# Can we Crack the Mind-Body Problem?

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## PART TWO: Matter and the Poached Egg

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ABSTRACT

*In this Part Two of what is now a four-part article, the main focus is on quantum entanglement – a strange feature of which we have only the wispiest grasp. It will be argued that nature flatly needs it, on grounds of consistency. The notion of holomatter will also be introduced. It will be shown that this "super-matter" sheds new light on the quantum world, one that makes it less… befuddling.*

*When I felt it was necessary, I took the liberty to coin a few words. Their definitions are given in the Appendix 2A. Also, many footnotes are added to the text. Nearly all of them can be ignored with no adverse effect on the global comprehension.*

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# A reminder of Part One

## "Stir-waves" and "stuff-waves"

In Part One, a distinction was made between "stir-waves" or **motion waves** on the one hand, and "stuff-waves" or **substance waves** on the other. It was suggested that quantum waves are substance waves, rather than the probability waves they're often made out to be.[1] Like any wave, they are not static. They need some wiggle room and they cannot be point-like. Accordingly, quantum waves are spread out in space and can be said to be fuzzy. This fuzziness is such that quantum objects, as a rule, obey a principle of superposition when they evolve in their wave-like fashion.[2]

Another important property of the ubiquitous quantum stuff-waves is that they are feelers of their environment. Being outstretched and nonlocal, they sense their environment out and adapt to it, regardless of the distances. They are "remote" feelers and can pull off uncanny feats that raise awkward questions such as: *How can a particle possibly "know" when it is and isn't being watched? How can it anticipate a future change in an experimental setup, and behave accordingly?* I'll tackle these questions in Part Three, when I'll discuss Wheeler's and the quantum eraser delayed-choice experiments.

Stir-waves or motion waves are free to interfere with whatever similar waves come their way – sound waves with sound waves, water ripples with overlapping ripples. Their interference is harmless. It never poses any threat to nature's consistency. However, it is not so with quantum waves *qua* substance waves. For example, two of them can add up to flat-out nothing by destructive interference. This is naught out of aught! This possibility, highlighted in Part One, is a definite no-no since it goes smack against nature's consistency. Nature can definitely ill afford to be contradictory and is never so, at least in damaging ways. To steer clear of such a risk, quantum waves come with strings attached. The way they interfere is put in check, as we now find out.

## Quantumhood and quantum threats

To nip any contradiction due to interfering quantum waves in the bud, nature relies on its anti-contradiction immunity to control and restrain their interference. It does so through the **principle of quantumhood**, which rules out any strictly wave-like evolution of an elementary particle that would break it in mutually non-interfering bits. As I explained in my *Expanding Matter* paper, "*The principle of quantumhood is a principle of wholeness that bears on the electron and on any particle more generally. It precludes them, as they move about in their deterministic and wave-like fashion, from being torn into bits that would no longer interfere mutually. This principle is iron-clad*."[3]

So far so good, but there's a catch, as "wave wholeness" cannot withstand quantum threats. A **quantum threat** is any situation which, left to its own device, would tear an elementary particle into independent bits.[4] This goes against wave wholeness and against the principle of quantumhood, and is therefore downright impossible. How will nature confront such a threat, then? We know the answer: nature copes by means of a quantum jump. The magic potato of Part One made it plain. The spud was initially threatened in a "fuzzy" state that spread it on both sides, left and right, of the knife. It reacted

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[1] According to the probability wave interpretation introduced by Max Born in 1926, the wave function is a mere mathematical tool that enables physicists to carry out their calculations. It is not a physical entity. Substance waves, on the other hand, have more to do with coming-into-being than with rock-solid existence (see Part One).

[2] Technically, the principle of superposition – that results from the linearity of the Schrödinger wave equation of quantum mechanics – allows superpositions (or linear combinations) of possible "sharp" states of the wavefunction to form another possible state, which is now "fuzzy". (These combinations are weighted sums whose weights are complex numbers. However, the values of all the physical quantities of interest are given by real numbers.) In the theory, fuzzy and sharp states are respectively known as superposed and eigen states. Let me add that quantum waves, rather than being solely spread out in space, are more accurately spread out in the space-time continuum that, according to Einstein's relativity, is the true fabric of our physical universe. Being outstretched or fuzzy with respect to both space *and* time raises some thorny issues as regards causation. More on this in Part Three.

[3] Passage from 'Expanding Matter: A New Post-Materialist Take on Quantum Consciousness', which is my contributing essay to the collective book *Expanding Science. Vision of a Post-Materialist Paradigm*, AAPS Press, 2020. (AAPS stands for the Academy for the Advancement of Postmaterialist Sciences. It is based in Tucson, Arizona, USA).

[4] Here, the bits or subunits (and indeed, the sub-wave packets) are *independent* if they cannot interfere mutually. This means that their respective waves can no longer interfere mutually. They *decohered*, as we often say now. It is worth stressing that his "wave independence" is *not* a spatial concept. It is sheerly interferential in nature.

to the menace of being cut in two chunks by suddenly jumping and shrinking to one side. Smart move! In this "sharp" end state, the knife's blade couldn't chop it off. The threat was gone.

This naive example captures an essential truth about quantum jumps. A particle will likewise jump or collapse when facing a quantum threat. Since a quantum threat feeds on some fuzzy state of the particle, the jump or collapse will shrink it abruptly, from its threatened fuzzy state to a threat-free one that will be sharp. We now gather that a quantum jump is a fuzziness-busting and sharpness-yielding event.

A fuzzy state is a superposition – or an array – of sharp and well-defined states, each having a clear-cut value of some attribute, be it its position, momentum, energy, intrinsic spin and whatever else. Because of this, a fuzzy state is actually a superposed state, and is usually called so. The sharp end-state of the jump is always one of these sharp states, selected out of the whole array. A quantum jump, then, abruptly jolts the collapsing object from a fuzzy state to a selected sharp state. This is how it saves the day, as it did for the magic potato. Now, a measurement works (1) by means of a detecting device that (2) creates a quantum threat that (3) prompts a jump or collapse that (4) selects and spawns a unique sharp end-state which, crucially, is unthreatened. This is how we always get a single outcome when we measure an electron, out of the many possibilities encoded in the "fuzzy" initial state of its wave function.[5]

In its narrow sense defined by Niels Bohr in 1913, a quantum jump, or leap, is the abrupt jerk of an electron in an atom, from one orbit (orbital) or energy level to another. Bohr claimed that electrons orbiting an atomic nucleus sometimes jump in discontinuous and random leaps, whose size depends on how many photons are either absorbed or given off in the process.[6] Throughout this article, though, I'll use the word jump – or leap, or collapse – as an umbrella word. It will be taken in a broad sense. It will be ascribed, somewhat abstractly, to all the *wave-less nonunitary evolutions*, or rather *wave-less nonunitary events*, that crop up in the quantum world.[7]

## In and out, causation-wise

A jump kicks in to free an object from a quantum threat, whether due to a measurement or not. This sudden event shrinks the object or system, say an electron, from its threatened state, which is fuzzy, to the threat-free and sharp state that it will take on by collapsing. The magic potato made it plain that the object's initial state is fuzzy. Otherwise, there simply would be no threat! For example, a fuzzy electron in an atom, which is smeared out over several orbits around the nucleus, may suddenly leap to a final sharp state, one that will find it on a well-defined orbit. This is because each of these several orbits tends, if you will, to absorb the snippet of the electron's waves that overlaps it. This of course cannot happen, since it would split the fuzzy electron in a way that goes against what the quantumhood principle allows. Thus, the electron faces a quantum threat. As a result, it jumps out of it sooner or later. It leaps to a sharp state, one that is threat-free.

In its fuzziness-busting role, a jump shifts the photon from an array of multiple potential states to an only one of them. Think of the act of choosing a card out of a deck. The deck of playing cards is "fuzzy" whereas any of its cards is "sharp". Now think of the jump as being in charge of selecting a single card out of the whole deck.[8] My core hypothesis is that this

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[5] The measured or observed object, say a quantum particle, is initially in a fuzzy state created by the analyser of the measuring apparatus (a measuring apparatus typically comprises an analyser plus a detector). Upon being measured, the particle is under a quantum threat. It reacts by jumping, from its fuzzy state to a sharp one. The latter, selected out or the former as we noticed, brings out a precise measurement result. Incidentally, it is often said that through a measurement, the potential become actual. The "potential" refers to the initial fuzzy state of the measured object and the "actual" refers to its sharp, definite and unique end-state. (Indeed, both are truly actual however, as the magic potato clearly shows. It can easily be proven through Heisenberg's uncertainty principle. See *L'Origine quantique de la conscience*.)

[6] As energy must be conserved in quantum jumps as anywhere else (barring reversible and short-lived virtual transition that occur in the vacuum), the abrupt transitions of jumping quantum systems from one state to another are often accompanied by the absorption or the emission of photons. These bring or take away a balancing amount of energy.

[7] Quantum waveless nonunitary events are a-relativistic. A quantum tunnelling event is a case in point. It is nonunitary and leads to (seeming) faster-than-light photons. These, then, travel faster than themselves! How can this be? We'll come back to this in Part Three, where an explanation of this apparent inconsistency will be offered. (A physical evolution is *unitary* when it preserves the value of the inner products between states. An evolution or an event is *a-relativistic* when it flouts the space-time constraints laid down by Einstein's relativity theories.)

[8] In the 'wavy' quantum microworld, absolute sharpness doesn't exist, because quantum waves are never point-like and because of the uncertainty principle. This principle states that more sharpness here is gotten at the cost of more fuzziness – or "uncertainty" – there (technically speaking, the uncertainty principle bears on pairs of incompatible observables, or attributes, corresponding to non-commuting operators). It is worth mentioning, too, that a quantum threat is somehow "degeneracy-blind". This implies that sharp or eigen states that belong to a degenerate part of the eigen spectrum of quantum operator, say, involved

selection, or “choice”, stems from an in-causal initiative – if by in-causation we mean some sort of decision-making ability. Of course, at the quantum level, this ability is bound to be exceedingly faint and limited. The point, however, is that it is *qualitatively different* from sheer blind chance.

In his book about panpsychism, Peter Ells expressed a similar idea. He wrote: “*A free choice made by the photon (…) determines the spot on the screen where it lands. The choice is wanton because the electron has no ability to think or reflect. The choice is not arbitrary, however (...). The choice made by a particular photon is still a legitimate explanation as to why it landed on a particular spot on the screen. (...) The choices discussed here, because they are based on unreflective, raw sentience, cannot amount to the free will experienced by humans*.”[9]

Recall that “*out-causation is causation from without whilst in-causation is causation from within. In the real world,* ***out-causation*** *feeds determinism whereas* ***in-causation*** *comes across as random. It drives quantum randomness. Determinism and randomness [at the quantum level] are therefore the hallmarks of the two major strains, “in-” and “out-”, of causation*.”[10] In Part One, I often used the words exo-causation and endo-causation as equivalents to out-causation and in-causation respectively, and as a reminder that out-causation is exogenous while in-causation is endogenous. From now on however, I’ll utilize the earlier and shorter “in-and-out” version, as it is specific to the approach outlined here. The “endo-and-exo” version is more general.

# Holomatter laid bare

## The two sides of holomatter

As I wrote in *Expanding Science*, “*The claim that in-causation pulls the strings of quantum randomness leads one to introduce the notion of holomatter and of holoparticles, or elementary particles of holomatter. Quite simply, holomatter is made up of two complementary dimensions: an out-causal one and an in-causal one*.” **Holomatter** is nothing but ordinary matter *plus* an assumed in-causal (or endo-causal) dimension. With it, there’s more to matter than meets the eye. With it, quantum objects harbour a hint of in-causation. If this “super-matter” holds water, then a shadowy in-causal world exists. It nevertheless hides from the scientist’s prying eye, because the “*in-causal dimension of holomatter is overwhelmingly dormant, or latent. This makes it well-nigh invisible, and it goes unnoticed. (…) At times however, the in-causal dimension pops out of its latency (…) and pulls the strings of quantum randomnes*s.” If a hint of in-causation lurks and dwells in ordinary matter as I surmise, holomatter is matter in its fullness – hence its name.[11]

On this insight, “*electrons and the like become particles of holomatter, or holoparticles. They are made up of two components, or parts: one is out-causal and hence deterministic, the other is in-causal and hence random. We can call* ***outdown*** *the “lower” out-causal part and* ***inup*** *the “upper” in-causal part (see Drawing 1). Both coexist within a holoparticle. They cannot be wrung apart, much like the two sides of a coin*.”[12] For clarity’s sake however, the drawing below separates these components. It slices the holoparticle in two layers, one on top of the other, the upper in-causal (and hence random) one being the **inup** while the lower out-causal (and hence deterministic) one is the **outdown**. By and large, the inup goes unheeded. It is flatly overlooked; yet it might be the core non-computational ingredient of quantum physics, as Roger Penrose would have it.

Drawing 1 (below) is a rough sketch of a holoparticle and is not meant to be taken at face value. For example, a (holo)particle cannot be put in a finite volume with clear-cut boundaries, as the drawing suggests, given the wave-like nature it is wont to display. Also, the inup and the outdown are tightly intertwined, but are inaccurately shown as separate.

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in a measurement, can still coexist and “cohere”, or preserve their mutual interference, in the end-state of a jump triggered by an ideal measurement (sharp or eigen states are said to be *degenerate* when they relate to the same eigenvalue of the operator; an *ideal measurement* is a non-destructive one). This, again, can easily be seen with the magic potato of Part One, simply by assuming that each one of its “left” and “right” end-states is in fact a degenerate multiplicity of states. Historically, the survival of degenerate superpositions in ideal measurements was first pointed out by Gerhart Lüders in 1951.

[9] Peter Ells, *Panpsychism, the Philosophy of the Sensuous Cosmos*, O-Books, 2011.

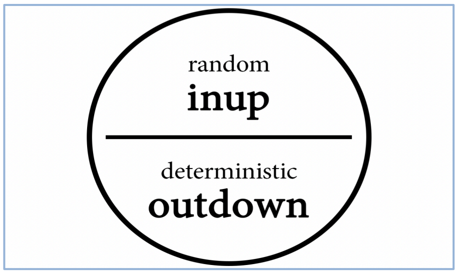
[10] Quoted from my essay in *Expanding Science*. Someone wittily remarked, by the way, that randomness in physics is often a physicist’s shorthand for: “We haven’t got a clue as to why this happens”.

[11] *Holo* is from a Greek word meaning “whole”, as in hologram and holistic.

[12] Again, from my paper in *Expanding Science*.

For all its shortcomings, though, Drawing 1 still provides some fruitful insights into the quantum world. Or so do I believe. That will be made plain with the M-P-S diagram.

**DRAWING 1** *The bi-dimensional holoparticle*



***The bi-dimensional holoparticle:*** A holoparticle is a tiny speck of holomatter. It is made up of two complementary parts that are inextricably bound up together (although they're shown as separate here, to be made graphically explicit). The upper one is the inup. It is random because it is in-causal. The other part, down or below, is the outdown. It is deterministic because it is out-causal. Due to this twofold nature and depending on the circumstances, a (holo)particle displays both deterministic and random features.

## The poached egg and the two-pilot racing car

A holoparticle can be likened to a poached egg, as both have two very dissimilar parts, one conspicuous and the other hidden. In this culinary model of, say, a (holo)electron, the inup becomes the yolk and the outdown becomes the white. An electron, then, combines a deterministic and wavy "white" with a random and wave-less "yolk".[13] The latter, as we know, appears random because it is in-causal, or very dimly "self-willed" as it were. It is definitely nondeterministic. Using the lump and jump image of Part One, we can say that lumps are "outdown-driven", or "white-driven", bundles of quantum waves.[14] By the same token, jumps are "inup-driven" or "yolk-driven" events that are wave-less and can be said to collapse the waves. The white/outdown and the yolk/inup take turns to drive the (holo)particle. They're active and latent in alternance. Actually, "*The outdown has the lion's share of activity. When it holds its sway, the particle behaves like a wave—or, rather, it looks like a bunch of interfering waves lumped together. On the other hand, the inup is nearly always resting or latent. When it kicks off in its active (and exceedingly short-lived) mode, the inup elicits a quantum jump, whose outcome is random and particle-like. We thus have a straightforward rule of thumb to determine which part of the (holo)particle is active at any time:* When we have a lump, the outdown is active. When we have a jump, the inup is active."[15]

This underscores the fact that (holo)particles and holomatter can put on two possible "guises" or states, much like liquid water and solid ice. One guise is **matter**, defined here as the state a particle is in when it is outdown-driven. Then its outdown is active and its inup is dormant or latent. The other is **paral**, defined as the state of a particle that is inup-driven. Then its inup is active and its outdown is latent. In the paral state, the genie of in-causation is out of the bottle![16]

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[13] Furthermore, unlike the white of a poached egg, its yolk is only half-baked and remains soft and sticky; to the effect that two or more of these yolks can easily be made to stick together, as though fastened with some glue. This ability will turn out to be akin to the property of "in-binding" or *supralness* which, according to holomatter, underpins quantum entanglement.

[14] These bundles of mutually interfering waves, or lumps, are better known as wave packets or as wave functions (or else, as state vectors). Recall that outdown-driven interactions and evolutions are strictly out-causal. They are unitary and comply with the mathematical principle of least action (the physical *action* equals an energy time a duration). The Schrödinger equation of quantum mechanics is a straightforward consequence of this principle.

[15] Excerpt from my contribution to *Expanding Science*.

[16] It is worth bearing in mind that, contrary to the outdown and to the matter state of holomatter, the inup and the paral state aren't relativistic. This mismatch is a big stumbling block that stands in the way of a thorough and seamless unification of quantum physics and general relativity. It is little wonder, then, that the so eagerly sought-after synthesis of these two theories, which would spawn a theory of quantum gravity, is doggedly elusive. In spite of huge efforts made over many decades now, quantum gravity is still out of reach. Actually, if holomatter is anything to go by, it is bound to remain so! I think that what needs to be done, if we're to make some real headway nevertheless, is to take into due account the relativity-blindness of the in-causal dimension of this "super-matter"; and then fully work out its formal consequences.

Given this matter-paral duality, a particle can also be likened, as it moves about, to some sort of a racing car. Of course, this "car" is no ordinary racing car. Not quite unexpectedly, it has a quantum twist of it own. It has two pilots on board instead of the usual one. The pilots' names are Matter and Paral. Matter drives singlehandedly when the outdown is active and runs the show. Then the inup is latent, and Paral cosily dozes off. Actually, it does so most of the time. As a consequence, his existence goes unnoticed, and he is widely ignored. Yet Paral calls the shots when the inup is active. Any looming quantum threat is like a wake-up call that spurs him into his active mode. Overall, the Matter-Paral partnership works perfectly well.

We may wonder why it takes two pilots to drive this odd racing car of a (holo)particle. Why is it that holomatter has two alternative guises or states, matter and paral, when one might possibly suffice? This is down to the fact that outdowns and the matter state lack an essential skill. They prevail, but they have a serious flaw, which is that they fail badly when it comes to handle quantum threats. Yet nature is resourceful. To make up for this shortcoming, it has a smart trick up its sleeve. This is where the inups and the paral state come in handy. Thanks to their unique mix of features, inups and paral have what it takes to cope with these looming threats. They have the work cut out for them, to stave quantum threats off when these are about to wreak havoc to nature's consistency. They do so, as we saw, by shrinking the threatened object on to a threat-free state. As I assume here, they pull off this feat by exerting their in-causal faculty of initiative and selection. This successfully turns things around. The magic potato of Part One illustrated this point.

The matter state is that of 'wavy' or wave-like lumps. The paral state is that of wave-less jumps. Moreover, a jump or collapse typically shrinks the particle to a point-like, and hence to a particle-like, end-state that conjures up the image of a point particle. We saw all this already; and we now gather that the lump-jump duality underlies the alleged wave-particle duality of quantum mechanics. Both these dualities, in turn, are but the **matter-paral duality** of holomatter by another name. They can also be seen as a determinism-randomness duality. Or else, as a fuzziness-sharpness duality.[17] Thus, if holomatter holds any water, we have one basic duality seen in five different garbs, as either lump-jump or matter-paral or wave-particle or determinism-randomness or fuzziness-sharpness duality… Take your pick!

Incidentally, quantum waves can be said to be **parallable**, if by this we mean that they vanish whenever a quantum object turns to paral. No sooner the jump or paral phase is over however, they're up and running again. The waves come back and take a new lease of life. Until the next jump, that is.

To recap, here are the main ideas seen so far. A jump, according to the holomatter hypothesis, is an inup-driven paral phase or paralling, whose job is to wash quantum fuzziness out somewhere in order to rid a relevant (holo)particle or system of a quantum threat. It is a fuzziness-buster which works by replacing a threatened state, which is fuzzy, by a threat-free one, that has to be sharp. The initial fuzzy state can be seen as an array of potential end-states, since the actual end-state is always picked out of their lot.[18] For holomatter, this sharp state is *in-causally* selected from them. It is important to be aware that the pre-jump state is threatened because it is fuzzy, so that the post-jump state has to be sharp if it is to be threat-free. This end-state brings about a definite value to some attribute.[19] Actually though, an electron or photon may be destroyed in the process, e.g., by being absorbed. This doesn't really matter here. What matters is that whatever evolution ensues, it will strictly comply with the quantumhood principle throughout.

In light of the foregoing, it appears that jumps or collapses are fuzziness-busters.[20] They're also shapeshifting and random. As parallings or paral phases, they are propagation-less and distance-blind too. This makes them instantaneous, which raises issues of causality in their interplay with the out-causal and relativistic spacetime. I'll come back to this in Part Three.

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[17] Fuzziness is on the initial mingled or superposed state, sharpness is on the final eigen state (this is why I respectively dub them fuzzy and sharp states as we know). We saw that jumps or collapses are game changers that abruptly shapeshift fuzzy states into sharp ones. They are "superposition collapses", with respect to some attribute. This is how they ward off quantum threats.

[18] In this article, I implicitly assume, for simplicity's sake, that the jumps don't destroy the quantum systems concerned, as it is the case with ideal measurements.

[19] Recall that the threat-free state has to be sharp, as we learnt from the magic potato of Part One. It was by shrinking to only one ("sharp") side of the knife's blade that the potato avoided being chopped by it. Here the relevant attribute is the position; but it could also be the spin, the polarisation, the energy, the direction of propagation and so forth. Interestingly and as we'll soon see, the pre-jump fuzziness turns out to play a key role in the build-up of quantum entanglement.

[20] Equivalently, they are sharpness-makers. This sharpness is attribute-specific or quantum observable-specific. We must bear in mind, however, that more sharpness here entails more fuzziness there, as regards pairs of incompatible observables associated to non-commuting quantum operators. This odd trade-off is encapsulated in Heisenberg's uncertainty principle.

## The **M-P-S** diagram

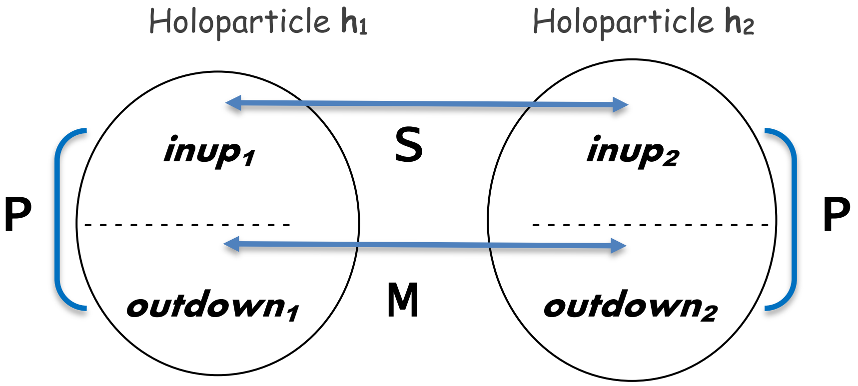
Three little friends join forces to pull the strings of the quantum world. They breathe life into it. The **M-P-S** diagram below (Drawing 2), based on a couple of (holo)particles sketched out as in Drawing 1, affords a quick and easy way to figure out who – or rather, what – these friends are. They are **M**, **P** and **S**. **M** stands for ***material*** interaction; **P** is for ***paral*** interaction or transition, or even phase; **S** is for ***supral*** interaction or link. This newcomer has much to do with quantum entanglement as we'll soon find out. **M** is "material" in that it hails from the matter state of holomatter. It stands for any strictly out-causal (and unitary) evolution while **P** stands for any "paral" transition or event, which I also call a **paral phase** or a **paralling**.[21] As we know, it pops out when a holoparticle's inup takes on an active role to see off a quantum threat. **S**, lastly, results from an *in-causal binding* of quantum objects. This in-causal binding, or *in-binding* for short, is a blending of their in-causal parts. It is a welding of their inups, which mingles and harmonizes them. We'll call **supralness** this property. *Supralled* particles take shared in-causal initiatives that *correlate* their choices or selections.

In the diagram below, $h_1$ and $h_2$ are two (holo)particles, or elementary particles of holomatter. Their inups and outdowns are noted $\text{inup}_i$ and $\text{outdown}_i$ respectively (i = 1, 2). One then has:

$$q_1 = (\text{outdown}_1, \text{inup}_1) \quad \textit{and} \quad q_2 = (\text{outdown}_2, \text{inup}_2)$$

The three interactions, **M**, **P** and **S**, involve either the inups or the outdowns or both of them. More specifically, **M** is between $\text{outdown}_1$ and $\text{outdown}_2$, **P** is between $\text{inup}_i$ and $\text{outdown}_i$ (i = 1 or 2), **S** is between $\text{inup}_1$ and $\text{inup}_2$.

***DRAWING 2*** *The **M-P-S** diagram*



Each holoparticle has a deterministic outdown and a random inup. This bi-dimensionality allows varied kinds of interactions, namely **M**, **P** and **S**, to take place. **M** is a *material* interaction between $\text{outdown}_1$ and $\text{outdown}_2$. It is fully deterministic. **P** is a *paral* interaction between *either* $\text{inup}_1$ and $\text{outdown}_1$ *or* $\text{inup}_2$ and $\text{outdown}_2$. It is inup-driven and is therefore random. **S**, finally, is a *supral* interaction, or link, between $\text{inup}_1$ and $\text{inup}_2$. It blends or "in-binds" them, thereby correlating their "choices" and initiatives.[22]

**Supral links** are like threads that run "stealthily" from one (holo)particle to another. This is how we can figuratively – and somewhat naïvely – think of them. Supralled partners are invisibly connected by their inups, no matter how far apart. Their in-causal connections, or supral links, don't fall off with the distance. They are distance-blind, which is a clear indication that the concept of locality does not hold for the in-causal dimension of holomatter. This in turn is a stark reminder that the relativistic

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[21] **P** encompasses subatomic transitions and events such as jumps, wavefunction collapses, and any inup-driven event more broadly. As I recalled in Part One, all these are sudden, random, un-wavelike and particle-like, irreversible, distance-blind and non-unitary. They're analgorithmic (non-computational) too. It is worth noting that the paral state is thoroughly a-relativistic, being altogether distance-blind and gravity-blind. It neither senses the gravity field nor contributes to it. Accordingly, the paral state is a spanner thrown in the works of the much-coveted theory of quantum gravity. Incidentally, the many peculiar features of the in-causal dimension of holomatter make it potentially feasible to put paral to the test.

[22] We can add what follows. **M** is smooth, wave-like, reversible, relativistic and unitary. **P** arises when the particle's inup snaps out of its resting or latent state (then a quantum jump is in order). **S** is hidden, instantaneous and distance-blind. Furthermore, it seems that no "cross-interaction" exists between $\text{inup}_1$ and $\text{outdown}_2$ or between $\text{inup}_2$ and $\text{outdown}_1$ (there are some compelling ontological reasons why it should be so). The drawing is adapted from my contributing essay, entitled 'Panpsychism, The Conscious Brain, and Beyond', to the book *Science and The Primacy of Consciousness* (The Noetic Press, 2000).

spacetime bears exclusively on the out-causal dimension of ordinary matter. Quite fittingly therefore, relativity is relative! It is relative to the sole out-causal dimension of holomatter. It holds no sway on its in-causal dimension which, as we know, isn't material and doesn't have, as such, to comply with the laws and constraints of ordinary – *viz*., out-causal – matter.

In the holomatter outlook and perspective, supralness underpins the property of quantum entanglement, as shown by its peculiar features. Then, *entangled* particles are nothing but *supralled* (holo)particles. By the same token, the correlations of entanglement are those of in-binding.[23] They involve some joint decision-making. They arise when the supralled inups of entangled particles make a collective and shared choice. This happens under the pressure of a quantum threat on at least one of them, and in response to it. These correlations are the only available evidence that a supral link exists, between otherwise distinct particles.[24] No physical force and no physical connections cause them (by physical, I mean here strictly out-causal).

When two electrons are entangled by their spin for example, perhaps after they collided and split off, measuring the spin of one (***a***) gives it a precise value that it didn't have before and (***b***) steers instantaneously the other electron, whatever its remoteness, into a state with a correlated spin value. Similarly, when two photons are entangled in polarization, measuring this attribute in one forthwith pins down the polarization of the other, no matter how far away it is. Before the observation, each had a polarization in a vertical-and-horizontal state that mingled, or superposed, a vertical state with a horizontal one with respect to, say, some spatial frame of a lab. In such a fuzzy state, the polarization was ill-defined and had no set value. After the observation, the polarizations of the entangled pair have definite values, either vertical or horizontal. Moreover, if one photon is measured in the lab as horizontally polarized for example, this very act instantly collapses the other into a vertically polarized state, even if it is light-years away. This sounds like magic! This is odd and puzzling, to say the least; but holomatter propounds an explanation. Here it is. *First up*, the shift from fuzziness to sharpness happens because *measuring is threatening*, in the sense that a measurement provokes a quantum threat that in turn prompts a fuzziness-busting collapse. *Then*, the correlated values of the measured attribute, spin or polarization or whatever, stem from a conservation law that binds the quantum systems. More specifically, they stem from a *supra*-conservation law as we'll see shortly.

Lest we get confused, it is worth emphasizing that, whether entangled or not, objects *always* behave as truly separate in their wave-like and unitary motions when they're sufficiently far off. As long as no jump rocks them, they *do* evolve independently, just as we expect intuitively. It is so because supralness and entanglement don't directly affect the out-causal parts of quantum (holo)objects, since they bear on their in-causal parts exclusively. Were it otherwise, the world would be a tangled mess of gigantic proportions, and physicists wouldn't be able to calculate and anticipate, let alone to study, the behaviour of matter…

We may wonder, *When do supral links arise, and why? Once they're established, can they be undone? And really, what's the point of entanglement?* These are the questions we tackle now.

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[23] These correlations are immediate. What plays out here is not an instantaneous propagation of something physical (i.e., of something out-causal) that would then have an infinite speed and would "cheekily" fly in the face of Einstein's relativity. It is a *propagation-less* shift from the matter state of holomatter to its paral state – to wit, it's a paral phase or a paralling. Note also that the supral welding or in-binding which results in the correlations of entanglement is attribute-specific and is therefore partial. It has various possible "strengths" (a supral link can be maximal – in a sense related to a famous result established by John S. Bell in 1964 – or it can be weaker; its strength can be assessed, often through the theoretical notion of "entropy of entanglement").

[24] This "otherwise distinct" really means "out-causally distinct" since, as we saw, entangled (holo)particles are in-causally intertwined but remain out-causally separate (the outdowns never mix or blend in the matter state of holomatter because the quantumhod principle forbids it).

# The root causes of entanglement

## Entanglement – a consistency enforcer?

Entanglement is a staple quantum feature that plays a key role in the fast-developing theory of quantum information. It nonetheless remains poorly understood, conceptually speaking. Adding it to the "quantumscape" shoots quantum weirdness to new heights. In Part Three, we'll see how it paves the way for creative experiments that bring out new tiers of quantum oddity. For holomatter, entanglement stems from supralness or in-binding as we know. It is an in-causal property whereupon two entangled partners, however far-off, are not truly separate. More accurately, they're *out-causally separate* but not in-causally so, as they share a supral link that binds their in-causal components.[25] As such, as I already pointed it out, entanglement isn't constrained by the out-causal laws, rules and constraints of ordinary matter, those of relativity included. It is little wonder, then, that it goes hand in hand with nonlocality. It is distance-blind and it correlates instantly supralled or entangled systems.

The in-binding of, say, entangled electrons implies that a direct quantum threat on *one* of them, whether induced by a measurement or not, will trigger a shared jump in *all* of them, even in those which were not directly threatened. This global jump will instantaneously correlate their respective end-states, with respect to some physical attribute. Incidentally, it implies that a particle can undergo a threat-free, and hence measurement-free, collapse *indirectly* triggered through its hidden and usually unknown, but as a rule quite likely, supral links with the environment. This collapse will bring about a sharp end-state that will "decohere" the particle under the influence of the environment. Put otherwise, a quantum threat can be either direct or indirect. A *direct* one is for example routinely created by the detector of a measuring device. An *indirect* one, for all practical purposes, is obtained through a *shared* jump. This jump is triggered in any particle which has an entangled partner jumping or collapsing because of a direct quantum threat. Therefore, a supral link forwards a direct quantum threat towards entangled targets, for which it becomes an indirect threat.

The holomatter hypothesis suggests that supralness and quantum entanglement are vitally important for nature's consistency.[26] They are a core resource of its anti-contradiction immunity. Let's find out why.

## The challenge of supra-conservation

Supralness-by-supra-conservation, or **entanglement-by-supra-conservation**, typically arises between particles moving off from a common past event, such as a collision or an atomic cascade. The particles are now interdependent. They're supralled or entangled, to the effect that measuring one causes an instant collapse of them all. These various collapses can be seen as a global one. Really, what's going on here? The answer hinges on the supra-conservation laws. A **supra-conservation law** is a physical conservation law that (**1**) is *shared*, i.e., involves more than one particle; and (**2**) can't be applied at once, and hence starts off being *virtual*.

In their virtual mode, the supra-conservation laws lie in wait, because quantum fuzziness stands in the way. They can't be actual. The snag is that some physical attributes – e.g., the position, the momentum, the spin, etc. – have ill-defined values in fuzzy quantum states, and so the shared conservation laws cannot be made to work if they bear on them. These attributes don't exist as *precise* values, which strips the laws of a concrete basis. The conserved quantities being indeterminate, these laws are so to speak rootless. On a practical level, they're meaningless. To become actual and effective, they must wait for precise values to emerge. Accordingly, they must wait for fuzziness to be gone. This, we know, happens only on the off-chance that a fuzziness-busting or sharpness-begetting paral phase, or collapse, takes place. Collapses will replace fuzzy states by sharp ones, giving definite values to the globally conserved quantities.

Trouble is, a collapse, if it occurs at all, may do so after an arbitrarily long time, and the entangled particles might then be wide apart. How can these particles retain their interdependence in such an inauspicious circumstance? No *physical* fix can

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[25] Going back to the poached egg metaphor, entangled (holo)particles can be likened to such eggs being glued together by their half-baked – and so, still soft and sticky – yolks whilst their whites retain their firm individualities. When particles are entangled, their in-causal initiatives are shared and interdependent. This goes hand in hand with their in-binding. Hence, we can ascribe a collective wavefunction to them but we can't give them individual wavefunctions.

[26] Also, supralness and entanglement knit a universe-wide web of unseen supral links, which brings unity and harmony to the world at large. This web is nothing short of amazing. It turns our universe in an awesome and inspirational whole. As for nature's consistency, it is worth noting that the no-communication or no-signaling theorem of quantum information theory demonstrates that quantum entanglement does not enable any faster-than-light transmission of classical information or of a meaningful signal on which we could knowingly act. In that sense, entanglement doesn't *causally* contradict the special theory of relativity.

be had. The challenge is huge. It is even more so in our relativistic universe where no physical entity can travel faster than light, let alone instantly. Nature is mighty, but still it cannot fit square pegs into round holes and, when its conservation laws are "supra", it seems poised to fall short of enforcing them. This is a sure-fire recipe for inconsistency.

Fortunately, though, nature knows better if I may say so. It is incredibly resourceful, and no matter how long the odds, it always gets the upper hand when faced with a risk of harmful contradiction. To handle supra-conservation laws and to keep track of them while they're virtual, nature has a trump card. This card, you guessed it, is entanglement. As long as the "supra" laws remain virtual, the information about them is stored and *memorized* by supral links. Owing to this memory, a "supra" law is applied no sooner a jump makes it possible. To that end, the latter is turned into a *shared* jump that unifies and correlates the in-causal choices made by the various entangled partners.[27] This is how the correlations of entanglement arise. We already know it. For example, two electrons can be entangled in such a way that their measured spin values – which can either be "up" or "down" – will always be opposed. This is due to the "singlet" conservation law or constraint that the electrons share. As long as these supralled partners are in fuzzy states that combine or superpose up and down spin states, this conservation law cannot be applied, for the definite spin values on which it bears are not available. They obviously don't exist yet, on account of the fuzziness. For want of them, the law remains suspended in a virtual limbo. It is therefore a supra-conservation law.

Now, the act of-measuring the spin of one electron forces it into a sharp state with a definite spin value, either up or down, through the jump which responds to the quantum threat generated by this act. This definite value makes the supra-conservation law shift from virtual to actual. Yet, for the law to be implemented, one definite spin value won't do. *Both* spin values must be definite. This requires that the unobserved electron of the pair, which can be very far off, gets on the spot a precise spin value as well. This is why the jump is immediately shared by the two entangled partners, and this is where a supral link comes in handy. It sees to it that the two electrons collapse together, whereupon both their spins become at once well-defined.[28] Then, if one is observed to be spin-up, the other will be found to be spin-down, and vice versa. The conservation law, now actual, is applied forthwith.

## THE FICKLENESS OF SUPRALNESS

The supral link caused by a supra-conservation law (*see main text*) becomes useless when, further to a shared collapse, this law becomes actual and effective. Then it is readily implemented, and it no longer needs anything to keep track of its existence. Hence the supral link becomes redundant, and it vanishes. Accordingly, collapses or jumps have the ability, exclusive to them, to break supral links. They can therefore be said to be **supralicide**.[29]

Given that a jump or a collapse – or a paralling, for holomatter – is supralicide, supral links aren't necessarily forever.[30] They only last until the next shared jump that will jolt the entangled partners. Because of this, entangled states are fickle and fragile. This makes supralness and entanglement far from easy to wield, as those working on quantum computers can testify. Put it on the fickleness of supralness…

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[27] Recall that, for holomatter, jumps are paral phases or parallings, and entanglement is underpinned by supralness. Both involve the inups of holoparticles. Both involve the in-causal dimension of holomatter. Entangled partners cannot be studied individually because, as stated in an earlier footnote, they share a global wavefunction but have no wavefunctions of their own. This impossibility is strictly theoretical though. In practice, entangled objects are routinely studied individually. This is good news indeed, since (***a***) most quantum objects are entangled to something in the environment; and (***b***) their entanglement, or their supral links, are hidden and hardly ever known. The study of these objects, as though they were separate and autonomous, is theoretically flawed and forbidden, and really makes no sense. Yet it is feasible concretely because, if quantum fuzziness causes entanglement, *it also hides it for all practical purposes* (as shown by the no-communication theorem).

[28] Within the holomatter framework, a supral link makes supralled or entangled objects, whether near or far, jump or collapse together by binding their in-causal components, or inups. This in-binding holds fast even when no influence can travel between them without breaking the relativistic speed limit of light (such objects are said to be space-like separated). For holomatter however, the immediacy of the collapsing events of entangled partners implies no violation of Einstein's relativity, since these events are *propagation-less* shifts of these partners. These shifts are transitions from their matter states on to their paral states.

[29] Technically speaking, the supral links of quantum systems are thoroughly washed out by performing on these systems a sequence of measurements corresponding to a complete set of commuting observables. This is how supralness-free or entanglement-free systems can reliably be prepared in the lab.

[30] There's a widespread belief that once a supral link takes shape, it will last forever… even, rather surprisingly, after some of the (holo)particles involved may have disappeared! (I'll come back to this in Part Three.)

To recap, a shared conservation laws become supra-conservation laws when quantum fuzziness – i.e., quantum superpositions – don't allow them to be readily implemented. Out of necessity, these "supra" laws spawn supral links that:

(**A**) keep track of constraints of shared conservation, and thus *memorize* them, as long as they're ineffective and virtual because they bear on the precise values of some physical attribute that, owing to quantum fuzziness, aren't available yet

(**B**) trigger shared and concerted jumps that meet this constraint once for all, by stamping the fuzziness out and correlating the precise values of the attribute thus obtained

Entanglement-by-supra-conservation is said to be monogamous. This means that a particle, through it and with respect to a given attribute, can't be entangled with more than one partner at a time. However, as the physicist Anton Zeilinger pointed out, "*Multiparticle entangled states can exist in theory. (…) We found a way to create one. To do this you need four photons – two photons entangled in one state and the other two photons entangled in another state.*" Each pair of photons is entangled by supra-conservation. But "*Then we send one photon from each pair into a detector, and you measure only one in such a way that you don't know where this one photon you measure came from, from the first pair or from the second pair. If you do that right, the remaining three photons end up being entangled*."[31] What plays out now is quantum indistinguishability. To get the hang of this, let us turn to the issue of supralness building through indistinguishability.

## The challenge of indistinguishability

Quantum indistinguishability – or "**indistt**", for short[32] – doesn't sit well with the principle of quantumhood. This is because the latter cannot work wherever the former, if I may say so, sticks its head out. In the event of indistinguishability, quantum waves are no longer anchored in a clear-cut community within which they interfere exclusively (see Part One).[33] These waves, under the blurring influence of indistt, are in the dark about which other quantum waves they must selectively interfere with. This is why the quantumhood principle cannot be applied. It cannot wield its sway, which threatens to swamp the quantum world into the murky waters of contradiction… When for instance two photons are indistinguishable, this ambiguity strips their respective waves of any objective means to determine which photon they belong to. These waves become totally clueless, as it were, as regards what other overlapping photonic waves they ought to interfere with. This is a major blow to the quantumhood principle, one which invites all manner of contradictions. Nature cannot let things stray that way. It has to take drastic protecting measures. This is how entanglement-by-indistt is called upon, and how quantum indistinguishability becomes a significant source of entanglement.

**Entanglement-by-indistt** – or for holomatter, supralness-by-indistt – is the label we'll ascribe to entanglement spawned by ambiguous situations. To grasp why indistinguishability, or "indistt", demands entanglement, we can use the easy metaphor of a tug of war which, as we know, is an athletic contest that pits two teams against each other in a test of strength. The teams pull on the opposite ends of a rope, and the first one that drags the other over a given line wins. Now imagine that, once the teams have fittingly been set up with an even number of players, some deft trickery robs these players of any means to know which team is theirs.[34] In this twisted game, the players find themselves in a very awkward position since, on the one hand, they *have* to be members of a team at all times and yet, on the other hand, they *can't* belong to a definite team given the ambiguity of the situation. What will happen, then? The players don't have much leeway. This odd situation gives them a freedom to switch team wantonly. This is their only wiggle room. The teams will accordingly have their players come and go unpredictably and on whim. They won't keep an even number of them, and the game will be very volatile. It will be messy, meaningless and inconsistent.

This wretched state of affair is not as hopeless as it looks, though. There is a way round it. The contest will be back on track if the players are paired up from the start, when the teams are even, with the twofold proviso that (***a***) initially, the players in each pair are always picked out of both teams and they never belong to the same team; and (***b***) whenever a player

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[31] Anton Zeilinger wrote *Dance of the Photon* (Farrar, Straus and Giroux, 2010).

[32] Because the word 'indistinguishability' is a tad too long and cumbersome, I'll take the liberty, time and again, to shorten it into "indistt" (the 'stt' at the end makes it obvious that this is not a genuine English word).

[33] An exclusive interfering community of quantum waves, or lump as I named it, is described in the theory by a wave packet or a wavefunction. This community becomes scrambled and uncertain when similar wavefunctions are in a close spatial overlap with it. (Here I assume that quantum waves are real, in some subtle ontological way – see Part One.)

[34] This blurring of the team memberships can be achieved in many possible ways. One of them is suggested in my book *Huit Leçons essentielles sur la science quantique*.

switches team, his pair partner does the opposite move simultaneously – they both swap side by a common agreement. This balancing act ensures that the teams keep an equal number of players throughout the game. The contest now becomes consistent and can be worth its while.

This twisted tug of war affords a metaphoric way to speak of the entanglement-by-indistt and to unmask its underlying rationale. To see that, we need to:

- think of each player as an individual quantum wave
- think of each team as, say, a photon's wave packet or wavefunction
- think of the mandatory team membership as the selectivity constraint on wave interference laid down by the quantumhood principle[35]
- think of the *twisted* tug of war as a game of wave interference between *indistinguishable* photons

Bearing all this in mind, the ploy of pairing up the players in the twisted tug of war shows that the quantumhood principle can be effective even in the untoward context of quantum indistinguishability. It is so *provided* supralness, and hence entanglement, is called in. Here is why. In the twisted tug of war, a full pairing up of the teams from the outset, when they have the same number of players, saves the day – and the consistency of the challenge. Likewise, when the lump membership of quantum waves is muddled by indistinguishability, establishing pairwise bonds between the photons' overlapping waves saves the consistency of their overall game of interference. These multiple *supral* pairings have the photons share an overall supral link. We may imaginatively fancy, then, that their waves are free to switch team, or indeed photon, haphazardly, *provided* the paired partner waves counteract by the opposite moves.[36] Then no contradictions arise, and no harm will be done.

I believe that this depiction, although quite naïve, nevertheless imparts a kernel of truth about what goes on at the (sub)quantum level. It spells out why, when faced with indistinguishability, nature responds with entanglement. It shows that when "indistt" muddies the water, entanglement aptly tames wave interference. That's all what it takes for the latter to play out with no damaging effect on nature's consistency.

Such is the rationale behind entanglement-by-indistt or supralness-by-indistt; which turns out to have original features. Some of these features have far-reaching consequences, such as the existence of bosons and fermions, and that of Bose-Einstein condensates. These condensates, in which zillions of (holo)particles may behave as a single super-particle through in-binding, give clear evidence that there's no notion of monogamy as far as entanglement-by-indistt is concerned. The latter is blithely polygamous – of course in the stern and narrow quantum sense that we saw earlier with supra-conservation. Also, entanglement-by-indistt can bind particles, e.g., photons, that originated from different sources and never interacted before. Today, physicists routinely create such photons in their labs. They do so through the process of entanglement swapping (see Part Three). Most stunningly, some of these photons didn't even coexist![37]

Here is finally a brief summary of the main ideas of Parts One and Two:

☞ Two basic kinds of causation may coexist in the world out there. One is out-causation, which is the ordinary deterministic causality. The other is in-causation, which comes out as random. It is hidden and somehow "self-willed", usually very faintly so.

☞ Holomatter is plain matter with an in-causal dimension added. This dimension seldom manifests itself. If it truly exists, then a dash of in-causation lurks, unbeknownst to us, within any speck and any chunk of matter.

☞ Quantum jumps and collapses on the one hand, quantum entanglement on the other, are in-causal features that shield nature's consistency. They arise in some situations where this consistency is in jeopardy.[38]

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[35] A quantum wave *has* to be member of a "team". It *has* to belong to a wave packet within which it interferes selectively. The quantumhood principle makes this compulsory, so that no contradictions can result from quantum wave interference.

[36] According to the holomatter hypothesis, these two opposing moves are strictly instantaneous because they stem from a joint and concerted in-causal initiative (one that is *suprally shared*).

[37] Creative experiments such as quantum teleportation and the delayed choice quantum eraser experiment probe "quantum-ness" in its most counter-intuitive and mind-blowing aspects. Both highlight how, in contemporary physics, the issue of time and the related one of causation can become knotty and hard to fathom. The delayed choice quantum eraser experiment will be investigated in Part Three. As for quantum teleportation, it is analyzed in my book *Huit Leçons essentielles sur la science quantique*; which also spells out how fermions, bosons and Bose-Einstein condensates relate to entanglement-by-indistt.

[38] I think, as an aside, that nature's consistency shouldn't be viewed as a given that kindly comes at no cost. It is no free lunch. Nature, if I may say so, strives hard to be and remain consistent. In so doing – again if I may say so – it goes out of its way and it

Coming next are the last two instalments of this paper. In Part Three, I'll go back to the issue of jumps or collapses and, more broadly, to that of the waveless nonunitary events that arise in the quantum world. I'll then examine the delayed choice quantum eraser experiment in light of holomatter. Wheeler's delayed choice experiment will also be considered. Finally, in Part Four, I'll address the tantalizing issue of brain-based sensory awareness and show that the holomatter framework brings a new window of understanding on the mind-body interaction. The question of a transcendent level of reality, existing over and above our mundane and immanent world, will also be touched upon.

## APPENDIX 2A: Glossary for Part Two

**Holomatter** = "super-matter" that is plain matter *plus* an invisible in-causal component. Holomatter takes on two alternative appearances, namely, matter and paral.

**Holoparticle** = elementary particle of holomatter. It combines two components, called its outdown and its inup, which are deterministic and random respectively.

**In-binding** = binding or welding of the in-causal parts, or inups, of diverse (holo)particles. (*See at* supralness.)

**Indistt** = short for quantum indistinguishability.

**Inup** = in-causal, and hence random-looking, part of a (holo)particle. It is active in the paral state of holomatter and latent in its matter state.

**Matter** = it refers here to the ordinary state of holomatter. It is deterministic and 'wavy'. A holoparticle whose outdown is active is in this state. Then its inup is latent or dormant.

**Matter-paral duality** = duality between the matter and the paral states of holomatter. It is the lump-jump duality by another name and comes across as a wave-particle duality.

**Outdown** = out-causal, and hence deterministic, part of a particle. It is active in the matter state of holomatter and latent in its paral state.

**Paral** = wave-less and random-looking state of holomatter gotten when its in-causal dimension runs the show.

**Parallable** = said of quantum waves because they briefly melt away when a particle undergoes a paralling, only to come back no sooner this paral phase is over.

**Paralling**, **paral phase** = quantum leap, jump, or wave collapse of a (holo)particle by another name. It is a wave-less and in-causal event where the particle switches from matter to paral. It is kicked off by the particle's inup, then active.

**Supra-conservation law** = conservation law shared by two or more particles, that quantum fuzziness makes inoperative and virtual at first.

**Supral** = qualifies what relates to supralness.

**Supralicide** = qualifies what wipes supral links out; the converse of supralling.

**Supralling** = qualifies what builds supral links; the converse of supralicide.

**Supral link** = in-causal bond between (holo)particles; its strength may vary from partial to "maximal".

**Supralness** = in-binding property of holomatter that would underpin quantum entanglement.

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becomes substantially enriched as a result. A wealth of unexpected, counter-intuitive and poorly understood quantum features supports this idea. It is worth noting, by the way, that only two types of entanglement have been mentioned so far, whose origins and properties differ. Both, whether arising under the challenge of supra-conservation or under that of indistinguishability ("indistt"), can be understood as consistency enforcers. However, the possibility that still other types do exist can't be ruled out. This opens up an exciting perspective since, by probing nature in extreme and unfamiliar areas (e.g., black holes), we might eventually put our finger on some unheard-of consistency-threatening situations. By defying nature's anti-contradiction immunity, these situations would elicit strong protective responses; some of which could involve new types of entanglement. New aspects, and perhaps even new laws of physics, would then be uncovered…

# APPENDIX 2B: Debunking four misconceptions

As Richard Feynman famously said, "*nobody really understands quantum theory*." This opinion is still widespread, and as we read in *The Quantum Divide*, "*at it very heart, quantum mechanics is totally inexplicable. (...) Quantum theory* predicted *[the] facts, it did not* explain *them*."[39] Another physicist, Jim Al-Khalili, wrote similarly that "*We can explain what we see but not why*."[40] The problem is not merely epistemological. It reaches deep into the ontological level. Because what we think we understand doesn't quite add up, or at least goes against our intuition of how things should work, a "quantum lore" appeared, to try and make sense of putative realities depicted by quantum theory. This lore is built on some widely held tenets that translate into statements that strike me as hasty and inaccurate, like these ones:

1/ In the quantum world, events can occur without reason (this is the random/causeless fallacy)

2/ A photon behaves as a wave if, after hitting a beam splitter, it travels at once in the two paths available, and as a particle if it travels in one path only (this is the which-path/particle fallacy)

3/ When two particles are entangled, some attribute of one are fixed by observing the other, even though these attributes were undetermined before the observation (this is the even though fallacy)

4/ A measurement produces a unique and definite outcome because the human observer acquires knowledge through it (this is the observer's knowledge fallacy)

Let us briefly examine these statements.

## 1/ The random/causeless fallacy

This fallacy deals with the issue of the apparent causeless-ness of many quantum events (e.g., measurement results, radioactive decays, etc.). It asserts that quantum randomness *necessarily* implies a lack of cause. For most specialists, this is a foregone conclusion, so obvious that it really goes without saying. For instance, we read, again in *The Quantum Divide*, that "*Classical intuition and the "common sense" of everyday life do not apply in the quantum world. Perhaps the most startling difference between these two worlds is with respect to the issue of causality. (...) In the quantum world, events can occur without any reason*." This is misleading in that it implicitly conflates the notion of causality or causation with the notion of *deterministic* causality. The latter, though, is but a sub-category of the former. Obviously enough, causality is potentially broader than deterministic causality. This being so, we can't dismiss nondeterministic causation – i.e., in-causation – by fiat. Indeed, it could turn out that in the world out there, some random events happen for an in-causal reason. This is why it would be more accurate, instead of claiming that quantum events can occur without any reason, to say that they can occur *without a deterministic or out-causal reason but possibly with a nondeterministic, and hence in-causal, reason*.

Nondeterministic causality is a legitimate possibility worth exploring. It will remain so as long as nothing rules it out. This is consonant with the holomatter hypothesis, which holds that quantum randomness occurs *with* a reason and *for* a reason. It is *with a reason*, as due to low-level in-causation. It is *for a reason*, as a means to keep nature contradiction-free under quantum threats. These two aspects – that of being in-causal and that of taking place to uphold nature's consistency – explain why random quantum events such as jumps happen at all. To fit the bill, these events need to have the markedly peculiar features they have been found to actually possess.

## 2/ The which-path/particle fallacy

It is commonly believed that a photon is a wave if, after hitting a half-silvered mirror or a beam splitter, it takes one path only (either the reflected or the transmitted one), and that it is a particle if it goes instead through both paths at once. This is exactly what the which-path/particle fallacy asserts. "One path only" is said to provide which-path information whereas "both paths" affords both-path information. Accordingly, it is often claimed that a photon has travelled as a particle when which-path information is known and went as a wave when both-path information is known.[41] For example, when a beam stopper is put in one path, the photon will obviously fly through the other path and will be reckoned to have travelled as a

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[39] Gerry, C. and Bruno, K, *The Quantum Divide*, Oxford University Press, 2013.

[40] These citations are from the book: Jim Al-Khalili, *Quantum*, Phoenix, 2003. In the same book, Al-Khalili also commented: "*If we have learnt anything about quantum mechanics, it is that searching for rational explanations is a futile exercise*." I beg to differ!

[41] To be more accurate, the "which-path" photon is held to be a point particle and the "both-path" photon is seen as a bunch of mutually interfering quantum waves – partially spread over the two paths, but still able to interfere mutually – in compliance with the quantumhood principle.

particle. If the beam stopper is removed, the photon will take both paths at once and will be regarded as having travelled as a wave. We thus read allegations such as: "*The appearance of either the wave or the particle nature of the electron depends strongly on the experimental setup. An experiment with one slit open will only detect the particle nature of the electron while an experiment with both slits open will only reveal its wave nature, these properties being mutually exclusive*." And also, "*The photon will behave like a particle if it is possible to determine* which-path *information. That is, in an experiment designed to elicit the particle-like nature of photons, the photons will oblige and behave just like particles. In fact, if we can perform some sort of which-path experiment on photons, we should be able to* force *them to act like particles if they really can have a particle-like nature*."[42]

The which-path *versus* both-path issue is not one of particle *versus* wave. Deep down, it's really one of sharp state *versus* fuzzy state because, loosely speaking, which-path information is linked to a sharp (or eigen) state of the photon and both-path information corresponds to a fuzzy (or superposed) state. A photon that travels "which-path" is *de facto* in some sharp state while a photon that travels "both-path" is in a fuzzy state. Now, *both sharp states and fuzzy states are wave-like*, which contradicts the which-path/particle fallacy. Both are particular states of a wavefunction. This entails that the photon *never* travels as a particle, whether along a sharp "which-path" or a fuzzy "both-path" route. So, which-path information doesn't mean that a photon travelled as a point particle. It only means that it travelled in some sharp state.[43]

### 3/ The even though fallacy

Oftentimes, we hear or read statements like this one: "*Two photons entangled in polarization will have well-defined and identical (or opposite) polarizations when measured, even though they did not have definite polarizations before the measurement*."[44] It is frequently claimed that when two particles are entangled, some property or attribute of one will be fixed by observing the other, *even though* none of these precise attributes were available before the observation. Granted, they didn't even exist! This is backed up by a wealth of experimental evidence. For example, it is well established that the spins of two electrons entangled in a singlet state have undefined values prior to their observation.[45] These values are nevertheless found to be precise (and opposite) when observed. However, what I take issue with is that the entangled photons will not be found having well-defined polarizations *even though* these were fuzzy or undetermined before being observed. It isn't *even though*, but precisely *because* of this fuzziness that they are entangled! This remark is not mere nit-picking: we must get the above statement right if we want to understand the quantum world.

Here is a reminder of why we should say *because* instead of *despite* or *even though*. Quantum fuzziness is the very reason behind the shift from standard shared conservation laws to *supra*-conservation laws, that cannot do without supralness and entanglement for their consistent implementation. We saw this with entanglement-by-supra-conservation. Because it is worth the effort, let me explain it anew. If the electrons' states were sharp from the outset, their spin values would already be precise and the overall conservation law would be applied forthwith, without hindrance and with no delay. No virtual conservation law, waiting in the wings, would crop up. There would be no supral link either.[46] This spells out why a

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[42] From *The Quantum Divide*, already cited.

[43] Since "which-path" somehow means "sharp state", the claim that a photon travels as a particle when which-path information is available becomes even more untenable. This is because fuzziness and sharpness are attribute-dependent; and so, by the uncertainty principle and for the very same unchanged photon, a fuzzy state with respect to one attribute may go hand in hand with a sharp state as regards some other attribute, and vice versa. Therefore, if we insist that, as a rule, sharp state means particle and fuzzy state means wave, then the photon is a wave and a particle simultaneously since it is at once fuzzy and sharp with respect to different attributes! This is absurd and doesn't make any sense. Let us notice in passing that the shift of a photon from a "both-path" to a "which-path" route is *either* due to a lack of an alternative path (e.g., because a beam stopper is in place) *or* due to a fuzziness-busting jump (e.g., because a detector is in place). In both cases, no point particle is involved. Let us also notice, finally, that a photon – and more generally, any ultra-relativistic quantum particle for that matter – is *never* point-like. Actually, its spatial localization can't be more accurate than half its mean wavelength. This is because, in our relativistic universe, no object can travel faster than the speed of light in the vacuum (barring iffy tachyons). This incidentally calls into question the probability wave interpretation, which contends that quantum waves are purely abstract and mathematical objects. Such an interpretation, due to Max Born, works only if quantum particles can be made truly point-like. (I'll come back to this in Part Three.)

[44] The two cases – identical or opposite polarizations – are conceptually equivalent since both are perfectly correlated (correlation and anti-correlation are mathematically similar).

[45] In a singlet state of spin, the "±1/2" spin values of the entangled electrons add up to zero when measured with respect to a given direction (an electron is a fermion, and fermions have half-integer spin values). Alternatively, if one of the electrons is found with spin "up" (+1/2), the other will always be found with spin "down" (–1/2), and vice versa.

[46] No supral link would be necessary here, since (a) no record or memory of the still-virtual-law would have to be stored and (b) no possible and casual fuzziness-busting jump would need to be shared on the spot.

supra-conservation law feeds on “pre-jump” fuzziness, which is an essential ingredient of entanglement-by-supra-conservation.

### 4/ The observer’s knowledge fallacy

This fallacy is the last one I mention here. It is the claim that a measurement produces a unique and definite outcome because a human observer acquires knowledge through it. It seems that it is roughly what Zeilinger means, when he writes: “*It seems that what we can say in principle about the world has a crucial influence on the elements of reality. (…) Not only does what we can say about the world play a significant role in forming our picture of the world, but it also plays a much deeper role in defining what can be an element of reality*.”[47] According to today’s received wisdom, what the human observer knows is what matters. Jim Al-Khalili also points it out implicitly, in this excerpt from one of his books: ”*It is only when the atom is being watched that it remains as a particle throughout. Clearly the act of observing the atom is crucial*.” And then: “*Nothing is real unless we look at it, and it ceases to be real as soon as we stop looking*.”[48] Sure enough, as Rudolf Peierls puts it, “*The quantum mechanical description is in terms of knowledge. And knowledge requires* somebody *who knows*.”[49]

A case in point is, again, the behaviour of a photon after it went through a beam splitter which creates a transmitted path and a reflected one. The photon will either travel in both paths at once or will fly through one path only. As we know, the one-path photon is akin to a sharp state and carries which-path information. The both-path photon, on the other hand, is akin to a fuzzy state and carries both-path information. Whether the photon is which-path or both-path can be ascertained experimentally, and it seems that “*When the path information is known, the light is a particle. When the path information is erased, the light is a wave*.”[50] Small wonder, then, that we can hear or find in the literature many statements like this one: “*The only difference between the both-path and which-path situations is what we, the observers, know about them*.” This, however, misses the point. Granted, the human experimenter plays a key role, if only by carrying out experiments that involve measuring instruments and other exquisite contraptions. Yet this role doesn’t go much deeper.

Indeed, there is some evidence that it is nature’s information, not the human observer’s knowledge, that counts. This evidence is compelling. It is that the mere *availability* of which-path information makes the difference. As we read in some textbooks, “*it is the mere possibility of obtaining which-path information that destroys the interference while no actual measurements need to be made*.“[51] Or else, “*it is enough just for the information to be* potentially *known even if the observer does not do anything to obtain that information*.”[52] Were human knowledge relevant here, which-path or both-path information would change the behavior of the photon only when the observer would *actually* possess it. But it is not the case. This speaks volumes! *Potential* human knowledge, not actual one, is enough because:

(1) the observer’s actual knowledge is irrelevant

(2) the potential availability of this knowledge means that it does exist somewhere, and hence nature has the information – it automatically knows, if you will

(3) nature acts on this knowledge, and this is why it’s what truly matters

What counts here is nature’s information. Human knowledge is plainly irrelevant. This conclusion is further bolstered by interaction-free measurements, in which something is ascertained about a quantum system without having to measure it or interact with it in any way. I’ll come back to this in Part Three.

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[47] Quoted from Anton Zeilinger’s book, *Dance of the Photon*, Farrar, Straus & Giroux, 2010. Here we find the usual view that fuzzy states are potential whilst sharp states only are actual and genuine elements of reality.

[48] All these sentences are from Jim Al-Khalili’s book: *Quantum. A Guide for the Perplexed*, Phoenix, 2003.

[49] This remark of Rudolf Peierls is quoted from *The Ghost in the Atom* (Davies & Brown *eds*., C.U.P., 1986).

[50] This passage was found on the Internet. I touched on this particle-or-wave issue in the which-path particle fallacy above.

[51] Quoted from G. Auletta, M. Fortunato & G. Parisi, *Quantum Mechanics*, Cambridge University Press, 2009. Note that “which-path” photons (that carry which-path information) don’t yield the interference produced in the both-path case. We’ll see that again in Part Three, when the delayed-choice quantum eraser experiment will be analyzed.

[52] From *The Quantum Divide* yet again.