superluminal velocities, even over very large distances. It is clearly shown that this is not at odds with quantum mechanics and Lorentz transformations provided a postulate, termed 'signal encapsulation', is substituted for Minkowski spacetime in special relativity. Finally, we consider possible momentous applications in computer technology (usable in various types of computers, the Internet, and even during a voyage to Mars) and astrobiology.

Key words quantum nonlocality, Einsteinian locality, Lorentz transformations, Young's interference, Fraunhofer diffraction, parametric down conversion.

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1 Introduction

Can information travel faster than c, the light speed in vacuum? This issue has intrigued theorists for about one hundred years because such an event would violate the principle of causality considered together with Einstein's special relativity [1]. Let us recall that since the mid-1960s physicists have been carrying out a number of experiments [2–31] indirectly demonstrating superluminal activity of Nature. None of them enabled anyone to send any useful faster-than-c signal, i.e., to accomplish a genuine superluminal transmission. Nevertheless, the situation was so disturbing that various explanations have been proposed. One of them is of a general nature; it maintains that there is a fundamental level [32, p. 133, 33, 34] at which, unlike the observational one, even immediate signals can be sent. And indeed, a consistent theory of both the levels has been developed. Nonetheless, in that approach [35–37] there is a distinguished inertial frame, the relativity principle is not exactly fulfilled, and Lorentz group transformations depend on the additional parameter: the fourvelocity of the preferred frame. On the other hand, according to the view presented in the paper, there is only one thing lacking in special relativity necessary to avoid contradictions. It is called signal encapsulation, and it replaces the easy and naive assumption that faster-than-c signals do not exist.

Let an experimenter O send a signal to an event at which two other experimenters O_1 and O_2 are situated. On the basis of naive understanding of signals assumed also by Einstein in special and even general relativity, O_1 will receive the signal without difficulties whenever O_2 is able to do it. In contrast, this will not be always possible on the ground of an interpretation of quantum physics developed by Everett [38]. Suppose that in order to receive the signal, O_1 has to perform a quantum measurement with the possible results 0 or 1 (whose probabilities can differ), where the latter corresponds to the reception of the message. Then, according to Everett's approach, the observer O_1 'branches' into two distinct observers O_{10} and O_{11} recording the outcomes 0 and 1, respectively. As their pasts are identical, O_{10} was at the event, but she could not receive the signal. The encapsulation postulate considered in the work bears a similar consequence: the experimenter located at the target event is not able to obtain the message by using any measurement. However, the reasons significantly differ from those of Everett's theory. Signal encapsulation is, in fact, the third relativistic effect, after time dilation and length contraction, caused by relative velocity. This phenomenon does not lead to fanciful consequences present in the many-worlds interpretation.

The first 'paradox' connected with superluminal velocities was found by Tolman in 1917. All anomalies of this type (cf. Section 7.) contain a characteristic element which is a causal loop. It can be illustrated by an example. If O receives 1, then he takes an action causing that, due to Lorentz transformations and relativity principle, O should get another message with 0 at the same event. Now, according to Everett's approach, O branches into O_0 and O_1, the latter takes the action, but he cannot obtain 0 by definition. Thus there is no contradiction here. Of course, this ought to be treated only as a very rough conception, since the many-worlds interpretation suffers grievously from a critical defect: it is completely nonrelativistic.

Another mechanism worth mentioning in this context is the so-called reinterpretation principle [39, 40]. It states that signals are carried only by objects appearing to be endowed with positive energy. Unfortunately, the principle does not eliminate (cf. Section 11.) all possible contradictions. In our opinion this is the main reason (as Nature must be exactly self-consistent) for lacking experimental evidence concerning superluminal (i.e., moving at speeds exceeding c) particles termed tachyons. On the other hand, signal encapsulation is entirely self-consistent (cf. Section 8.) and we do not predict the existence of any new particles. The method presented in the paper enables one to perform a faster-than-c transfer of information but not of energy.

The memorable paper [41] of Einstein, Podolsky and Rosen created a stir among physicists and began a discussion whether local causality is strictly obeyed by Nature. Later [42] a practical method of answering this question was found, known today as Bell inequalities. They place bounds on the degree of correlation admissible between measurements made at two spatially separated detectors if local causality is valid. Bell's method has been successfully applied in a number of experiments [43–53] corroborating that in quantum world a measurement affects the whole system being measured. That is, the result of a measurement at one detector depends not only on its local parameters but can be coupled via a quantum correlation to the parameters at the other detector. However, the power of quantum physics consists also in admitting measurements made 'in principle', i.e., such that even the mere possibility of performing them changes quantum reality. So far this fact, enabling us to demonstrate nonlocality with the use of a single detector, has not been employed in experiments showing the failure of Einsteinian causality. Our counterpart of the Bell inequality (but completely independent of the latter) and statistical procedure suitable for violating it are given in Section 5.

In Sections 2.–4. we present the outlines of three apparatuses for sending signals with speeds, at least in theory, arbitrarily exceeding c. The underlying quantum phenomena (Young's interference, far-field diffraction, and parametric down conversion) of our devices are well-known, but experiments, even only *gedanken*, have never been arranged in this manner. The closest experiment was performed by two young physicists, Hessmo and Mair, in 1997. An idea applied by them as well as its variant did enable us to overcome an experimental difficulty. In Section 3. we calculate that if Hessmo and Mair [54] had used two clocks and a shutter situated at a suitable location, they would have measured the transfer speed of the order of $10c$.

The shutter (or another, also electronic, device performing the measurement 'in principle' whose result is of no relevance) plays a very important rôle in the experiments suggested in the paper because it replaces a detector. The argument of [55] against superluminal transmission via quantum phenomena does not apply here just inasmuch as each our apparatus enjoys merely one detector (cf. Section 9.).

The main result of the work is presented in Section 12. Using the signal encapsulation postulate we examine a variant of the experiments of Fig. 2. and 3., showing that it will be probably possible to employ it in order to send information with faster-than-c speeds over greater distances. This is a crucial prediction of our approach. If it is in accord with experience, it will become the source of many fruitful applications in computer technology (giving SIT, i.e., Superluminal Information Technology) as well as in astrobiology.

In a civilization such as ours the amount of information needed to be transmitted grows much faster than the state of infrastructure. For instance, businesspeople and other consumers increasingly rely on information downloaded from the Internet and become frustrated with the slow download speeds, but the number and capacity of cables and bands of frequencies can be augmented only gradually. It seems that we will witness the worsening of the situation. However, a solution must be found. In Section 13. we advance the supposition that quantum links with single detector will enable one to achieve, most probably within a dozen or so years, the average signal velocity of the order of 10^9c in wide-area networks. As messages are permanently being exchanged in them, this should significantly increase their capacity as well.

Another class of equally serious problems is connected with the partial breakdown of Moore's law, stated recently by computer scientists and engineers. The process of computation being still relatively fast, it is difficult to transmit quickly the results between various parts of the computer. Here our approach enables one to regard every digital system as a palm-sized computer or even a single microchip. And if this method is applied during a voyage to Mars, the velocity will be of the order of $10^{15}c$, i.e., a supercomputer on the earth will be able to control the flight in real time.

In Section 2. we begin our journey with the relatively small speed $1.005c$, but in Section 14. (in connection with the project SETI: Search for ExtraTerrestrial Intelligence) we reach the mind-boggling $10^{30}c$. Welcome on board!

2 Archetypal experiment

Our first experimental proposal is presented in Fig. 1., where the source L emits spatially coherent monochromatic light with a wavelength λ.

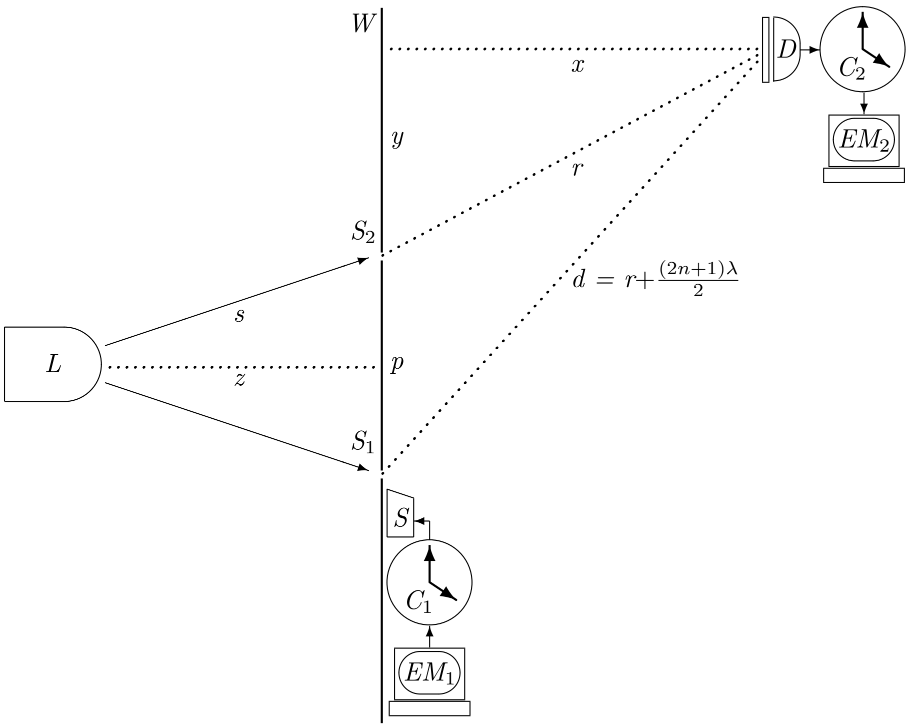

Fig. 1. Fundamental quantum nonlocality with single detector.

The light can get behind the wall W solely through two slits S_1 and S_2 having the same width w such that

$$w < \lambda, \tag{1}$$

and situated at the same distance s from L. The distance z between L and W satisfies

$$\frac{w^2}{\lambda} \ll z, \tag{2}$$

which is implied by, e.g., $w \ll z$. S_2 is constantly open, whereas S_1 can be closed by the shutter S activated by means of the computer EM_1. When it generates a signal, the clock C_1 registers a time t_1, and in a moment S starts closing S_1. There is also a photon detector D located behind W in such a way that its distances from S_2 and S_1 are equal to r and $d = r + (2n+1)\lambda/2$ respectively, where n is a nonnegative integer. The distances: x from D to W and p between the central lines of the slits satisfy

$$p \ll x. \tag{3}$$

In agreement with the rules of quantum optics [54], the probability P that a photon will be detected by D fulfills

$$P \propto \left|\varphi_1 \mathrm{e}^{\mathrm{i}kr_1} + \varphi_2 \mathrm{e}^{\mathrm{i}kr_2}\right|^2, \tag{4}$$

where $k = 2\pi/\lambda$ is the wave number of the photon. Thereby, no photon emitted by L normally reaches D, but after the beginning of closing S_1 some of them can be registered. The clock C_2 records a time (in reality somewhat later) t_2 of the event. We see that there is a correlation between sending a signal by EM_1 and detecting a photon by D.

According to [56], "... speed of quantum information can be defined formally in any frame. Its definition goes as follows: since correlations were observed, the quantum information must have traveled the distance between the two detectors in the time interval between the two detections." We adopt this definition with a correction: the rôle of the first detection should be played by the generation of a signal by the computer. (It can be replaced by, e.g., pressing a button by the first experimenter. He may do this after long hesitation.) Having the time interval $\langle t_1, t_2 \rangle$ and distance between the clocks, no less (as may be assumed) than d, we are in a position to define what we want to measure in this experiment. Namely, it is

$$v = \frac{d}{t_2 - t_1}, \tag{5}$$

i.e., the speed of quantum information. Note that it, unlike the one considered in [56], can be treated as the speed of the transmission of a useful signal. (If D has recorded photons, then the second experimenter knows that, e.g., she has been asked out to dinner.)

Calculating v is no easy task because owing to uncertainty we may get a different speed each time. By $v_{\max}$, the *maximal speed*, we denote the least upper bound of the set of all speeds which can be obtained in a great number of experiments. We try to estimate $v_{\max}$ considering a worst-case scenario. Suppose that the interference has not been destroyed by the partial closing of S_1, i.e.,

$$t_2 \geq t_1 + T_0 + T, \tag{6}$$

where T_0 is the 'idle time', i.e., the sum of two periods of time: from t_1 to the beginning of closing S_1 and from detecting a photon by D to t_2, while T is the total time of closing the slit. From the definition of p it follows that

$$w < p,$$

whence using (1) and (3) we get

$$\frac{w^2}{\lambda} \ll x. \tag{7}$$

It and (2) mean that x and z are effectively infinite. Therefore, when S_2 is the sole open slit, Young's interference will be eventually replaced by far-field diffraction. Then the probability amplitude $A(D)$ that a photon passing through the aperture will be recorded by D satisfies [54]

$$A(D) \propto \operatorname{sinc}\left(\frac{\pi w y}{\lambda r}\right), \tag{8}$$

where y is the position of D at a virtual screen (see Fig. 1.), and

$$\operatorname{sinc}(\alpha) = \frac{\sin\alpha}{\alpha}.$$

As $y < r$, from (1) it follows that (8) does not vanish for any y, so D can register photons. (The same can be achieved even if (1) is not satisfied, but (7) still holds. This follows from the fact that diffraction fringes depend on the position of one slit, while fringes of Young's interference — on two.) Thus D will record photons whenever the number of experiments or luminous intensity of L is sufficiently large.

At this point we can estimate the arrival time. In our worst-case scenario Fraunhofer diffraction involves only wavepackets generated by L after the entire closing of S_1. Thus photons emitted by L and detected by D must cover the distance $s + r$. We agree entirely with the following general remark [57]: "In practice, one cannot extend the arrival time to any time before the detection of the first photon." Therefore, instead of considering front velocity and related notions, we shall be using operational definitions expressed in terms of photons straight away. In this section we assume that experiments are performed in a near-perfect vacuum. The equality of the light speed in a perfect vacuum to c means, operationally, that if photons travel a distance u, then for every $\varepsilon > 0$ at least one of them will be detected before elapsing the time

$$\frac{u}{c} + T_0 + \varepsilon, \tag{9}$$

as long as the intensity of light or the number of experiments is sufficiently large. Here T_0 can depend on the wavelength and properties of the used sources, detectors, and clocks, but it has to be independent of u whenever the vacuum is really perfect. Indeed, otherwise the speed would be simply different from c. By virtue of (9), using (5), and taking (6) into account (as we may assume that T_0 of (6) and (9) has the same, sufficiently large, value), we get

$$v_{\max} \geq \frac{d}{T_0 + T + \frac{s+r}{c}}. \tag{10}$$

The right side of (10) exceeds c if and only if

$$d - r > (T_0 + T)c + s. \tag{11}$$

Note that we have to have $d - r < p$, and choosing x and y sufficiently large (which enables one also to ensure (3)) one can obtain $d - r$ arbitrarily close to p. Furthermore, if we increase p keeping z and w constant, then $p - s$ tends to positive infinity, while (2) remains true. Thus (11) will be fulfilled whenever p, x, and y are sufficiently great with unchanged z and w. Obviously, no perfect vacuum exists, but if we have found a configuration fulfilling (11), then we can try to create a state, in a bounded region, such that at least some photons interact with no atoms, i.e., the time (9) is adequate for them.

We see that the superluminal transmission will be workable regardless of the possessed shutter (the time T) as well as detector and clocks (T_0). Let us note that uncertainty and other possible side effects (any 'standard retardation time', bunching and antibunching of photons, etc.) are already contained in T_0. However, a more detailed analysis shows that, even though T and s can be omitted in (10), the velocity of the information transfer remains here of the order of c. It is caused by the necessity of (3). For example, the speed exceeds c by 0.5% whenever $p = x/100$. This suggests that the apparatus of Fig. 1. will not be probably used for practical purposes. Nevertheless, it is of great theoretical importance, inasmuch as from the viewpoint of relativistic consistency there is no difference between the speeds $1.005c$ and, e.g., $10^{30}c$.

3 Superluminal transmission by two postgraduates

If you have found the foregoing experiment too difficult to carry out, you may try out the method of superluminal information transfer discovered by a Scandinavian-Austrian group [54]. Hessmo and Mair applied the configuration presented in Fig. 2., albeit without the shutter nor clocks, which impeded measuring any speed. We shall see, however, that some velocities of the experiment must have been superluminal, and they will be possible to be measured.

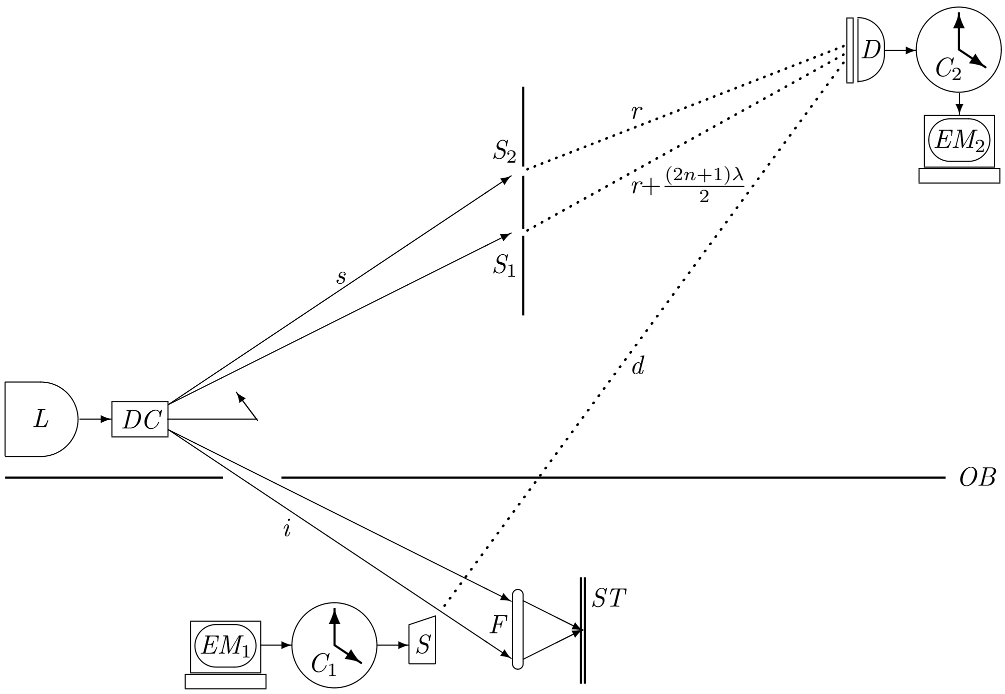

Fig. 2. Quantum nonlocality by two postgraduates.

The main intention of the two ingenious postgraduates was 'to understand certain aspects of diffraction and complementarity' [54] in the context of Young's double slit experiment. Note that, in principle, we tried to do the same in the previous section. However, our considerations were limited to single-particle states, while the young scientists reached out for quantum entanglement, i.e., multiparticle superposition according to Schrödinger's definition [58, 59].

In Fig. 2. pump photons of a frequency ω emitted by L interact with a nonlinear medium DC in the process called parametric down-conversion [60–63]. It can cause that an incident particle splits into two photons, historically known as signal and idler, whose frequencies add up to ω. The twins emerge simultaneously in different directions and their state is an entangled quantum state. Hessmo and Mair were probably the first to demonstrate experimentally that the manipulation of idlers can influence the second-order interference of signal photons behind two slits. Just this fact is utilized in our second proposal for sending superluminal signals.

It is known [64] that energy and momentum must be conserved in the process of parametric down-conversion. Therefore, if the idler leaves DC in a specific angle with respect to the propagation of its high-frequency parent, and the entanglement of twins is perfect, then it is possible to say with the probability unity in which direction the signal photon propagates. In other words, a position measurement on the idler photon determines the position of its signal partner.

In reality the entanglement can be partial; we have, limiting considerations to two pairs of paths, the following state [54]

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|U\rangle_i (\cos\alpha\, |L\rangle_s + \sin\alpha\, |U\rangle_s) + |L\rangle_i (\cos\alpha\, |U\rangle_s + \sin\alpha\, |L\rangle_s)), \quad (12)$$

where the subscripts i and s refer to idler and signal photons respectively, $|U\rangle$ and $|L\rangle$ denote their upper and lower paths (see Fig. 2.) correspondingly, and α of $\langle 0, \pi/4\rangle$ depends on the size of the pump beam. If it is sufficiently wide, then α vanishes, i.e., the entanglement is maximal [65]. In this case we know certainly that, e.g., the signal photon passes through S_1 whenever the idler has been detected on the upper path. Then, of course, there should not be any interference behind the double slit. In general, the detection of an idler in the upper or lower arm does not allow one to infer with certainty that its twin is in the opposite arm. Instead we find that it has the amplitude $\cos\alpha$ ($\sin\alpha$) for the opposite (same) arm.

The distinguishability $\mathcal{D}$ of paths in a double-slit experiment was defined [66, 67, 54] as

$$\mathcal{D} \stackrel{\text{def}}{=} |p_1 - p_2|\,,$$

where p_i is the probability of passing through S_i. Here it is equal to $1 - 2\cos^2\alpha$. Thereby $\mathcal{D}$ vanishes solely for $\alpha = \pi/4$, i.e., when the twins are not entangled at all. At the same time [54] we have

$$\mathcal{D}^2 + \mathcal{V}^2 = 1,$$

where $\mathcal{V}$ is the visibility. Hence we infer that whenever they are partially entangled, and a position measurement performed on the idler particle determines its path, then the visibility cannot be unity.

However, in order to obtain $\mathcal{V} = 1$ we cannot simply give the position measurement up. In a variant of the experiment by Hessmo and Mair the idler photons were 'ignored', which means that they were absorbed by, e.g., a wall. But it is, from the viewpoint of Nature, a type of detector; one could in principle to measure the height of the point where the absorption took place. Thus a crucial observation [54] is that "If momentum is measured on the idler photon, all knowledge of its position is destroyed since momentum is complementary to position. Also the possibilities of knowing the position of corresponding signal photon are lost, then there should be interference with full visibility behind the double slit." The vectors corresponding to twin photons can be represented with the use of a basis rotated by 45° in the Hilbert space

$$|U\rangle_t = \frac{1}{\sqrt{2}}(|\Lambda\rangle_t + |\Lambda^\perp\rangle_t),$$

$$|L\rangle_t = \frac{1}{\sqrt{2}}(|\Lambda\rangle_t - |\Lambda^\perp\rangle_t),$$

transforming $|\Psi\rangle$ of (12) into its Schmidt decomposition [68]

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|\Lambda\rangle_i |\Lambda\rangle_s (\sin\alpha + \cos\alpha) + \left|\Lambda^\perp\right\rangle_i \left|\Lambda^\perp\right\rangle_s (\sin\alpha - \cos\alpha)). \qquad (13)$$

The observable with the eigenstates $|\Lambda\rangle$ and $\left|\Lambda^\perp\right\rangle$ is complementary to the one having the eigenstates $|U\rangle$ and $|L\rangle$. If $|\Lambda\rangle$ or $\left|\Lambda^\perp\right\rangle$ is measured on the idler, it will be impossible to get path information (about $|U\rangle$ and $|L\rangle$) for the photon. From (13) it follows that the measurement will also project its signal twin into the same state. As the amplitudes for the paths U and L are equal in the states $|\Lambda\rangle$ and $\left|\Lambda^\perp\right\rangle$, the full visibility should be recovered. This has been exactly corroborated in the experiment [54].

When the shutter S of Fig. 2. is shifted down, idler photons, not disturbed by it, reach the lens F. In its focal plane there is a detecting (in principle, maybe) station ST. Normally, ST performs a position measurement, but in this case, owing to F, different momenta of idlers are mapped to distinct points of the plane. Thus ST measures momentum. As the results for photons $|U\rangle_i$ and $|L\rangle_i$ can be identical (their paths are able to be parallel), this measurement does not reveal the paths of signal photons. Thereby the visibility far behind the slits S_1 and S_2 equals unity. Therefore, λ being the wavelength of signal photons, the detector D of Fig. 2. cannot register them.

Now suppose that S is shifted up in such a way that at least some lower idler photons cease to reach F. The shutter acts exactly as the wall; it is a type of detector enabling one, in principle, to determine the paths of idlers. Thus if the twins are at least partially entangled, then the visibility decreases, whence at least some signal particles can be recorded by D. We see that, similarly as in Section 2., there is a correlation between generating a signal by EM_1 and detecting a photon by D. The speed of quantum information is also given by (5) with d being the distance between S and D.

In Fig. 2. i denotes the distance from DC to S, while s — from DC to S_2. In the section we assume that

$$i \leq s. \qquad (14)$$

If an idler is absorbed by the shutter, then its twin, to be registered by D, has to travel the distance $s - i + r$. The locations of C_1 and C_2 may not coincide exactly with those of S and D correspondingly, but this is taken into account via T_0 defined here as the sum of two periods of time: from t_1 to the beginning of disturbing idlers by S, and from detecting a photon by D to t_2. Thus we get

$$v_{\max} = \frac{d}{T_0 + \frac{s-i+r}{c^*}}, \qquad (15)$$

where c^* is the maximal real number such that if photons travel a distance u, then in a great number of experiments at least one photon emitted by the source will be detected before elapsing the time $u/c^* + T_0 + \varepsilon$. Of course, c^* can be treated as the speed of light in the laboratory, i.e., it is possible that $c^* < c$.

In the above argument, we assumed that ST enjoys near-unit efficiency. Nonetheless, the lack of such detectors does not have to be any essential obstacle; in Sections 5. and 6. we present alternatives for this case. The method the postgraduates used, who had just a detector ST with low efficiency, cannot be recommended here. They sent simply an electric signal from ST to EM_2, and the latter omitted the detections done by D unless they occurred in coincidence. In experiments proposed in the paper no conventional connection between ST and EM_2 can be utilized, although it may, of course, exist and carry delayed information. In any case, let us say clearly: *The necessity of waiting to record interference or not until a subluminal message is received does not follow from the equations of quantum physics and would be contrary to its spirit.* Besides, it is necessary to note that if ST measures the momentum of an idler, its signal twin (whose path is then certainly unknown and cannot be, even in principle, disclosed) has to interfere even if no information about this fact leaves ST. Therefore, even if ST is poor and isolated from other devices except F, a difference of intensities recorded by D should appear. This confirms that ST may be also a detector 'in principle'. It seems that a photographic plate, screen, beam stop, wall, or other objects absorbing light will work equally well.

It is worth admitting that Hessmo does not write either that the registration of detections done by ST somewhere outside ST is necessary. His explanation is, in my opinion, entirely correct.

It is easy to see that d of (15) can be greater than the analogous distance in Fig. 1. Nonetheless, d will not be able to be arbitrarily large yet as long as the distances between the slits and the detector are fixed. The reason for that is, of course, diffraction. It causes that the photon paths are not exactly rectilinear, whence, for example [54], "If the diffraction pattern is wide enough to cover both slits of a double slit inserted in the path of the signal photon, even an optimal position measurement on the idler will not reveal with certainty the path of the signal photon." This limits not only s but d as well, since

$$d \leq 2s + r, \tag{16}$$

is implied by (14). How one can break this barrier will be explained only in Section 12.

Hessmo [54, Fig. 1.3] has reported that even for $s = 1\,\text{m}$ there were points at which no signal photon was registered in coincidence with a momentum measurement on the idler, and at which over 50 particles per second were recorded when the idler was ignored. This is already a correlation that can be utilized at least in our statistical procedure given in Section 5. The double slit in the experiment by Hessmo and Mair had the slit separation 250 μm and slit width 80 μm. Thus to get (3) we may assume that, e.g., $r = 5\,\text{cm}$. Right after creating twins they could be send, with the use of mirrors, in opposite directions; this does not destroy the position entanglement. Hence we get $d = 2.05\,\text{m}$ (cf. (16)). From Fig. 2. it follows that we would be able to set S and F in such a way that, from the practical point of view, $i = s$. Suppose that the atmosphere is so dense that $c^* = 0.9c$. (We would obtain speeds exceeding c in this experiment even if it was performed in water. To tell the truth, the speed of conjugate photons equal to $0.05c$ would be still sufficient.) Finally, let us put $T_0 = 0.5\,\mathrm{ns}$. This time should be enough for an electric current to flow from C_1 to S and from D to C_2 as long as the devices are separated by at most a few centimeters. Substituting the quantities into (15), one obtains $v_{\max}$ equal to about $3\,\mathrm{m/ns}$. We see that by the simple addition of a shutter and clocks to the experiment of Hessmo and Mair one can measure velocities with the order of magnitude of $10c$.

The question arises if the path information carried by idler photons can be erased by a position measurement as well. For example, one could introduce a second double slit instead of F. In [54] Hessmo states that "Only path information in the double slit is relevant for the interference. Therefore it is sufficiently to erase this information to obtain interference. It is not necessary to do this with a momentum measurement. For instance, to detect the idler photon on a screen behind a second double slit introduced in the idler's path will also erase path information." The words confirm once more that no subluminal connection between ST and EM_2 is needed. Note that after passing through the double slit and its small neighborhood the idler may be ignored because then any wall will play the rôle of a far screen, i.e., detector with near-unit efficiency. Therefore, the path of the signal twin will not be able to be revealed. Nonetheless, if two double slits are used, then it may happen that the fourth-order effects, causing that 'the detection of one photon at one point rules out certain positions where the other photon can appear' [61], will mask the second-order ones. This will be able to be examined using a statistical method given in Section 5. Although it is possible that under suitable conditions the second-order interference will dominate over the fourth-order one, in the next section we suggest another position measurement in which the latter phenomenon certainly does not occur at all.

4 Usable superluminal device

The device of our third proposal does not contain any double slit at all, so it may be more convenient to utilize. The apparatus whose outline is presented in Fig. 3. consists of nine mirrors (denoted by M), two beam splitters (BS) with equal transmission and reflection probabilities, two clocks (C), a laser (L), a photodetector (D), at least one computer (EM), a shutter (S), two lenses (F), a small aperture (A) in a wall (W), and two identical nonlinear crystals (DC) able to realize parametric down conversion. The crystals should be optically pumped by a coherent pump wave emitted by L and split at BS_1. This may cause the conversion of the photons at one or both crystals, each with the emission of a signal particle s_j and an idler i_j, where $j = 1, 2$.

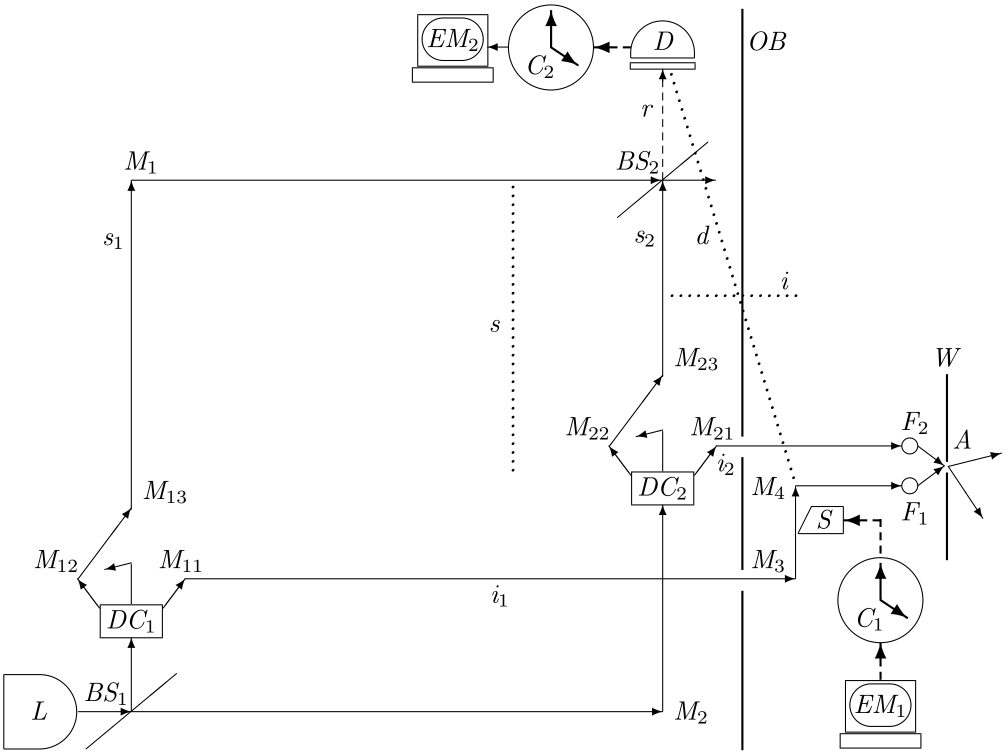

Fig. 3. One more quantum nonlocality with bounded propagation speed.

Consider first the situation when S allows idler photons to arrive (after focusing by F) at A. We assume that the optical paths from L through DC_1 and DC_2 to F are made as nearly equal as possible. It is important that the uncertainty principle not only does not stand in the way of our experiment being done but it even helps. Let us recall that [69] "One can readily show, from the uncertainty principle, that the packet must always be fairly large compared to a wavelength, in order not to spread too rapidly." We use this fact to replace the momentum measurement of the previous section by a position measurement enjoying an unusual property: the result is always identical. We get each time that the position of an idler is just the one of A with the accuracy $\triangle A/2$, where $\triangle A$ is the diameter of A. (The wall surrounding the hole is a type of detector with near-unit efficiency. And if a detector with an efficiency p has not recorded a particle, then we know with the probability p that it is or was at another location. Note that the aperture certainly does not measure momentum.) The measurement is not destructive, but if $\triangle A$ is sufficiently small, then independently of how and how well idler particles are measured after A, no information about their paths before A can be obtained. In fact, otherwise we would know that a photon was at A and had a definite momentum, which contradicts the uncertainty principle. As the accuracy of the momentum measurement can be expressed by the angle between indistinguishable paths, we have to have

$$\triangle A \triangle i < k\lambda,$$

where $\triangle i$ is the angular separation of i_1 and i_2, λ — the wavelength of idlers, and k — a constant.

Let us calculate an adequate size of the aperture. Suppose that it is still very large compared to the wavelength. Rayleigh showed, theoretically and experimentally, that the resolving power of a perfect objective with diameter δ such that $\lambda \ll \delta$ is $\delta/1.22\lambda$, i.e., $k = 1.22$ in this case. Thereby it seems that an aperture with the diameter $\lambda/\triangle i$, where $\triangle i \ll 1$, is sufficient, which gives the order of magnitude of 0.1 mm at laboratory conditions. This should ensure that, according to the discussion of the previous section, the *welcher Weg* information is lost after passing through the aperture. We assume that the optical paths from L through DC_1 and DC_2 to BS_2 are also nearly equal. Thus the waves reaching BS_2 recombine in phase, whence applying Dirac's reasoning [70, p. 9] in the case of single particles we infer that no photon (above the vacuum level) is recorded by D.

Now suppose that EM_1 sends a signal to C_1. (Of course, the clock can be a part of the computer.) Then it registers time t_1 and shifts S to the left. This causes that idler particles cease to be mixed at A, and i_1 are 'recorded' by a 'detector' having 100% efficiency, i.e., the shutter. But this enables one, from the viewpoint of Nature, to determine whether a signal photon arriving at BS_2 comes from DC_1 or DC_2. Thus, according to the Feynman uncertainty principle ("Any determination of the alternative taken by a process capable of following more than one alternative destroys the interference between alternatives." [71, p. 9]), signal particles stop interfering, and some of them can be recorded by D. Then it sends a signal to C_2 which registers a time t_2. We see that there is a clear difference between stopping idler photons before and after A. Just its existence is used in the suggested experiment.

More precisely speaking [cf. 72, p. 26], let $|P\rangle$ denote a photon emitted by L. At BS_1 we have $|P\rangle \to (|DC_2\rangle + \mathrm{i}\,|DC_1\rangle)/\sqrt{2}$. At M_2, $|DC_2\rangle \to \mathrm{i}\,|DC_2\rangle$. At the crystals, $|DC_j\rangle \to \eta\,|s_j\rangle_1\,|i_j\rangle_2$, where η is the amplitude for parametric down conversion. At M_1, $|s_1\rangle \to \mathrm{i}\,|s_1\rangle$. At the second beam splitter, $|s_1\rangle \to (|{\sim}D\rangle + i\,|D\rangle)/\sqrt{2}$ and $|s_2\rangle \to (|D\rangle + i\,|{\sim}D\rangle)/\sqrt{2}$. At the shutter absorbing idlers with a probability p,

$$|s_1\rangle_1\,|i_1\rangle_2 \to \sqrt{p}\,|s_1\rangle_1\,|S\rangle_2 + \sqrt{1-p}\,|s_1\rangle_1\,|i_1\rangle_2\,. \tag{17}$$

Finally, at A, $|i_1\rangle \to |A\rangle$ and $|i_2\rangle \to |A\rangle$. Combining the terms we obtain, after some algebra,

$$|P\rangle \to \frac{\mathrm{i}\eta}{\sqrt{2}}\left(\sqrt{p}\left[\frac{\mathrm{i}(|{\sim}D\rangle + \mathrm{i}\,|D\rangle)}{\sqrt{2}}\right]_1 [|S\rangle]_2 + \right.$$

$$\left. + \,2\sqrt{1-p}\left[\frac{\mathrm{i}\,|{\sim}D\rangle}{\sqrt{2}}\right]_1 [|A\rangle]_2 + (1-\sqrt{1-p})\left[\frac{|D\rangle + \mathrm{i}\,|{\sim}D\rangle}{\sqrt{2}}\right]_1 [|A\rangle]_2\right). \tag{18}$$

We have here four events: DA, DS, $^\sim DA$, and $^\sim DS$. Denote by P the probability of the two first ones, i.e., the probability that the photon reaches D. From (18) it follows that

$$\frac{P}{\eta^2 - P} = \frac{(1-\sqrt{1-p})^2 + p}{(1+\sqrt{1-p})^2 + p},$$

whence we get

$$P = \frac{\eta^2(1-\sqrt{1-p})}{2}. \tag{19}$$

This confirms, first of all, that if p vanishes, then the amplitude of detecting a signal photon by D equals zero. And if the shutter is shifted left entirely, then D records half of signal particles (whenever it has near-unit efficiency). But (19) holds also for p of the interval (0,1). Just to prove this relationship we have used (18) instead of a nonlinear hamiltonian; the latter does not describe the action of the shutter.

In Fig. 3. i denotes the distance from DC_2 to S, while s — from DC_2 to BS_2. In the section we have to assume that (14) is fulfilled. Indeed, otherwise at the moment when i_1 is absorbed by S, s_1 would not exist, i.e., we could not write (17). Let d, T_0, and c^* be defined as in the previous section. The speed of quantum information is given here by (5) as well. At an instant $t_1 + T_0 + \varepsilon$ we have $p > 0$, which, according to (19), implies $P > 0$. This means that in a great number of experiments an idler will be really absorbed by S at the time, and its twin will be recorded by D. The signal particle has to travel the distance $s - i + r$. Thus the maximal speed is also given here by (15). In this experiment $v_{\max}$ can be arbitrarily large. For example, in the geometry of Fig. 3. it is close to $c\sqrt{5}$ whenever T_0 and r are small, and c^* is almost equal to c (note that T_0, r, and c^* are independent of d and $s - i$).

Concluding the section we consider whether the idlers can be equally well mixed with the use of a device different from the aperture. Suppose that i_1 and i_2 are made to be parallel and focused by a lens with a screen in its focal plane. Then idlers belonging to distinct paths can be absorbed at the same point of the screen, and the absorption rules out any later detection of the photons. We see that the method of Hessmo and Mair can be here successfully applied as well. Conversely, the unique position measurement could be used instead of the momentum measurement in the experiment of Fig. 2. In this case F should be replaced by a system of lenses.

It is tempting to remove M_4 and install a first-surface mirror *FSM* at the intersection of i_1 and i_2. Two possibilities are worth mentioning in this context. If *FSM* is a see-through (two-way) mirror [73], then some photons of i_1 will be reflected, while some of i_2 — transmitted. As this is not connected with interference, it seems that they will be, at least partly, indistinguishable. This resembles the solution of [52, 74], where i_1 and i_2 were lined up. The method of Zou *et al.* is useless here because they utilized the transparency of the down conversion crystal, and in our apparatus one cannot return to it. Nonetheless, they were able to corroborate that if idler beams are indistinguishable, then one can obtain ordinary single-particle interference fringes at D by varying the phase, while otherwise the fringes at D disappear independently of the phase. Finally, suppose that FSM is a 50:50 beam splitter, and at least one of the output beams is detected (before reaching one more possible splitter) in any way. The situation is similar to the one of the conclusion of the previous section; the two-particle interference may affect the single-particle visibility. (The coincidence rate for simultaneous detections of signal and idler photons was measured in [75, 76].) Again, this can be examined using the approach of the next section (the results will likely depend on the difference of phases).

5 Basic inequality: how to violate it

In the section we give our counterpart of the Bell test of Einsteinian locality. The method can detect even minimal differences of intensities yielding the locality violation and solve a number of practical issues connected with the experiments proposed in the paper. For instance, it would be difficult enough to ensure that D records photons are exactly at a point. It is possible to decrease the operation region of D and at the same time adjust its sensitivity, but this is not entirely reliable. Another problem, connected with uncertainty, is that each time we may obtain a different speed. What is more, owing to vacuum fluctuations the apparatus can trigger an alarm without any reason, or due to problems with adjusting sensitivity it can remain silent despite EM_1 sending a signal. We suggest, therefore, the following statistical procedure.

Consider an experiment performed by EM_1 and consisting of cycles following one another repeatedly, each of which involves two stages. In the first stage (termed the *action period*) the shutter begins to close S_1 or the way for idlers, at a moment absorbs or scatters a maximal number of photons, and finally returns to the initial position. In the second stage (termed the *standby period*) the way for photons is entirely open all the time. The duration a of the action period is fixed for all cycles, while the length z of the standby one is increased gradually. The intensity of the light source either is constant or changes periodically. In the second case we recommend that $a+z$ remains a multiple of the pulse duration. Let d be the distance from C_1 to C_2, V — a positive number termed the *propagation speed*, and w — a nonnegative one called the *waiting period*. (To be certain that the speed is superluminal, and there are no side effects, the distance should be measured between the nearest parts of the clocks or computers containing them.) Denote by Q be the quantity of alarms (in times of detecting a photon by D) raised during the time interval $(t{+}w{,}t{+}a{+}z]$, and by Q_0 — during $(t{,}t{+}d/V]$, where t is the initial instant of a cycle. For each foregoing parameter x, denote by x^+ and $x^\sim$ its sum and arithmetic mean respectively over all cycles performed so far. The *unreliability* of the apparatus with the propagation speed V is defined by

$$U(V) = \lim_{z\to\infty} \frac{Q^\sim d}{Q_0^\sim V(a+z^\sim - w)}. \tag{20}$$

For numerical purposes the equivalent formula

$$U(V) = \lim_{z\to\infty} \frac{Q^+d^+}{Q_0^+V(a+z-w)^+},$$

can be better. If Q_0 does not vanish (which holds in practice because there is always some noise), then $U(V)$ is a number of $\langle 0,1\rangle$. The *reliability* of the device with the speed V is defined by

$$R(V) = 1 - U(V).$$

This measure seems to be more convenient, at least verbally. One may also apply (if you like numbers greater than 1)

$$S(V) = \frac{R(V)}{U(V)} = \frac{1}{U(V)} - 1,$$

termed the *signal-to-noise ratio* of the superluminal device. This is a counterpart of the ratio of signal power to noise power, employed in the transmission of electromagnetic signals. The least upper bound of the set $\{V\colon\, R(V) > 0\}$ (i.e., the set of all propagation speeds for which a systematic action of the apparatus can be observed) will be called the *actual speed* v_{act} of the transmission. Thereby v_{act} is the maximum speed achieved actually. In the case of $R(V) = 1$ the device works at the speed perfectly, since $Q_0{}^\sim/(d/V)$ is the frequency of 'good' alarms, while $Q^\sim/(a+z^\sim-w)$ for z converging to infinity — of noises. $R(V) = 0$ for every V signifies that the apparatus operates in an entirely random way.

Obviously, in practice to calculate $U(V)$ it suffices to increase z merely to a ceiling. From the theoretical point of view the waiting period is not essential, but its nonzero value can improve the convergence of (20).

In Section 7. we show that if Einsteinian locality were true, then $U(V)$ would be less than 1 for no V exceeding c, that is, we should have

$$v_{\text{act}} \le c. \tag{21}$$

On the other hand, we prove also that breach of (21) does not cause any contradictions on the ground of the theory, similarly as that of Bell inequalities is not at odds with quantum mechanics. Thus (21) is our counterpart of the Bell inequality.

Violating (21) ought to be relatively easy. In practice, it suffices to set devices, turn on them, and wait for a sufficiently long time. Of course, one should previously estimate using, e.g., (15) whether $v_{\max} > c$. All disadvantageous factors (uncertainty, masking, etc.) are already taken into account in the definition of unreliability, whence in the one of v_{act} as well. If the number of experiments is large, then v_{act} will be close to $v_{\max}$ albeit the reliability can be small. This method will work even in the case of the experiment of Fig. 1. because the probability that a photon reaches D changes somewhat when S begins to close the slit.

In the case of Bell inequalities the distance between the detectors is irrelevant. For example, the polarization of a two-photon state is depicted [54] by the quantum state vector

$$|\Phi\rangle = \frac{1}{\sqrt{2}}(|H\rangle_1 |H\rangle_2 + |V\rangle_1 |V\rangle_2), \tag{22}$$

where the subscripts 1 and 2 are assigned to distinct (but being in a perfectly entangled state) photons, and H and V — to their horizontal and correspondingly vertical polarization. As the probability amplitudes of events corresponding to $|H\rangle_1 |V\rangle_2$ and $|V\rangle_1 |H\rangle_2$ vanish, a measurement of polarization of the photons gives the same result with the probability unity. Notice that (22) states nothing about the distance between the photons. Thus the two entangled photons should be found with the same polarization regardless of distance between them [54]. On the other hand, the parameter d appears in (20), whence also in (21).

The correlation between analyzing stations, such as the one implied by (22), is sometimes [56] considered as due to a superluminal influence that the first photon sends to the second one. In [56] the speed at which this influence should propagate from one analyzing station to the other one is called the speed of quantum information (cf. Section 2.). If it is superluminal, then there is always a frame in which the two measurements are simultaneous, i.e., the speed becomes infinite. This can happen even in a preferred or laboratory frame, e.g., by accident, although the perfect simultaneity cannot be confirmed experimentally due to finite accuracy of measurements [56]. Again, in our apparatuses the situation is different. The speed of quantum information will never be infinite; even only in theory (we shall see that this is caused by signal encapsulation). World records will be able to be set and broken in at least the three branches: speed v_{act}, reliability $R(V)$ with $V > c$ (or, later, maximal speed with the reliability 1), and distance d with a superluminal speed.

6 Shutter visibility

Consider an experiment with a shutter S, interference device I, and detector D. We shall say that S is *visible* (by D) if the probability that a particle being within I at the time 0 will be recorded by D changes when S can stop (absorb, scatter, etc.) a particle at a time $-T_1$ such that $T_1 \geq 0$, and

$$\frac{r}{c^*} + T_1 < \frac{d}{c}, \tag{23}$$

where c^* is the speed of the flight from I to D, r is the distance between I and D, and d — between S and D. The particles do not need to be photons; (23) ensures that we shall have a superluminal effect here even if c^* is very small. The numerical value of the shutter visibility is

$$\mathcal{W} \stackrel{\mathrm{def}}{=} \frac{P_{\mathrm{a}} - P_{\mathrm{b}}}{P_{\mathrm{a}} + P_{\mathrm{b}}},$$

where P_{a} and P_{b} are the probabilities of the detection with the shutter advanced and shifted back respectively. The visibility is *full* if $|\mathcal{W}| = 1$. Note that, unlike fringe visibility, $\mathcal{W}$ can be negative, but in all the experiments discussed in

Sections 2.-4. the shutter was positively and fully visible, I being the double slit or BS_2. Using parametric down conversion, T_1 can be nonzero, for it equals $(s-i)/c^*$ whenever (14) holds. From (23) it follows that in the case of negative visibility the particle absorbed by S is not the one lacking at D. Thus the shutter can be visible only if there is really an interference within the device I.

By shutter we mean any device performing a measurement 'in principle' whose result — unlike the case of detectors — is irrelevant. Indeed, the position of scattering not only does not matter, but it may not arise at all. The shutter should simply shut — at least with a nonvanishing probability — a way, and that is all. (Of course, a detector can be used as a shutter, but note that then it may be arbitrarily turned.) Thus it does not need be a mechanical part. For instance, it is possible to use a beam of electrons scattering photons. We remain such solutions to the inventiveness of experimenters.

Denote by N_1 and N_2 the average numbers of particles registered by D in a period of time T_2 when S visible by D scatters a maximal number of particles and none of them correspondingly. The computer EM_2 analyzes the results on-line. Only if the number of detections during $\langle t, t+T_2\rangle$ for a t becomes greater (less in case of $N_1 < N_2$) than

$$N_2 + l(N_1 - N_2), \tag{24}$$

where l is a fixed real number of $\langle 0,1)$, EM_2 activates an alarm, i.e., it affirms that a signal is received at a time $t_2 > t + T_2$, probably owing to the generation of a signal by EM_1 at $t_1 < t + T_2$. For example, in the experiments of the article we may put $l = 0$ and take any $T_2 > 0$, since $N_2 = 0$, and $N_1 > 0$. The parameters T_2 and l are arbitrary, but the reliability can depend on them. (Alternatively, l can be a number of $(0,1\rangle$ provided the number of detections equal to (24) gives an alarm as well.) As we have proved that in the experiments of Fig. 2. and 3. the maximal speeds have no upper bound, it is possible to find T_2 such that the transmission speed, equal here to

$$\frac{d}{T_0 + T_1 + T_2 + \frac{r}{c^*}},$$

is arbitrarily large as well.

In this manner, the second computer enters into operation. The method is of no great importance from the purely theoretical viewpoint, while practical applications may require high reliability. The connection of the receiver to the electronic digital machine working on-line can just reduce the frequency of false alarms. Furthermore, it is indispensable for the shutter to be negatively visible.

7 Fundamental contradiction with Einstein's relativity

It is sometimes stated that superluminal transfer of information is not at odds with special relativity itself, but only with the theory combined with causality principle. In the section we add to special relativity something treated frequently as the opposite of causality, namely, indeterminacy, and we obtain a contradiction as well. Our proof does not need the concepts of 'cause' and 'effect' [cf. 77, 78]. We use here the terminology of information theory [79], although it is not crucial.

Suppose that we have an apparatus for sending signals with a speed $V > c$. It can be utilized, by virtue of the relativity principle and the stipulation of the isotropy of space, by any inertial observer and in any direction. Even if the device does not work perfectly, due to, e.g., quantum uncertainties, it is still possible to use it to build a noisy discrete binary channel. Let an experimenter O travel from $(\boldsymbol{x},s)$ to $(\boldsymbol{y},w)$. During the journey he performs an experiment whose result X has a probability p_1 distinct from 0 and 1. At $(\boldsymbol{y},w)$ he sends a signal S to $(\boldsymbol{r},t)$, fulfilling

$$\mid \boldsymbol{y} - \boldsymbol{r} \mid = (t-w)V,$$

if and only if X has been obtained. Thus 1 if X and 0 otherwise form the input alphabet, while receiving S at $\boldsymbol{r}$ within a time interval $\langle t-\varepsilon, t+\varepsilon\rangle$ corresponds to 1 at the channel output. By virtue of Lorentz transformations we may assume that a computer O' at $(\boldsymbol{r}',t')$ moves in such a way that

$$\mid \boldsymbol{x}' - \boldsymbol{r}' \mid = (s'-t')V. \tag{25}$$

Using an analogous device, O' copies the output sending the acknowledgment S' to $(\boldsymbol{x}',s')$. Therefore, if O receives S' at $(\boldsymbol{x},s)$, he knows that the probability of obtaining X in the starting experiment is equal to

$$p_2 = \frac{p_1(p_{11}^2 + p_{10}p_{01})}{p_1(p_{11}^2 + p_{10}p_{01}) + p_0 p_{01}(p_{00} + p_{11})}, \tag{26}$$

where $p_0 = 1 - p_1$, and p_{ij} is the transition probability that if i is transmitted, then it is received as j. (Note that $p_{i0} + p_{i1} = 1$.) It is not hard to check that if our device works at least somewhat, that is,

$$p_{01} < p_{11}, \tag{27}$$

or merely $p_{0j} \neq p_{1j}$ for some j (i.e., the channel capacity is positive, which is equivalent also to $p_{00} + p_{11} \neq 1$), then p_2 is greater than p_1, a contradiction. And even if we substituted p_2 for p_1, then by virtue of the continuity of (26) we would get 1 in the limit. This means that by using the superluminal device Einstein's dream could be eventually realized; all indeterminacies (in quantum physics, Las Vegas, etc.) would be removed!

If the channel is perfect (it suffices that $p_{01} = 0$), the contradiction consists in that O can exactly predict the result of the experiment. Nevertheless, the apparatus still transmits a positive amount of information whenever, for instance, both p_{00} and p_{11} are greater than 0.5. According to the spirit of information theory, the effect should be similar, and it really is.

Now consider the case of a device for which

$$v_{\mathrm{act}} > c \tag{28}$$

has been affirmed. Increasing, if necessary, T_0 we obtain the existence of a $V > c$ such that for every $W > V$ we have

$$R(W) < R(V).$$

Thus assuming that the device sends signals with the speed V one can build a channel satisfying (27) with an arbitrary ε. In this way we have proved that Einsteinian locality implies $R(V) = 0$ for every $V > c$, that is, (21). Therefore, (28) will refute special relativity.

8 Solution: signal encapsulation

All superluminal anomalies appearing in the literature [80–82] are based, in fact, upon the causal loop of the previous section. They contain, from our point of view, a subtle (albeit principal) error. Namely, one supposes in them that every signal sent by an observer O is received by another observer O' moving with a nonvanishing relative velocity. In reality, this is not always true. We shall see in a moment that this simple remark clarifies everything and eliminates all contradictions.

We postulate adding to special relativity the following rule (and consequently removing Minkowski spacetime). We regard 'signal' as a primary notion, and we assume that it is transmitted between distinct events, i.e., its speed can be calculated.

Ⓢ **(Signal Encapsulation.)**

A signal transmitted by one observer will be received with positive probability by another if and only if its speed measured by the latter would be nonnegative and finite.

The question arises if we can still derive Lorentz transformations. One answers in the affirmative whenever we apply, similarly to Einstein, the law of the constancy of the velocity of light in vacuo. We cannot deal here with details, but note that a spherical light wave is seen by all observers with a positive probability, while the occurrence of energy at other events is less or more random. On the other hand, if the classical composition law for velocities were true, then distinct observers would see the distribution of the energy in different shapes with greatest probabilities.

The postulate Ⓢ admits signals transmitted with superluminal albeit still finite and nonnegative speeds. Indeed, assuming that both the observers in Ⓢ are identical we obtain

8.1. Corollary. *No observer can send any signal with infinite or negative speed.* ⊠

At this point we can eventually unravel the causal loops, for another consequence of Ⓢ is

8.2. Corollary. *If a signal sent by O from ($\boldsymbol{x}$,s) to another event ($\boldsymbol{y}$,t) is received by O' with a positive probability, then $s' < t'$.* ⊠

Thus a signal leading to an anomaly will be always obtained with the probability zero. For instance, in Section 7. we have $s<w<t$, while by (25) $t'<s'$, i.e., by Ⓢ O is not able to receive S' at $(\boldsymbol{x},s)$. Thereby, the apparatus works in a completely random way, which removes the paradox at once.

Let us recall also, for relaxation, Arthur Buller's popular limerick [83]:

> There was a young lady named Bright,
> Whose speed was far faster than light;
> She set out one day,
> In a relative way,
> And returned home the previous night.

In this case the error consists in the assumption that the heroine of this rhyme, moving in the frames O and O' probably at using superluminal teleportation, will be able to return. In reality, she may find a rubbish heap (in the frame O') in the place where her home should be (in the frame O).

Consider a more complicated example termed 'negative transmission'. Suppose that O transmits a superluminal signal S from $(\boldsymbol{r},t)$ to $(\boldsymbol{r}_1,t_1)$, where there is (also in the frame O) another experimenter O_1. If O_1 gets S, then she sends a subluminal signal S_1 from $(\boldsymbol{r}_1,t_1)$ to $(\boldsymbol{r}_2,t_2)$, where one more researcher O', moving with respect to O and O_1, is on the watch. We assume that $t'_1 < t'_2 \leq t'$, whence, by virtue of Ⓢ applied for the concatenation of $S+S_1$, O' cannot receive S_1. However, the sole essential obstacle is here the signal S; if it were not, O' could obtain S_1. As the observers are frequently in this situation, they have arranged that the lack of S will be a message. In this case O_1 will transmit a signal S_2 which will be able to be obtained by O'. Thus if O' receives S_2, he will know that he has got the message from his future.

The explanation of this 'paradox' is easy. O_1 has to have a quantum detector D to record S. But if it has not been transmitted, and there is no other connection between O and O_1, then D will register noise. This means that O_1 does not send S_2 with the probability 50% because he thinks that S is received. Next, if S has been really transmitted, O' will record noise, i.e., he will get a 'false' signal S_2 with the probability 50% again. We see that O' cannot obtain any piece of information.

Corollary 8.2. and Lorentz transformations imply also the following necessary condition for superluminal transmission. If O sends a signal with a velocity $\boldsymbol{W}$, and O' moving with a velocity $\boldsymbol{V}$ with respect to O receives it, then

$$\boldsymbol{V}\cdot\boldsymbol{W} < c^2, \tag{29}$$

has to hold. Notice the fact that the inequality is vectorial; $\boldsymbol{W}$ can be arbitrarily large whenever the relative velocity is sufficiently small or suitably directed. Every space-ship whose crew will wish to come into almost immediate contact with the earth will have to go into an orbit ensuring that the ship velocity $\boldsymbol{V}$ relative to the earth fulfills (29). We see that signal encapsulation will be able to be verified experimentally. What is more, as we believe that Nature is self-consistent, the results will have to be positive.

Let us note that Ⓢ could be considered also together with Galileo transformations, but then the result would be trivial: every signal sent by an observer can be received by another one. This was implicitly assumed by Einstein, but in the case of Lorentz transformations it cannot be preserved. We see that signal encapsulation is their natural complement.

Suppose that the speed of a signal S from $(\boldsymbol{x},s)$ to $(\boldsymbol{y},u)$ does not exceed c under O. From Ⓢ and Lorentz transformations it follows that O' should see the transmission with a positive probability p'. But if there is another signal S^* from $(\boldsymbol{r},t)$ to $(\boldsymbol{x},s)$ such that $u' \leq t'$, then by Corollary 8.2. O' cannot receive the concatenation $S^* + S$, whence also S at all. However, S^* must also be recorded by a quantum detector working with a probability p^* (obviously under O). Since S^* carries an amount of information, we have $p^* < 1$. Thus S is obtained by O' with the probability $p'(1 — p^*) > 0$, which still agrees with Ⓢ. This example shows that the usage of probabilities in Ⓢ is indispensable. In particular, we cannot assume that subluminal signals are surely experienced by all observers.

To recapitulate, Corollary 8.2. ensures that if an experimenter transmits a superluminal signal, and another moving researcher gets a piece of information from their future whenever they obtain the message, then in reality the latter will receive solely noise. On the other hand, from Ⓢ it follows that the communication can be established as long as the temporal order of the transmission's begin and end remains unaltered (i.e., (29) holds). We see that the situation is as simple as possible.

9 Consistency with quantum physics

At this point we know that the superluminal transmission suggested in the paper is not at odds with special relativity provided Minkowski spacetime is replaced by the signal encapsulation postulate. Nevertheless, the question remains whether it is consistent with quantum physics. To answer let us pay attention to the fact that in our devices the transmission is initiated by advancing the shutter, while a detector occurs solely at the end. Just owing to the asymmetry we omit technical difficulties with sending information between quantum events registered by two detectors.

Suppose, for instance, that we have a channel from D_1 to D_2 such that the eigenvalues recorded at D_2 form the output alphabet, and there is a one-to-one correspondence between the results at the detectors. Therefore, to transfer information we would have to control the eigenvalues at D_1. But having solely detectors just this is not possible; if we try to do it utilizing another detector D_0, then the problem of controlling the eigenvalues at D_0 arises, etc. And in the case of partial entanglement sending information is all the more impossible.

We see that detectors are not suitable for transmitting messages (thereby correlations between detectors are not signals in the sense of Ⓢ), albeit can receive them. This has nothing in common with Lorentz transformations, and there is no mystery here. What is more, this fact is independent of the signal velocity, but it was used to prove that on the ground of quantum physics superluminal transmission is allegedly impossible [84, 33, 85, 55, 86]. In reality, those authors did not take into account devices with single detector and proved solely that no signal can be sent with any speed at using two quantum detectors.

More precisely speaking, although a wavefunction can be connected with the visible shutter, the eigenvalue (or its lack, since no particle may be absorbed) obtained in the measurement 'in principle' is completely irrelevant (the subsystem containing the shutter is independent of that containing the detector, but not conversely). And just thanks to it quantum links with one detector — unlike those with two detectors — are controllable and able to transfer information.

10 Simultaneity and clock synchronization

Einstein's conclusion [1] that events that are judged to be simultaneous for one inertial observer are not simultaneous for another remains true. Of course, this follows from Lorentz transformations. In addition, we can give an operational method, not referring to any properties of any physical space, for determining when two — arbitrarily distant — events i and j stand in the relationship of the observer simultaneity. Namely, i and j are simultaneous if and only if the observer can send (using, e.g., a sort of the apparatuses described in Sections 2.–4.) a signal from the infinitesimal neighborhood of i to the infinitesimal neighborhood of j and conversely. The speed of the signals has to be, therefore, arbitrarily large albeit finite. As they can be concatenated, the relation is transitive [cf. 87], and even is an equivalence. The simultaneity is not absolute because, owing to the encapsulation, signals sent by the observer may not be seen by another one.

In order to work (e.g., to measure c) the experimenter needs clocks synchronized with any required accuracy. (It is known [88, 89] that 'no experimental procedure exists which makes it possible to determine the one-way velocity of light without use of superluminal signals'. But in the paper we have just such signals.) Suppose that a basic clock at i is set at zero, and another clock at j, where j is simultaneous with i according to the criterion of the previous paragraph, is equipped with a photocell switch circuit. Using a kind of the devices of Sections 2.–4., a signal sent from i reaches the infinitesimal neighborhood of j after arbitrarily small time ε. Then the photocell circuit will start the clock, and both they will show almost identical time (with the accuracy ε).

At first sight, according to textbooks, we have here introduced an absolute time because we have used signals transmitted with arbitrarily large speeds. It is certain that the above procedure enables one to synchronize all clocks being at rest in the same universe. On the other hand, if the clocks at i and j are at relative motion, then it may happen, by virtue of our encapsulation principle, that the signal will not be received at j, i.e., the photocell will not react. Thus we have not obtained any absolute time, since 'to have this time everywhere in the Universe, we would have to synchronize all possible clocks' [90]. Let us note that we avoid here any circularity because we do not assume the knowledge of c or any other speed.

11 Superluminal transfer of energy

In the paper devoted to the superluminal transfer of information, a few words should be mentioned about the possibility of the spacelike transmission of energy. It could be accomplished if, for example, there were particles moving with speeds exceeding c. Such objects were described and called 'tachyons' in [91]. Their, albeit only theoretical, existence was the source of many complications with causality [90, p. 58, 92–105]. In order to avoid them, a mechanism termed 'the reinterpretation principle' has been proposed [39, 106, 107, 40, 108, 109]. It commands us to reinterpret particles traveling backwards in time (whence appearing to be endowed with negative energy) as antiparticles traveling forwards in time (i.e., moving in the contrary space direction and endowed with positive energy). This argument removes, in fact, the simplest anomalies. Nevertheless, it seems that the principle does not unravel all contradictions involving two or more cooperating observers.

Suppose, for instance, that an observer O has apparatuses for sending and registering tachyons. Another observer O', moving with an arbitrary velocity with respect to O, emits a radio signal S_0 from $(\boldsymbol{r}'_0, t'_0)$ to $(\boldsymbol{r}',t')$. Immediately after obtaining S_0, O (a computer, strictly speaking) sends a tachyon from $(\boldsymbol{r},t)$ to $(\boldsymbol{r}_1,t_1)$. We assume that $t < t_1$, i.e., the tachyon has a positive energy for O, and it can be, according to the reinterpretation principle, used to send a message. As soon as a detector records the tachyon at $(\boldsymbol{r}_1,t_1)$, another computer transmits a radio signal S_1 to $(\boldsymbol{r}_2,t_2)$. The experiment can be arranged in such a way that the interval between $(\boldsymbol{r}_0,t_0)$ and $(\boldsymbol{r}_2,t_2)$ is spatial. O' knows (and even wishes to know) nothing about tachyons and the reinterpretation principle. She is certain that her radio receiver is not any transmitter, and conversely. She emits normal radio waves at $(\boldsymbol{r}'_0, t'_0)$, receives normal radio waves (carrying the same message) at $(\boldsymbol{r}'_2, t'_2)$, and sees that she is able to do it with a speed not lying in the interval $\langle 0, c\rangle$. If the speed is negative, then she has the information transfer backwards in time at once. Otherwise, she enjoys a normal superluminal device that can be used to obtain all the paradoxes encountered in the literature.

This is not the only example [cf. 82, 110] indicating that the reinterpretation principle contributes too little to the goal of implementing superluminal transmission. (In the case of our superluminal devices the reinterpretation principle is completely useless, since in them neither positive nor negative energy is propagated with tachyonic speed.) Nature has to be exactly consistent, so it should be of no surprise that, despite many experimental efforts [111–127], no Feinberg-type tachyon has been ever detected. One of the last attempts made in this direction was the experiment — being a subject of extensive propaganda in the media — done by Wang and collaborators [30, 31]. They affirmed, basing on the classical light wave theory, the negative velocity of the light pulse peak. Nevertheless, no single photon with this property (such a particle would be just a tachyon) was recorded [57]; the signal velocity was always positive and less than c (and this event was not equally well publicized).

Wang *et al.* had to lose because their work was not preceded by the elaboration of a theory removing all contradictions. It is true that some things have to depend on the observer, but the entirely correct mechanism is only signal encapsulation. It works reliably also in the foregoing example, since the concatenation of signals is a signal. Thereby Ⓢ implies that O' will receive noise instead of S_1 at $(\boldsymbol{r}'_2, t'_2)$ unless $t'_2 > t'_0$ and no causal loop has been arranged.

Although Ⓢ allows also superluminal transmission of energy, we do not think that classical massive particles crossing the speed of light limit can exist. This is, of course, caused by the fact that at this point they should have infinite energy. However, it is possible to accomplish such a transfer on the ground of quantum physics. Indeed, since quantum particles do not enjoy trajectories, no contradiction will be able to be obtained. The details will be given in another paper.

12 Superluminal long-distance transfer of information

The section displays the principal result of the paper, closely connected with the experiments considered in Sections 3. and 4. We assumed there that (14) was satisfied. But nobody and nothing whatsoever could prevent us from arranging the configuration of Fig. 2. or 3. in such a way that

$$s < i. \tag{30}$$

Here comes a moment when we could ask a question as to what will happen then? What will be the maximal speed in this case?

In order to examine it a relativistic analysis is required. Note, first of all, that our considerations remain valid for apparatuses moving, without clocks and computers, rectilinearly and uniformly relative to the experimenter as long as

$$t_i \leq t_s, \tag{31}$$

where t_i and t_s are respectively the times — measured by stationary clocks — of the flight of idler and signal photons to the shutter and interference device. As the moving aperture A is even more difficult to pass, the uncertainty is not decreased. Alternatively one may use the fact that the momentum and position measurements are still mutually exclusive. For the experiment of Section 4., although $BS_1M_1BS_2M_2$ can be a parallelogram instead of a square, (17) and (18) remain true. In the case of Section 3. the Doppler effect is irrelevant, since the source of light is motionless with respect to the detector. As the same involves the slits and the shutter, the conditions for Young's interference (the existence of amplitudes for passing through slits, etc.) and far-field diffraction (the size of the source) are unchanged. Thus we have a right to describe the behavior of signal photons by (4); it is true because r_1 and r_2 are modified by the same addend. The equation implies that when the shutter does not absorb idlers, the detector does not register particles. Knowing the position of absorption of an idler by the shutter one can determine (in the same way as for the stationary apparatus) the probability of finding its signal twin at a position. As, owing to (31), this can be done before or just when the latter reaches the plane of the slits, we infer that (12) is satisfied (with α found as for the stationary device). We see that to depict the experiments with satisfied (31) it suffices to apply state equations even if in the frame of the apparatus (14) does not hold.

We shall need a definition involving devices such as those in Section 3. and 4., within which a high-energy photon is down converted. An apparatus is called *Archimedean* (this term is used to enrich the language and it means 'regular in a sense') if

$$l > c(t_i - t_s), \tag{32}$$

where l is the distance between the interference device and shutter. This property, unlike (14) and (31), is Lorentz invariant. The configurations with the geometry of Fig. 2. or 3. are Archimedean even if (30) holds (as long as the speed of idlers is sufficiently close to c).

Suppose that within a stationary (under O) Archimedean apparatus the progeny of a high-energy photon reach the interference device and shutter (or a place where it would be if it were advanced) at ($\boldsymbol{r}$,t) and ($\boldsymbol{x}$,z) respectively, and (31) does not hold, that is,

$$t < z. \tag{33}$$

As by virtue of (32) the interval between the events is spatial, there exists O' moving with respect to O such that

$$z' < t', \tag{34}$$

i.e., from the viewpoint of O' (31) holds. Note that since the apparatus is stationary, $z - t$ is independent of z and t. Suppose further that the shutter remains in the same state from w to $w + u + z - t$, where $u > 0$. Denote by $t^\sim$ be the time of flight from the interference device to the detector at $\boldsymbol{y}$. Let it record a quantum event under O at s fulfilling

$$w + t^\sim < s < w + u + t^\sim. \tag{35}$$

Putting $t = s - t^\sim$ we get $w < t$, whence by (33) $w < z$, and

$$w' < z'. \tag{36}$$

Similarly, we have $t < w + u$, whence adding $z - t$ one obtains

$$z' < (w + u + z - t)'. \tag{37}$$

We may assume that O sends a signal S_0 from ($\boldsymbol{x}$,w) to ($\boldsymbol{y}$,s). (36) and (34) imply

$$w' + t^{\sim\prime} < s', \tag{38}$$

i.e., by virtue of Ⓢ we infer that O' receives S_0 with a positive probability. If the shutter does not stop idler particles from w to $w+u+z-t$, then from (36), (37), and our previous reasoning it follows that O' does not register signal particles, whence O cannot do it either. Conversely, if S absorbs photons in the time interval, then O' records, with a positive probability, a twin in a neighborhood of s'. Since one may also assume that O' sends a signal from $(\boldsymbol{x}',w')$ to $(\boldsymbol{y}',s')$, using the first inequality of (35) and Ⓢ we obtain that the probability of registering a signal particle by O is positive as well. In this way we have proved the main result of the work, that is,

12.1. Theorem. *Given a stationary Archimedean apparatus for sending superluminal signals, the probability of recording signal photons in the time interval*

$$(w + t^{\sim}, w + u + t^{\sim}),$$

is positive (vanishing) provided the shutter scatters (allows to pass correspondingly) idlers in

$$(w, w + u + \max(t_i - t_s, 0)),$$

where $u > 0$*, and* $t^{\sim}$ *is the sum of* $\max(t_s - t_i, 0)$ *and the time of flight from the interference device to the detector.* ☒

In the case of the apparatuses of Fig. 2. and 3. satisfying (30) we obtain

$$v_{\max} \geq \frac{d}{T_0 + \frac{r}{c^*}}, \tag{39}$$

where c^* is defined as in Section 3.

It is significant that Theorem 12.1. has been already in part corroborated experimentally. Namely, Hessmo [54] has reported that the visibility was low when idler photons were ignored, i.e., their momentum was not measured. This means that something else, e.g., a wall, played the rôle of a shutter. Thus Hessmo and Mair had s equal to 0.23 m and i — a few meters. On the other hand, the experiments with the shutter shifted back permanently can be described also on the ground of standard quantum mechanics. Indeed, we may use the fact that (12) and (18) do not depend on the time of the performance of the momentum (or unique position) measurement; there ought to be interference, since alternatives occur.

As we have mentioned in Section 3., a feature of the experiment by Hessmo and Mair consisted in the fact that the position entanglement between two down-converted photons was degraded by propagation. In spite of that, this should not make it impossible, in the light of Theorem 12.1., to perform a long-distance transfer of information using the apparatus of Fig. 2. Indeed, we propose here to increase rather i than s; the latter remaining such that the diffraction pattern of signal photons does not cover both the slits. For instance, s might be always equal to 0.23 m.

The question arises if r/c^* is essential in (39), since at first sight it seems that O will be able to detect a signal photon, without contradictions, at any time $t+\varepsilon$ whenever the shutter scatters idlers from t on. However, ε should not be less than the Planck time, since otherwise we would get, in practice, infinite signal speed. This implies that a positive value has to be added to w and w' in (35) and (38) respectively, and only the flight time has a physical meaning. Therefore, combining (39) with (15), we get finally

$$v_{\max} = \frac{d}{T_0 + \frac{\max(s-i,0)+r}{c^*}}, \tag{40}$$

or, more generally,

$$v_{\max} = \frac{d}{T_0 + \max(t_s - t_i, 0) + \frac{r}{c^*}}. \tag{41}$$

We see that the transfer speed (even neglecting T_0) cannot be infinite yet.

It is certainly interesting to consider if it is imperative to use the words 'stationary' and 'Archimedean' in Theorem 12.1. An apparatus with moving parts can be examined with the aid of the encapsulation postulate (see the next section). In the latter case the best thing to do is to verify this experimentally: a non-Archimedean configuration should not be difficult to arrange, since the optical paths may be arbitrary. (E.g., one could aim at $l=0$ changing, with the use of a mirror, the direction of idlers.) Note, in addition, that if $i-s$ is very large, and the speed of idler photons is even only slightly less than c, then the devices of Fig. 2. and 3. can cease to be Archimedean. Luckily, there is a general method of archimedeanisation: the retardation of arriving signal particles at the interference device. This does not decrease the transmission speed as long as t_i remains no less than t_s. Nonetheless, this means that a 'warming' of some superluminal apparatuses may be necessary.

13 Superluminal information technology

Theorem 12.1. suggests the possibility of transmitting bits by allowing the shutter to perform arbitrary motions. It should be completely feasible to recognize the bits by a computer (microprocessor, maybe) analyzing the number of detections during the unit transmission time u in a way similar to the one of Section 6. The connection created in this fashion will be termed a quantum channel or link with single or one detector.

Nevertheless, there is a disturbing, at first sight, inconvenience. Theorem 12.1. says that in the most interesting case $t_s < t_i$ the shutter should remain in the same state for a time longer than u. The usage of $1+(t_i-t_s)/u$ apparatuses would be usually uneconomical, and a considerable tardiness of signal photons (even up to $t_s = t_i$) could be disadvantageous or hard to achieve. Fortunately, a heuristic reasoning shows that a single Archimedean device ought to be sufficient without any additional retardation. For suppose that its work is controlled by a nuclear decay: if it happens, the apparatus will begin to transmit the next bit. As the time interval between two decays can be arbitrarily long, and u of Theorem 12.1. can be arbitrarily small, the probability of the detection of signal photons has to be altered right after $w + t^{\sim}$. This follows from Corollary 8.1., since otherwise a signal could be sent to the past. And after the next decay another bit will be transferred according to the same rules.

As bits transmitted in practice cannot be predicted either (e.g., an arbitrarily long sequence of zeroes or units can occur), one may relinquish the decays and fix a time u. Thus the shutter should simply either scatter or allow idlers to pass during intervals $(w,w+u)$ corresponding, provided (30) holds, to $(w+t^{\sim},w+u+t^{\sim})$ at the detector.

At this point we are in a position to clarify what is the line OB in Fig. 2. and 3. It represents any obstacle, even an ocean or cosmic space, since by virtue of Theorem 12.1. $i - s$ can be arbitrarily large. The theory should be first thoroughly verified, of course, in physical laboratories, but later we will be able to try to transfer information at longer distances. There is only one difficulty: How to send idler photons if OB is, for instance, an ocean? In this case, however, the answer is obvious; we have to utilize light pipes. Indeed, they act as mirrors, so the idler photons will remain indistinguishable if directed to ST or A after leaving the fiber-optic cables. On the other hand, before sending into cosmic space, i_1 and i_2 can be amplified in two lasers. In both the cases Nature will assume that we register the idlers if those of at least one pipe or laser are scattered.

It should be emphasized that in the transmission the exact quantum states of i_1 and i_2 do not need to be preserved. In fact, they could be equally well replaced by quite different particles (even not being photons provided this is done without scattering). For if they travel in separate channels, then we will be still able to come to know which idler was sent. And this possibility vanishes if the particles of both the channels are mixed using the complementarity or uncertainty principle.

Let us imagine that OB is wide enough, i.e., $s \ll d$. Then it is easy to distinguish two parts of our apparatus: the *transmitter* being on the right of OB in Fig. 3. (beneath OB in Fig. 2.), and the *receiver* — on the left. Both the devices will be able to be very small in comparison with d. For example, r can be measured in one-tenths of a millimeter, s — in centimeters, while i and d — in hundreds of kilometers. Furthermore, T_0 can be treated as the time needed to travel a distance of a few one-tenths of a millimeter with a speed close to c. Thus by virtue of (39) we get the maximal speed of the order of 10^9c, possible to be achieved in the Internet.

The most unusual feature of a quantum channel with single detector is the phenomenon (see Fig. 4.) that information is here transferred in the direction opposite to the one of transmitted energy. (As the latter is positive, this stays at odds with the reinterpretation principle. This should not be surprising since the principle — as we saw in Section 11. — raises its own serious difficulties.) Only the potential possibility of the energy transfer is essential because after sending information the further destiny of idlers is of no relevance.

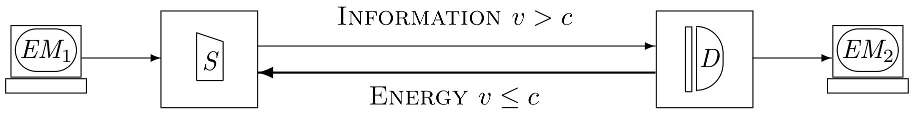

Fig. 4. Quantum channel with single detector.

Another peculiar property is the fact that the communication of this type can be hastened by improvements to the transmitter and receiver, whilst fiber-optic cables or lasers may remain unchanged. (The latter conventional component of quantum links with single detector was successfully verified during the mission of SMART-1 [128]. The AMIE camera on board the spacecraft detected a laser beam sent from the earth.) This is of great importance because in a civilization such as ours, the amount of information needed to be transferred increases much faster than the state of infrastructure. There are more and more businesspeople who habitually rely on information downloaded from the Internet, other consumers who wish to have a chat, etc., while the number of cables or bands of frequencies remains limited. At this point a quantum channel with one detector can meet users' expectations, since its capacity will be able to be augmented preserving the same conventional component.

There is also another class of serious problems. At present, computer scientists and engineers are finding that Moore's law has ceased to be effective. The process of calculation remains still relatively fast, but a quick transmission of the results between various parts of the computer causes difficulty. They are trying to replace normal cables by fiber-optic ones, but since the latter are used in the classical fashion, the transfer speed cannot still exceed c. Thus they are looking forward to a technological breakthrough. In this connection note that thanks to our devices the actual distance d becomes irrelevant; any transmission must cover merely the local distance r (T_0 is unaltered). Thereby all parts of the digital system seem to be at the same place. And then the same light pipe can send bits (in the opposite direction) with the speed, e.g., $100c$.

One hundred years ago, Einstein mainly thought of energy and he did not strive with the troubles of information. He was able, therefore, to assume with unconcern and ease that superluminal signals do not exist. However, it seems that in the 21st century we cannot do the same. It is even possible to imagine that quantum links with single detector will be the sole chance of our civilization.

The longer is the distance d, the larger speed (with the same transmitter and receiver) can be achieved. Thus the maximum benefit with minimal expenses will be probably obtained in the Internet. That is why we think [129] that in the first place the solution will be practically applied in wide-area networks, and only later in other fields. Since $v_{\max}$ in (39)–(41) depends also on T_0 and r, they should be as small as possible. Fig. 5. gives the greatest attainable speeds within a few typical areas under the condition that r and cT_0 are no less than 0.1 mm (i.e., without using nanotechnology which will be able to increase the speeds still more).

Transmission within	*The order of maximal speed*
mobile phone	10^2c
PC	10^3c
supercomputer	10^4c
Internet	$10^{11}c$
Earth-Moon	$10^{12}c$
Earth-Mars	$10^{15}c$
solar system	$10^{17}c$
Milky Way Galaxy	$10^{24}c$
present universe	$10^{30}c$

Fig. 5. The speed of superluminal signals.

The velocity of transferring information is the most essential when many signals are exchanged, e.g., in the Internet or a computer. The method can be useful also during a voyage to Mars. In this case minutes will be replaced by fractions of a nanosecond, so the flight will be able to be controlled on-line by a supercomputer on the earth.

In the case of cosmic applications it would be difficult to assume that the relative velocity of the transmitter and receiver vanishes. Suppose, therefore, that the detector (together with other devices above or on the left of OB) moves with a velocity $\boldsymbol{V}$ with respect to the shutter. From Theorem 12.1. it follows that if the devices were at relative rest, the signal could be received. Thus we ask here whether the message sent in the frame O (of the shutter) will be obtained by O' moving with the relative velocity. This problem was already solved in Section 8. By virtue of (29) we get that if the transmitter sends the signal at $(\boldsymbol{x},s)$, and it is to be received at $(\boldsymbol{r}',t')$, then

$$\boldsymbol{V} \cdot (\boldsymbol{r} - \boldsymbol{x}) \, < \, c^2(t - s) \tag{42}$$

has to be fulfilled. Conversely, from Ⓢ it follows that if (42) holds for all events of the transmitter and receiver in a time interval, then the channel capacity will be positive. This ensures that during missions in the solar system the lowest attainable speed (even without using nanotechnology) will be still of the order of 10^3c.

The experiments of Fig. 2. and 3. are not the only ones that can be applied to carry out a superluminal long-distance transfer of information. (Some of them do not include parametric down conversion.) If the results are positive, we will be able to say that SIT (Superluminal Information Technology) is a fact.

14 Intergalactic communication

Our method of sending information requires a specific transmitter and receiver. During a mission to Mars the speed $10^{15}c$ can be achieved, but in Fig. 5. there is as well a value with the doubled exponent. The data transfer with the speed $10^{17}c$ will be able to be accomplished relatively easily at using unmanned deep-space probes. In the case of greater signal velocities, however, a sort of the devices of Fig. 2. or 3. would have to be situated far outside the solar system. Thus the question arises whether transmissions with such speeds will be workable in our lifetime.

In order to provide an answer here let us consider first another issue. For centuries humans have wondered if they are alone in the universe or if there might be other worlds populated by creatures more or less like themselves. A modern scientific examination of extraterrestrial intelligence started in the second half of the 20th century, when the physicist Drake made pioneering efforts in that matter (the Green Bank equation, Project Ozma). A branch of biology dealing with the search for extraterrestrial life, especially intelligent life, has been created and called astrobiology. Since the early 1960s astronomers have been attempting to seek out signals from supposed highly developed technical civilizations, relying mainly on radio astronomical technology. The most extensive ongoing project, the Search for ExtraTerrestrial Intelligence (SETI), focuses on analyzing electromagnetic signals received from space [130]. However, no evidence of intelligent extraterrestrial life has been observed so far. Does it mean that no other technologically advanced civilizations are in the universe?

In our opinion this is not the case. Above all, astronomers are not observing the current outer space but they can see only what it was a few or a dozen or so billion years ago. And experience (our existence) seems to indicate that the probability of the rise of intelligent life in a galaxy is nonzero. Nonetheless, the probability can be extremely small. (This could be caused by the fact that the form of intelligent life in our universe is unique (encoded in the Big Bang), that is, they are similar to us. Note that even if the probability equals 10^{-7}, the number of civilizations in the universe can be still greater that 100, i.e., approximately equal to the number of the member states of the United Nations.) Thereby the mean distance between two technical civilizations can be enormous. It is also conceivable that their development requires time. The last two assumptions together with the Big Bang theory suggest that civilizations must communicate via superluminal channels. For example, if the mean distance equals $2{\cdot}10^9$ light-years (this value corresponds roughly to the probability 10^{-7}), the minimal development time — $14{\cdot}10^9$ years, and the age of the universe — $15{\cdot}10^9$ years (i.e., the oldest civilization arose 10^9 years before ours), then we shall have to wait for one billion years to receive electromagnetic signals from another civilization.

If humans living on the earth are not the first technical civilization in the universe, then the work will be able to be experimentally verified in one more way. For such civilizations should maintain a permanent tachyonic watch (in search for savages similar to us). Therefore, it suffices to install the transmitter (a shutter before a measuring device) and receiver (with lenses focusing idlers before their emission) of Fig. 2. or 3., and repeatedly send a message, e.g.,

1011011101111101111111011111111111

in the same direction of space. The devices may be even of poor quality because it is likely that our possible interlocutor possesses very good ones. Nevertheless, it still may happen that our apparatus will have to be located on board of a satellite. The frequency of photons has no meaning. We assume that low visibility corresponds to a cleared bit, that is, the shutter should be normally advanced sending zeroes. Each bit ought to have a fixed, albeit arbitrary, duration. Initially, the detector will also receive mostly zeroes, i.e., signal photons will be recorded. If the number of detections during the same period of time falls below a value B, the computer will register a set bit. You should not be irritated obtaining merely random units inasmuch as the other civilization must be given time to focus a sufficiently powerful telescope system (or something of that sort) towards the earth. They undoubtedly will not be able to see us, but this will create the possibility of mixing our idler photons up. When they set to do it, our computer should begin to get almost exclusively units, i.e., the number of detections of signal photons will be smaller. This can be used to establish the value B. And if finally a reply such as, e.g.,

111111111111101111111111111111101111111111111111111,

is regularly received many times, we will be certain to have joined the family (called, maybe, the Cosmic Union). The event can be highly advantageous for us because they probably have subjects such as teleportation or immortality [131] (which can involve even humans who died a long time ago) at their fingers' ends.

Note that our method enables one to accomplish a true and pure quantum teleportation because the two bits describing the result of the measurement [132–134] can be transmitted — without energy — via a quantum link with one detector instead of a classical channel. Of course, the teleportation of more complicated systems is an extremely difficult challenge, but it will have to be taken up.

15 Conclusion

In the paper we have demonstrated a few experimental proposals allowing one to transfer information with superluminal speeds. As far as relativistic contradictions are concerned, they vanish provided the signal encapsulation postulate is substituted for Minkowski spacetime in special relativity. We have shown that Ⓢ yields exactly what is needed here.

We are far from maintaining that the performance of the experiments will be trivial. We suppose, however, that they should be workable with the use of current technology, and we have attempted to show that the effort can be a worth-while enterprise. Computer scientists and engineers are looking forward to it, for it is possible that the failure of experiments similar to the ones suggested in the paper will bring a practical end to the development of our civilization. In the history of physics one was witnessing events in which the elimination of contradictions led to important applications, also as far as means of communication are concerned. We are in principle confident that this will be the case here as well.

There is also an unusually important theoretical motivation [135] for signal encapsulation. Let us recall that one of the aims of quantum field theory was to explain the eternal mystery: How can distant particles interact with each other? The answer was to be given by using virtual bosons. However, for the time being we have obtained a quasi-response that only moves the problem elsewhere. Because, to send suitable bosons, distant particles have to communicate with each other. For example, a quark has to receive information on the current color of another colored particle. Thus quantum reality cannot do without the transmission of superluminal signals, and no experiment is even needed.

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