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Time Symmetry and the Einstein Paradox. - II

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Summary. — To the predictive Einstein correlation between future measurements corresponds a retrodictive Einstein correlation between past preparations, exemplified by Pflegor and Mandel's interference experiments between independent laser beams (one cannot retrodict from which laser each detected photon has come, so that the two emissions are « nonseparable »). It is shown that the Schwinger-Feynman S-matrix formalism describes both of these phenomena, which thus belong to *relativistic quantum mechanics*. Intrinsic time symmetry *plus* Born's addition of partial amplitudes are the essential ingredients of the Einstein correlation, which is tied *via* the Feynman zigzag (that is *indirectly*). Joint absorption of two polarized photons in an anticascade induced by two superposed laser beams (« echelon absorption ») is suggested as a convenient, fast and precise procedure for testing the well-known quantal sinusoid (absorption rate *vs.* angle between the polarizers). As a throught experiment, this arrangement allows an illuminating discussion of intrinsic time symmetry *vs.* factlike, macroscopic, time asymmetry with respect to 1) varying the lengths of the beams and 2) turning the polarizers while the photons are in flight.

1. – Introduction.

In a recent paper ([1]) devoted to Bell's theorem, EBERHARD concludes that the overall experimental verifications ([2]) of the reality of the Einstein ([3]) (1927),

([1]) P. H. EBERHARD: *Nuovo Cimento*, **46** B, 392 (1978).

([2]) S. J. FREEDMAN and J. F. CLAUSER: *Phys. Rev. Lett.*, **28**, 938 (1972); J. F. CLAUSER: *Phys. Rev. Lett.*, **36**, 1223 (1976); E. S. FRY and R. C. THOMPSON: *Phys. Rev. Lett.*, **37**, 465 (1976); L. R. KASDAY, J. D. ULLMAN and C. S. WU: *Nuovo Cimento*, **25** B, 663 (1975); A. R. WILSON, J. LOWE and D. K. BUTT: *J. Phys. G*, **2**, 613 (1976);

or Einstein-Podolsky-Rosen [4] (1935), paradox [5] allow four, and only four issues:

1) « Do not think, just compute, and thus avoid headaches ». This is playing the ostrich (and the majority's vote).

2) It may be that quantum mechanics is only an approximation, that under sophisticated conditions the paradoxical Einstein correlation fails and that locality can be saved after all. Numerous papers have been and still are [6] exploring this (ever narrowing) possibility.

3) If not quantum mechanics, it is special relativity which may turn out to be wrong. Specifically, the collapse of the state vector looks like a non-local phenomenon implying some sort of telegraphing outside the light-cone [7].

4) If the general scheme of neither quantum mechanics nor special relativity can be shaken (and, after all, neither of them has ever been found faulty [8]), the only issue left is changing the accepted, macroscopic, causality concept. In this respect EBERHARD cites three proposals: Stapp's [9], Everett's [10], and mine [11]; he could have added Bohm and his co-workers' [12] one.

As implied in my above presentation of Eberhard's conclusions, I disregarded issues 1, 2, 3, and thus have to go through issue 4. Everett's fascinating science fiction has, in my opinion, two drawbacks: first it is (in Popper's words)

M. LAMEHI-RACHTI and W. MITTIG: *Phys. Rev. D*, **14**, 2543 (1976); M. BRUNO, M. D'AGOSTINO and C. MARONI: *Nuovo Cimento*, **40** B, 143 (1977).

(3) A. EINSTEIN: in *Rapports et Discussions du V Conseil Solvay* (Paris, 1927), p. 253-256.

(4) A. EINSTEIN, B. PODOLSKY and N. ROSEN: *Phys. Rev.*, **47**, 777 (1935). The formalism in this paper is nonrelativistic.

(5) Paradox: *A surprising but perhaps true statement* (meaning No. 1 in all dictionaries). « Copernicus' heliocentrism has been a paradox ».

(6) F. SELLERI: *Found. Phys.*, **8**, 103 (1978); G. SCHIAVULLI and F. SELLERI: University of Bari preprint (1978).

(7) B. D'ESPAGNAT: *Conceptual Foundations of Quantum Mechanics*, 2nd ed. (New York, N. Y., 1976). There is, as it seems, a paralogism in *choosing* (p. 27) « to focus ... on ... nonrelativistic quantum mechanics » and then *stating* (p. 90, 238, 265 and 281) that « the wave packet reduction is a noncovariant process ». *Epist. Lett. (Lausanne)*, **19**, 19 (1978). C. PIRON: *Epist. Lett. (Lausanne)*, **19**, 1 (1978).

(8) Of course, there *are* unsolved problems in both schemes (and some important ones); but this is quite a different matter.

(9) H. P. STAPP: *Nuovo Cimento*, **29** B, 270 (1975).

(10) H. EVERETT III: *Rev. Mod. Phys.*, **29**, 454 (1957).

(11) O. COSTA DE BEAUREGARD: *Compt. Rend.*, **236**, 1632 (1953); *Rev. Intern. Philos.*, **61-62**, 1 (1962); *Dialectica*, **19**, 280 (1955); in *Proceedings of the International Conference on Thermodynamics*, edited by P. T. LANDSBERG (London, 1970), p. 539.

(12) D. BOHM and co-authors, various preprints.

« nonfalsifiable »; second, it assumes an intrinsic time asymmetry which I consider inappropriate at the microlevel. Stapp's « Whiteheadean » concept implies, as it seems, a metaphysical determinism very remote from physical operationalism. Bohm's theory of the manifest and the unmanifest is still in gestation; one point emphasized in it looks very akin to Dirac's [13] and Landé's [14] interpretation of a « state » $|\psi^a(x)\rangle$ as a transition amplitude $\langle x|a\rangle$ between a $|x\rangle$ and an $|a\rangle$ representation. While this is a point made in appropriate presentations of the orthodox quantum mechanics, including relativistically covariant ones [15], it certainly deserves more thinking (which may uncover important physical or metaphysical points).

Thus I am left (and how could it be otherwise?) with my own [11] interpretation, as presented in a previous paper [16] (hereafter referred to as I). Essentially, this interpretation is *relativistically covariant* and *time symmetric*. The present paper aims at completing its characterization.

Making use of a previous hint by GARUCCIO and SELLERI [17], sect. **1** below shows how the very S-matrix formalism, in its Schwinger-Feynman expression, does indeed imply the « paradoxical » Einstein correlation; that is, a « nonseparability » of systems « presently » separated but connected either by their common past (*predictive Einstein correlation between future measurements*) or their common future (*retrodictive Einstein correlation between past preparations*). The Einstein correlation is thus unambiguously shown to be *tied via the Feynman zigzag* consisting of two (or more) timelike vectors with a common relay either in the past (Einstein correlation proper) or in the future (time-reversed Einstein correlation). The thesis I am defending since 1953 [11] thus receives a concise expression.

While the Einstein correlation proper is now quite familiar, the time-reversed one is much less so. Suspecting that it might be implicit in some experiments already performed, I finally realized [18] that it is demonstrated in Pflegor and Mandel's [19] interference experiments implying two independent lasers. As emphasized by PFLEGOR and MANDEL, these experiments demonstrate the « nonseparability » of the two (spatially separated) sources of *each* individual photon: observing the interference precludes that one can retrodict from which

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[13] P. A. M. DIRAC: *The Principles of Quantum Mechanics*, 3rd ed. (Oxford, 1948), p. 79.

[14] A. LANDÉ: *New Foundations of Quantum Mechanics* (Cambridge, Mass., 1965), p. 83.

[15] O. COSTA DE BEAUREGARD: *Précis de mécanique quantique relativiste* (Paris, 1967).

[16] O. COSTA DE BEAUREGARD: *Nuovo Cimento*, **42** B, 41 (1977).

[17] A. GARUCCIO and F. SELLERI: *Nuovo Cimento*, **36** B, 176 (1976). See also O. COSTA DE BEAUREGARD: *Lett. Nuovo Cimento*, **19**, 113 (1977).

[18] O. COSTA DE BEAUREGARD: *Compt. Rend.*, **286** A, 535 (1978); *Phys. Lett.*, **67** A, 171 (1978).

[19] R. L. PFLEGOR and L. MANDEL: *Phys. Rev.*, **159**, 1084 (1967); *Journ. Opt. Soc. Amer.*, **58**, 946 (1968).

of the two lasers each received photon has been emitted. In other words, *each* photon is emitted *jointly* by *both* (phase coherent) lasers working in unison. They are connected through their common future.

Section 2, after reminding these important facts, proposes a transposition of the Pflegor-Mandel scheme in the form of joint absorption of two polarized photons in an anticascade. This very sort of experiment ([20]) has already been performed more than once since the advent of the dye-laser; however, it has not been thought of as the time symmetric of the famous cascade experiments ([21]) implying pairs of polarized photons. My proposal aims at three interconnected ends: 1) discussing definite aspects of intrinsic time symmetry *vs.* factlike (macroscopic) time asymmetry in this problem; 2) thus countering various objections *a priori* raised against the existence of the Einstein correlation; 3) defining the scheme of a (possibly) very fast and precise experiment that would test all at once numerous counterproposals to the quantal formula for correlated polarizations.

Finally, what seems to me the metaphysics of « the expanding paradigm of the Einstein correlation » is sketched in the conclusion.

2. – Feynman zigzag as the link in Einstein correlations.

Intrinsic time symmetry *plus* wavelike addition of partial amplitudes (replacing classical addition of partial probabilities) are essential ingredients of the spacelike Einstein correlations. Both of these traits are also characteristic of Feynman's technique for computing transition probabilities. Thus it is only natural to inquire if perhaps this similarity does not reflect an intrinsic link between these two conceptual schemes. The aim of this section is to articulate an answer *yes* to this question.

The ennuple Einstein correlation proper is expressed as an expansion ([17])

$$|\Phi\rangle = \sum_j c_j \prod_\lambda |\varphi_{\lambda j}\rangle\,, \tag{1}$$

the $|\varphi_\lambda\rangle$'s spanning disjoint Hilbert spaces.

M denoting the direct product of Hermitian operators m_λ acting respectively on the $|\varphi_\lambda\rangle$'s, the « correlated mean value »

$$\langle\Phi|M|\Phi\rangle = \sum_i \sum_j c_i^* c_j \prod_\lambda \langle\varphi_{i\lambda}|m_\lambda|\varphi_{\lambda j}\rangle \tag{2}$$

([20]) A. Kastler: *Ann. de Phys.*, **6**, 663 (1936); P. F. Liao and G. C. Bjorklund: *Phys. Rev. Lett.*, **36**, 584 (1976).

([21]) Three first references in ([2]).

comprises a sum of diagonal terms

$$\langle\Phi|M|\Phi\rangle_0 = \sum_j \omega_j \prod_\lambda \langle m_{\lambda j}\rangle \tag{3}$$

with by definition

$$\omega_j \equiv c_j^* \cdot c_j, \qquad \sum_j \omega_j = 1\,, \tag{4}$$

$$\langle m_{\lambda j}\rangle \equiv \langle\varphi_{j\lambda}|m_\lambda|\varphi_{\lambda j}\rangle\,, \tag{5}$$

plus a sum of off-diagonal terms

$$\Delta\langle\Phi|M|\Phi\rangle = \tfrac{1}{2}\sum_{i\neq j} c_i^* c_j \prod_\lambda \langle\varphi_{i\lambda}|m_\lambda|\varphi_{\lambda j}\rangle + \text{c.c.} \tag{6}$$

neither of which is basis invariant.

In this context the distinction between the new, wavelike, probability calculus and the classical one consists in the replacement of formula (3) implying partial probabilities by formula (1) implying partial amplitudes. If, and only if, the off-diagonal, interference style contribution (6) is rendered zero by using a representation diagonalizing at least one of the m's, (3) is a consequence of (1). But this is merely the semblance of a mixture, as it is *relative* to the reference frame (the basis).

The expansion (1) is a specification of the more general expansion (summation sign omitted)

$$|\Phi\rangle = c^{ij\ldots}|\varphi_i\rangle|\psi_j\rangle\,. \tag{7}$$

M denoting the direct product of Hermitian operators m, n, ... acting, respectively, in the disjoint Hilbert spaces $|\varphi\rangle$, $|\psi\rangle$, ..., the « correlated mean value »

$$\langle\Phi|M|\Phi\rangle = c^{*i'j'\ldots}c^{ij\ldots}\langle\varphi_{i'}|m|\varphi_i\rangle\langle\psi_{j'}|n|\psi_j\rangle \tag{8}$$

comprises a fully diagonal contribution, where $i=i'$, $j=j'$ ..., namely

$$\langle\Phi|M|\Phi\rangle_0 = \omega^{ij\ldots}\langle m_i\rangle\langle n_j\rangle \tag{9}$$

with (no summation this time on repeated indices)

$$\omega^{ij\ldots} \equiv c^{*ij\ldots}c^{ij\ldots}, \tag{10}$$

$$\langle m_i\rangle \equiv \langle\varphi_i|m|\varphi_i\rangle\,, \qquad \langle n_j\rangle \equiv \langle\psi_j|n|\psi_j\rangle\,, \tag{11}$$

plus an off-diagonal, interference style contribution

$$\Delta\langle\Phi|M|\Phi\rangle \equiv \langle\Phi|M|\Phi\rangle - \langle\Phi|M|\Phi\rangle_0\,. \tag{12}$$

Again the transition from the classical to the wavelike probability calculus consists in the replacement of (9) by (7). This time, however, the off-diagonal contribution (12) is rendered zero if, and only if, the representation diagonalizes *all* the Hermitian operators m, n, ...

So far the reasoning is purely quantal, without any reference to space nor time, and no committment either pro or against relativistic covariance.

From now on we refer explicitely to relativistic quantum mechanics by considering the Schwinger-Feynman-Dyson transition amplitude in the S-matrix formalism. For simplicity we consider the interaction picture proper [22] with (fig. 1) initially incoming L_1, M_1, N_1, ... and finally outgoing L_2, M_2, N_2, ...

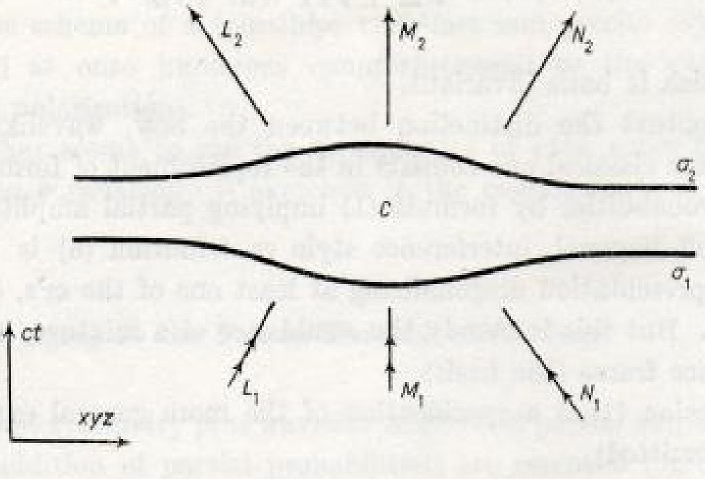

Fig. 1. – Predictive and retrodictive Einstein correlations as described in the S-matrix interaction picture. L_1, M_1, N_1, preparations of incoming particles. L_2, M_2, N_2, measurements of outgoing particles.

particles in respective states $\langle\varphi_1|$, $\langle\psi_1|$, $\langle\chi_1|$ ... and $|\varphi_2\rangle$, $|\psi_2\rangle$, $|\chi_2\rangle$ ... For example, in quantum electrodynamics, these states will be the photons A's, the electrons $\bar{\psi}$'s and the positrons ψ's.

The point is that, when expressed, for prediction, in terms of the outgoing states, the Schwinger-Feynman transition amplitude is precisely of the general form (7). Moreover, when expressed, for retrodiction, in terms of the incoming states, the Schwinger-Feynman transition amplitude is again of the form (7) (with bras instead of kets). Formulae (8) to (12) then follow. This shows (fig. 1) that the interaction existing inside the C spacelike region does entail the Einstein correlations between the (spatially separated) incoming particles L_1, M_1,

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[22] When appropriate the « bound interaction picture » could of course be used. Why the interaction picture, rather than the mathematically equivalent Heisenberg picture, is chosen, is essentially that it describes the incoming and outgoing particles as isolated.

N_1, ... on the one hand, and the outgoing particles L_2, M_2, N_2, ... on the other. *Thus these particles are truly « nonseparable » and the correlation between them is tied via the Feynman zigzags.*

This is the relativistically covariant formalization of both a predictive correlation between future measurements L_2, M_2, N_2, ... (as, for example, with the correlated polarizations in cascade experiments ([21])) and a retrodictive correlation between past preparations L_1, M_1, N_1, ... (as in the Pfiegor-Mandel ([19]) experiments).

An important remark is that no hypothesis whatsoever is made concerning the space-time regions where the preparations L_1, M_1, N_1, ... and the measurements L_2, M_2, N_2, ... are performed (except of course that any of the preparations is in the past of all of the measurements, and any of the measurements in the future of all of the preparations). Thus the Schwinger-Feynman transition amplitude is invariant with respect to translating any of the L's ... along the corresponding space-time beam—a point very well substantiated experimentally ([23]). Now, if two preparations or measurements L and M are performed on massless particles, the separation between them is necessarily spacelike. But, if they are performed on massive particles, as in Mittig and Lamehi's ([22]) experiments, the separation between them may very well be timelike; moreover, no discontinuity should appear if, say, M is moved relative to L so that the separation between L and M changes from spacelike to timelike, or *vice versa*—a point that could be tested experimentally. Incidentally, in the case of a timelike LM separation, the Einstein correlation would remain extremely paradoxical, as implying some sort of retroaction of the later measurement, or preparation, upon the former one ([24]).

One more step can be taken in this formalization. The Schwinger-Feynman transition amplitude between an initial state $|\Phi_1\rangle \equiv |\Phi(\sigma_1)\rangle$ and a final state $|\Psi_2\rangle \equiv |\Psi(\sigma_2)\rangle$ is of the form

$$\langle\Phi|\Psi\rangle \equiv \langle\Phi_1|U^{-1}\Psi_2\rangle = \langle\Phi_1 U^{-1}|\Psi_2\rangle \tag{13}$$

with U denoting that specification of the unitary evolution operator $U(\sigma)$ leading from σ_1 to σ_2. Denoting by $|\Theta\rangle\langle\Theta|$ the complete set of orthogonal projectors adapted to a given set of preparations or measurements, one expands (13) as (summation sign upon Θ omitted)

$$\langle\Phi|\Psi\rangle \equiv \langle\Phi|\Theta\rangle\langle\Theta|\Psi\rangle\,. \tag{14}$$

([23]) Wilson *et al.*; Bruno *et al.*, ref. ([2]).

([24]) This set of remarks contitutes a set of very strong objections against d'Espagnat's feeling ([7]) that the Einstein correlation is tied *directly* rather than *indirectly* (as in the S-matrix formalism).

In a predictive problem we interpret the $\langle\Theta|\Psi\rangle$'s as the components of the final state (in the Θ representation) and the $\langle\Phi|\Theta\rangle$'s as the coefficients of the expansion. In a retrodictive problem we interpret the $\langle\Phi|\Theta\rangle$'s as the components of the initial state (in the Θ representation) and the $\langle\Theta|\Psi\rangle$'s as the coefficients of the expansion. In both cases the expansion has the general form (7).

To conclude this section, *the Feynman zigzag truly is the « deus ex machina » of the Einstein correlations, and the wizzard of the Einstein paradox.*

3. – Time-reversed Einstein correlation: proposed experiment with polarized photons absorbed in an anticascade.

As emphasized in the introduction, Pflegor and Mandel's interference experiments using independent laser beams truly are retrodictive correlation experiments between past preparations, and it is this way that they are interpreted by their authors [19]. The measured magnitudes are occupation numbers at emission, and the « paradox » [5] is blatant when the intensities are lowered to the point at which « there is no more than one photon flying inside the apparatus » (that is, when the transit time is smaller then the mean internal between two absorptions).

A similar scheme can be used (that is, interacting independent laser beams) with the measurement of polarization states replacing that of occupation numbers, and the joint absorption of a pair of photons in an anticascade replacing that of one single photon in a photomultiplier. Indeed this sort of experiment [20] has become a routine experiment since the advent of the dye-laser; the experimentalists call it an « echelon absorption ». However, the emphasis here will be more specifically related to our problem.

Preliminary remarks are as follows:

If two photons of (well defined) frequencies ν_1 and ν_2 are to be absorbed jointly so as to lift the energy eigenstate of an atom from W_i to $W_f = W_i + h(\nu_1 + \nu_2)$, it is not strictly necessary that the intermediate level $W_i + h\nu_1 = W_f - h\nu_2$ be a resonant state. The cross-section, however, will be strongly enhanced if it is a resonant state, and only then are the expressions *anti-cascade* or *echelon absorption* appropriate.

Another remark is that the joint absorption occurs only when a definite phase relation exists between the two beams. These beat at the frequency $|\nu_2 - \nu_1|$, so that the absorption occurs in pulses.

Thirdly, the intrinsic transition probabilities in emission and in absorption are equal to each other—a fact not contradicted by the existence of Einstein's « spontaneous-emission probability », as made obvious by replacing in the formulae the initial occupation numbers of the final state by the final occupation numbers of this final state [25].

All this points to the fact that if, say, two linearly polarized independent laser beams are made to interfere, so that the energy eigenstate of detecting atoms is raised from W_i to W_f, and the number of atoms excited per time unit is measured, one shall obtain exactly the same intensity law *versus* the orientations of the polarizers as in the cascade experiments proper [26].

This is interesting, because the anticascade experiment is *a priori* very much easier, faster and more precise than the cascade experiment. No simultaneous counting of photons is needed, as a simple photometric measurement of the radiation emitted by the excited atoms will suffice to evaluate the number of pairs of photons jointly absorbed per time unit. It even seems that a continuous rotation of the polarizers will be possible, together with a continuous measurement of the re-emitted radiation.

As is well known, the simplest, and also the optimal, formula for the polarization Einstein correlation obtains when the angle of the interfering beams is either 0 or π radians. The angle π commonly used with the cascades is also quite appropriate with the anticascades, as there is no objection to illuminate one laser, M, by the other, L, and also as high-quality monochromators could be used if necessary [27] (fig. 2). All the rest is experimental routine and, by

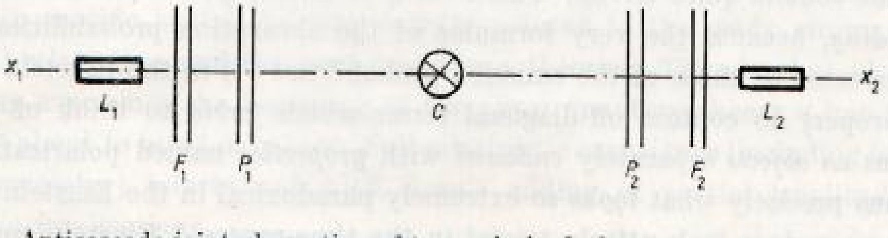

Fig. 2. – Anticascade joint absorption of two polarized photons. L_1, L_2, lasers shooting in opposite directions along the axis x_1x_2; F_1, F_2, monochromators; P_1, P_2, linear polarizers; C, cell containing the anticascading atoms.

using this approach, a fast and precise [28] check of the theoretical sinusoid [29] would be possible. Thus a whole set of counter proposals to the quantum theory could be neatly tested.

The rest of this section will be devoted to a theoretical discussion of aspects

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[25] This remark si made by L. de Broglie: *La mécanique ondulatoire du photon*, Vol. 2 (Paris, 1942), p. 63.

[26] O. Costa de Bauregard: *Ann. L. de Broglie*, **3**, 105 (1978).

[27] A. Kastler: private communication.

[28] One reason among others for more precision with anticascades than with cascades is the quasi-zero aperture of laser beams.

[29] For the (well known) formulae see for example ref. [16].

of this experiment considered as a thought experiment. The matter discussed will be intrinsic time symmetric versus factlike (macroscopic) time asymmetry. It will turn out that some extremely paradoxical ([5]) aspects of the Einstein correlation proper have completely trivial corresponding aspects in the time-reversed Einstein correlation.

Two aspects of the Einstein correlation proper (one that has been ([23]) and one that will be ([30]) tested experimentally) are felt to be extremely paradoxical: first, that the correlation holds irrespective of the distance between sources and analysers (nonlocality problem ([31])); second, that the significant orientations of the analysers are those existing while the photons do pass them (retroaction problem ([32])). What of the two corresponding points in the time-reversed experiment?

First, one feels *certain* that the beam lengths between the polarizers at L and N (fig. 2) and the absorbing atoms at C are completely irrelevant. Experimentally, there is no known limit to the conservation of a polarization state, which may be observed over cosmological distances. In particular, the coherence length of wave trains has nothing to do with this.

Second, one also feels *certain* that the significant orientations of the polarizers at L and N are indeed those existing while the photons do pass them.

In both cases the intuitive feeling is that the two photons considered do « retain » the polarizations which they « acquire » when passing the polarizers, and this sounds quite trivial. This feeling of triviality, however, is *completely misleading,* because the very formulae of the absorption probabilities (which are the same as those of the emission probabilities ([16]) in the Einstein correlation proper) do contain off-diagonal terms which *forbid* to think of the two photons as *objects* separately *endowed* with *properties* named polarizations ([33]).

Thus precisely what looks so extremely paradoxical in the Einstein correlation proper does look utterly trivial in the time-reversed Einstein correlation (though on closer inspection it is not so).

One need not say that in the intrinsically time-symmetric scheme here advocated the quantal transition *per se* should be conceived as time symmetric—a point I have previously discussed ([16]). One author, among others, who has made

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([30]) A. Aspect: *Phys. Rev. D*, **14**, 1944 (1976).

([31]) E. Schrödinger: *Proc. Camb. Phil. Soc.*, **31**, 555 (1935); W. H. Furry: *Phys. Rev.*, **49**, 393 (1936), have independently proposed that the Einstein correlation may perhaps die out with increasing distance between the two measuring devices. It has more than once been suggested that a characteristic distance for this may be the coherence length of the wave train—a very doubtful suggestion in the case of correlated polarizations. See ref. ([16]), p. 61.

([32]) Interaction of the analysers *via* the Feynman zigzag through the source is my specific interpretation of the Einstein paradox: ref. ([11]).

([33]) F. J. Belinfante: *Am. Journ. Phys.*, **46**, 329 (1978) has an essentially identical argument. The apparatus in fig. 2 is in fact the second part of Belinfante's ideal apparatus.

quite clear that the so-called time asymmetry of the quantal measurement process is of *macroscopic* origin and a mere semblance, is DAVIES [34]. The intrinsically time-symmetric concept of the measurement process can be connected with the information approach to probability, and with reference to the symmetry between information as cognizance and as organizing power [35].

It thus turns out that what makes the direct Einstein correlation so paradoxical and the reversed one so (apparently) trivial is the *factlike* macroscopic time asymmetry, that is *the retarded causality concept*. In other words, *what is paradoxical in the Einstein correlation is the intrinsic time symmetry*.

4. – Conclusions.

As conceived inside the framework of relativistic quantum mechanics and as expressed in the Schwinger-Feynman S-matrix formalism, the Einstein correlation does indeed entail (as emphasized by EBERHARD [1]) an *entirely new causality concept*: one which is both *intrinsically time symmetric* and *consonant with Born's principle of adding partial amplitudes* (rather than probabilities). In Kuhn's [36] words a « scientific revolution »—and quite possibly « the third storm of the 20-th century »—is over our heads. When Lord KELVIN, in a famous 1900 lecture [37], said he saw two small clouds over the otherwise clear sky of theoretical physics (the unexplained Michelson experiment and the anomalies in specific heats), he very exactly pointed to the ready storms of the « special relativity » and the « old quantum » theories. Thunder has also been rumbling ever since the beginning of the « new quantum theory », but the big storm is about to burst only now. Full relativistic covariance (including intrinsic time symmetry) intertwined with Born's adding of partial amplitudes has dramatic implications.

CLAUSER and SHIMONY [38] recently wrote: « Bell's theorem ... has ... inspired various experiments, most of which have yielded results in excellent agreement with quantum mechanics, but in disagreement with the family of local realistic theories. Consequently, it can ... be asserted with reasonable confidence that

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[34] P. C. W. DAVIES: *The Physics of Time Asymmetry* (Surrey, 1974), p. 174-175.
[35] O. COSTA DE BEAUREGARD: *Phys. Lett.*, **67** A, 171 (1978).
[36] TH. KUHN: *The Structure of Scientific Revolutions*, 2nd ed. (Chicago, Ill., 1970). Essentially Kuhn's thesis concerning a change in paradigm is found in P. DUHEM: *The Aim and Structure of Physical Theory*, Part. II, Chap. IV and VI (translated after the French 1913 edition) (Princeton, N. J., 1954). That today no two theorists agree as to what the new paradigm should be, although all of them agree that a new paradigm is needed, is characteristic of an impending « scientific revolution ».
[37] W. KELVIN: *Phil. Mag.*, **2**, 1 (1901).
[38] J. F. CLAUSER and A. SHIMONY: preprint UCRL (1978). This paper contains a very careful evaluation of the experimental results quoted in ref. [2], the conclusion being that only the three first ones are compelling.

either the thesis of realism or that of locality must be abandoned. Either choice will drastically change our concepts of reality and of space-time ».

My conviction is that *both* the *locality* concept and the *reality* concept have to yield, because in this problem they are tied together. *Intrinsic time symmetry* here entails *intrinsic symmetry between retarded and advanced waves* together with *intrinsic symmetry between information as gain in knowledge and information as organizing power*. This I have discussed elsewhere (39).

In quoting freely from the Vedas « *Separability* is an *illusion* which is *relative* to our ordinary, *pragmatic*, approach ». « Cosmic consciousness, on the other hand, (if acquired) would be knowledge of the past, the future and the elsewhere, together with awareness of siddis, or paranormal powers ». Was it not EINSTEIN who wrote twice (40) that the Copenhagen-style interpretation of his correlation implies « telepathy »? SCHRÖDINGER (41) that it is magic »? And DE BROGLIE (42) that it is not consistent with « our classical views concerning space and time »?

As formalized in the *relativistic wavelike probability calculus*, the space-time telegraph is very, very strange indeed.

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(39) O. COSTA DE BEAUREGARD: *Studium Generale*, **24**, 10 (1971); *Found. Phys.*, **6**, 539 (1976); *Synthèse*, **35**, 129 (1977).

(40) A. EINSTEIN: in *Albert Einstein Philosopher Scientist*, edited by P. A. SCHILPP (Evanston, Ill., 1949), p. 85 and 683.

(41) E. SCHRÖDINGER: *Naturwiss.*, **23**, 844 (1935). See p. 845.

(42) L. DE BROGLIE: *Une tentative d'interprétation causale et non-linéaire de la mécanique ondulatoire* (Paris, 1956), p. 73. See also *Etude critique ... de la mécanique ondulatoire* (Paris, 1963), p. 29.

● RIASSUNTO (*)

Alle correlazioni predittive di Einstein tra misurazioni future corrisponde una correlazione retrodittiva di Einstein tra preparazioni passate, esemplificate da esperimenti sull'interferenza di Pflegor e Mandel tra raggi laser indipendenti (uno non può retrodeterminare da quale laser ogni definito fotone è venuto cosicché le due emissioni sono « non separabili »). Si mostra che il formalismo di Schwinger-Feynman sulla matrice S descrive entrambi questi fenomeni, che così appartengono alla *meccanica quantistica relativistica*. La simmetria intrinseca di tempo più l'addizione di Born delle ampiezze parziali sono gli ingredienti essenziali della correlazione di Einstein, che è vincolata tramite il zig zag di Feynman (cioè indirettamente). L'associato assorbimento di due fotoni polarizzati in un'anticascata indotta da due raggi laser sovrapposti (« assorbimento a scaglioni ») è suggerito come procedura conveniente, veloce e precisa per controllare il ben noto sinusoide quantale (valore di assorbimento rispetto all'angolo tra i polarizzatori). Come esperimento pensato, questo schema permette una discussione illuminante della simmetria di tempo intrinseca rispetto all'asimmetria di tempo macroscopica fattiforme, nei confronti del 1) variare le lunghezze dei raggi e 2) voltare i polarizzatori mentre i fotoni sono in volo.

(*) *Traduzione a cura della Redazione.*

Временная симметрия и парадокс Эйнштейна. II.

Резюме (*). — Чтобы предсказанная Эйнштейновская корреляция между будущими измерениями соответствовала послесказанной Эйнштейновской корреляции между прошлыми приготовлениями, рассматриваются интерференционные эксперименты Флегора и Мандела между независимыми лазерными пучками (невозможно сказать, каким лазером был испущен каждый зарегистрированный фотон, т.е. два излучателя являются неразличимыми). Показывается, что формализм S-матрицы Швингера-Фейнмана описывает оба эти явления, которые относятся к *релятивистской квантовой механике*. Симметрия собственного времени *плюс* борновское добавление парциальных амплитуд представляют необходумые ингредиенты Эйнштейновской корреляции, которая связана через зигзаг Фейнмана (т.е. *косвенно*). Предполагается, что совместное поглощение двух поляризованных фотонов в анти-каскаде, индуцированном двумя лазерными пучками («ступенчатое поглощение») представляет удобный, быстрый и точный метод проверки хорошо известной квантовой синусоиды (интенсивность поглощения в зависимости от угла между поляризациями). Этот мысленный эксперимент позволяет обсудить симметрию собственного времени в зависимости от макроскопической временной асимметрии при 1) изменении длительности импульсов, 2) вращении поляризации во время движения фотонов.

(*) *Переведено редакцией.*