**Photon Physics and the Classical Ontology**

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**1.0 The Classical Ontology –**

 We live in a material world and physicists, like all of us, model reality accordingly. A particle is a material model as is a wave hosted (or not) by a medium. Both have been used as models for radiation. The problem is that together they are incompatible and apart each explains some features of radiation but not others. Niels Bohr tried to bridge the compatibility gap – discrete particle vs. continuous wave – by accepting both as consequences of an unknowable reality based on opposites. Clearly this was to make a defect into a virtue or in software engineering parlance, declaring a bug to be a feature.

 Material models are based upon the classical ontology founded on: (1) **existence**; (2) **rest mass;** and (3) particle **space motion**. Trying to model radiation and the photon based upon these leaves us with unexplained issues (e.g., the double slit problem).[[1]](#footnote-1)

1. **Existence** does not apply to radiation. The latter occurs in time; radiation’s essence is oscillation frequency in time.
2. **Rest mass** has no place in radiation. Photon kinetic energy (KE), not rest mass, explains photon momentum; termination at a point can be explained without invoking the particle impact analogy.
3. **Space motion** with a trajectory does not apply to the photon. A photon has no defined trajectory and its energy can never be fractionated in space (by slits or pinholes).

The classical physics ontology of entities based on existence, matter (particles) and space motion (trajectory) is too limited in light of mass-energy equality (E = mc2) and space-time equality (relativity). In what follows, quantized entities that exist (mass/particle) will be compared with quantized entities that occur (radiation/photon) for their commonalities.

**2.0 Time, the Photon and Kinetic Energy –**

The photon has kinetic energy (KE) with no rest mass; its logical compare is (inertial) rest mass with no KE. The justification here is that this makes both entities stationary in a dimension. Inertial rest mass is stationary in space by definition. And the photon is stationary in time because anything at the speed of light incurs infinite time dilation. A requirement that entities be stationary in one dimension excludes moving electrons from consideration here. Their duality differs from that of photons in that it involves a real, rest mass particle which is not the case for the photon.

Both mass and energy have their conservation laws. A rest mass particle obeys the law of the conservation of mass as it progresses in time. Successive observers in time experience the same particle with the same mass; they have the existing particle and its mass in common. We explain this by saying that time progression does not affect existing particles; that time progression is orthogonal to existing objects in space.

Photon kinetic energy (KE) too has its conservation law. Photon energy must be constant as it progresses in space within an inertial system. Assume we have a single photon from a laser moving on a line (ideal case) through space. This photon presents the exact same KE to all space observers along its path were they to measure it. Now imagine this linear-path photon encountering and passing through a double slit. The photon interferes with itself and now has multiple paths toward termination on some target screen. Observers situated on these multiple, diffracted paths have the same (possible) experience as the observers on the linear path: if the photon terminates on their path, it will have the undiminished KE from photon origin. All of these paths have the photon KE in common although the diffracted paths differ in probability of photon reception.

This behavior of the single photon tells us that space-residing, material devices (slits, pinholes) cannot affect (fractionate) photon KE but they can fractionate probability of photon reception. This means that the photon has two identities or facets:

1. **A potential (probabilistic) identity that has a presence in space and so will fractionate there.**
2. **A KE identity not divisible in space and common to (available for) all possible space path observers.**

Neither simple progressing in space (linear path) nor progressing-diffracting in space (multi-path) has any effect upon photon KE. Photon KE is therefore orthogonal to space and what happens there, namely diffraction and velocity diminution (e.g., in glass). And something is orthogonal to a dimension when it does not reside in that dimension. We conclude that photon KE does not reside in space where it might dissipate or rarefy. Photon KE resides in time! [[2]](#footnote-2)

**3.0 Entity Identities –**

Any entity must: 1) be quantized; 2) reside (be present) in a dimension; and 3) store its opposite via E = mc2. We take these requirements in order. First, quantization for an entity is a given; entities are discrete, not continuous. Second, to reside in a dimension means to occupy an interval (or volume) in that dimension; this ensures that the entity is “physically real” (a dimensional presence). Third, an entity storing its opposite via E = mc2 limits our real entities to mass and energy.

The rest mass particle is an entity: it is quantized (space discrete); it resides in (occupies) space; and it stores its opposite, namely potential energy (e.g., thermal, intrinsic).

By these criteria, photon KE is also an entity. It is quantized (time discrete oscillation cycles); it resides in time as we have seen; and it stores its opposite, namely potential (relativistic) mass.

Since entities store their opposite, they have two facets/identities, namely a essential (unstored) identity and a potential (stored) identity. The essential identity always resides in one dimension: matter occupies/requires space and photon KE occupies/requires time. What each of them stores will progress in the alternate dimension toward release.

Nature is even-handed between existence and occurrence, matter and radiation.

* **Quantized matter is an entity: its essential identity is mass; its potential identity is stored (thermal, intrinsic) energy.**
* **Quantized radiation is an entity: its essential identity is KE; its potential identity is stored (relativistic) mass.**

While entities have two identities, their essential identity is primary. Hence it is convenient to refer to the whole entity just by its essential identity. So “rest mass” is shorthand for the material entity and “photon KE” for the radiation entity.

An entity’s essential (unstored) identity resides (occupies an interval) in a dimension: rest mass in space, photon energy in time. By virtue of E = mc2, each entity has a potential (stored) identity which progresses in the opposite dimension.

The photon can have incompatible attributes because it has two identities operating in different dimensions. The photon’s KE identity resides in time and its oscillation cycles occupy time intervals there. The photon’s alternate (potential, probabilistic) identity progresses in space at the speed of light making it subject to space division (diffraction) on multiple paths

. The photon is not a simple object; dualism of photon attributes relies upon a dualism of photon identities.[[3]](#footnote-3)

* **The photon entity has it essential (unstored) identity, namely KE, residing-occurring in time; its alternate (latent-stored) identity progresses/occurs in space.**

**4.0 First Identity: Photon Kinetic Energy in Time –**

When a charge is accelerated the photon KE created must reside (have a presence) somewhere so it can be available at photon termination. Attaching the KE as quantity to a massless, multi-path photon is to fall back into modeling based on existence, matter and space. The photon is an (energy) occurrence; it is not an “object” with a defined space presence. Work done on a charge creates energy without rest mass; it creates photon KE as an entity in time whose oscillation does not involve anything material residing in space. Photon KE then is pure oscillation residing in time; such pure occurrence is not unknown in physics.[[4]](#footnote-4)

Because photon KE resides in time, its cycles cannot be affected by any space-dependent intervention or instrument we devise. Material objects will only receive whole action quanta although the time rate of delivery (energy) varies with cycle frequency. Hence photon KE is always quantized for amount received and you can never receive half a cycle.

The classical ontology (existence, matter, space) imagines that some object (particle, virtual or real) carries KE as a payload along space paths. This is the only mode of transport the classical ontology permits: some entity/object residing in one dimension, namely space, is transported in the same dimension. Thus you may transport your space-residing chair from its current space position (your den) to its new space position (your living room), a transport with a defined space trajectory. This model works fine for space-residing chairs moving in space; it does not work for the photon KE which does not reside in space and hence can have no defined trajectory there as we shall see.

Being orthogonal makes photon KE common to (shared by) all possible observers on said diverging space paths. Photon KE is not transported through space from one location (origin) to another (termination) because it does not reside in space. By residing in time, photon KE is not involved in space progression at the speed of light; that is left to the photon’s potential identity (next section).

**Conceptualizing**: Difficult concepts are: 1) dimensions supporting orthogonal functionally (residing vs. progressing); and 2) entities in one dimension being common for observers in another dimension. If they were easy the photon would have been deciphered long ago. These concepts apply to stationary rest mass objects in space are easier to understand there.

If we reflect upon the stationary objects around us, we realize that their presence in space obviates their being transported in time. The chair you are sitting in has rest mass that is simply present (orthogonally available) to register its presence for the time dimension via an event: perceiving the chair, sitting in the chair. Confined to space, the rest mass of your chair: 1) is common for possible observers over time; and 2) can only be accessed over time via an event.

It is the same with the photon’s kinetic energy. By residing in time this energy does not undergo transport in space. This energy is simply present (orthogonally available) to register its presence for the space dimension via an event: reception on a detector. Confined to time, the photon’s energy: 1) is common for possible observers over space; and 2) can only be accessed over space via an event.

For a single, diffracted photon, there may be multiple observers (detectors) at different space locations on the many paths that the photon potential identity follows. Each observer hopes to receive the photon’s essential identity (time-residing KE). Each space-separated observer has the possibility of receiving the same (shared, common) occurring photon KE residing in time. Assume the photon is created at point A in space and received far away at point B on one of its paths. Photon probability waves have traveled in space between A and B at the speed of light, but photon energy has not.

Photon KE is but one identity of what we call the photon. The second identity must provide for the: 1) probabilistic nature of photon reception; 2) spreading and progressing (rapidly!) on all available space paths; and 3) collapse of what is on those space paths.

**5.0 Second Identity: Photon Potential (Relativistic) Mass –**

If a single photon of known wavelength enters a double slit one can calculate probable reception locations on a target screen. The mathematics tells us that something travels those photon space paths between double slit and target; something immaterial that is latent and hence probabilistic. And what is on those widespread photon paths must disappear without a trace when photon KE is received at a point. This dependency of probabilistic, latent space path content upon time-residing photon KE tells us that E = mc2 storage must be involved. We conclude that the photon’s second identity must be its stored, potential (relativistic) mass.[[5]](#footnote-5)

* **Potential (relativistic) mass is the photon’s second identity; it progresses along all available space paths as an occurring waveform.**
* **Like the at-rest particle, the photon’s identities reside in one dimension and progress in the alternate dimension.**

So, the photon is a single entity but with two identities, essential and potential. Photon KE is the essential (unstored), time-residing identity. It is common for observers on space paths because it is orthogonal to those paths. A photon’s stored (relativistic) mass is the potential, space-progressing identity. It has the waveform, will diffract and therefore vary in intensity for individual space paths.

By residing in time, photon KE has no role to play in space transport. Photon KE employs its potential identity to execute speed-of-light, probabilistic space progression. When our Sun sends us a photon, it is photon potential (relativistic) mass – not photon KE – that space progresses for eight minutes to reach us. Stripping photon KE of its space transport function is very (extremely!) difficult for us; we are so immersed in the classical ontology (existence, matter, space) where KE must be the payload of a space-navigating particle. But that view just leads to paradoxes.

Entities either exist or occur as a whole: the host (essential) identity and the stored (potential) identity both either exist (particle) or occur (photon KE). This means the occurrence-oscillation of photon KE is shared with the mass it stores. Hence photon potential (relativistic) mass progresses and oscillates giving it the waveform. Its space progression and wave nature means it diffracts into multiple paths at pinholes or slits.

Photon potential (relativistic) mass has a space presence but only as something latent (stored) that occurs. It only interacts with itself yielding all the usual wave behavior: interference, superposition, reinforcement and diffraction. But our knowledge of its behavior is indirect since our physical instruments only receive photon energy and momentum. Because of this, various features of photon reception are not well understood. They include: 1) the objective reality of probability; 2) randomness; and 3) instantaneous collapse.

**5.1 Objective Probability in Space –**

We can model photon wave progression mathematically and we recognize that our computed waveforms only govern probable (potential) photon reception. Nevertheless, we don’t make the connection between photon probability and photon stored (relativistic) mass. This despite the fact that release of something stored is generally probabilistic (e.g., radioactive energy release). For many, a more attractive explanation for photon probability is to invoke something abstract and mathematical that was designed for the electron: the wave function in multi-dimensional configuration space.[[6]](#footnote-6)

Potential (relativistic) mass, when not discounted (i.e., rejected), is only seen as a mere quantity. It is never granted a space presence such that it can interact with slits and pinholes. We have noted that kinetic energy was identified in the mid-nineteenth century and made into a quantity possessed by matter-in-motion. At the turn of the twentieth century physicists were grappling with another problem: the increase of effective mass with velocity. Once more they opted for a quantitative formulation. So, both KE and relativistic mass got incorporated into physics as simple energy/mass quantities and denied a dimensional presence. All of this is understandable given the knowledge at the time, but we have paid a price for those choices; and we keep paying.

Nature gives us only two types of entities: quantized matter (particle) and quantized radiation (photon KE). Each store their opposite by virtue of E = mc2. That which is stored (thermal-or-intrinsic energy for quantized matter, or relativistic mass for quantized photon energy): 1) depends upon, is hosted by, the entity’s essential identity; 2) is probabilistic for release in its progression dimension which alters (or eliminates) its host;

Photon potential (relativistic) mass is a collapsible wave of probable photon reception (of photon KE transfer). The potential (relativistic) mass wave of a single photon interferes with itself when passing through a pinhole or double slit. The result on a target screen is regions whose intensity may be high (wave crest reinforcement) or low (wave crest cancellation). The intensity distribution on the screen determines the probability of photon KE reception, but only in the aggregate. Individual reception is random.

**5.2 Photon KE Reception as Random –**

 Photon KE can only terminate (impinge) on matter and at a point in space and time (absorption). Photon KE resides in time and to terminate on space-residing matter it must bring about a cross (an orthogonal intersection) of occurring KE in time with existing rest mass in space. In a word it becomes an event: 1) something involving both KE and rest mass; 2) something that is discrete in two dimensions because the two entities involved reside in opposing dimensions. Photon reception on matter is the intersection of ontologically different entities (existing vs. occurring). But we don’t see that and insist that KE is a quantity carried by a particle. Alas, Nature’s ontological subtlety eludes us and we keep trying to make photon KE into the payload of a particle that “impacts” matter.

That which controls the tendency (probability) of photon KE termination on matter is photon potential (relativistic) mass which is continuous as a waveform progressing in space. Meanwhile, the actual transfer of quantized time-residing KE to quantized space-residing matter is discrete and event based; it cannot be continuous. So it is that photon termination is individually random but in aggregate it reflects the distributed intensities of photon potential (relativistic) mass.

Whenever something is stored – potential energy (thermal, radioactive) in matter, or potential (relativistic) mass in radiation – there is always an associated probabilistic rate for aggregate release. But this aggregate release rate is combined with randomness for individual release: random in time for thermal emission; random in space for photon absorption. Photon emission from a warm body is discrete/random but it is correlated to that body’s (bulk, continuous) property, temperature. Photon absorption is discrete/random but it is correlated to the local (continuous) wave intensity of photon potential (relativistic) mass.

**5.3 Collapse –**

 Collapse of radiation’s probable space paths at photon reception was something that bothered Einstein deeply; he regarded it as what we now call nonlocality. Ironically, what collapses is something he disowned, namely relativistic mass.

**Total Collapse due to Photon Termination**: Photon potential (relativistic) mass waves progressing over space paths have but a single (common) source of occurrence and the latter is orthogonal to said waves. That is, the photon’s potential (space wave) identity is an expression of the photon’s orthogonal essential (time oscillation) identity. Photon potential (relativistic) mass waves progressing in space depend upon this single time source for their entire occurrence, whether that occurrence is oscillation/progression or cessation of oscillation. When a photon terminates, photon KE in time ends that oscillation upon which all space-progressing potential (relativistic) mass depends. The cessation and disappearance of dispersed space-progressing waves is instantaneous and nonlocal because: 1) these waves have a single, orthogonal point of failure; and 2) these are waves of occurrence and have neither rest mass nor energy.

**Partial Collapse due to Path Blockage**: A single photon may have multiple paths some of which are blocked by a detector preventing potential (relativistic) mass wave transmission. If termination occurs on that detector, then a general path collapse is triggered as described above. If termination does not occur on that detector, the potential (relativistic) mass waves the detector blocks cannot progress in space and they collapse without a trace. Any unblocked waves continue in space with enhanced probability of release. Photon potential (relativistic) mass waves occur and progress; they will cease to occur (collapse) when denied space progression. Similarly, rest mass particles will cease to exist if denied time progression.

**6.0 Photon as Particle –**

 The debate over radiation as a particle (Newton) or as a wave (Huygens) got reopened early in the twentieth century. Those quantum pioneers born before 1900 (Einstein, Bohr, Planck) grew up with Maxwell’s wave theory of radiation and found it difficult adjusting to radiation quanta and the dualism it implied [1, p.231,233]. But succeeding generations of physicists grew accustomed to advancing science by studying particle properties; the conflict with the wave behavior of radiation got pushed to one side. Richard Feynman [2] exemplifies this shift to particle physics; he argues that radiation is composed of particles [p. 14] and dismisses wave behavior as a paradox not worth pursuing. [p. 24, 81]

 But the photon does not behave like a material particle: it has no rest mass; no defined location or trajectory and it leaves no tracks in a cloud chamber. In spite of all this, Feynman’s idea of photon-as-particle is still widely embraced. There are two reasons for this.

 First, when explaining something unknown everyone’s first impulse is to employ familiar concepts. Photons deliver energy and momentum to a point in space and this looks very much like particle impact. This (lazy) idea that the photon is a particle traversing space and impacting on a material target: 1) depends upon a bad analogy; 2) applies the matter-based classical ontology to radiation. It is doubly wrong.

 Second, it is assumed that energy cannot be real on its own;[[7]](#footnote-7) it must be a property of something and that something is a particle (or field), even if the particle is imaginary (virtual). In addition, photon wave behavior does not lend itself to KE interactions. Photon waves, as we have seen, are probabilistic; they can collapse without a trace and they don’t carry KE. So, the wave side of photon behavior – something necessary for explaining optical phenomena – is of little use to physicists writing energy exchange equations. It is the termination (and emission) of photons where KE is involved; this energy resides in time but physicists with their existence-mass-space worldview can imagine that said energy is a quantity belonging to a particle moving in space. This permits equations to be written based entirely on the classical ontology. In the words of Abraham Pais, physicists “…call a photon a particle because, just like massive particles, it obeys the laws of conservation of energy and momentum in collisions, with an electron say (Compton Effect)” [1, p. 350-1] {\displaystyle |\mathbf {r} \rangle }.

 So, it is easy to see why photon-as-particle is a popular analogy and why it is mathematically useful. But neither of these rationales survives serious scrutiny and photon-as-particle still leads to paradoxes.

Photons terminate at a space and time point because that is how two orthogonal entities intersect. That is, photon KE residing in time can only meet (impinge upon) target matter residing in space at a point (an event) in space and time that both share. Our limited view of what is real (i.e., particles, impact, photon as simple object) leads us to underestimate the subtlety of nature.

**7.0 The Photon in the Double Slit –**

 A photon’s two identities are interdependent yet are very different. One is essential (unstored), the other potential (stored); one resides in time and registers on our instruments and the other progresses in space and must be inferred because it involves probability. This is what has made the modeling and interpretation of radiation so difficult.

**Identity #1**: Photon oscillation KE residing in the time dimension naturally passes through the space-residing slits unaffected and terminates (transfers its energy) on a material target at a point in space and time.

**Identity #2**: A photon’s potential (relativistic) mass is a space-progressing waveform. When a single photon passes through a double slit its potential mass wavefront divides to go through both slits and these two paths mutually interfere.[[8]](#footnote-8) This creates multiple space paths of differing intensity governing probable release (termination). The identification of this as wave behavior is correct but with a caveat: these are retractable, collapsible waves of probability (stored mass); these waves do not carry energy as sound waves and water waves do. When diffracted, water waves dissipate their energy; diffracted light waves do not since they have no energy.

Experimenters have tried to resolve the wave versus particle identity of the photon by modifying the double slit. By placing a photon detector behind one or both of the slits the hope is to determine “which way” (particle) information.

**One Slit Blocked:** When waveform potential (relativistic) mass enters a slit and impinges on a detector just behind that slit, one of two things will happen. Photon reception may occur and the waves in the other, no-detector, slit collapse instantly. Alternately, no photon termination results for this slit’s detector and the waves it blocks collapse and disappear (Section 5.3) while waves in the other slit continue on in space. This latter case leads people who believe in the classical ontology to assert that “the particle [and its KE payload] chose the no-detector slit.”

**Two Slits Blocked:** We assume the detector at each slit has an equal chance of termination (reception). If termination occurs at detector A, then photon potential mass waves at detector B simply disappear since A has triggered a global wave collapse. It is a mistake to assume that nothing ventured into the slit where termination did not take place; potential (relativistic) mass traverses both slits.

**Interaction-free measurement**: The photon’s two identities are unitary but function in two dimensions. The potential (relativistic) mass of a single photon progresses in space and so can be split into two paths, say by the first beam splitter of an interferometer; each path/arm then has a 50% probability of terminating the entire photon. The photon KE of course does not split. If you block one of the two arms and termination does not occur, then the other arm immediately converts to 100% probability of termination. But you have thereby altered the photon; one of its paths is “live” (potential/relativistic mass progressing) and the other path is “dead” (no potential/relativistic mass). This eliminates any possibility of interference when reuniting the two paths of the single photon at the second beam splitter, one path active, the other not. One photon identity (namely occurring potential/relativistic mass) has “touched” the obstacle and undergone a change without the other radiation identity (photon KE) “registering” (terminating) on the obstacle. Put another way, the potential (space wave) identity has been altered but not the essential (KE) identity; our instruments can measure the latter but not the former. Commentators call this “interaction-free measurement” [3]. But in fact interaction of one photon identity has taken place, namely the blockage and collapse of potential (relativistic) mass on one path; this constitutes a change of the photon. The mystery of interaction-free (counterfactual) measurement disappears once you understand the role space-progressing photon potential (relativistic) mass plays. That is, once you realize the photon has two identities and you stop applying the classical ontology (existence, mass, space) to the realm of radiation (occurrence, energy, time).

**8.0 Conclusion –**

 Previous attempts at understanding the photon over the decades have failed because they have been based upon a classical ontology. The photon is not a particle following a defined trajectory in space. Work done on a charge creates an occurring entity: photon KE as pure oscillation residing in time. This time-residing KE entity has (via E = mc2) stored (relativistic) mass that progresses (and oscillates) in space (as a wave) toward release of this mass.

* **The photon is a quantum whole (an entity) with two identities.**
* **Photon oscillatory KE resides in time and so does not diffract (fractionate) in space.**
* **Photon waveform potential (relativistic) mass progresses on all available space paths, can diffract and determines probable photon reception (termination).**
* **These two identities permit the photon to display opposing attributes: 1) a discrete, particle-imitating nature since time-residing photon KE can only intersect (impinge upon) space-residing matter at a point; and 2) a probabilistic wave nature due to photon potential (relativistic) mass oscillating and progressing in space (these are Einstein’s “ghost” waves [4, p.2-3]).**

**8.1 Additional Topics –**

Recognizing that photon energy resides in time resolves wave-particle dualism which for Richard Feynman was the central issue of quantum theory. It also resolves other long-standing photon issues.

**Constant velocity of light:** With photon energy residing in time, two immaterial wavefronts traverse space at the speed of light, namely, potential (relativistic) mass waves and the EM waves that Maxwell’s equations describe. Both have their sustaining, oscillatory occurrence in space dependent upon photon energy in time. This makes them subject to instantaneous collapse regardless of their spatial expanse. As pure waveform, their velocity is their wavelength divided by their period with both measures derived from changing electric and magnetic fields. An observer moving toward a photon’s source measures a proportional contraction for both wavelength and period; as a result, their ratio –velocity – is unchanged. If the observer moves away from the photon source, both wavelength and period increase proportionally. Hence, the constant velocity of light is simply the fixed ratio of wavelength to period for a pure, un-hosted wave. A postulate for the constant velocity of light is unnecessary [see 5, Sec.6.1].

* **The ONLY way a single energy packet/quantum can reach all velocity-differing inertial systems with the packet at the same velocity is if it is the immaterial (probability) wavefront that has the constant (phase) velocity while the energy packet itself does not even traverse space!**

**Entanglement:** Material objects (particles) have rest mass as their essential identity and rest mass resides in space. Radiation objects (photons) have energy as their essential identity and photon energy resides in time. Two space-adjacent particle rest masses may bond (entangle) in space; a chloride ion bonds to a sodium ion to yield salt. Two time-adjacent photon energies may bond (entangle) in time. Photon energies are adjacent in time if they are the product of a single event, say parametric down conversion producing two daughter photons from a single high energy photon. Hence photon entanglement is in time; so is photon spin (angular momentum).

**Nonlocality:** Entangled photon energies reside together in time, but they send their probability-of-reception waves out over space. When the wave of one photon triggers a reception on a space target, that photon energy exits its entanglement in time. In the process it acquires a right (or left) spin and its bonded partner simultaneously acquires the opposite spin. This is occurrence (change) of occurrence (spin) and naturally it takes place in time. There is no coordination of spin over space; hence there is no nonlocal space communication. It is a mistake to think of two entangled photons as particles in space with separate trajectories that somehow coordinate their spin regardless of separation. Einstein was right; there is no “spooky action at a distance” [see 6, Sec.7.0].

\* \* \* \* \* \* \* \* \* \* \* \* \* \* \* \*

**Sources**

 [1] Pais, Abraham. *Niels Bohr’s Times, In Physics, Philosophy, and Polity*, Clarendon Press, Oxford, 1991.

[2] Feynman, Richard. *QED: The Strange Theory of Light and Matter*, Princeton Univ. Press, 1985.

 [3] *Wikipedia, The Free Encyclopedia*, s.v. "Elitzur–Vaidman bomb tester," (accessed February, 2020), <https://en.wikipedia.org/wiki/Elitzur%E2%80%93Vaidman_bomb_tester>

[4] Dongen, Jeroen van. “The interpretation of the Einstein-Rupp experiments and their influence on the history of quantum mechanics,” <https://arxiv.org/abs/0709.3226> (accessed Nov. 2019).

[5] Klevgard, P.A. “The Mach-Zehnder Interferometer and Photon Dualism: with an Analysis of Nonlocality,” <https://arxiv.org/abs/2108.08222> (2021). Original article SPIE conference proceedings: [**https://doi.org/10.1117/12.2575213**](https://doi.org/10.1117/12.2575213) (2020).

1. Existence and occurrence are used in these pages strictly within the confines of physics. They encompass physical reality and are the two co-equal divisions within traditional ontology as expanded for physics. Entities either exist or occur and the more familiar one, of course, is matter existing in space and persisting over time. [↑](#footnote-ref-1)
2. Locating photon KE in time allows it to occur/oscillate as we shall see. Photon KE as a mere quantity with no hosting dimension doesn’t allow that. [↑](#footnote-ref-2)
3. Our instruments respond to photon KE and we can infer photon probabilistic space paths. These two sides or facets of the photon are – for lack of a better word – hereafter called “identities.” [↑](#footnote-ref-3)
4. Physicists have embraced the concept of oscillation of “nothing” or oscillation from “nothing”; vacuum state fluctuations in QFT are just that. [↑](#footnote-ref-4)
5. Potential (relativistic) mass is a bit controversial these days; even Einstein spoke against it. The dispute is less about physics and more about semantics and pedagogy (“don’t confuse students!”). Some argue that relativistic mass is the same as (kinetic) energy and so we should employ the latter and discard the former. What they mean is that relativistic mass depends upon KE; however, that does not make them the same. The photon has both and they may cause different effects: in the Compton Effect the deflected (re-emitted?) photon has reduced frequency (energy change); it also has a new direction (momentum change). Stored mass, potential mass and relativistic mass all refer to the same thing: the mass a photon has. Photon potential/relativistic mass is measurable as a quantity; what is new here is its progressing, waveform space presence. It occurs as a consequence of photon KE. It does not exist! Only rest mass exists. [↑](#footnote-ref-5)
6. Applying the wave function to radiation is not correct. You can’t write a Schrödinger equation for a massless “particle.” [↑](#footnote-ref-6)
7. The reader will note that this sentence is not phrased as: “…energy cannot exist on its own…” Radiation kinetic energy does **not** exist, it occurs. We use the phrase “to exist” to mean “to be real.” Our obsession with existence, matter and space carries over to our language: something is real only if it exists (and resides in space); this is very parochial. Actually, something is real if it involves mass or energy and resides in a dimension, space or time. In light of E = mc2 and relativity (where space and time are equal), why should it be otherwise? [↑](#footnote-ref-7)
8. The photon’s wave interferes with itself. Dirac: “Interference between two different photons never occurs.” [↑](#footnote-ref-8)