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Relativistic Quantum Mechanics as a Telegraph

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A derivation by Fröhner of non-relativistic quantum mechanics via Fourier analysis applied to probability theory is not extendable to relativistic quantum mechanics because Schrödinger's positive definite probability density $\psi^*\psi$ is lost (Dirac's spin 1/2 case being the exception). The nature of the Fourier link then changes; it points to a redefinition of the probability scheme as an information carrying telegraph, the code of which is Born's as extended by Dirac and by Feynman. Hermitian symmetry of the transition amplitude $\langle \varphi \mid \psi \rangle$ between Dirac representations expresses reciprocity of preparation and measurement (the quantal coding and decoding), two equally active interventions of the physicist; as "the measurement perturbs the system" retrodiction implies retroaction evidenced in "delayed choice." Reciprocity of knowledge and organization vindicates Wigner's claim that "reciprocal to the action of matter upon mind there exists a direct action of mind upon matter": psychokinesis, branded by Jaynes as "a psychiatric disorder of the Copenhagen school." As for factlike irreversibility, it is expressed by the enormity of the change rate from information to negentropy: while gain in knowledge is normal psychokinesis is paranormal. Stapp's recent discussion of psychokinesis in a quantum context should be resumed in association with an EPR correlation; an experimental test is proposed.

1. FOURIER ANALYSIS OF PROBABILITY AND TELEGRAPHED INFORMATION

Fröhner,[1] in an interesting paper, argues that a 1915 Riesz–Fejer[2] theorem in Fourier analysis entails, if applied to the probability theory, the Born–Heisenberg–Jordan[3] wavelike set of rules. Then a *correlation* between distant occurrences expressed in the x, y, z, ct variables is synonymous to *telegraphed information* in the form of an *oscillating signal*. What

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sort of physics is implied, and how it is covariantly formalized, are then natural questions.

Applying his argument to Hamilton's equations, and borrowing the value of h from experimentation, Fröhner derives de Broglie's and Heisenberg's wave-particle relations and Schrödinger's equation, whence all the essentials of non-relativistic quantum mechanics. The radicality of the argument establishes quantum mechanics as *the physical statistical mechanics*—a new *wavelike* one, in which *interaction* is synonymous to *telegraphed information* connecting *coded* $\langle \varphi|$ and *decoded* $|\psi\rangle$ Dirac[4] *representations*.

The "law enforced" in the present investigation is: *Draw the extreme consequences of the lawlike symmetries displayed in the formulas regardless of any sort of accepted macroscopic prejudice*. If (in Mehlberg's[5] wording) a *factlike* interpretation exists for a formula evidencing a deeper *lawlike symmetry*, *precedence will be given to law over accepted fact*. This amounts to proposing a new paradigm.

Lawlike reciprocity of preparation and measurement (*retroparation* in Hoekzema's[6] wording) is displayed as *Hermitian reversibility of the transition amplitude*

$$\langle \varphi \mid \psi \rangle = \langle \psi \mid \varphi \rangle^* \tag{1}$$

We intend to discuss its far reaching implications viewed as updating various aspects of Aristotle's symmetries between *information-as-organization* and *as-knowledge*, and between "efficient (retarded) and final (advanced) cause."

It was well understood in the twenties that what Schrödinger's ψ *represents*[4] is *not* "a *reality* existing by itself out there," first because "a measurement contributes in producing the result" (the classics knew that, but in quantum mechanics the perturbation is very strong) and *second for a much deeper reason*: presence of crossed, *interference*, terms in a *transition probability*.

$$(\varphi \mid \psi) := |\langle \varphi \mid \psi \rangle|^2 \tag{2}$$

As a consequence *reality* (say a *particle*) is *veiled*[7] in its *representation* (the *wave*). For example a photon flying between two linear polarizers is *neither in* the *prepared* (*retarded*) *representation* $\langle \varphi|$ *nor in* the *measured* (*advanced*) *representation* $|\psi\rangle$; these *interfere* via the transition amplitude $\langle \varphi \mid \psi \rangle$.

Formulas often say far more than what their discoverers intended. Maxwell's equations, for example, are Lorentz invariant, but how would Maxwell have reacted to Einstein's rejection of the ether? Fresnel's ether drag formula is isomorphic to the composition law of hyperbolic tangents and thus of relativistic velocities; had he noticed that, how would Fresnel have reacted?

2. BAYESIAN INVERSION, THE TWIN FACED INFORMATION, AND WIGNER'S RADICAL CLAIM

Written as[8]

$$|A).(B| = |A \mid B)(B| = |A)(A \mid B| \tag{3}$$

Bayes' *reversible conditional probabilities formula* expresses as *symmetric* the *joint probability* $|A).(B|$ of two correlated *occurrences*—as it is grammatically. In physics the symmetry may even be stronger: in quantum mechanics the joint probability for detecting two EPR correlated particles is CPT symmetric.

Statistical correlation is synonymous in physics to *interaction*; *conditional probability* is thus likened to *causation*. This irritates Jaynes[9] as an "undue confusion of epistemology and ontology." But *in any theory holding probability as essential* this is *law*.

Bayesian reversal thus expresses *action-reaction* or *efficient-final cause symmetry* according as the correlated occurrences are spacelike or timelike distant. This is at variance with the name "principle of probability of causes" applied to Bayes' principle—by blind acceptance of retarded causation.

That a Bayesian updating is a *postselection*, a *retrodiction* allowing use of an *advanced wave*, is exemplified[10] by Heisenberg's microscope thought experiment. In it the impact of a photon in the image plane is used to retrodict *either* the position or the transverse momentum in the object plane of an electron having scattered the photon. The choice is done via the microscope's angular opening: a wide opening yields a *position* measurement, a small opening a *momentum* measurement. If the microscope is thought of as very long this can be turned into a *delayed choice* experiment of the sort Wheeler[11] has discussed at length. He has even gone so far as to write[12] "No elementary quantum phenomenon is a phenomenon…" before registration.

Law suggests one more radical step. Wigner[13] argues that the universal action-reaction principle requires that, reciprocal to the action of matter upon mind, there exists a *direct action of mind upon matter*—likely "a small effect" says he (let us say, one *strongly repressed in fact*). This means, in the present context, that *psychokinesis is corollary to observation*—a preposterous statement at the macro-level; not so at the micro-level, and even less so in view of the quantum subtleties.

Psychokinesis has been tested[14] as a *small but consistently repeatable* phenomenon; Stapp[15] has discussed it in the form of *retropsychokinesis* in relation with quantum measurement. An original test is proposed in Sec. 6 below.

Lawlike reversibility and factlike irreversibility we now discuss with the help of Bayes formula and the information-negentropy equivalence law $N/I = k \log 2$. Cybernetics updates the twin faces of Aristotle's information concept in its *coding* and *decoding*: coding *impresses organization*, *decoding expresses knowledge*.

Any equivalence law contains a *factlike* conversion factor, the change rate between currencies in use in two provinces of physics. Somewhat like the largeness *in practical units* of the velocity of light c had long hidden *but its finiteness finally unveiled* the *equivalence of space and time*, so the smallness *in practical units* (the *bit* and, say, the *clausius*) of Boltzmann's constant k long hid *but its finiteness finally unveiled* at one stroke *the minute negentropy cost of knowledge* and *the legality of psychokinesis.* Setting implicitly $k = 0$ the "theory of epiphenomenal consciousness" viewed observation as purely passive, cost-free, and free will as an illusion. Not so cybernetics: *elementary level coding is psychokinesis*—what else could it be? Sure, the operator does borrow negentropy from the Universal Fall in the form of ingested food, etc, like Carnot's heat engine did from stocked fuel. But *the click* triggering the amplifying process is, inside the operator's nervous system, *a free decision*, the *direct conversion of a concept into an impulse*—the turning of a *representation* into a *realization*, a *control of Bayes' final prior*.

This is how the neurosurgeon Eccles[16] views voluntary motion—in accord with Wigner's claim. Without going so far as neurosurgery *psychokinesis is testable by placing an amplifier on line of an electroencephalograph*: by controlling one's thoughts one can generate macroscopic effects without any body motion.

So, as far as it is concerned, physics expresses the lawlike-reversibility-and-factlike-irreversibility by the *finiteness-but-smallness* of $k \log 2$, explaining *how* knowledge is normal and psychokinesis paranormal.

Decoherence (*collapse of the* ψ in the twenties' wording) is crucial in the problem. Loosing a needle in a haystack is not an objective but a subjective *fact*: the inability to retrieve it, formalized via coarse graining and probability. Loss of the phase relations in a measurement is not an objective fact either—but the wavelike quantum probability rules make the problem much more recondite.

Many papers are presently devoted to decoherence. But a very professional analysis of *how* the phase relations get lost is *definitely not an explanation of the why*; it is *normal science* in Kuhn's wording, formalized as the *mathematical approximation* describing what comes out of an *appositely designed setup*. Can an approximation generate a "self sustaining reality?" Of course not; it yields a *deliberately chosen* aspect of what d'Espagnat[7] names *empirical reality*. In that it is *reciprocal* to a preparation (where the choice, however, is more abrupt).

Ending the observation line, there is *the physicists' eye-and-brain* causing "a negligible interaction" at the macro-level, *but one needing a thorough discussion at the quantum level*—where a measurement is a retroparation.

A common saying[17] in "the Copenhagen school" was that *collapse of ψ results from the act of observation.* To Jaynes[9] this is anathema, "a psychiatric disorder, a form of arrogance as if you or I were pretending to control the world by psychokinesis." The world at large of course not—*but why not my body*?

Anyhow, there is a decent traditionally Bayesian way for expressing this: If a measurement *updates* the ψ, then ψ just is "an estimation" veiling "reality." But beware! *Aristotle's information is twofold*; a *representation* has an active face showing up in the wavelike phenomenology—for example in the EPR correlations to be discussed later.

3. PARADIGMATIC IMPLICATIONS OF THE LORENTZ AND CPT INVARIANCES

If, according to Fröhner, a wavelike telegraphing of information is implied in the calculus of probabilities relativistic covariance knocks at the door—but a *no entry* sign is blatantly posted: *Schrödinger's positive definite probability density $\psi^*\psi$ is lost* (Dirac's spin 1/2 case being *the exception*).

If Fröhner's "missing link" is to be recovered the only possibility is: turn over the approach, namely: Start from the covariant Fourier analysis associated with a relativistic wave equation *and investigate the radical changes needed so that the probability formalism expresses a wavelike telegraphing of information.*

Lorentz and CPT invariances are in the forefront. The latter is concisely rendered by the *Hermitian symmetry of the transition amplitude*: in an x, y, z, ct picture PT exchanges *bra* and *ket* and C goes to the conjugate.

Feynman's graph, the topologically invariant **N**-uple extension of Dirac's transition amplitude, pictures well the telegraphic network correlating prepared and retropared representations. Due to complementarity these are truncated, Picasso style. So what the Feynman web carries is *signals* emitted (prepared, coded) as *retarded* and received (measured, decoded) as *advanced*; Cramer's[18] "transactional" paradigm formalizes this; I[10] had sketched it in 1953, and it is now upheld in more or less similar forms by many.[19–22]

4. INVERSE FOURIER TRANSFORMS AND PARSEVAL'S EQUALITY FOR SOLUTIONS OF THE KLEIN–GORDON EQUATION

Expressed in the 4-frequency, k picture, the Klein–Gordon (K.G.) equation reads

$$(k_i k^i + k^2)\,\zeta(k) = 0 \tag{4}$$

implying *either*

$$k_i k^i + k^2 = 0 \tag{5}$$

or $\zeta(k) = 0$, namely: $\zeta(k)$ is an arbitrary complex function over the two sheeted hyperboloid of Eq. (5). One easily writes with Marcel Riesz[23] a covariant Fourier expansion of $\zeta(k)$, a quadratic norm, etc. *Here we want something more*: covariant *reciprocal* Fourier transforms, etc. This I[24] have done long ago, presented[25] at the 1983 ISQM conference, and reproduce here for the reader's convenience.

As the 4-vector volume element dv^i on the hyperboloid is collinear with the 4-frequency k^i we can write, with k positive,

$$k_i\,dv^i = -k\,dv, \qquad k^i\,dv = k\,dv^i \tag{6}$$

Also, we introduce the sign factor

$$\varepsilon(k) = \pm 1 \text{ according as the time frequency is positive or negative,}$$
$$\text{zero otherwise} \tag{7}$$

Indexing by a and b two solutions of the K.G. equation we *define* the transition amplitude between them as the following integral, where the double bar emphasizes reference to the second-order K.G. equation:

$$\langle a|\;|b\rangle := \iiint \zeta_a^*(k)\,\zeta_b(k)\,\varepsilon(k)\,dv = -k^{-1}\iiint \zeta^*(k)\,k_i\zeta(k)\,\varepsilon(k)\,dv^i \tag{8}$$

The x expression of the K.G. equation is

$$(\partial_i^i - k^2)\,\psi(x) = 0 \tag{9}$$

Denoting by $[\partial_i]$ the Schrödinger or Klein–Gordon current operator (the difference of the partial differential operators acting to the right and to the left) we *define* the x expression of the transition amplitude $\langle a|\,|b\rangle$ via the *conservative* integral

$$\langle a|\,|b\rangle := -\tfrac{1}{2}\,i \iiint \psi_a^*(x)[\partial_i]\,\psi_b(x)\,du^i \tag{10}$$

extended over an arbitrary spacelike 3-surface.

Symbolized à la Dirac, the Parseval equality then reads

$$\langle a|\,|b\rangle = \langle x_a|\,|x_b\rangle = \langle k_a|\,|k_b\rangle \tag{11}$$

evidencing the equivalence $-i\partial_i \leftrightarrow k_i$; this allows a concise writing of the forthcoming formulas.

The Fourier nucleus, with k obeying formula (5), we denote as

$$\langle x|\,|k\rangle := \exp\{ik_l x^i\} \tag{12}$$

as it is "the pure plane wave" *solving the K.G. equation in both of its forms* we can express the *covariant reciprocal Fourier transforms* (with "automatic summation") as

$$|x\rangle = |k\rangle\langle k|\,|x\rangle, \qquad |k\rangle = |x\rangle\langle x|\,|k\rangle \tag{13}$$

Thanks to the definition (8) the Fourier transform of the Fourier nucleus comes out as the propagator $D_+ - D_- \equiv D_{\text{ret}} - D_{\text{adv}}$ (integrating as usual in the complex plane, the closed contour consisting of two clockwise circles around the poles is equivalent to that consisting of two antiparallel straight lines, one above, one below the real axis); this is the Jordan–Pauli (JP) propagator

$$\langle x_a|\,|x_b\rangle := D(x_a - x_b) \tag{14}$$

As it is zero outside the light cone the formula

$$\langle x_a|\,|x_b\rangle = \langle x_a|\,|k\rangle\langle k|\,|x_b\rangle = \langle x_a|\,|x\rangle\langle x|\,|x_b\rangle \tag{15}$$

expresses orthogonality of any two J.P. propagators; so the formula

$$|x_b\rangle = |x_a\rangle\langle x_a|\,|x_b\rangle \tag{16}$$

solves the Cauchy problem (the double bar reminding the presence of a normal derivative). In k-space analogous formulas express *inter alia* orthogonality of *any* two plane waves.

Now comes the snag. Because of the sign factor $\varepsilon(k) = \pm 1$ *formula (8) has not the canonical form needed in Fröhner's argument*. The k integral has the form of the mean value of a density of value $+1$ on one sheet, -1 on the other; thus the double sign refers to particle-antiparticle exchange.

On the left-hand side (10) of the Parseval equality (11), the integrand is *very* far from Schrödinger's $\psi^*\psi$. This stems from the probabilistic meaning of Schrödingers 3-current $\mathbf{j} = -\frac{1}{2}i\psi^*[\partial]\,\psi$ and of Gordon's 4-current $j_l = -\frac{1}{2}i\psi^*[\partial_l]\,\psi$: $\iiint \mathbf{j}.\mathbf{ds}\,dt$ expresses the *probability* that the particle crosses the surface element **ds** in the time interval dt; as it can go both ways **j**'s sign is indefinite; **j** and j^i are *vectorial probability densities.*

Does the indefinite sign of the time component of Gordon's current mean that "the particle can move backward in time?" Not exactly; as Minkowski's matter is time-extended the indefinite sign refers to particle-antiparticle reciprocity.

Concluding: Fröhner's clever derivation of quantum mechanics from the classical calculus of probabilities cannot be duplicated for relativistic quantum mechanics.

5. INVERSE FOURIER TRANSFORMS AND PARSEVAL'S EQUALITY FOR SPINNING WAVE EQUATIONS

Dirac's form of the spin 1/2 equation has been generalized to higher spin values: by Petiau–Duffin–Kemmer for spin 1, and formally to all orders by Umezawa and Visconti.[26] In these formalisms there exists a projector projecting any solution of the Klein–Gordon equation onto a solution of the spinning wave equation.

Using the spinning wave equation and its adjunct

$$(\alpha^i\partial_i + k)\,\psi(x) = 0, \qquad \bar{\psi}(x)(-\alpha^i\partial_i + k) = 0 \tag{17}$$

together with their k space transcriptions

$$(\alpha^i k_i + ik)\,\zeta = 0, \qquad \bar{\zeta}(\alpha^i k_i + ik) = 0 \tag{18}$$

(with as usual $\bar{\psi} = \psi^*\beta$ and $\bar{\zeta} = \zeta^*\beta$), we write the Parseval equality as

$$\langle a \mid b\rangle = i\iiint \bar{\psi}_a\alpha^i\psi_b\,du_i = i\iiint \varepsilon(k)\,\bar{\zeta}_a\alpha^i\zeta_b\,dv_i \tag{19}$$

the x integral is over an arbitrary spacelike surface and the k integral over the two sheeted hyperboloid of Eq. (5); the single bar means that we are using a first order equation. So (15) reads

$$\langle a \mid b\rangle = \langle x_a \mid x_b\rangle = \langle k_a \mid k_b\rangle \tag{20}$$

As the Gordon and Dirac 4-currents differ by a divergence

$$\langle a \mid b \rangle = \langle a| \, |b\rangle \tag{21}$$

Using the Fourier nucleus $\langle x \mid k \rangle$, we express the inverse Fourier transforms as

$$|x\rangle = |k\rangle\langle k \mid x\rangle, \qquad |k\rangle = |x\rangle\langle x \mid k\rangle \tag{22}$$

and the J.P. propagator as

$$\langle x_a \mid x_b \rangle = \langle x_a \mid k \rangle \langle k \mid x_b \rangle \tag{23}$$

Analogous formulas hold in k space.

The integrated canonical energy-momentum tensor and its Fourier transform yield as expressions of *the particle's mean energy-momentum*

$$\langle P_j \rangle = -\tfrac{1}{2} i \iiint \bar{\psi}_a [\partial_j] \, \alpha^i \psi_b \, du_i = \iiint \varepsilon(k) \, k_j \bar{\zeta}_a \zeta_b \, dv \tag{24}$$

incidentally, as the antisymmetric part of Tetrode's tensor is divergenceless, the index summation in the x integral can equivalently be done over $[\partial]$'s index; or one can use the first and last expressions in (15) together with the $-i\partial \approx k$ equivalence.

Here ends our guided tour of Fourier analysis in connection with a relativistic wave equation.

What is definitely lost is normalization via a positive definite sum—together with a literal use of the Fröhner recipe for deriving quantum mechanics. But what remains is the idea of likening the probability formalism to the code of an information transmitting telegraph. *Relativistic quantum mechanics is exactly that*, emitting coded (prepared) representations $\langle \varphi|$ and receiving decoded (measured) representations $|\psi\rangle$. It formalizes *an ungoing questions-and-answers game* between *reality* and *representation*, between mind and matter.

6. ZIGZAGGING CAUSATION IN EPR CORRELATIONS; A PROPOSED TEST VIA PSYCHOKINESIS

At the 1927 Solvay Conference (the quasi official promotion of "The New Quantum Mechanics") Einstein[27] pinpointed the conundrum to reappear as "the EPR paradox." His argument can be summarized thus: If a plane matter wave carrying just one particle falls normally on a plane screen, is diffracted by a small hole at *O*, and is absorbed in a semi-spherical film centered at *O*, the particle blackens just one grain *A*. How are we to understand that any other grain, say *B*, is not blackened? There would be "no problem" if the chance event had occurred at *O* "in the hole;" but the "new quantum mechanics" claims that it occurs at detection—or not detection—which implies faster than light signalling between *A* and *B*: nonsense, and something forbidden by the relativity theory.

It is queer that Einstein, expert as he was in statistical mechanics, remembered then neither Loschmidt's reversibility objection to Boltzmann nor van der Waals[28] rendering of physical irreversibility via Bayes formula. *Retarded causation he questioned not*.

However, read literally, the quantum formula say this:[8] *The correlation between the two spacelike detections is telegraphed as zigzagging along two timelike vectors via the past event at O. And at O the chance event cannot have occurred, because the correlation amplitude is a superposition*; *so the joint probability of detections is not a mixture*. This settles the matter: *There is a zigzagging telegraphing of causation contradicting not the relativity theory but the macroscopic prejudice of retarded causation*.

The 1935 Einstein–Podolsky–Rosen[29] paper enlarges the problem by discussing two distant measurements performed on *entangled* particles; this has triggered all the work on "EPR correlations," often in the EPRB[30] form, consistently vindicating quantum mechanics.

The V-shaped Feynman graph yields[31] a concise Lorentz and CPT invariant derivation of the correlation formula, valid for any sort of separation, spacelike or timelike.

One often reads that "two entangled particles make up a single whole" so that "measuring the state of one immediately reveals the state of the other." *I disagree*: not only are two *independent* measurements *allowed*, *but they are usually performed*; as Wheeler[11] puts it "an unperformed measurement is not a measurement." *The entangled particles behave like true twins* who, questioned *independently* and *arbitrarily*, answer insolently *yes* or *no* as if corresponding telepathically[32] *via their birth*. *Independence of the questions* and *correlation of the answers* displays a *zigzagging transaction* evidencing *operationality* of the twin Aristotelian symmetries.

Blind faith in retarded causation and rejection of Wigner's cognizance-psychokinesis reciprocity has persisted after Einstein. Thus Shimony,[33] followed by others, states that an EPR correlation cannot be used for faster than light signalling because it establishes not *action* but "passion at a distance;" so there is a "peaceful coexistence," not a full harmony between relativity and the quantum. But acceptance of Wigner's cognizance-psychokinesis reciprocity restores at one stroke *action at a distance* and *full CPT invariance*.

This can be tested by associating psychokinesis with an EPR correlation. A simple setup could comprise a low intensity laser beam divided (say) half and half by a semi reflecting plate and two photon detectors. This *is* an EPR correlation, because at the plate each photon "chooses" according to Born's prescription. An "agent" operating at A, *retroacting at the plate*, will biase the final prior at A, thus raising or lowering "by will" the flux of photons he observes. *Correlatively* the flux of photons detected at B will be lowered or raised. The hypothesis is of course that retroaction does not go further back than the plate, which can be tested.

This is faster-than-light signalling if the AB separation is spacelike, back in time signalling if it is past-timelike.

7. SKETCH OF AN ENLARGED PARADIGM

Existence and operationality of Minkowskian-probabilistic formalisms would be quite paradoxical if matter "existed by itself out there." Not so if *what is extended in space-time is an agreed upon representation of reality*: reality precedes representation in decoding, representation precedes realization in coding. *Learning and willing—knowledge and psychokinesis*—are *reciprocal*. A metaphor borrowed from hydrodynamics likens Aristotle's *efficient* and *final* causes to *sources upstream* and *sinks downstream.*

Psychokinesis essentially is retropsychokinesis. Discussed by Stapp,[(15)] it affords a *sui generis* form of delayed choice—because its verification is *delayed.*

The questions-and-answers game going on via *preparing* and *measuring* in quantum mechanics codes and decodes *an agreed upon empirical reality*. Of what consists *veiled reality*, "the object of the search?" What the laboratory files contain is not "consistent histories of particles" but *faithful records of accepted representations*. The object of the search is *yet unknown Laws of Nature–the triggering of insights inspiring new paradigms.*

The claim here is that *beyond* the empirical reality entangled in the telegraph there is, exchanged between the investigators, discarded by *decoherence*, *the paranormal.*

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