Reassessing Time, Energy and Nonlocality in Quantum Mechanics with Observations on Schrödinger's Cat

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Abstract:

Radiation was a big challenge for the quantum pioneers since the photon was massless, probabilistic and appeared to be both wave and particle. Einstein's special relativity equated mass with energy and space with time. But the equality of mass with energy, then and now, is regarded as quantitative and the equality of space with time is anything but equal; space hosts material entities; time hosts nothing. Exploring these equality issues raises some questions as to how measurable entities – particles and photons – depend upon dimensions. The particle resides in a dimension, space, while also progressing (or persisting) in a dimension, time. The photon certainly progresses in one dimension, space; does it reside there as well? These questions lead to some new conclusions regarding the nature of the photon, its dualism and its nonlocal behavior.

Keywords: photon, double slit, Mach–Zehnder interferometer, nonlocality, dualism, delayed choice, measurement problem, Schrödinger's cat

Part I The Photon

1. Introduction

In quantum physics, time plays a subordinate role compared to space. Relativity tells us that time and space are: 1) equal; and/or 2) have the same standing in physical reality. But physics (and our view of reality) currently doesn't support that. Space is where physics plays out. Time is merely a measure between events.

An equality between time and space has its counterpart in the equality of energy and mass. $E = mc^2$ tells us that energy and mass are also: 1) equal; and 2) have the same standing in physical reality. But our current physics does not support that either. Mass, as matter, is an entity residing in a dimension, namely space; kinetic energy (KE) is a quantity with no presence on its own in a dimension. Currently only space is seen as hosting entities (of rest mass). Time hosts nothing; our current physics takes place in space with time as simply a duration measure; time is a second-class dimension. Our physics features asymmetries rather than ontological equivalence.

2. Roadmap and Thesis

What follows is an attempt to take these equalities seriously: time with space, energy with mass. Of course, "particle" and "photon" are descriptors; what we measure with our instruments are their essential identities, rest mass and energy, respectively. Particle rest mass and photon energy are each subject to $E = mc^2$, a formula typically regarded as a conversion event equation. But $E = mc^2$ is really a storage equation of mass and energy. Rest mass is kinetic (unstored) and it stores dependent, potential energy (e.g., thermal, intrinsic); the photon's oscillatory energy is kinetic and it stores dependent, potential (relativistic) mass. Hence particle has a kinetic and a potential side, as does the photon; both sides are always present.

An inertial particle's kinetic identity, rest mass, resides in (occupies) *space*; its potential identity, stored energy, progresses in *time* toward probable termination (release). Thus, a carbon-14 atom's rest mass resides in space but its potential energy progresses in time toward decay and energy release. If an inertial particle can "function" in two dimensions (as residing-kinetic in space versus progressing-potential in time) then the photon can do the same; they both obey Einstein's storage equation. This means we don't have to regard the photon as a singular object that magically changes from particle (discrete) to wave (continuous).

Discrete and continuous (and kinetic and potential) are ever-present for an object because they function differently (residing versus progressing) in different dimensions. Understanding the photon's dual identity – and dual behavior – as operating in *different dimensions* is the first step in resolving the asymmetries and paradoxes of our current physics.

- **The photon has a kinetic identity and a potential identity. They function in different dimensions.**

2.1 Limitations

All arguments that follow are limited to constituents we can measure with our instruments. In addition to time and three-dimensional space, this (barebones) list includes mass and energy in both unstored versions (rest mass, KE) and stored versions (relativistic mass, potential energy,).

Excluded from consideration are computed measures, mathematical constructs and speculative entities that do not qualify as ontic or as directly measurable. Spacetime and its interval measure, $\Delta S^2 = -(\Delta t)^2 + (\Delta r)^2$ with $\Delta r/\Delta t = c = 1$, may be useful elsewhere, but spacetime cannot be directly measured and, as later sections will show, space and time can appear to be orthogonal rather than merged/combined.[1] Feynman's integral path formulation is certainly relevant for calculations in QM and the mathematical rigor of the theory has certainly improved over the years [1]. Nevertheless, the stochastic nature of the calculations [2] is hard to square with something physically real progressing on actual space paths. Quite speculative, and even less relevant, are string theories (branes), higher dimensions, many worlds, other universes, etc. The wave function, however, is a special case; its mathematics does model something physical real.

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[1] Minkowski diagrams have space and time axes as orthogonal (perpendicular for two-dimensional representation); hence space and time merging cannot have a graphical representation; the claimed merging is really the computational combining of inversely varying space and time measures for observers in relative motion.

3. Contradictory Features in Quantum Mechanics

There are two central issues in quantum mechanics, namely dualism and probability.[2] Both involve the presence of incompatible or contradictory features leading to paradoxes. The dualism of wave versus particle is really the contradiction of the continuous with the discrete; say the photon continuously rarefying over space, but being received as discrete at a point. Probability versus its opposite is the incompatibility of what is merely probable with what is real/actual; say a photon's probability diffraction pattern versus the photon's actual, measurable energy.

Physicists have used various approaches to avoid the paradox of contradictory features joined together. Bohr and others have extended superposition of states (e.g., spin up, spin down) and argued that wave and particle also superpose; exactly how these incompatibles join together is never spelled out [3, Sec. I.D]. A second approach, in quantum field theory (QFT), is "…to introduce mathematical objects… that are simultaneously particulate and wavelike [4, p. 134]. Yet another approach is to replace traditional logic with a "quantum logic" that only applies to the micro world [5]. Unfortunately, none of these approaches are ontic; i.e., none are grounded on anything physical, namely mass or energy. They are after-the-fact coping strategies.

4. Contradictory Features in Separate Dimensions

The paradox of contradictory features is based upon a hidden assumption, namely that the entities in question – particle and photon – play out their opposing features in a single dimension, namely space. This space-centric view is built in to mechanics and was inherited from classical physics. Thus, a particle (or photon) cannot be simultaneously continuous and discrete in space; nor can that particle (or photon) be both real/actual yet also merely probable in space. The object must be one or the other and in space. But the particle and the photon do unite contradictory features and they do so by having separate identities whose features play out (function) in separate dimensions.

The inertial particle and the photon are both entities, which means they are physically real (i.e., composed of mass or energy) and have a presence in a dimension. As noted, the particle's essential (kinetic[3]) identity is rest mass while the photon's essential (kinetic) identity is KE. The particle's essential identity extends and resides in space while its dependent, potential identity (stored energy) progresses in time toward probable termination (release). Particle stored energy release may be partial (via photon emission) or entire (particle annihilation). A particle's two identities are dimensionally functional: extending/existing in space versus progressing toward release in time.

[2] Collapse (to be covered later) is a third issue, but it is not a union of incompatibles.

[3] **"**Kinetic" denotes movement (*kinētikos*), but is also means "unstored." Hence it is convenient to use the term "essential" for unstored mass or energy. This avoids "kinetic mass" being understood as mass that is moving.

Particle physicists ignore the potential identity of rest mass particles. They see particles as singular objects with but one (kinetic, essential) identity. This serves their space-centric view well since their only interest is in particle location/movement in space. They can ignore particle probable termination because that takes place over time, a secondary dimension. But that parochial view comes back to bite them in the case of the photon whose probable termination (reception) plays out in space, not in time. Ignoring probability of termination/release in one dimension (time, for the particle) and then being forced to confront it in the opposite dimension (space, for the photon) is neither consistent nor an ideal strategy.

5. $E = mc^2$ and the Ontological Equivalence of Energy and Mass

$E = mc^2$ tells us that mass and energy are always found together. We should occasionally write this equation as $M = e/c^2$ to remind ourselves that either constituent can be kinetic making it real/actual in which case the other is then potential and probabilistic. If M (mass) is kinetic you have particle rest mass possessing potential energy; if E (energy) is kinetic you have photon KE possessing potential (relativistic) mass. Einstein's equation, however written, has a significance for physical reality (for ontology) that has been quite over looked ever since it was announced; perhaps even the author failed to notice all its implications.[4]

Current physics retains the 19th century concept of KE as a quantity possessed by rest mass in motion with massless and virtual "objects" given honorary particle status. But $M = e/c^2$ equality is deeply subversive of this position. Everyone acknowledges the particle and the photon as measurable entities with a presence in a dimension. The particle is an entity by virtue of its essential identity, rest mass, occupying a dimension (space). But the photon's essential identity, KE, is not given entity status; it is merely a quantity (a payload). This is wrong. Photon KE should be regarded as a quantized, occurring (cyclical) entity requiring (extending in) a dimension, just as particle rest mass is currently acknowledged as a quantized, existing entity requiring (extending in) a dimension.

6. Photon Energy as Occurring Entity

A photon's energy cannot be divided in space. No space instrument – pinhole, slit, beamsplitter – can divide the photon's essential identity, energy. However, a photon's potential, probability-of-reception waves can be so divided. For the photon's two identities, "[o]ne photon identity is following paths in space and the other is not [6, Sec. 2.]."

As is the case for a photon's energy in space, so a particle's rest mass cannot be divided in time. Rest mass can't be divided in time because it doesn't reside there; i.e., rest mass doesn't physically occupy an interval in time. It follows that photon energy can't be divided in space because it doesn't reside there; i.e., doesn't physically occupy an interval in space. We are left with the option that, like the inertial particle, the photon's two $E = mc^2$ identities indeed operate (reside versus progress) in different dimensions. Photon energy must be an oscillation occurrence whose cycles reside/extend in time.

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[4] He famously discounted potential (relativistic) mass.

Photon KE originates from work done on a charge. This KE is physically real and must reside in some dimension to be available for transfer later to a material target. By residing in time as pure oscillation,[5] photon KE is safe from diffraction or division.

Photon KE functions (cycles) in time. Courtesy of $E = mc^2$, this KE's potential identity, stored (relativistic) mass, functions (progresses) in space. The oscillation of photon KE is passed to its dependent, potential mass making the latter progress in space as a waveform of pure occurrence. Because this wave has relativistic mass, it can deliver momentum to a material target.

Having one of the photon's identities, energy, function in time is less radical than it appears. Since radiation energy is oscillatory, its cycles require (occupy) time. Something that is oscillatory and massless should naturally reside/occur in time. Like the inertial particle, the photon spans two dimensions via functions we quite overlook: residing in one dimension versus progressing in the opposite dimension.

- **The photon, like the inertial particle, is a unified whole (an entity) having an essential (kinetic) and a potential identity due to $E = mc^2$.**

- **The particle's essential identity resides in space (as rest mass) while the photon's essential identity resides in time (as photon KE). In both cases a potential identity progresses in the opposite dimension toward release of what is stored.**

While particle rest mass and photon KE only reside/extend in one dimension, they have access to the opposite dimension via events that necessarily combine mass (from space) and energy (from time). Photon KE residing in time is available for interaction events on a target in space, just as the rest mass of your desk residing in space is available for interaction events in time. You cannot access your desk's rest mass in space except via an event: perception, touching, etc. You cannot access a photon's energy in time except via an event: reception or absorption. In general:

- **An entity's essential identity (your desk's rest mass, a photon's energy) occupies (resides in) but one dimension and is only accessed via an event.**

7. The Photon is Not a Particle

7.1 The Photoelectric Effect

For over a century the photoelectric effect has been put forth as an argument proving that the photon is a particle. Actually, what this argument proves is that we all have a propensity to conceive of the unfamiliar in terms of the familiar. We try to understand photon reception as analogous to macroworld impact and we envisage massless radiation as a kind of familiar, space-based particle mechanics.

[5] Physics (Quantum Field Theory) already has pure oscillation, namely vacuum state fluctuations.

Because photon reception features point reception and energy-momentum transfer, everyone makes the *analogy* with particle impact, this being "…a classic instance of underdetermination [7, Sec. 2.]." In fact, we have absolutely no proof that the photon is a particle. Aside from reception at a point, all other photon features suggest the opposite. No self-respecting particle would lack rest mass, have no trajectory and violate Galilean relativity. These contraindications are dismissed with hand waving, vague, nonphysical concepts (e.g., complementarity, "takes all paths") and a postulate (next section).

The photoelectric effect does prove that radiation KE is quantized and that quanta below a certain energy level will not eject electrons from a target regardless of the number of quanta that reach the target. It also proves that radiation is received discretely which leads to two universal assumptions based on physics-as-mechanics: 1) only an impacting particle can produce a reception event at a space and time point; and 2) KE can only be transferred as the payload of a particle. Brilliant physicists (e.g., Richard Feynman) have (unconsciously) adopted these assumptions without questioning their factual basis.

The point reception of photon KE on detector rest mass is a consequence of the two residing in different, orthogonal dimensions. Rest mass, the essential identity of the particle, resides in space, photon KE, the essential identity of the photon, resides in time; the two can only meet via an event which is discrete in both space and time. Invoking an imaginary particle to explain point reception does not take much imagination or deep thinking; it simply foists a particle mechanics, one based on rest mass, on to massless radiation.

The photon's KE functions (occurs/cycles) in time making it available for possible observation (reception) events at multiple, mutually exclusive, space locations. This availability for discrete events is a general pattern in physics. Hence the inertial particle's rest mass functions (exists/resides) in space making it available for observation events at multiple possible time locations.

Photon KE doesn't navigate a route across space to reach a destination; nor does rest mass navigate a route across time to reach a destination. In both cases, the essential identity is simply available for observation events in the orthogonal dimension. Nature is subtle; our interpretation of it is usually not.

Physicists want to write equations describing the transmission of energy or force across space. Waves rarefy so if the photon is a wave, then photon energy transmission becomes hard to explain; things are easier if the photon is a particle with an energy payload. So it is that physicists induct the photon into the Standard Model as just another particle because "…just like massive particles, it obeys the laws of conservation of energy and momentum in collisions, with an electron say (Compton effect) [8, p. 350−1]."

7.2 The Electron is Dualistic, but the Photon is Not

Both the electron and the photon have KE which by nature is oscillatory leading to probability wave effects due to relativistic mass. But the photon is not dualistic since it has no rest mass and its point reception is not a consequence of it being a particle. The moving electron is dualistic by combining oscillatory KE yielding wave effects (of probability) with rest mass yielding particle behavior. The result is real impact of electron rest mass, but with a fuzzy, wavelike trajectory due to oscillatory KE [9, Sec. 9.1].

8. The Constant Velocity of Light

When work is done on an electron, the acceleration of the electron's charge generates self-sustaining EM fields. In addition, the work itself, as pure energy cycling in time, has relativistic mass due to $E = mc^2$. Both the EM fields and the relativistic mass share the same oscillation frequency and progress in space as waves at the speed of light. Both of these waves are dependent for their occurrence upon time-residing KE; the waves in space are dimensionally orthogonal to their sustaining source: time source versus space progression.

As pure waves without a supporting medium, these waves progress in space at a velocity of their cycle wavelength divided by the time a cycle requires, namely its period. If an observer moves toward the wave source, then the wave cycles contract by the same factor for wavelength and for period. If the observer moves away from the wave source, then both wavelength and period expand by the same factor. Observer movement can alter radiation wavelength and period, but only in the same proportion; the constant velocity of light is clearly the fixed ratio of wavelength to period for any EM radiation. What we measure as the "velocity of light" is the phase velocity of light's immaterial, probability-of-reception waves. These waves progressing in space govern the possibility of a reception event (of photon energy), with everyone assuming (from mechanics) that it is photon KE that is doing the travelling.

Physicists have long known about the constant phase (e.g., crest) velocity of light. But waves rarefy and can't carry quantized energy. Hence the assumption has always been of an energy "packet" traversing space and with energy's reception at a point reinforcing the idea of particle energy delivery. The problem appeared insoluble, so in 1905 Einstein used his second postulate to declare constant velocity as a feature that didn't require explanation. It is possible now to see that an ad hoc postulate is unnecessary.

The irony is that Einstein's other accomplishments in that year – the equality of mass with energy and of space with time – pointed the way toward a solution. Neither inertial particle rest mass nor photon KE require transport over time or space respectively; these kinetic identities are merely present in the dimension they occupy. This makes them available for interaction events that link space with orthogonal time; it is their potential identities that progress in the opposite dimension.

- **It is the photon's potential identity – probability-of-reception waves – that have constant velocity, although not constant frequency, for all observers.**

- **The constant velocity of light is proof that: 1) photon oscillatory energy resides and occurs in time exempting it from space travel; and 2) the velocity we measure is simply a phase velocity of immaterial, unhosted waves governing possible reception of time-residing photon KE.**

9. Photon Probability and Collapse

Our common experience of matter-in-motion is very hard to overcome and we apply it everywhere, including to radiation. We think of our sun as emitting a "photon object" which then travels across space in a straight line to be absorbed by the earth 8 minutes later. But radiation is not mechanics; there are no quasi-particle energy "objects" following a trajectory in space

Upon creation, a solar photon has its potential identity – relativistic mass plus synched EM cycles – progressing and rarefying along all available space paths at the speed of light. The leading edge of this probability wave may, at any instant, be impinging upon multiple detectors (or observers), with each detector having an objective probability of reception (i.e., the chance of reception as real). The earth has a very small chance of intercepting this wavefront, but if it does, there are two possible earthly outcomes for the photon probability wave, either reception or no reception.

- **No reception, local collapse**: If a photon's probability wave fails to initiate photon KE reception on a detector, then the blocked waves collapse and do so without a trace since they are immaterial occurrence and potential, not kinetic. A wave of pure occurrence that cannot progress in space ceases to occur; a rest mass particle that cannot progress in time ceases to exist.

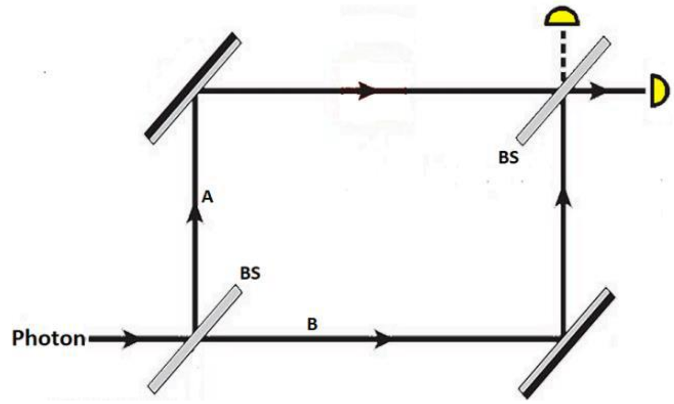
- **Reception, general collapse**: In this case a wavefront has initiated local reception at a point on a specific detector; the photon energy then participates in a transfer event with the rest mass detector. The photon, as entity, has its kinetic oscillatory occurrence in time and the cessation of this source collapses all dependent, potential occurrence cycling across space without limit. The wavefront collapse is nonlocal and complete.

The random, nonlocal collapse of a photon's probability-of-reception wavefront was first noted by Einstein. It has been especially puzzling for commentators and physicists who regard the photon as unitary without a potential (latent) identity. They may recognize that unstable (radioactive) particles have an objective *temporal* probability of termination. But they don't relate that to objective *spatial* probability of termination, perhaps because they, like Einstein, discount dependent, relativistic mass. Photon wave collapse has been overshadowed by the electron's wave function collapse, but the mechanism is the same for both [9, Sec. 3.2, 11.1].

The photon is a single entity with kinetic, time-residing energy sustaining (via $E = mc^2$) a potential, space-progressing (probabilistic, collapsible) wavefront; we receive the former randomly but the diffraction of the latter proceeds deterministically (wave optics). Realization of this finally permits an understanding of various long-standing photon puzzles: the Mach–Zehnder Interferometer, the double slit and entanglement-nonlocality.

10. The Interferometer and the Double Slit

10.1 Mach–Zehnder Interferometer



A Mach–Zehnder interferometer (MZI) features two mirrors and two beam splitters (BS) diagonally opposite. When a single photon meets the first beam splitter, its probability-of-reception waves divide equally on the two paths, A and B, while time-residing photon energy is unaffected. Wave interference at the second beam splitter requires both paths to be unblocked. If a detector blocks probability-of-reception waves at A without triggering photon reception, then the blocked waves undergo local collapse and vanish without a trace. Path A then contains no waves so wave interference at the second beam splitter will not take place. Remaining photon waves then traverse path B (now at 100% probability) and terminate particle-like at a point on a detector outside the MZI. The fact that a non-registering detector (at A) can change photon behavior from wave (interference) to particle (termination at a point) has been a great puzzle. Most assume that “the photon” chose path B and nothing traversed blocked path A. Our (classical physics) ontology doesn’t accommodate the physical reality of things (probability waves) that do not register on our instruments.

Most people regard the photon as an object possessing both wave and particle natures, all in space, of course. One way to accommodate this is to argue that the photon is a superposition of wave with particle allowing either to be invoked as convenient [10, p. 3]. Another approach is to argue that “there is no quantum world [11, p.12]” and objects are defined by how we measure them; measure for a wave and the photon is a wave; measure for a particle and the photon is a particle. These metaphysical approaches are unnecessary if we acknowledge that: 1) the photon has two identities, only one of which is divisible at a beam splitter; and 2) the “particle” nature of the photon is something we invent based upon point reception on a target.

John Archibald Wheeler concluded that the photon as unitary object made a defined choice at the beam splitter: follow both paths as wave, or follow a single path as particle. He proposed a “delayed choice experiment [12]” whereby detectors are inserted into interferometer paths after the photon had “made its choice” at the first beam splitter.

Wheeler’s concept of a wave-particle choice at the first beamsplitter is wrong; there is neither particle nor choice at the first beamsplitter. It is the photon’s potential (wave) identity that divides at the beam splitter; the photon’s essential identity (energy) follows no paths since it is not even in space. Wheeler compounded his error by suggesting retrocausality as an explanation.

10.2 The Double Slit

A photon traversing a double slit also reveals the kinetic/potential identities of the photon. A single photon's potential (waveform) identity passes through both slits, interferes, and produces a distinct pattern on a target screen; i.e., bands of high and low probability intensity, inferable only after many repetitions. The photon's essential identity (energy), whose cycles function in time, is not fractionated by the slits and is always received on the screen at a point with its energy undiminished. Wave intensity in space only determines probable photon energy reception location. Placing a detector behind one slit has the same effect as a detector on one path of an interferometer. That is, if photon waves collapse on the detector without triggering reception, that blockage (unregistered, unrecorded) prevents the interference pattern on the target screen.

11. Entanglement and Nonlocality

At the quantum level, entanglement depends upon energy sharing, typically between photons. There are experiments incorporating electrons in this energy sharing [9, Sec. 10.0]. These experiments are interesting, but the basic process is revealed if we stick to the case of two photons coordinating their spin (or polarization) over apparent space separation [13].

11.1 Like Entities Bond Together

Like entities (two particles or two photons) will have their essential identities bond/entangle in the (shared) dimension wherein they occupy an interval/volume (where they extend). Space-adjacent rest mass quanta will bond together in space; that is the basis of our material world. Time-adjacent photon energy quanta will bond together in time. Two photon energy quanta are adjacent in time and bond if they are the product of the same event, e.g., parametric down-conversion.

The instantaneous spin coordination of entangled photons that are received far apart is taken as proof of nonlocal effects between objects. The common (universal) mistake here is to take the space location of a measurement (reception) event and attribute it back on to an object that never had such a location. We can see this clearly in the case of entangled rest masses and their respective termination events.

Let's say you have two space-stationary carbon-14 atoms whose rest masses have bonded (entangled) in space where they reside. If their separate termination (decay) events are one thousand years apart, you are not going to say that the atoms are separated by a thousand years. It is not correct to project the time location of a termination event back on to the essential identity (rest mass) of an atom that by residing in space has no defined time location.

So it is with two photons whose energies have bonded (entangled) in time. If their separate termination (reception) events are a thousand kilometers apart, you should not say that the two photons are located a thousand kilometers apart. It is not correct to project the space location of a termination event back on to a photon's essential identity (energy) that by residing in time is orthogonal to space and therefore has no defined space location.

Commentators are implicitly thinking of the photon as a particle traversing space so that its reception event on a detector reveals its last space location. But the photon is not a particle and it has no trajectory because its essential identity is not even in space; time-residing photon KE is merely common (present) for possible space-located events (reception).

11.2 Summation

An entity's essential identity resides in but a single dimension, either space (inertial rest mass) or time (photon KE). For the photon, its KE is orthogonal to, and simply available for, observation events in space. A specific space location characterizes the photon observation (reception) event, not the photon itself (not the photon's KE).

Receiving photon energy at a space location means that the photon's potential identity traversed space at the speed of light as a multi-path wave; it does not mean that photon's essential identity, KE, traversed space. Being in time, photon KE is merely available for reception events along whatever space paths the photon probability wave traverses.

12. Lifecycle of an Entangled Pair

High energy light from a laser enters a crystal. Within the crystal photon's probability of reception waves may trigger quantized photon KE which in turn may split into two lesser, entangled photon KEs, say red and blue on the color spectrum. Together the two daughter photon energies preserve (conserve) the energy and momentum of their parent. Photon energy spin is normally one, but the joining (superposing) of two spins yields a net spin of zero.

Meanwhile, the two photons have potential identities – probability-of-reception waves – that spread out in space as speed-of-light wavefronts. Any observer (detector) on a wavefront has a small chance to participate in a reception event. Finally, at some point in space, the red photon's wavefront initiates reception on a detector. Red photon energy now exits its time entanglement and acquires right circular spin. Simultaneous with this, blue photon energy assumes left circular spin thereby preserving zero angular momentum. Spin coordination is simultaneous since both photons have their essential (energy) identities entangled where they occur/cycle, in the time dimension; both constitute pure, massless energy occurrence.

At some distant point in space the blue photon's wavefront triggers reception on a different detector and the photon (its KE) registers as left circular spin . The two, space-separated observers believe that photon spin is determined for both photons when the first photon is received and they are correct. But they also believe (from mechanics) in each "photon" as a unitary object travelling on a space path whose end point is revealed by its reception location and this is not correct.

Checking respective photon reception times against space separation, the two observers conclude that spin definition for the second photon happened before any speed-of-light coordinating signal could have arrived from the first photon's spin definition. Hence the entangled photons have coordinated their spins by violating the principle of locality.

This lifecycle analysis indicates that the current interpretation of photon nonlocality is not correct; it is based on confusing reception event location with photon location plus regarding the photon as a quasi-particle. Photon spin coordination (or communication) is in time, not over space. Einstein is correct in his realism that space separated causal effects are limited by the speed of light, his critics are wrong and that is not the first time. "Spooky action at a distance" does not take place because entangled photon energies are adjacent in time and spin-coordinate there.

13. Discussion: Radiation Freed from Mechanics

Classical physics has a world view consisting of matter, fields and forces operating in three dimensional space. Quantum physicists inherited this viewpoint (mechanics) and used it to interpret the photon while adding sophisticated mathematics and multiple space dimensions (Hilbert space). Like classical physics, quantum physics embraces two unreflective assumptions drawn from our everyday experience, namely that: 1) physics plays out exclusively in space; 2) objects are singular and what they store is of no consequence for their behavior in space. Added to this, quantum physics continues to adhere to the 19th century concept of KE as a quantity, not an entity; mass-energy equality is then quantitative, not ontic.

With all these assumptions, the quantum pioneers tried to make radiation into just another mechanics, hence the name quanutm mechanics. Inevitable difficulties arose, but clever minds could produce work-arounds or compromises or postulates when required. Sometimes it was as simple (simplistic) as making the photon into whatever our measurement said it was, particle one day, wave the next. The quantum pioneers did the best they could, but the issues at the time were very confusing and hard to separate. With 100 years of perspective, we should be able to do better; it is our material and space-centric view of reality that holds us back

Nature embraces a very subtle symmetry for matter and radiation: some objects (rest mass) exist and require space; their inverted twin objects (KE oscillation cycles) occur and require time. In both cases these (quantized) objects have, courtesy of $E = mc^2$, two identities – kinetic and potential – giving them a functionality (residing versus progressing) spanning two dimensions. The photon's kinetic identity functions in time and is received on space-residing rest mass as a discrete event (not a particle); the photon's potential identity functions (progresses) in space and rarefies as a wave. This is how Nature combines two incompatibles. And it is why dualism, the constant velocity of light and nonlocality all have a common explanation.

So far only entities that don't mix rest mass with KE have been covered: an inertial particle's rest mass without KE, and a photon's energy without rest mass. Neither one exhibits wave-particle dualism. Next up is a mixed entity – matter-in-motion – which certainly exhibits wave-particle dualism because it combines rest mass with KE.

Part II The Electron

14. Matter Waves

Louis de Broglie has enduring fame in physics for his theory that matter-in-motion exhibits a wave character. But he was more of a philosopher than a physicist; his career is ironic because while his theory was correct, his supporting arguments were mostly wrong or didn't apply. He had convinced himself that waveform light quanta possessed tiny rest mass making such quanta intrinsically dualistic. He then assumed that rest mass particles must have this same dualism. His 1924 thesis, where he argued for this dualism, constitutes a "…barrage of novel ideas and confusing developments … [14, p.1047]." It was only Einstein's imprimatur – at least for de Broglie's central thesis – that caused physicists to take notice. Even then, de Broglie's supporting arguments were ignored, both then and now. But his strange idea prompted a search for experimental evidence of matter waves; a search that was successful due to Davisson and Germer. De Broglie's basic idea that matter-in-motion involved oscillation was correct, but attributing this oscillation to the intrinsic energy of rest mass was incorrect. He overlooked the connection of oscillation with KE and work. Oscillation energy is an entity (a measurable, physical object) created by work done; when rest mass receives that work, oscillatory de Broglie waves result.

15. Work Done on Rest Mass

The 19th century concept of KE as a passive *quantity* devoid of oscillation is wrong. It is wrong for the photon and it is wrong for matter-in-motion. When force overcomes an object's resistance to motion, work is done and oscillatory KE is created as an entity with both an essential/kinetic (time residing) identity plus a potential (space progressing) identity.

An electron has both rest mass and a charge. Doing work – accelerating an electron's charge – creates the EM radiation already covered. Doing work upon the electron's rest mass creates KE that joins with the electron's rest mass; the result is a mixed entity: rest mass joined with the KE of motion. The always-moving electron is a composite entity whose tiny rest mass has particle features that are sufficiently attenuated to be compromised by KE's oscillatory, relativistic mass features; both features are in space, one kinetic, one potential-probabilistic.

Because our instruments are in space, we can only manipulate that which resides or progresses there, namely electron rest mass (as residing) plus de Broglie waves of relativistic mass (as progressing). Because wavelength and momentum vary inversely, de Broglie waves are big enough to be detected only when momentum is small: tiny rest mass and low particle speed.

16. The Wave Function and Momentum

Schrödinger wrote his famous wave equation to describe the hydrogen atom's electron as a true wave in space. It was a great success in terms of predicting certain parameters. But no one realized that his equation describes the evolution in space of the *potential* (relativistic mass) identity of electron KE. That is understandable; no one, then or now, gives much credence to measurable relativistic mass despite $E = mc^2$.[6]

The always-moving electron has two sources of momentum whose vectors do not coincide. The electron has momentum from the velocity of its rest mass. The electron, like the photon, also has momentum from its potential, relativistic mass generated by oscillatory KE. Relativistic mass augments rest mass; both have momentum.

Electron momentum from relativistic mass derives from an undulatory wave packet and it superposes with the momentum of the electron's rest mass. The electron's combined momentum vector takes on the oscillatory character of the wave packet. The result is a combined, undulatory momentum that has the electron rest mass imperfectly following waveform relativistic mass. If the electron encounters a double slit, its waveform relativistic mass will, like the photon's relativistic mass, go through both slits and interfere, creating paths of high and low probable electron location. Meanwhile, the electron's rest mass goes through only one slit.

17. The Measurement Problem

The wave function has been with us for about 100 years and numerous questions about it still remain; they are known collectively as the measurement problem. These questions include: 1) what is the physical basis of matter waves and what is their relation to the wave function; 2) why does the wave function only give us probability measures for electron location; and 3) how can the expanding wave function collapse nonlocally over space to yield a single value?

1. **Physical basis:** Kinetic energy occurs and functions (cycles) in time, just as rest mass exists and functions (resides) in space; in both cases $E = mc^2$ provides a potential identity progressing in the alternate dimension. For electron KE, its potential identity (relativistic mass) both progresses and oscillates in space as a wave that governs probable release. *The wave function models this waveform relativistic mass*. This has not been recognized because: 1) KE is still regarded as a mere quantity; and 2) relativistic mass has been deprecated. Physicists are more comfortable interpreting measurable, relativistic mass as quantitative KE which has no presence in a dimension; this leaves nothing physical in space for the wavefunction to represent.

2. **Probable location:** Rest mass in motion always features conjoined waveform relativistic mass as an expression of associated KE. Providing the rest mass is significant, these de Broglie waves reinforce to a packet surrounding the rest mass; the two momentum vectors (see preceding section) then coincide yielding classical behavior. At the atomic level where particle mass is tiny and wave reinforcement (to

[6] A rest mass object moving with respect to an observer undergoes length contraction and mass augmentation by the same factor; nevertheless, some accept one and reject the other. Don Koks writes: "There is no argument in the literature about the uses of rest length versus moving length, so why should there be any argument about the uses of rest mass versus moving mass [15]?"

a packet) is minimal, the momentum vectors do not coincide and particle location becomes uncertain. If a particle's KE (its motion) is constrained (e.g., orbital, or potential-well restraints), then mathematics (the wave function) can model the waveform for probable values of either particle position or particle momentum.

3. **Collapse:** The electron's relativistic mass occurs and it progresses as a wave in space as the potential expression of electron energy oscillating in time. This relativistic mass is orthogonal to the electron energy that sustains it; i.e., they both occur but function in different dimensions. When electron energy is received by a material target, all its dependent, dimensionally orthogonal, space-dispersed relativistic mass ceases to occur. As a discontinued pure occurrence, it vanishes without a trace.

17.1 Uncertainty and Indistinguishability

As a mixed entity of space-residing rest mass and time-residing KE, the electron in motion is objectively blurred between: 1) rest mass particle features; and 2) oscillatory (waveform) energy features. This makes it objectively uncertain for measurement because competing characteristics (discrete vs. continuous) get diluted by their opposite. This dilution is deeper than merely imprecise values; this dilution is at the ontological level of melding what exists with what occurs; specific features follow from those categories.

When mass and existence dominate an object, the object can be distinguished from other objects by features, state and space position. But for subatomic rest mass particles, energy and occurrence dominate and objects are indistinguishable since features are uniform and space position compromised.

17.2 Superposition

The assumption has always been that the electron, like the photon, is a unitary object with but a single identity; for the electron that identity is rest mass. But if the wavefunction is regarded as an objective description of electron location in space, then electron rest mass is dispersed and not discrete in space. Physicists justify this through the theory of superposition.

The superposition of waves is both familiar and well understood. Hosted by a medium or not, waves progress in space and can overlap and reinforce (or cancel) there; energy oscillations (including spin) can also overlap and even be undefined (mutually cancelling). However, the application of superposition to static material entities means an existing rest mass can be in two places or two states at once. This theoretical ploy got a bit of well-deserved ridicule from Erwin Schrödinger when he put forth his famous thought experiment involving a cat that was both dead and alive. Schrödinger took the probabilistic state of an unstable atom and projected it on to a living cat. It encapsulates the measurement problem of QM and the wave function: incompatible features; objective probability; and collapse to a value. No cat has ever been so famous or discussed.

18. Schrödinger's Cat

Suppose there is a heavy atom (many electrons/protons) with an alpha particle (two protons and two neutrons bound together) oscillating within the potential well of this atom's nucleus. Just like the much lighter electron, the energetic alpha particle has KE joined to its rest mass. The alpha particle's KE has its potential (relativistic) mass accompanying the alpha particle's rest mass as a standing wave; the latter can be modeled by the wave function Ψ. Applying the wave function to the confined alpha particle yields a smeared probability density field that corresponds to the likely position of the oscillating particle. Via quantum tunneling [16] a portion of this computed field will extend beyond the potential barrier limits. This allows a probable particle release (decay) rate per hour or per day to be calculated. While the alpha particle rest mass remains in the nucleus the cat lives; once the alpha particle rest mass escapes the nucleus, the lethal causal chain (detector, hammer, poison) is triggered and the cat dies. As the wave function shows both cases (solutions) simultaneously, the inference is that the cat is both dead and alive plus shades in between. Schrödinger's point is made; superposition of rest mass is silly enough; superposition of a living feline is ridiculous.

Recognizing that the alpha particle has a potential, probabilistic identity – distinct from its rest mass – resolves the cat problem. It is the location of the alpha particle's rest mass that determines the cat's state: inside the nucleus and alive, or outside the nucleus and dead. But the wavefunction only characterizes the space distribution of the standing wave of potential, relativistic mass. The wave function is not modelling that entity, alpha particle's rest mass, that can trigger the chain of events that kills the cat.

By virtue of their KE, moving particles have waveform, potential relativistic mass. These waves may superpose as is the case with electron waveform "orbits" for atoms with many electrons. Spin (angular momentum) is also an expression of oscillatory KE; hence superposition applies to it. In general, superposition applies to waves, including those of probability; it does not apply to rest mass entities such as a cat or an alpha particle's rest mass. The cat is never in a mixed, dead/alive, state. Cats may die for many reasons, but not from probability waves.

19. Conclusion

The transition in the early 1900s to the new, quantum, physics was done via ad hoc adjustments by participants who wished to save as much of classical physics as possible and lacked the perspective we enjoy. Most of the challenges for the new physics came within radiation: Planck and Einstein quantized radiation; Bohr's atomic model explained the Balmer spectral series; and de Broglie gave us matter wave radiation.

It was also within radiation where the major missteps occurred. Those mistakes include: 1) continuing to regard KE as merely a quantity; 2) failure to grant KE real equality with mass and time real equality with space; 2) conflating photon reception with particle impact; 3) applying mechanics to radiation with the waveform photon made into a particle; 4) regarding the photon as a unitary object that is somehow both discrete and continuous; and 5) accepting potential energy as physically real but discounting potential (relativistic) mass. Once QFT appeared on the scene, every particle (and quasiparticle) acquired its quantized field and particle interaction mediated every possible exchange of energy, momentum and force. Particle physics as mechanics now dominates. It is a strange, essentially incoherent mix of ideas that ignores the paradoxes it creates; but for the most part it permits experimental, and even theoretical, progress to be made.

At 100 years removed from that revolution we can see it more clearly as part of a pattern of infrequent episodes of reorienting physics. Thomas Kuhn examined these episodes in his book, "*The Structure of Scientific Revolutions,"* first published in 1962. He points out that scientists in any era are guided by a paradigm: a set of assumptions as to what objects are real, plus theories that define how these objects can interact. For Kuhn there was a major paradigm shift in the transition from classical physics to quantum physics. But at a deeper level, some basic assumptions hardly changed at all.

- **The paradigm of classical mechanics:** All real objects (particles, fields, forces) reside in space; kinetic energy is a quantity transferred via particle payload.

- **Minimal changes made by QM/QFT: 1)** a particle may be massless/virtual but still carries a quantitative energy payload; 2) effective mass is velocity dependent; and 3) all particles are manifestations of quantized fields, only two of which we can measure (gravity field and electromagnetic field).

The classical physics paradigm gave ontological preference to mass (an entity) over energy (a quantity); and to space (where physics plays out) over time (a duration measure for events). This paradigm ran into difficulties after 1900 when applied to radiation. First, applying classical, Galilean relativity to light was a failure; second, the photon and then the electron exhibited wave-particle duality; and third, the EPR paper questioned QM by reasserting two classical physics tenets: 1) quantum particles have definite values before being measured; and 2) nonlocal action at a distance is impossible.

These failings of the classical paradigm were serious and aroused considerable debate, then and now. But, as Kuhn points out [17, p. 77] a paradigm is not abandoned unless a new paradigm can take its place. Defenders of an accepted paradigm "...will devise numerous articulations and ad hoc modifications of their theory in order to eliminate any apparent conflict [17, p. 78]."

Kuhn is correct; the classical physics paradigm had to be saved. Galilean relativity and physics-only-in-space was made safe by carving out the speed of light as an exception via an ad hoc postulate (Einstein). Another ad hoc assertation (complementarity) promoted wave-particle duality as an essential feature of Nature for reasons that will always be hidden and hence in need of no explanation (Bohr). In addition, duality and nonlocal action at a distance are features we can't explain, not because our paradigm is wrong, but because our intellects are so puny and Nature is so vast and complex (Wheeler and various).

Humans don't welcome change. It is particularly unsettling if it calls into question one's everyday experience that all physics consists of energy-as-quantity and material objects (and their inferred fields) in space. The current paradigm is pervasive and institutionalized; it underpins all grants, research, academic promotions and publishing within physics. The cost is a few paradoxes that don't seem to go away but have mostly been sidelined by a postulate and the coping arguments already cited.

Physics needs a new paradigm to correct the missteps of the quantum pioneers. But those who study the history of physics tend to assume that any new paradigm will follow the historical pattern: some flaw in the current paradigm will be revealed by some new experiment or observation (e.g., the precession of Mercury) that can't be explained and a new theory will arise to incorporate all old observations plus the new one.

But it is very simplistic to believe that change to come will always resemble the change of the past. Why would one believe that? Doesn't change imply that change can itself change?

The flaws in the current paradigm are numerous and quite apparent if one cares to look (as Einstein did). The new paradigm we need is simply a correction to the one we have, one that involves so many conceptual compromises and asymmetries. The new paradigm is unlikely to predict any new, decisive experiment. It will just make sense of KE (as an entity), of time (as a real dimension) and of nonlocality. It will take equality and symmetry seriously; and it will eliminate the remaining, mostly unrecognized vestiges of classical physics (all physics in space; KE as quiescent particle payload) that we continue to either overlook or defend.

Unfortunately, getting physicists and philosophers of physics to recognize this is quite another matter. "Like the rest of humanity, physicists tend to cling tenaciously to what they know or think they know, and give up traditional thinking only under extreme duress. [18, p.137]."

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Abbreviations
The following abbreviations are used in this manuscript:

KE	kinetic energy
QM	quantum mechanics
MZI	Mach–Zehnder interferometer
EM	electromagnetic field

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