Foundations of Physics, Vol. 15, No. 8, 1985

On Some Frequent but Controversial Statements Concerning the Einstein–Podolsky–Rosen Correlations

O. Costa de Beauregard[1]

Received June 5, 1984; revised December 5, 1984

Quite often the compatibility of the EPR correlations with the relativity theory has been questioned; it has been stated that "the first in time of two correlated measurements instantaneously collapses the other subsystem"; it has been suggested that a causal asymmetry is built into the Feynman propagator. However, the EPR transition amplitude, as derived from the S matrix, is Lorentz and CPT *invariant; the correlation formula is symmetric in the two measurements irrespective of their time ordering, so that the link of the correlations is the Feynman zigzag, and that causality is* CPT *invariant at the microlevel; finally, although the Feynman propagator has the* P *and* CT *symmetries, no causal asymmetry follows from that. As for Stapp's views concerning "process" and "becoming," and his Whiteheadean concept of an advancing front, I object that they belong to "factlike macrophysics," and are refuted at the microlevel by the EPR phenomenology, which displays direct Fokker-like space-time connections. The reason for this is a radical one. The very blending of a space-time picture and of a probability calculus is a paradox. The only adequate paradigm is one denying objectivity to space-time—but this, of course, is also required by the complementary of the x and the k pictures, which only "look" compatible at the macrolevel. Therefore, the classical "objectivity" must yield in favor of "intersubjectivity." Only the macroscopic preparing and measuring devices have "factlike" objectivity; the "transition" of the "quantal system" takes place beyond both the* x *and the* k *4-spaces. Then, the intrinsic symmetries between retarded and advanced waves, and statistical prediction and retrodiction, entails that the future has no less (but no more) existence than the past. It is the future that is significant in "creative process," the "elementary" forms of which should be termed "precognition" or "psychokinesis"—respectively symmetric to the factlike taboos that "we can neither know into the future nor act into the past." It is gratifying that Robert Jahn, at the Engineering School of Princeton University, is conducting (after others) conclusive experiments demonstrating "low level psychokinesis"—a phenomenon implied by the very symmetry of the negentropy–information transition. So, what pierces the veil of "maya" is the (rare) occurrence of "paranormal*

[1] Institut Henri Poincaré, 11 Rue Pierre et Marie Curie, 75005 Paris, France.

0015-9018/85/0800-0871$04.50/0

phenomena." The essential severance between "act" and "potentia" is not a spacelike advancing front, but the "out of" and the "into" factlike space-time. Finally, I do not feel that an adequate understanding of the EPR phenomenology requires going beyond the present status of relativistic quantum mechanics. Rather, I believe that the potentialities of this formalism have not yet been fully exploited.

1. INTRODUCTION

Three demonstrably wrong statements concerning the Einstein–Podolsky–Rosen (EPR) correlations are the following:

1. The phenomenon of EPR correlation is more or less incompatible with the requirements of relativistic covariance (the "more" to "less" spectrum varying from one author to an other, or with the publication date for one given author).

2. The first in time of two distant measurements at L and N performed upon correlated systems issuing from a common preparation at C instantaneously collapses the other subsystem into the strictly associated state.

3. There is a causality asymmetry built into the very definition of the Feynman propagator D_F, and whence in the S matrix scheme, from which the EPR transition amplitude can be derived.

The first two statements have been issued so often, and by such distinguished physicists, that no quotation nor reference need be given. The third one has occasionally been expressed.

The truth, however, is that:

1. The EPR correlations, either proper (distant measurements at L and N issuing from a common preparation at C) or reversed (distant preparations at L and N converging into a common measurement at C), are formalizable straightaway via the S matrix algorithm, and thus have full Lorentz and CPT invariance.

2. The correlation formula is symmetric in L and N, and, thus, insensitive to their time ordering—which is "relative," when the LN vector is spacelike. Moreover, as the distant measurements (or preparations) at L and N need not fit each other, "which one collapses the other subsystem"?

3. The Feynman propagator D_F has the symmetries $P = -CT = 1$, but, as will be shown, no causality asymmetry follows from that.

In addition to these three anonymous rebuttals, I intend to criticize Stapp's[1] concept of "process" and "becoming." Not that I deny that there

is "process" and "becoming"; but, in my opinion, Stapp's concept of becoming as tied with a *rigorous* exclusion of advanced actions is untenable in two respects. First, the exclusion of advanced actions and, whence, of decreasing probabilities is, in Mehlberg's[2] wording, not lawlike, but factlike, very much like the preponderance of particles over antiparticles. Second, far from being tied with retarded actions, "creative process" essentially proceeds via advanced actions, thus substracting, à la Prigogine, negentropy from the universally cascading entropy. Of course one would very much like to observe the "creative," anti-Carnot, transition *information* → *negentropy* as an elementary phenomenon. Such an opportunity is provided by the so-called "psychokinesis" experiments, the most recent and extremely convincing ones being those conducted by Jahn[3-5] in the Engineering Faculty of Princeton University.

More cogently than nonrelativistic quantum mechanics, relativistic quantum mechanics does entail very drastic consequences concerning our world view. First, being "complementary" to each other, neither the space-time x nor the 4-frequency k S matrix pictures can be said to be "objective." Therefore, being "relative" to the experimental procedure, both the "reality" and the "objectivity" concepts must yield in favor of "intersubjectivity," thus entailing a world view very akin to the Hindu "maya" concept, that is, to the concept of a sort of common daydream, the illusory character of which is pinpointed by the so-called "paranormal phenomena" to which I will come back.

Via the CPT invariance of the S matrix algorithm, that is, also via the symmetry $\langle \Psi | U | \Phi \rangle = \langle \Phi | U^{-1} | \Psi \rangle^*$ of the transition amplitude, consisting of their dual predictive and "blind" retrodictive interpretations (from preparation to measurement, or from measurement to preparation), follows the *intrisic symmetry of the negentropy* $\rightleftharpoons$ *information transition* (as it did already from Loschmidt's 1876 T symmetry). This entails the *lawlike symmetry between cognizance and psychokinesis*, as also emphasized implicitly (as it seems) in a striking statement by Wigner.[6]

Relativistic quantum mechanics is in itself a paradoxical, but extremely fruitful, marriage of water and fire—water being an extended space-time or 4-frequency picture, and fire a (wavelike) probability calculus. How is this possible, and even conceivable? Again "maya" is the answer. Being macroscopic, the preparing and measuring devices and procedures seem to have objectivity, and to be embedded in both the (x) and the (k) continua, which look compatible at the macrolevel. In this sense, the prepared $|\Phi\rangle$ and the measured $|\Psi\rangle$ can be thought of as "objective." But *the "quantum system" transiting from* $|\Phi\rangle$ *to* $|\Psi\rangle$ *does this outside space-time*, from which information as cognizance (gained in measurements), and into which information as organization (injected in

preparations), is flowing. *This is "process" and "becoming," in its passive and in its active aspects, respectively.*

Coming back to the EPR correlations, it is quite true, as clearly seen by Einstein[7] as early as 1927, that *they are incompatible with the* 1905 *macrorelativity theory*, defined as invariance of the physical laws, *including the irreversibility law* under the *orthochronous* Lorentz group. But microrelativity should be as sharply distinguished from macrorelativity as Loschmidt's microanalysis of collisions is from Boltzmann's macroderivation of the H theorem. In the *microrelativity* theory CPT invariance replaces Loschmidt's T invariance, and enforces a *lawlike arrowlessness of the causality concept*, which is *emphasized*[8,9–12] *in the very phenomenology of the* EPR *correlations.*

Concluding this Introductory, I see absolutely no reasons, in the present state of interpretative problems, to try to go beyond both the relativity and the quantal theories, as Bohm and Hiley[13] are suggesting. Quite the contrary, it seems to me that the very internal logic of relativistic quantum mechanics, with the full implications of its Lorentz and CPT invariances, does uncover, from the vantage point where it stands, a wonderful panorama extending from the clearly outlined near scenery to vistas shimmering in the distance, so that we have plenty to do by just trying to interpret consistently the mathematical formalism as it exists.

2. THE *CPT*-SYMMETRY AS A GENERALIZATION OF THE 1876 LOSCHMIDT *T* SYMMETRY

Figure 1a, b, c displays, à la Feynman, either in the space-time or in the 4-frequency picture, the C, the PT, and the CPT reversals. The example chosen is the reversible one exchanging an electron–positron pair and a photon pair.

The *particle–antiparticle exchange* C shows up, in Fig. 1a, b, as a symmetry acting upon the arrows but not the trajectories. The *covariant motion reversal* or *emission–absorption exchange* PT shows up, in Fig. 1b, c, as a symmetry acting upon the trajectories but not the arrows. The overall CPT reversal then shows up, in Fig. 1a, c, as a complete symmetry operating on both the arrows and the trajectories (as emphasized independently by Recami and co-workers[14,15] and me[16]). The $CPT = 1$ theorem is then quite consonant with geometrical intuition. The physical interpretation is that emission of a particle and absorption of an antiparticle (and vice versa, of course) are just two "relative" pictures of one and the same "process." How the ψ and $\bar{\psi}$ symbols "follow the arrows" when Fig. 1a, c are exchanged should be noted.

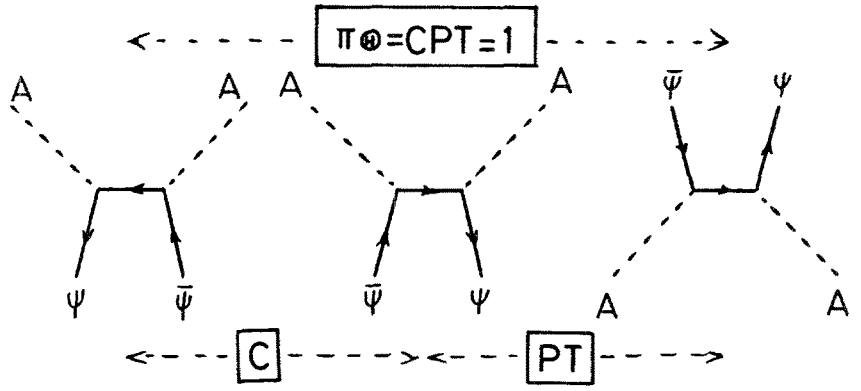

Fig. 1. Particle–antiparticle exchange C and covariant motion reversal PT as the passive and active aspects of the same operation. $CPT = 1$ as geometrical reversal $\Pi\Theta$ of all four space-time axes.

A little fable will illustrate the matter. Let us denote *particle* as an automobile moving forward and *antiparticle* as an automobile moving backward, *absorption* going into and *emission* coming out of a garage. The *same* film, run one way or the other, will thus display, say, either the emission of a particle of the absorption of an antiparticle. However, when reversing the motion of the film, we must also turn it upside-down, because Lorentz invariance requires that an active T reversal be associated with an active P reversal, exchanging right and left.

So, had Loschmidt imagined his colliding particles as rotating rifle bullets, where the distinctions between fore and aft, right and left, make sense, he would have been led to a concept quite akin to CPT invariance, rather than to his T invariance.

On the whole, the CPT-invariance entails the law of detailed balance

$$A + \bar{B} + \cdots \rightleftharpoons C + \bar{D} + \cdots$$

where (beware!) a bar means "particle" on the left-hand side and "antiparticle" on the right-hand side (and vice versa, of course). So, the quantal and relativistic process of "particle's collision" is a faithful generalization of the classical one.

3. *S*-MATRIX DERIVATION OF THE POLARIZATION CORRELATION FORMULA FOR PHOTON PAIRS

The source or sink of the photon pair will be idealized[17] as a spin 0 particle either scalar φ or pseudoscalar $\varphi\varepsilon_{ijkl}$, and the electromagnetic field

amplitudes of the two photons will be denoted H_a^{ij} and H_b^{ij}. In this C, P, and T conserving electromagnetic process the transition amplitude is a scalar, the two possible expressions of which are, up to normalizing factors,

$$\bar{\varphi} H_a^{ij} H_{ij}^b \quad \text{or} \quad \bar{\varphi} \varepsilon_{ijkl} H_a^{ij} H_b^{kl}$$

that is, in prerelativistic notation and Gaussian units,

$$\bar{\varphi}(\mathbf{E}_a \cdot \mathbf{E}_b - \mathbf{H}_a \cdot \mathbf{H}_b) \quad \text{or} \quad \bar{\varphi}(\mathbf{E}_a \cdot \mathbf{H}_b + \mathbf{H}_a \cdot \mathbf{E}_b)$$

The a and b symmetry of these formulas should be emphasized.

Taking the axes x and ct coplanar with the three energy-momenta, so that the two photons fly oppositely with field strengths orthogonal to x, denoting A the angle between $\mathbf{E}_a$ and $\mathbf{E}_b$, that is, also between $\mathbf{H}_a$ and $-\mathbf{H}_b$, and normalizing, we obtain the well-known transition amplitude for correlated linear polarizations of photons

$$2^{-1/2} \cos A \quad \text{or} \quad 2^{-1/2} \sin A$$

depending on the type of cascade or anticascade.

So, *it cannot be denied that the correlation formula for linear polarizations of spin* 0 *photon pairs does have full Lorentz and CPT-invariance.*

4. *S*-MATRIX DERIVATION OF THE POLARIZATION CORRELATION FORMULA FOR FERMION PAIRS

We consider an electron–positron pair, $\bar{\varphi}$ denoting the electron and ψ the positron. Reasoning as in the previous section, we see that the two possible amplitudes for a spin 0 pair are

$$\bar{\varphi}\psi \quad \text{or} \quad \bar{\varphi}\gamma_5\psi$$

Choosing units such that $c = 1$, we take the time axis along the overall 4-momentum, so that both particles then have the same energy w and opposite momenta, $+p$ for the electron and $-p$ for the positron. In the "low velocity representation" of the γ's

$$\bar{\varphi}\psi = \varphi_1^*\psi_1 + \varphi_2^*\psi_2 - \varphi_3^*\psi_3 - \varphi_4^*\psi_4$$
$$\bar{\varphi}\gamma_5\psi = \varphi_1^*\psi_3 + \varphi_2^*\psi_4 - \varphi_3^*\psi_1 - \varphi_4^*\psi_2$$

As is well known, the "large components" φ_1 and φ_2 of the electron,

ψ_3 and ψ_4 of the positron, are arbitrary, and the "small ones" φ_3, φ_4 and ψ_1, ψ_3 are such that

$$w\varphi_3 = (p_x + ip_y)\varphi_2 + p_z\varphi_1, \qquad w\varphi_4 = (p_x - ip_y)\varphi_1 - p_z\varphi_2$$
$$w\psi_1 = (p_x + ip_y)\psi_4 + p_z\psi_3, \qquad w\psi_2 = (p_x - ip_y)\psi_3 - p_z\psi_4$$

so that, as $w^2 - p^2 = m^2$ and $m^2/w^2 = 1 - \beta^2$,

$$\bar{\varphi}\psi \equiv 0, \qquad \bar{\varphi}\gamma_5\psi = (1-\beta^2)[\varphi_1^*\psi_3 + \varphi_2^*\psi_4]$$

As φ_1 and ψ_4 are the eigenfunctions of "spin up," φ_2 and ψ_3 those of "spin down" along the z axis, and as the bracket is a pseudoscalar, we end up with

$$\bar{\varphi}\psi \equiv 0, \qquad \bar{\varphi}\gamma_5\psi = (1-\beta^2)[\uparrow\downarrow - \downarrow\uparrow]$$

which is the covariant expression of the well-known formula for correlations of a spin 0 fermion pair.

It is interesting that the expression of $\bar{\varphi}\gamma_5\psi$ is invariant with respect to the orientation of the opposite momenta $\pm\mathbf{p}$. If $\mathbf{p}$ is parallel to the z axis the formula is in terms of helicities; if p is orthogonal to z, the formula is the one associated with a Stern–Gerlach experiment.

Incidentally, the above formulas are consistent with the fact that the positronium atom can decay into the $[\uparrow\downarrow - \downarrow\uparrow]$, but not into the $(\uparrow\downarrow + \downarrow\uparrow)$ mode.

It is also interesting that the preceding conclusions have been derived entirely from relativistic covariance, and not by resorting to the Fermi–Dirac statistics.

Coming back to the Stern–Gerlach type of experiments, it is of course possible to measure the two spins along arbitrary directions of relative angle A perpendicular to the $\mathbf{p}$ direction. In this case all four answers do show up, with respective probabilities

$$\langle +, - \rangle = \langle -, + \rangle = \tfrac{1}{4}(1 + \cos A)$$
$$\langle +, + \rangle = \langle -, - \rangle = \tfrac{1}{4}(1 - \cos A)$$

Then "angular momentum is not conserved," meaning that "there is a reaction of the measuring device upon the system." In other words, the angular momentum is a property shared between the system and the measuring device.

Concluding this section, *it cannot be denied that the correlation formula for correlated polarizations of a spin* 0 *fermion pair does have full Lorentz and CPT-invariance.*

5. ARROWLESS CAUSALITY AND CONDITIONAL PROBABILITY CALCULUS

What element is essential inside the causality concept? It is the possibility to adjust arbitrarily something around some point-instant, then acting as a source (or sink) of influences termed "consequences." The question is, do these precede or follow the cause in time? The answer depends on an experimental and theoretical inquiry, for which the EPR correlations are highly privileged.

In the EPR correlations (either proper or reversed) adjustable parameters exist at L and N, but not at C. Therefore *causes exist at L and N, not at C.*

Now, there is a "correlation" (and a "paradoxical" one indeed) between the two measurements (EPR proper) or preparations (reversed EPR) performed at L and N. To this I will come back.

What is the link of the correlation? Physically and mathematically there is no other answer than this one: *the link is* (Fig. 2a, b) *the Feynman zigzag LCN* consisting of two timelike vectors (either in the space-time or in 4-frequency pictures) with a relay at C, in the past or the future, respectively.

Therefore causality has no time arrow at the microlevel. This was already implied in Loschmidt's 1876 analysis of particle collisions, and was then judged "paradoxical," although mathematically undisputable, as *inherent in the very symmetry of transition probabilities* $P_{ij} = P_{ji}$. The *S*-

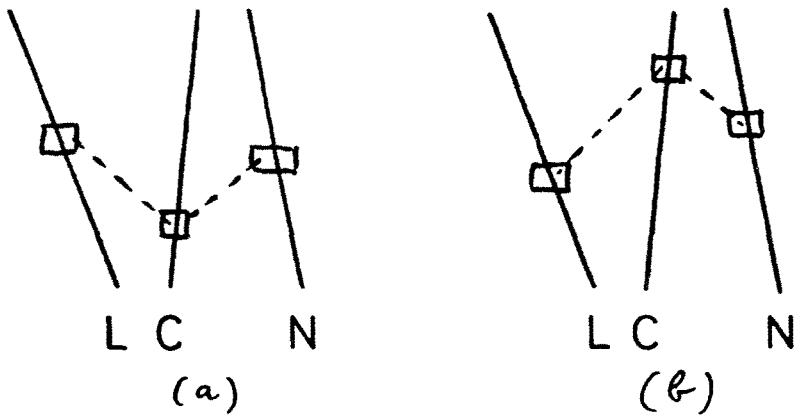

Fig. 2. Space-time diagrams for cascades (2a) or anticascades (2b). L, C, N are space-time trajectories of the pieces of apparatus, the positions and velocities of which are arbitrary in the (x, ct) plane.

matrix scheme also deals with particle collisions, and also uses symmetric transition probabilities. What renders the sting of the "EPR paradox" still more painful than Loschmidt's one is the replacement of, first, the *T*- by the *CPT*-symmetry, and, second, of the classical by the wavelike probability calculus.

The EPR correlation formula is essentially symmetric in L and N (in a and b, in the wording of Sections 3 and 4). Thus, it is *insensitive to the time ordering* of these two distant measurements (or preparations)—which is "relative," if the LN vector is spacelike.

Therefore *there is an obvious nonsense in the (often issued) statement* that "the first in time of the two distant measurements instantaneously collapses the other subsystem into the strictly associated state."

Twin paradoxical aspects of advanced causality, and trivial aspects of retarded causality, are: that the correlation formula holds for arbitrarily large (spatial and temporal) distances CL and CN; and that the polarizers can be turned freely while the photons are on their way. The point is that, phenomenologically and mathematically, *causality is CPT invariant at the microlevel.*

The *proper wording for these correlations* is the very wording of the *conditional probability calculus*: the transition amplitude $\langle \Psi | U | \Phi \rangle$ holds *iff* each and every one of the partial preparations $|\varphi\rangle$ making the $|\Phi\rangle = \Pi|\varphi\rangle$, and each and every one of the partial measurements $|\psi\rangle$ making the $|\Psi\rangle = \Pi|\psi\rangle$, *as written down in the formula*, is performed. And *this "is" must be understood atemporally, à la Minkowski*, because, as has been said, the time ordering of either the $|\varphi\rangle$'s and the $|\psi\rangle$'s is irrelevant.

The preceding statement is none else than a way of expressing Bohr's well-known saying, that the specifications of the preparing and measuring devices are essentially part of the phenomenon studied.

6. CAUSALITY AND THE FEYNMAN PROPAGATOR

The well-known expressions of the Jordan–Pauli D, the Feynman D_F, and the "anti-Feynman" D_{AF} propagators in terms of the retarded D_R, the advanced D_A, the particlelike D_+, and the antiparticle like D_- propagators are

$$D \equiv D_+ - D_- = D_R - D_A$$

$$D_F = D_R + D_- = D_A + D_+$$

$$D_{AF} = D_R - D_+ = D_A - D_-$$

We recall also that $D=0$ and $D_+ = D_-$ outside the light cone, so that, as Feynman put it "$D_F = D_+$ if $t>0$, $D_F = D_-$ if $t<0$" ($D_{AF} = -D_-$ if $t>0$, $= -D_+$ if $t<0$).

Defining the C and T symmetries as

$$C: D_+ \rightleftharpoons D_- ; \qquad T: D_R \rightleftharpoons D_A$$

we see that[2] D is invariant under $-C$ and $-T$, that D_F and D_{AF} are invariant under P and CT, and D_F and D_{AF} are exchanged by $-C$ and T.

As is well known,[18] use of the D_F propagator for representing virtual particles entails, in a predictive calculation, an exponential decay of higher energy levels for either of two CPT associated transitions, that is also, in a retrodictive calculation, an exponential buildup of such levels. This faithfully formalizes the irreversibility paradigm as it is discussed since the days of Loschmidt and Zermelo; no causality asymmetry whatsoever follows therefrom. Use of the anti-Feynman propagator would paradoxically associate prediction with buildup and retrodiction with decay.

7. NONOBJECTIVITY OF SPACE-TIME

"Process" and "creative act" are two key concepts in Stapp's[1] article entitled "Mind, Matter, and Quantum Mechanics." Although both his interpretation, and mine, of the "EPR paradox" do emphasize that the link of the correlation is the "V-shaped" *LCN* zigzag, quite a few points of radical disagreement exist between our respective understandings of the concepts of "process" and of "creative act."

For one thing, Stapp assumes, à la Whitehead, the existence of an advancing more or less fuzzy front separating an "actualized past" from a "potential future." Nothing of this sort exists in the formalism, where there is absolutely no need for it. Thus it is an untestable, or "metaphysical" idea.

The only argument in favor of it is that it fits our macroscopical prejudices; but of these we know well, from careful analyses by numerous authors, that, first, the space-time concept must be some sort of statistical emergence, and, second, that the past–future asymmetry is "factlike and not lawlike."[2] So what is wrong in the Whiteheadean view is that it confers absoluteness and, so to speak, rigidity to macroscopic approximations which vanish into utter fuzziness at the microlevel.

[2] Solutions of an equation need not enjoy the same invariance properties as the equation (here, the Klein–Gordon equation).

The space-time concept (and also the 4-frequency space concept) are nothing more than symbolic means for dealing with the information we extract as knowledge from measurements, or inject as organization in preparations: the chain *preparation–evolution–measurement* "corresponds," in the quantal physicist's jargon, to the chain *coding–transmitting–decoding* of the cybernetist, with all the extra sophistication brought in by *CPT* invariance and a wavelike probability calculus. As for the *quantal transition*, it proceeds, as we have said, *beyond space-time*; being the "elementary phenomenon" par excellence, it *must* be the *hinge around which mind and matter are interacting*, holding the gate through which information-as-organization is flowing in, and information-as-knowledge is flowing out of our "factlike," and much illusory, space-time. To think of "act" and "potentia" as separated by a spacelike surface σ is macroscopic "maya." Truly, "act" and "potentia" are separated as being the one "inside" and the other "outside" space-time; and space-time is a very porous sort of vessel for that ... Space-time (or k space) are *nothing more* than symbols for computing transition probabilities.

As already said, transition probabilities P_{ij} are symmetric ($P_{ij} = P_{ji}$) under *CPT*. Moreover, they are symmetric in that they make sense either predictively, from preparation to measurement, or retrodictively, from measurement to preparation. There is no difficulty in displaying the "frequency," or the so-called "objective" aspect, of these probabilities: one has simply to collect the measurements having issued from a chosen preparation, or the preparations having led to a chosen measurement.

An important point, independently stressed by Fock[19] and by Watanabe,[20] is that, in the wavelike probability calculus, retarded waves are used for prediction and advanced waves for retrodiction, so that *macroscopic probability increase* and *wave retardation* are just two associated aspects of the *factlike irreversibility*. This is conspicuous in von Neumann's[21] discussion of the quantal H-theorem; it also settles a famous Einstein–Ritz[22] controversy, where both contenders were defending *reciprocal* rather than *contradictory* statements.

It is a big mistake—in fact, a macroscopic prejudice—to think of the elementary phenomenon of "wave collapse" as implying a retarded wave. Retardation emerges only macroscopically, together with statistical frequency, and it is then "factlike," not "lawlike."[2] This is rendered fairly obvious by the well-known formula

$$\langle x'|a\rangle = \langle x'|x\rangle\langle x|a\rangle$$

solving the Cauchy problem, that is, expressing the wave function $\langle x'|a\rangle$ at any point-instant as a superposition of Jordan–Pauli propagators

$D(x'-x) \equiv \langle x'|x\rangle$ with apexes x on an arbitrary spacelike surface σ, the "coefficients of the expansion" being the values $\langle x|a\rangle$ of the wave function on σ.[3] So, *strictly speaking, wave collapse is collapse-and-retrocollapse*, a trait emphasized by the *very phenomenology of the EPR correlations.*

8. "FOREKNOWLEDGE" AND "PSYCHOKINESIS" AS INHERENT IN A "CREATIVE ACT"

The twin concepts of "foreknowledge" and of "psychokinesis," far from being incompatible as a superficial look may see them, are the complementary aspects of a "creative act," being the respective reverses of the twin statements of factlike irreversibility that "we can neither see into the future nor act into the past." Let it be made clear that psychokinesis essentially is retropsychokinesis—if only because much less energy control is needed at the level of a random event than after its amplification for "registration." That the actual occurrence of such rare phenomena is not incompatible with the macroscopic, factlike, irreversibility has been explained by Schmidt.[23]

So, contrary to Stapp,[1] I deem that "*creative acts*" *are essentially associated with advanced actions and decreasing probabilities*, as when, say, birds are building a nest: repetitive adjustments of appropriate elements, producing a highly improbable contraption, is the exact opposite of "scattering" or "dispersion." At the elementary level past and future are on the same footing, as shown by the very symmetry of transition probabilities, and by their dual predictive or retrodictive interpretations. And so, *in a "creative act," the future exists no less—but no more—than the past does in a "cognitive act."* Of course, as previously said, *neither has full objectivity*, but rather is "indissolubly objective and subjective."

As expressed in the space-time picture, the transition probabilities display long-range, direct, Fokker like[24] connections, which are blurred at the macrolevel if special care is not taken for preserving the EPR correlations they contain. Significant information is thus lost, and this, together with the (factlike) preponderance of the *negentropy → information* over the *information → negentropy* transition, produces the macroscopic time arrow, in a manner "corresponding" to the one analyzed by Boltzmann[25] in his days.

This bring us to a very *fundamental expression of the intrinsic past–future symmetry*: *reversibility of the negentropy-information*, or $N \rightleftharpoons I$,

[3] The formula holds in connection with either the second-order Klein–Gordon equation or the first-order system of spinning wave equations; respectively, the "Gordon current operator" $[\partial]$ or the "Dirac-like current operator" γ is inserted in the projector $|x\rangle\langle x|$.

transition, as evidenced in, say, the sending, transmitting, and receiving of a message, $I_1 \to N \to I_2$.

Factlike irreversibility is expressed in Brillouin's[26] "generalized Carnot principle" $I_1 \geqslant N \geqslant I_2$, from which stems that information as knowledge is trivial while information as organization is recondite—or at least was so before the advent of cybernetics. However, some philosophers, such as Aristotle, Thomas Aquinas, and Schopenhauer,[27] had been aware of it.

As it occurs in other cases where an "equivalence" exists between two physical magnitudes ($x = ct$ in relativity, $\mathbf{p} = \hbar\mathbf{k}$ in quantum mechanics), the very value of the conversion coefficient, as expressed in "practical" units, displays the "facklike" situation. Thus, in the conversion formula $N = k \ln 2\, I$, where N is expressed in thermodynamical and I in binary units, $k \ln 2$ is very small. In the limit $k \to 0$ knowledge would be rigorously costless and action rigorously impossible—a paradigm once known as "epiphenomenal consciousness." Cybernetics requires consciousness-the-spectator to buy her ticket, at a very low price. At the same stroke it allows consciousness-the-actor to exist, but then at very high wages, because the exchange rate plays the other way round.

That "creative act" logically should exist in the "elementary" form $I \to N$ has been clearly emphasized by Descartes[28] and by Wigner[29] in their own terms. What interests primarily the physicist is to inquire if direct evidence of psychokinesis can be displayed—and indeed this is the case. Here I will only quote the recent work performed in this field by Jahn,[3–5] Dean of the School of Engineering of Princeton University, which works have been triggered by the search for possible causes of malfunctioning in sensitive electronic equipment.

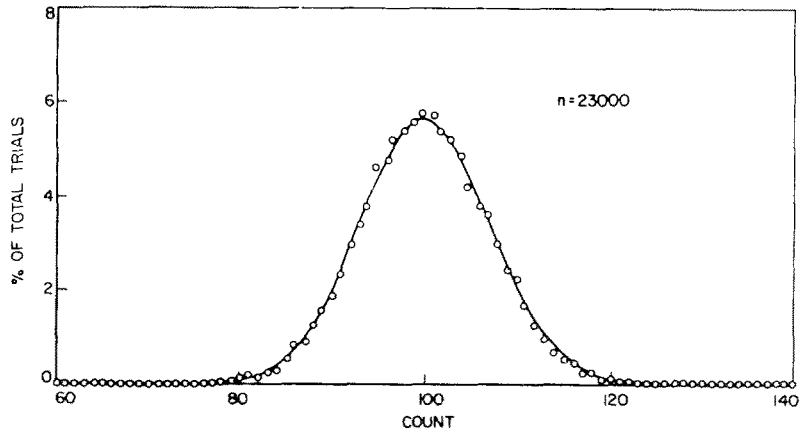

Fig. 3. Random event generator baseline frequency of count distribution; data on theory.

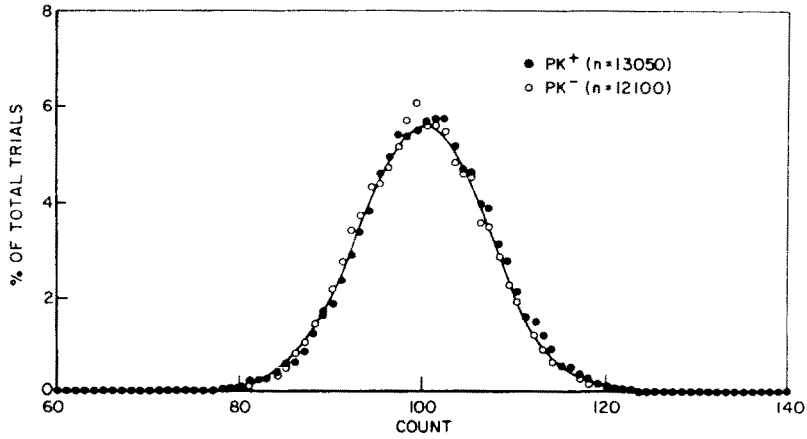

Fig. 4. Random event generator psychokinesis data on baseline theory.

With the written permission of Jahn, I present, together with their captions, Figs. 3–6, all referring to different aspects of one of his series of experiments using "random event generators" (R.E.G.'s). The figures and captions are self-explanatory. Figure 3 compares theory and experimentation in "blind statistical prediction," as in the classical probability theory; the curve, of course, is the Gauss bell-shaped curve. Figure 4 is similar, except that a human "operator" tries to biase the outcome by psychokinesis (PK) either one way (PK +) or the other (PK −); Fig. 5 displays the statistical adjustment to these results, clearly showing the "reality" of psychokinesis, that is, of a (small) contribution from "statistical

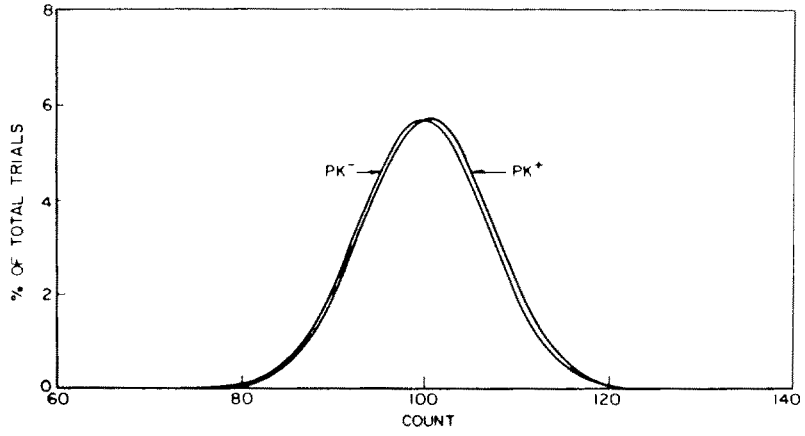

Fig. 5. Random event generator best Gaussian fit to psychokinesis data of Fig. 4.

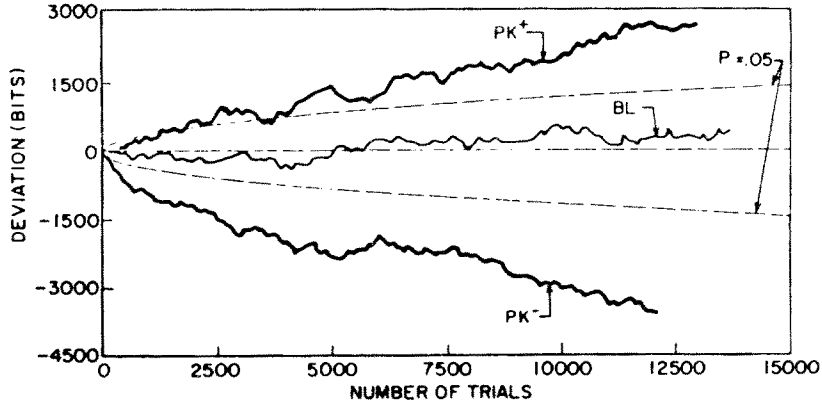

Fig. 6. Random event generator cumulative deviations from theoretical mean.

retrodiction," that is, from advanced actions; Fig. 6 displays the two cumulative deviations as compared to the (experimental) "neutral baseline" of the machine (if a blind walker slightly deviates preferentially either right or left at each stroke, he will "cumulatively" do so).

By emphasizing Jahn's[3–5] recent work, I am definitely not implying that previous, and similar, works by other authors have less significance. Simply, Jahn's work is one of the most recent ones, and the position which is his guarantees excellence in protocols, apparatus, and analysis.

It seems to me that these experiments, following similar ones by other authors, do display the *physical existence of an open theoretical possibility*, and do shed much light upon the concepts of probability, of information, of "process" and "becoming," and upon the problem of the mind–matter interaction.

9. BRIEF CONCLUSIONS

"Scientific revolutions," in which the encounter of a true "paradox" (a "surprising but actual" fact) need the shaping-up of a new "paradigm" (a "surprising but successful view" of facts) is a game that has been played again and again in physics. The "EPR paradox" fits well into this scheme.

Three technical points, as mentioned in the Introduction, have been discussed first, directly leading to a consideration of very general issues.

The only "Weltanschauung" consistent with relativistic quantum mechanics, and its S-matrix scheme, is one in which space-time has no more than a "factlike" semblance of objectivity, so that objectivity must yield in favor of intersubjectivity, and that (rare) occurrences of "paranor-

mal phenomena" can pierce the veil of this "maya." In such a view of things the future "exists" no less, but no more, than the past; it is implied in "creative act," just as the past is in "cognitive act."

At the elementary level, Whitehead's "creative advancing" spacelike σ becomes completely fuzzy, as evidenced by the (paradoxical) EPR correlations, where direct, long-range, Fokker-like[24] connections do show up, emphasizing an intrinsic arrowlessness of causality.

At the macrolevel, of course, advanced actions are much repressed by retarded ones, very much like antiparticles are by particles. *These two factlike asymmetries define the realm of validity of macrophysics*, which would merely collapse in their absence. This builds up the confortable "maya" in which we feel we are living.

But the *raison d'être* of theoretical inquiry is to pierce through the veil of maya, and to *display the consequences of the intrinsic symmetries obliterated by factlike asymmetries.*

REFERENCES

1. H. P. Stapp, *Found. Phys.* **12**, 363 (1982).
2. H. Mehlberg, "Physical Laws and the Time Arrow," in *Current Issues in the Philosophy of Science*, R. Feigl and N. Maxwell, eds. (Holt, Rinehart and Winston, New York, 1961), p. 105.
3. R. G. Jahn, *Proc. IEEE* **70**, 136 (1982).
4. B. J. Dunne, R. G. Jahn, and R. D. Nelson, "An REG Experiment with Large Data Base Capability" (Engineering Anomalies Research Laboratory, School of Engineering and Applied Science, Princeton University, Princeton, New Jersey, 1981).
5. R. D. Nelson, B. J. Dunne, and R. G. Jahn, "A Psychokinetic Experiment with a Random Mechanical Cascade" (Princeton Engineering Anomalies Research, School of Engineering and Applied Science, Princeton University, Princeton, New Jersey, 1983).
6. E. P. Wigner, *Symmetries and Reflection* (M.I.T. Press, Cambridge, Massachusetts, 1967), pp. 171–184.
7. A. Einstein, in *Rapports et Discussions du Cinquième Conseil Solvay* (Gauthier-Villars, Paris, 1928), pp. 253–256.
8. O. Costa de Beauregard, *Compt. Rend.* **236**, 1632 (1953).
9. O. Costa de Beauregard, *Physis* **22**, 211 (1980).
10. O. Costa de Beauregard, *Found. Phys.* **6**, 539 (1976).
11. O. Costa de Beauregard, *Found. Phys.* **10**, 513 (1980).
12. O. Costa de Beauregard, *Am. J. Phys.* **51**, 513 (1983).
13. D. Bohm and B. J. Hiley, *Found. Phys.* **14**, 255 (1984).
14. E. Recami and G. Ziino, *Nuovo Cimento A* **33**, 205 (1976).
15. E. Recami and W. A. Rodrigues, *Found. Phys.* **12**, 709 (1982).
16. O. Costa de Beauregard, "*CPT* revisited," in *The Wave Particle Dualism*, S. Diner *et al.*, eds. (Reidel, Dordrecht, 1984), pp. 485–497.
17. O. Costa de Beauregard, *Phys. Rev. Lett.* **50**, 867 (1983).
18. J. M. Jauch and F. Rohrlich, *The Theory of Photons and Electrons* (Addison-Wesley, Cambridge, Massachusetts, 1955), pp. 408–410.

19. V. Fock, *Dokl. Akad. Nauk SSSR* **60**, 1157 (1948).
20. S. Watanabe, *Rev. Mod. Phys.* **27**, 26 (1952).
21. J. von Neumann, *Mathematical Foundations of Quantum Mechanics* (Princeton University Press, 1955), Chap. 5.
22. W. Ritz and A. Einstein, *Phys. Z.* **10**, 323 (1909).
23. H. Schmidt, *Found. Phys.* **8**, 464 (1978).
24. A. D. Fokker, *Time and Space, Weight and Inertia* (Pergamon Press, Oxford, 1965).
25. L. Boltzmann, *Lectures on Gas Theory*, S. G. Brush, translator (University of California Press, Berkeley, 1964), pp. 446–448.
26. L. Brillouin, *Science and Information Theory*, 2nd edn. (Academic Press, New York, 1967).
27. A. Schopenhauer, *The World as Will and Idea* (Keegan Paul, London, 1883).
28. R. Descartes, *Correspondence*, C. Adam and P. Tannery, eds., re-edition (Vrin, Paris, 1974), letter CCCII, Vol. 2, p. 663 (see also p. 666).
29. E. P. Wigner, *Symmetries and Reflections* (M.I.T. Press, Cambridge, Massachusetts, 1967), pp. 171–184.